Formal methodologies for modelling IT projects Critical Success Factors

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Abstract

IT projects are different than other engineering projects as they are characterised by high complexity and high chances of project failure. Therefore, it is important to identify those Critical Success Factors (CSFs), which increase the chances for project success. This paper reviews two emerging methodologies for identifying, classifying and evaluating CSFs in IT projects: Analytic Hierarchy Process (AHP) and Fuzzy Cognitive Maps (FCM). Both methodologies are compared; their advantages, disadvantages and limitations are analysed with the objective to provide decision-makers concerned with the success of an IT project with an understanding which will help them to identify the most suitable methodology in view of the project specifics and circumstances.

Keywords*: IT projects; Critical Success Factors; Fuzzy Cognitive Maps; Analytic Hierarchy Process*

Resumen

Los proyectos de Tecnologías de la Información se caracterizan por una alta complejidad y altas tasas de fracasos. Por lo tanto resulta de interés la identificación de los Factores Críticos de Éxito que incrementan sus oportunidades de éxito. Este trabajo revisa dos metodologías emergentes para identificar, clasificar y evaluar los Factores Críticos de Éxito en proyectos de Tecnologías de la Información: Proceso Analítico Jerárquico (Analytic Hierarchy Process, AHP) y Mapas Cognitivos Borrosos (Fuzzy Cognitive Maps, FCM). Se comparan estas dos metododologías y se analizan sus puntos fuertes, débiles limitaciones con el objetivo de que los Directores de Proyectos de Tecnologías de la Información puedan elegir la metodología más adecuada en función de las características de cada proyecto específico.

Palabras clave: *Proyectos de Tecnologías de la Información; Factores Críticos de Éxito; Proceso Analítico Jerárquico; Mapas Cognitivos Borrosos*

1. Introduction

Implementing an IT system is not a risk-free project. In fact, we consider that these systems are very often seen as high-risk projects. Due to the fact that many stakeholders take part in this process and that they are so closely linked to one another, the chances that something may go wrong are high. Therefore, it does worth to study the factors that, to a great extent, determine whether the implementation will be successful.

When analysing failures of IT projects, it seems clear that the widely accepted assessment criteria for measuring projects success (delivered on time, to budget and meeting the specification) cannot guarantee success when IT projects are concerned. Saleh and Alshawi (1995) reported data from several thousand IT projects, revealed that only 26% of those projects were finished on time, and within the estimated budget, 28% were terminated before they were completed while the remaining 46% involved costs higher than the original estimates and were completed behind their schedule.

The nature of IT projects creates many risks that must be managed diligently (Kwak and Stoddard, 2004). It is therefore imperative at the outset of each new IT project to reach an agreement with all stakeholders on the objectives and main success indicators for that project (Wateridge, 1995; Wateridge, 1998; Turner, 2004). However, industrial project managers are often faced with the dilemma of selecting a single most appropriate technology from a range of competing options (Shehabuddeen et al., 2006). Hence, there is a need to further study and identify the specific critical success factors influencing IT projects success.

The study of Critical Success Factors (CSF) helps scholars and practitioners to extract from the multidimensional business process the core activities that are essential for business success (Butler and Fitzgerald, 1999). For a long time, from the late 1970s to the late 1990s, research and practice were dominated by three classical methodologies for managing success in information systems (IS): Critical Success Factors (CSF) (Rockart, 1979), Technology Acceptance Model (TAM) (Davis, 1989), and DeLone and McLean Success Model (DeLone and McLean, 1992).

However, in the last few years a couple of methodologies for identifying, classifying and evaluating CSFs in IT projects emerged. These are Analytic Hierarchy Process (AHP) (Salmeron and Herrero, 2005) and Fuzzy Cognitive Maps (FCM) (Rodriguez-Repiso, Setchi and Salmeron, 2007). The aim of this paper is twofold: (i) to review these emerging methodologies, compare and contrast them by focusing on their processes and results and (ii) to identify those important aspects that should be considered for selecting the most suitable methodology.

The remainder of the paper is organised as follows. Section 2 review briefly the CSF concept. Section 3 presents AHP and FCM methodologies and identifies their advantages, disadvantages and limitations. Finally, Section 4 outlines the conclusions.

