Content and Applications of Artificial Intelligence for Cost Management in Civil Engineering Projects

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Abstract

During the last few decades many developments in computer science, software programming and application production have been adopted by various engineering disciplines. These developments are mostly focusing on Artificial Intelligence Techniques. Therefore, a number of definitions are presented, which focus on the concept of Artificial Intelligence from different viewpoints. This paper reviews existing applications of Artificial Intelligence (A.I.) that facilitate cost management in civil engineering projects. An analysis of the Artificial Intelligence in its specific partial branches is presented. These branches or approaches contributed to the creation of a significant group of models that concern analysis, interpretation and prediction of various parameters. A list of selected, up to date models is provided, that concern cost management for civil engineering projects. The models are analyzed according to the activity, field of operation, input and output data and the methods and techniques they implent. It becomes clear that Artifial Intelligence will be the future essential tool for every engineer and it will lead to significant improvements in the construction sector.

Keywords

Artificial Intelligence Applications, Civil Engineering, Cost Management

1. Introduction

In construction projects, plans are usually drawn to ensure that work is carried out to the desired quality, in the allowed time and according to budget (Al-Jibouri, 2003, Abudayyeh, 1993, Diekmann and Al-Tabtabai, 1992, Yu *et al.*, 2006). Certain types of projects, such as road construction, building renovation and maintenance projects are characterized by set of activities that are performed in the same order throughout the various parts of the project (Shtub and Raz, 1996). Divergences from the plan however occur and within construction such occurrences are common. Such divergences are nevertheless expected because of the nature of construction work and the uncertainties associated with it. In the case where the differences between the plan and the actual work performance are great, control action is

normally required to try to bring the actual performance on course with the desired state of the plan (Al-Jibouri, 2003).

In addition to effectively support construction project process management, a project control system is needed to facilitate the collection of quality data in a timely fashion and to provide quality historical databases for future planning of new projects. However, many projects suffer from ineffective control due to inefficient flow of information. This inefficiency in control is a fundamental problem in construction management (Abudayyeh *et al*., 2001).

Furthermore, the increasing turbulence found in the corporate environment today, creates a growing demand on the flexibility of project management and the ability to anticipate the future (Nikander and Eloranta, 2001). It is common experience in the implementation of construction projects that the meticulous "Project Evaluation" at the beginning loses much of its importance during latter stages because of various uncertainties related to the environment (frequently combined with managerial inadequacies), resulting in varying degrees of cost overrun (Nandi and Dutta, 1988).

It is a fact that the financial control of construction projects is an integral part of effective project management. The subject has benefited from a number of advances in theory and techniques that have resulted from research. These have included value engineering, lifecycle costing, elemental cost planning, cost modeling, buildability, and the use of knowledge-based systems (Betts, 1992).

It is clear that, Project Cost Management is an extremely complex and very difficult process. It requires the collection and processing of a plethora of information, as well as making lengthy calculations (Chen, 2008). Abudayyeh (1993) also suggests that effective management of construction projects depends on good access to and control of data, especially data pertaining to cost and schedule control functions. In a construction project, cost and schedule data are closely related to each other (Chen, 2008). Typically, projects utilise a control system, which monitors the difference or gap between the planning variables and the actual performed results (Rozenes *et al*., 2004). Construction industry requires vast stores of interdisciplinary knowledge (Brandon *et al*. 2005). Today, however, the evolution of technology leads to new methods based on computers, providing valuable tools for every engineer. Many new system developments that are being created in relation to research findings are getting more sophisticated with the current trend of integrating everything (Benjaoran, 2008). In particular, through the development of Artificial Intelligence, many computer programs have been created for a more effective monitoring of project construction and project management.

This paper is reviewing existing models based on AI, with application in construction cost management, with the aim to make predictions about future research areas and agendas. In the following section the concept and areas of Artificial Intelligence are analyzed. Then follows a review of selected number of cost models implementing AI applications and a brief analysis of their operation. Finally, the conclusions are discussed, concerning the models' efficiency and future approaches based on AI are highlighted.

2. Artificial Intelligence

2.1 Definition of Artificial Intelligence

Through the last decades various definitions of Artificial intelligence (AI) have been provided. One of the first definitions, which is given by Barr and Feigenbaum (1981) proposed that AI is the area of computer science that deals with the design of smart (intelligent) computer systems. In other words, it deals with systems that exhibit characteristics associated with human intelligence.

According to Haugeland, AI is the effort of building computers with intellectual capacity to the full and literal sense (Haugeland, 1989). Another definition of AI could also be the following: AI is the field of computer science that deals with the automation of intelligent behavior (Luger & Stubblefield, 1997). Also according to another definition AI is the study of computers, which makes possible the perception, reasoning and reaction (Winston 1992).

In addition Rich and Knight (1991) define AI as the study of how to make computers do things which at the moment people are better. Finally a general definition that covers most of the above mentioned could be the following: AI is the area of computer science that deals with designing and implementing programs that are able to emulate human learning abilities. So AI displays features, which are normally attributed to human behavior, such as problem solving, perception by vision, learning, drawing conclusions, understanding natural language, etc. (Vlahavas *et al.,* 2002).

2.2 Areas of AI

2.2.1 General areas of action and evolution

The AI research encompasses a variety of fields, from general purpose such as perception and reasoning to more specific. Often researchers from different disciplines rely on AI to find tools to automate the logical steps used in their work. Similarly, the researchers use AI methods of different areas where human intelligence is required. Thus, it is clear that the methodologies developed over time for AI have applications in many different areas of science such as: Proof of theorems, Natural language processing, Computer vision, Machine learning, Planning and scheduling, Robot, Expert systems and knowledge (Vlahavas *et al.,* 2002).

All these developments, therefore, in the field of Artificial Intelligence can be classified into the following eleven areas: Genetic Algorithms, Neural Networks, Fuzzy logic, Intelligent Agents, Problem Solving & Planning, Expert System, Natural Language Processing, Robotics, Computer Vision, K-means clustering and Learning, which is presented in figure 1.
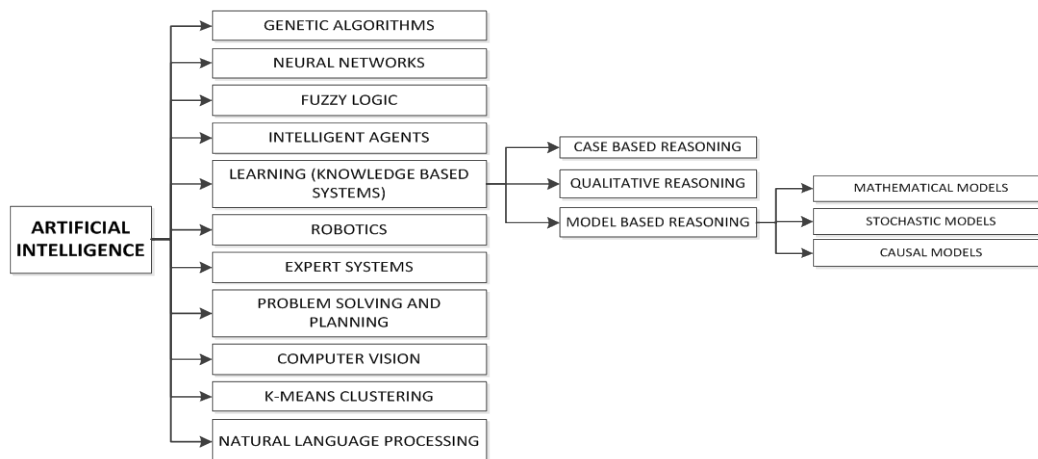

Figure 1: Artificial Intelligence Analysis

2.2.2 Learning through Knowledge-based systems

Learning (the ability of a PC to learn) is done through knowledge-based systems that represent and use knowledge to perform a function. Each system includes expert knowledge systems and non-expert knowledge systems. The knowledge of the non-expert systems does not come from experts but has scientific-technological origin that is captured in databases, technical reports, etc. (Vlahavas *et al.*, 2002).

A system is a series of planned actions that lead to desired results. Intelligence is the product designed to save steps, work and money. A system provides a sense of direction, balance and alertness and is a plan to keep a project under control by using data (Richard and Westney, 1997).