2. Critical Success Factors

IT projects have certain components that make them different from the rest of engineering projects and increase the chances of their failure. Most of the specifics are related to the fact that IT projects involve software. These characteristics must be considered when developing and managing any IT project. The main characteristics are classified in seven categories (Salmeron and Herrero, 2005): abstract constraints, difficulty of visualisation, excessive perception of flexibility, hidden complexity, uncertainty, tendency to software failure, and goal to change existing business processes.

The study of CSF of IT projects was developed by Rockart (1979) as a method to enable CEOs to recognize their own information needs so that information systems could be built to meet those needs. Rockart defined CSF as the limited number of areas in which results, if they are satisfactory, will ensure successful competitive performance for the organization. They are the few key areas where “things must go right” for the business to flourish.

This concept has received a wide acceptance among scholars and practitioners (Butler and Fitzgerlad, 1999, Poon and Wagner). CSF is an interpretative method and, as such, it may be employed for research on the information systems development process.

Experts (Glass, 1999; Procaccino et al., 2002) suggest a deep divergence between managers/users and the members of the development team regarding the success of the different IT. Whereas managers/users focus their attention on budget, dates and business objectives, the members of the development team mainly pay attention to information systems development. In this work, we analyze the different views of managers and users.

Numerous scientific publications address the issue of CSF in the IT field (Butler and Fitzgerald, 1999; Poon and Wagner, 2001; Rodriguez-Repiso, Setchi and Salmeron, 2007, Salmeron and Herrero, 2005) as well as in other fields. According to Salmeron (2009), little efforts have been done about formal methods in CSF research. Project management of complex IT projects is challenging even when measures of success are known and understood. Therefore, we think that a study of the use of formal methods in Critical Success Factors is an useful endeavour.

3. Formal methodologies for mapping success factors in IT projects

Three methodologies for identifying, classifying and evaluating CSFs, which emerged during the last few years, are discussed in this section. These are AHP and FCM.

3.1. Analytic Hierarchy Process (AHP)

AHP is a formal methodology (Salmeron and Herrero, 2005) for assessing and ranking CSFs in IT projects. The goal is to obtain and rank users' perceptions about the importance of certain CSFs. The AHP methodology was developed by (Saaty, 1977, 1980) in the 1970s.

The AHP was developed by Saaty (1977,1980). It is a powerful and flexible decision-making process to set priorities among different attributes. AHP is a method that uses a hierarchic structure to present a complex decision problem by decomposing it into several smaller subproblems. AHP has been widely used to reflect the importance, or weights, of the factors associated to priorities (Zahedi, 1986).

AHP has been widely applied in the IT field (Khoo, Chen and Yan, 2002; Lu et al., 2001). However, little has been done to design a formal method for the assessment of critical success factors.

The AHP method encompasses three basic steps: firstly, the decision problem has to be broken down into a hierarchy of interrelated elements; secondly, the data has to be collected by pairwise comparisons of former elements and the attributes' weights in each level have to be computed using the eigenvalue method; finally, the categories' weights have to be calculated.

As an example, figure 1 shows an real application of a CSF analysis using AHP and Table 1 the final results from Salmeron and Herrero (2005).

Figure 1: AHP application hierarchy (Salmeron and Herrero, 2005)

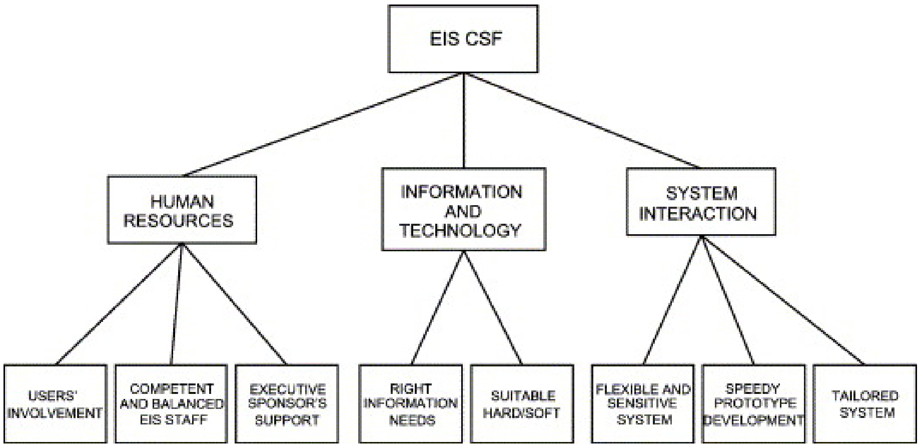


Tabla 1: AHP application results (based on Salmeron and Herrero, 2005)