When systems are consisted of multi-level subsystems and components that interact in a logical order, this is called hierarchy systems. The Work breakdown Structure is one such system. It is a typical sequential structure of the scope of the project, summarizing the project at the highest level of analysis and then it subdivides into operating systems, natural areas, the phases or other major subdivisions (Richard and Westney, 1997).

A concept which has an important role in system-designing is the usability of the system. According to international standard «ISO 9241», the usability of the system is the ability of the system to operate in an effective and efficient manner and provide to users subjective satisfaction. The usability of systems can be analyzed in accordance with the parameters: easy to learn application, high performance, minimize errors by users, easy mnemonic recall mode and subjective user satisfaction (Avouris, 2000)

In order to create these systems three techniques have been developed, which draw conclusions based on knowledge that can be obtained from sources independent of experts, such as physical or mechanical models, technical manuals, troubleshooting case reports, etc. These techniques are: the case-based reasoning, the qualitative reasoning and the model-based reasoning (Vlahavas *et al.,* 2002).

The model-based reasoning represents the structure and operation of real systems, using basic scientific principles or techniques (deep knowledge) rather than empirical and often shallow knowledge on a specific behavior of test system (Vlahavas *et al.*, 2002).

The structure and basic functions of a physical system are the model of the system. There are three types of models: the mathematical models (which describe a system with analytical equations), the stochastic models (which statistics-describe the operation of a system) and the causal models (which describe a system through interactions between its different parts) (Vlahavas *et al.*, 2002).

3. Cost Models

3.1 Definition of Cost Model

A general model is called the representation of a physical problem. The cost models in particular are a graphic representation of cost management. They consist one of the most important information outputs generated by the analysis of economic data earlier works (Mitten, 1997).

A cost model is an expression of cost distribution, associated with a particular part, product or system (Richard and Westney, 1997).

3.2 Cost Models for project management

Different cost models have been developed that contribute to a more efficient financial project management. Cost models give a more vivid picture of the costs for the various elements of the project, they help to identify the most appropriate subheadings to monitor the cost reduction and they allow comparison between different approaches to select the optimal solution (Mitten, 1997). The following table (1) presents a list of 15 cost models, which have been published recently and significantly help in managing the technical costs. The list provides the title of publication, the author and the date of issuance:

Table 1: List of Publications

No	Title of publication	Author	Date
1	Prediction of the life cycle cost using statistical and artificial neural network methods in conceptual product design	Seo, Park, Jang, Wallace	2010
2	Project cost estimation using principal component regression	Chan & Moonseo Park	2005
3	An integrated regression analysis and time series model for construction tender price index forecasting	Thomas, Cheung, Skitmore, Wong	2010
4	Web - based conventional cost estimates for construction projects using Evolutionary Fuzzy Neural Inference Model	Cheng, Tsai, Liu	2009
5	Neural network model incorporating a genetic algorithm in estimating construction costs	Kim, Yoona, An, Cho, Kang	2004
6	Data modeling and the application of a neural network approach to the prediction of total construction costs	Emsley, Lowe, Duff, Harding, Hickson	2010
7	Forecast models for actual construction time and cost	Skitmore &, Thomas	2003
8	Approximately predicting the cost and duration of school reconstruction projects in Taiwan	Chen & Huang	2010
9	The use of fuzzy logic in predicting house selling price	Kusan, Aytekin, Ozdemir	2009
10	Generalized linear model-based expert system for estimating the cost of transportation projects	Chou	2008
11	Applying AHP-Based CBR to Estimate Pavement Maintenance Cost	Chou	2008
12	Web-based CBR system applied to early cost budgeting for pavement maintenance project	Chou	2008
13	Predicting final cost for competitively bid construction projects using regression models	Williams	2002
14	Predicting completed project cost using bidding data	Williams	2002
15	Bidding ratios to predict highway project costs	Williams	2005