CSFs	Local weights	Global Weights
Users' interest	0.540	0.153
Competent and balanced EIS staff	0.163	0.046
Executive sponsor's support	0.297	0.084
Right info needs	0.889	0.532
Suitable hard/soft	0.111	0.066
Flexible and sensitive system	0.320	0.038
Speedy development of a prototype	0.122	0.014
Tailored system	0.558	0.067

The advantages, disadvantages and limitations of the AHP methodology are discussed below (Salmeron and Herrero, 2005; Zahedi, 1986). The advantages are the following:

- The AHP methodology provides a formal multi criteria decision-making mechanism for ranking CSFs. It collects users' perceptions about the importance of CSFs in order to establish a ranking among them.
- The AHP methodology allows managers to express their individual preferences, and these are further used in the evaluation of each IT project.
- The AHP methodology provides a consistent measure of results.
- It achieves better results compared to other approaches that involve a qualitative analysis based on the experts' opinion of the absolute priority of each CSF.

The disadvantages and limitations are shown below:

- The estimation of the importance of the CSFs during the process of data collection and pairwise comparisons may involve some inconsistency. It is clear that given three factors A, B and C within the same category, the degree of importance of A over B should be consistent with the importance of A over C, and C over B. The difficulty arises when dealing with a larger number of factors.

- Possible inconsistencies in the answers of the people interviewed may lead to wrong computation of the CSFs weights.

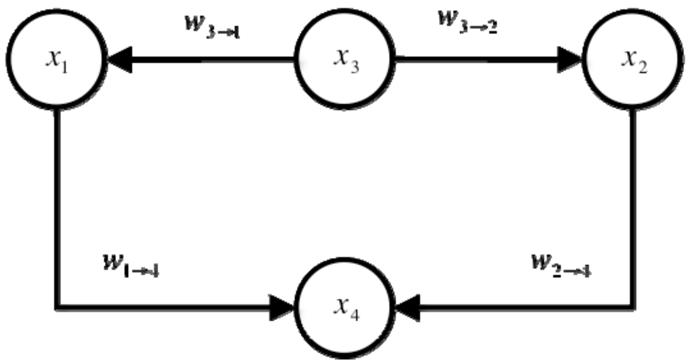
3.2. Fuzzy Cognitive Maps (FCM)

Fuzzy Cognitive Maps (Kosko, 1986) have emerged as a tool for representing and studying the behaviour of systems and people. The main goal of building a FCM around a problem is to be able to predict the outcome by letting the relevant issues interact with one another (Xirogiannis and Glykas, 2004).

FCMs have been applied in such different fields as medicine, computer science, information systems, and other domains. As yet, there have been few attempts at applying FCMs as real-world tools for supporting decisions (Salmeron, 2009) within real business environments.

FCM nodes represent concepts or variables relevant to a given domain. The causal links between these concepts are represented by the edges, which are oriented to show the direction of influence. The other attribute of an edge is its sign, which can be positive (a promoting effect) or negative (an inhibitory effect). The FCM nodes (x_i) would represent such concepts as performance, sales, costs, or investment, to name a few within a business environment.

Figure 2: Fuzzy Cognitive Map Example



The relationships between nodes are represented by directed edges. An edge linking two nodes models the influence of the causal variable on the effect variable. Since FCMs are hybrid methods mixing fuzzy logic and neural networks (Kosko, 1986), each cause is assessed by its intensity $w_{i\to j} \in [0,1]$, where i is the pre-synaptic (causal) node and j the post-synaptic (effect node) one.

An adjacency matrix A represents the FCM nodes connectivity. FCMs measure the intensity of the causal relation between two factors and if no causal relation exists it is denoted by 0 in the adjacency matrix.

$$A = \begin{pmatrix} 0 & 0 & 0 & w_{1\to4} \\ 0 & 0 & 0 & w_{2\to4} \\ w_{3\to1} & w_{3\to2} & 0 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix} \quad (1)$$

FCMs are dynamical systems involving feedback, where the effect of change in a node may affect other nodes, which in turn can affect the node initiating the change. The analysis begins with the design of the initial vector state ($\dot{C}_0$), which represents the initial value of each variable or concept (node). The initial vector state with n nodes is denoted as

$$\vec{C}_0 = \left(C_0^{[1]} \quad C_0^{[2]} \quad \ldots \quad C_0^{[n]} \right) \tag{2}$$

where $C_0^{[i]}$ is the initial value of the i concept.