3.3 Analysis of Cost Models

Each one of the previous 15 models could be analyzed based on the following characteristics (figure 2):
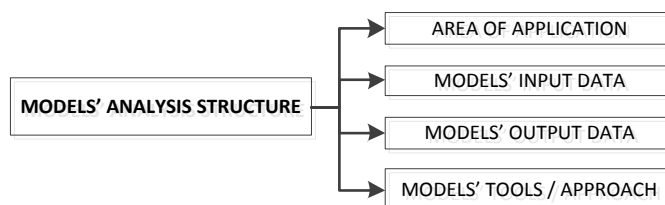

Figure 2: Structure of Models' Analysis

3.3.1 Area of models' application or type of projects where the models are applied to
This section describes the type of projects where the models are applied. The models concern specific types of projects, which for example could be: Highway Projects, Road Maintenance, and School Buildings.

3.3.2 Models' Input Data
The models use specific kind of input data in order to make a prediction. So the input data concern pieces of information such as: Bidding Data, Initial Procurement Offers and Project Scheduled Duration.

3.3.3 Models' Ouput Data
Every model produces a certain result or prediction, based on an amount of input data. So the output of every model can be classified in the following: Prediction of final cost, early cost budgeting, Cost Estimation, Selling prizes, Life cycle cost, Tender price index forecasting, Forecast of time.

3.3.4 Models' Approach
The 15 models are based on the field of A.I., and at the same time use many specific tools. The approaches applied in the abovementioned models are shown in the following table:

Table 2: List of approaches, that are applied in every model

No	Title of publication	Approaches
1	Prediction of the life cycle cost using statistical and artificial neural network methods in conceptual product design	Neural Network and Statistics
2	Project cost estimation using principal component regression	Regression Analysis
3	An integrated regression analysis and time series model for construction tender price index forecasting	Regression Analysis and Time - series
4	Web - based conceptional cost estimates for construction projects using Evolutionary Fuzzy Neural Inference Model	Fuzzy logic, Neural Network and Genetic Algorithms
5	Neural network model incorporating a genetic algorithm in estimating construction costs	Neural Network and Genetic Algorithms
6	Data modeling and the application of a neural network approach to the prediction of total construction costs	Neural Network
7	Forecast models for actual construction time and cost	Regression Analysis
8	Approximately predicting the cost and duration of school reconstruction projects in Taiwan	Neural Network and Regression Analysis
9	The use of fuzzy logic in predicting house selling price	Fuzzy logic
10	Generalized linear model-based expert system for estimating the cost of transportation projects	Expert Systems and Generalized Linear Correlations
11	Applying AHP-Based CBR to Estimate Pavement Maintenance Cost	Case-Based Reasoning and Analytical Hierarchy Process
12	Web-based CBR system applied to early cost budgeting for pavement maintenance project	Case-Based Reasoning
13	Predicting final cost for competitively bid construction projects using regression models	Regression Analysis
14	Predicting completed project cost using bidding data	Neural Network and Regression Analysis
15	Bidding ratios to predict highway project costs	Neural Network and Regression Analysis

4. Conclusions

This focused analysis of the ongoing approaches reveal the extended and increasing adoption of AI in the management of Civil Engineering Projects and especially project cost management.

It became apparent in the last few years that every application of AI has its strong and weak points. As soon as these points were identified, the new approaches focused on hybrid systems. The latter ones are systems which combine two or more different AI branches. Each AI approach is applied at a specific portion of the problem. Selection of the available AI technique is based on the awareness of the performance of each technique at each specific sub-problem. This way a final system can utilize the best AI approaches. Their combination results in systems with optimum performance. The next step is to find the best combination of AI branches for the system under consideration.

The content of the future research is the application of the existing models in Greek Highway Projects and the evaluation of their efficiency. The second aim is to design and implement a hybrid system, which will incorporate one or more of the available technologies and will be customized according to Greek legislation. The system will be used to predict the final cost of highway projects.

The previous analysis, concluded that the most common and appropriate approaches of artificial intelligence, that are used in order to develop models for construction projects are Fuzzy logic, Neural Networks and Genetic Algorithms. These techniques combined with Statistics and especially Regression Analysis could produce predicting models easy to use, and at the same time efficient and accurate.

Finally, as the hardware is becoming more robust and efficient, and at the same time applications aim at a total integration, the resulting systems will exhibit remarkable performance.

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