The new values of the nodes are computed in an iterative vector-matrix multiplication process with an activation function, which is used to map monotonically the node value into a normalized range [0,1]. The sigmoid is the most used function (Bueno y Salmeron, 2009) when the concept (node) value maps in the range [0,1]. The component i of the vector state $\dot{C}_{(t+1)}$ at the instant $t+1$ would be

$$C_{(t+1)}^{[i]} = \left(1 + e^{-\lambda \cdot C_t^{[i]}} \right)^{-1} \tag{3}$$

where λ is the constant for function slope (degree of fuzzification). The FCM designer has to specify the lambda value. For large values of λ (e.g. $\lambda \geq 10$) the sigmoid approximates a discrete function that maps its results to interval (0,1), for smaller values of λ (e.g. $\lambda = 1$) the sigmoid approximates a linear function, while values of λ closer to 5 provides a good degree of fuzzification in [0,1] interval (Grant and Osei-Bryson, 2005). It is fitter to use a lambda value that provides a degree of fuzzification rather than other that would binarize or linearize, because decision-making processes are fuzzy.

FCM inference process finishes when the stability is reached. The final vector state shows the effect of the change in the value of each node in the FCM. After the inference process, the FCM reaches either one of three states following a number of iterations. It settles down to a fixed pattern of node values, the so-called hidden pattern or fixed-point attractor. Alternatively, the state could to keep cycling between several fixed states, known as a limit cycle. With a continuous function, a third possibility would be a chaotic attractor. This occurs when, instead of stabilizing, the FCM continues to produce different results (state vector values) for each cycle.

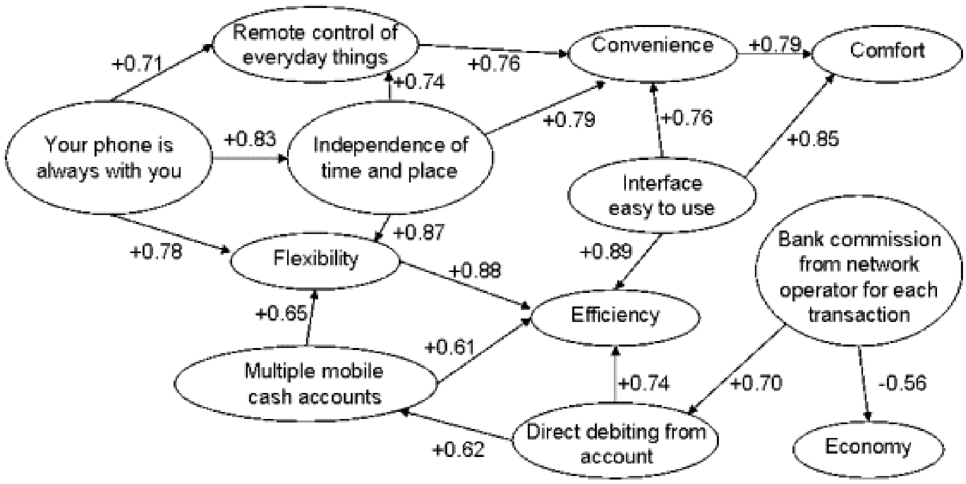
Various methodologies could be used in order to reach a consensus among the experts in FCM (Salmeron, 2009). Delphi is a well-known methodology used to structure the experts' communication process to reach a consensus regarding a complex problem (Linstone and Turoff, 1975). One of the main features of the Delphi study is when the experts receive feedback reports; they have the opportunity of changing their own opinion based on this feedback. The Augmented FCM approach (Salmeron, 2009) does not need that experts change slightly their former opinions for consensus. The augmented adjacency matrix is built adding the adjacency matrix of each expert (Kosko, 1996). The element $w_{i \to j}^{Aug}$ in the augmented matrix is computed by

$$w_{i \to j}^{Aug} = \frac{\sum_{k=1}^{n} w_{i \to j}^{k}}{n} \tag{4}$$

being n the number of FCMs added (one by data source or expert), k the identifier of each FCM, and i and j the identifier of the relationships.

Figure 3 shows an application of FCM tool. The applicability of the FCM methodology is demonstrated through a case study (Rodriguez-Repiso, et al., 2007) based on a new project idea, the Mobile Payment System (MPS) project, related to the fast evolving world of mobile telecommunications.

Figure 3: FCM application (Source: Rodriguez-Repiso et al., 2007)



The advantages, disadvantages and limitations of the FCM methodology are discussed below. The advantages are:

- FCM is a useful tool for achieving consensus between all stakeholders involved in an IT project since they have active contribution during the development of the map and feel committed to the project success.
- The FCM methodology allows modelling of the beliefs which stakeholders share with respect to every relationship in the model.
- Using FCM, knowledge can be represented in a much richer way than using tables or matrices. FCM is not only able to map the CSFs but also represent the relations between them.
- Positive and negative interactions between factors can be highlighted and analysed.
- FCM allows conducting, in a systematic manner, impact analysis of alternative project ideas and success factors, and suggesting specific project objectives for achieving its success.
- FCM are flexible and can be customised in order to consider the specifics of different IT projects.
- The concepts of success and its perception are complicated, difficult to formalise and not readily quantifiable. FCM is the methodology best equipped to deal with this ambiguity.
- With the FCM methodology, even if the initial mapping of the problem concepts is incomplete or incorrect, further additions to the map can be included, and the effects of the new parameters can be quickly seen.
- FCM modelling and simulation provides planners with means to cope with complexity, enhances their ability to focus on certain success issues and evaluate their impact to the overall project, following the causal paths of the model. Decision makers are empowered to draw appropriate inferences from more beliefs than they could handle without cognitive maps (Axelrod, 1976).

- The simulation and analysis of FCM allows planners to provide the answers to the following queries:
  - What are the alternative ways to achieve success?
  - Which alternative does it seem to be more feasible?
  - What effect will the new IT project have upon the organization, i.e., increase or decrease of certain variables?
  - What will be the consequences of changing the sign of a certain factor?

The disadvantages and limitations are the following:

- Most individuals have different perspectives and use different scales to evaluate the importance of CSFs. A number of experts are required to ensure objective and globally valid results as the opinion of one expert is never 100% accurate and always contain some level of subjectivity.
- The computation process and data manipulation can be very complex. The complexity increases with the number of CSFs considered and the number of individuals interviewed. The higher the number of people interviewed, the more accurate the results obtained are, and more complex data analysis and manipulation is.
- In order to achieve an accurately structured FCM, more knowledge than that contained in the numerical vectors provided by users is required. For example, extra knowledge and experience is required to determine the direction of causality between the CSFs in the model.

4. Conclusions

CSFs, indicators of success or success criteria are those necessary conditions that a project must satisfy for being perceived as a success. In view of the fact that IT projects have added complexity and increased chances of failure, there is a need to identify ways to augment the successful delivery of IT projects, and the important factors influencing that success.

The methodologies used for identifying, classifying and evaluating CSFs in IT projects in the focus of this paper are AHP and FCM. These methodologies have valuable advantages as well as a number of disadvantages and limitations. This paper offers an analysis of these advantages, disadvantages and limitations with the objective to provide decision-makers concerned with the success of an IT project with an understanding which will help them to identify the most suitable methodology in view of the project specifics and circumstances.

The AHP methodology has certain advantages compared to methodologies using qualitative analysis based merely on the experts' opinions of the absolute priorities of each CSF as it allows a measure of the consistency of the results. However, there is a possibility of incorrectly computing the CSFs' weights.

FCM methodology represents a system in a form that corresponds closely to the way humans perceive it. Therefore, the model is easily understandable, even by a non-professional audience and each parameter has a comprehensible meaning. The model can be easily altered to incorporate new factors, and if its behaviour is different than expected, it is usually easy to find which factor should be modified and how.

Finally, in order to achieve an accurately structured FCM, more knowledge than that contained in the numerical vectors provided by the user is required. The direction of causality usually requires more information than that embedded in numerical vectors representing the CSFs in the model. Therefore, an expert is required which introduces a level of subjectivity in the methodology.

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5. References

Axelrod, R. (1976). *Structure of Decision: The Cognitive Maps of Political Elites*, Princeton: Princeton University Press.

Bueno S. & Salmeron, J. L. (2009). Benchmarking main activation functions in Fuzzy Cognitive Maps. *Expert Systems with Applications,* 36, pp. 5221-5229.

Butler, T. & Fitzgerald, B. (1999), Unpacking the systems development process: an empirical application of the CSF concept in a research context. *Journal of Strategic Information Systems* 8, pp. 351–371

Davis, F. D. (1989) Perceived usefulness, perceived ease-of-use, and user acceptance of information technology. *MIS Quarterly* 13, pp. 319–340.

DeLone, W. H. & McLean, E. R. (1992) Information systems success: the quest for the dependent variable, Information Systems Research 3, pp. 60–95.

Glass, R. L (1999). Evolving a new theory of project success. *Communications of the ACM* 41, 8.

Grant, D. & Osei-Bryson, K. (2005) Using fuzzy cognitive maps to assess MIS organizational change impact. 38th Annual Hawaii International Conference on System Sciences, 2005.

Khoo, L. P., Chen C. & Yan, W. (2002). An investigation on a prototype customer-oriented information system for product concept development. *Computers in Industry* 49, pp. 157–174.

Kosko, B. (1986) Fuzzy Cognitive Maps. *International Journal of Man-Machine Studies* 24, pp. 65–75.

Kwak, Y. H. & Stoddard, J. (2004) Project risk management: lessons learned from software development environment. Technovation 24, pp. 915–920.

Linstone, H. A. & Turoff, M. (1975). *The Delphi Method, Techniques and Applications*. London: Addison-Wesley.

Lu, H., Yu H. & Lu, S. S. K. (2001) The effects of cognitive style and model type on DSS acceptance: an empirical study. *European Journal of Operational Research*, 131, pp. 649–663.

Poon, P. & Wagner, C. (2001) Critical success factors revisited: success and failure cases of information systems for senior executives. *Decision Support Systems*, 30, pp. 393–418.

Procaccino, J. D. Verner, J. M., Overmeyer S.P. & Darter, M.E. (2002). Case study: factors for early prediction of software development success. *Information and Software Technology*, 44, pp. 53–62.

Rockart, J. F. (1979). Chief executives define their own data needs. *Harvard Business Review*, 52, pp. 81–93.

Rodriguez-Repiso, L., Setchi, R. & Salmeron, J. L. (2007). Modelling IT projects success with

Fuzzy Cognitive Maps. *Expert Systems with Applications*, 32, pp. 543–559.

Saaty, T. L. (1977). A scaling method for priorities in hierarchical structures. *Journal of Mathematical Psychology*, 15, pp. 234–281.

Saaty, T. L. (1980) *The analytic hierarchy process: Planning, priority setting, resource allocation*. New York: McGraw-Hill.

Saleh, Y. & Alshawi, M. (2005). An alternative model for measuring the success of IS projects: the GPIS model. *Journal of Enterprise Information Management*, 18, pp. 47–63.

Salmeron, J. L. (2009). Augmented fuzzy cognitive maps for modelling LMS critical success factors. *Knowledge-Based Systems*, 22, pp. 275-278.

Salmeron, J. L. & Herrero, I. (2005). An AHP-based methodology to rank critical success factors of executive information systems. *Computer Standards & Interfaces*, 28, pp. 1–12.

Shehabuddeen, N., Probert D. & Phaal, R. (2006). From theory to practice: challenges in operationalising a selection framework. *Technovation*, 26, pp. 324–335.

Turner, J. R. (2004). Five necessary conditions for project success. *International Journal of Project Management*, 22, pp. 349–350.

Wateridge, J. (1995). IT projects: a basis for success. *International Journal of Project Management*, 13, pp. 169–172.

Wateridge, J. (1998). How can IS/IT projects be measured for success?. *International Journal of Project Management*, 16, pp. 59–63.

Xirogiannis, G. & Glykas, M. (2004) Fuzzy Cognitive Maps in business analysis and performance-driven change. *IEEE Transactions on Engineering Management*, 51, pp. 334–351.

Zahedi, F. (1986). The analytic hierarchy process. A survey of the method and its applications. *Interfaces*, 16, pp. 96–108.

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