Fuzzy Cognitive Map to Model Project Management Problems

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***Abstract*—Project management is a complex process impacted by numerous factors either from the external environment and/or internal factors completely or partially under the project manager's control. Managing projects successfully involves a complex amalgamation of comprehensive, informed planning, dynamic assessment and analysis of changes in external and internal factors, and the development and communication of updated strategies over the life of the project. Project management involves the interaction and analysis of many systems and requires the continuous integration and evaluation of large amounts of information. Fuzzy Cognitive Maps (FCM) allow us to encode project management knowledge and experiential results to create a useful model of the interacting systems. This paper covers the representation and development of a construction project management FCM that provides an integrated view of the most important concepts affecting construction project management and risk management. This paper then presents the soft computing approach of FCM to project management (PM) modeling and analysis. The resulting PM-FCM models the interaction of internal and external factors and offers an abstract conceptual model of interacting concepts for construction project management application.**

Keywords—Project management, approximate reasoning, complex systems, modeling, fuzzy cognitive maps, decision support, risk analysis, soft computing.

I. Introduction

Soft computing, and its foundational aspects such as *fuzzy logic*, continue to be applied to new application areas [1]. Soft computing and fuzzy logic methodologies offer a useful approach when modeling complex application domains requiring incorporation of subjective information and significant uncertainties, and when comprehensive, quantitative data sets are unavailable [2]. These conditions are often present when modeling construction engineering and management problems. Already, in this domain, fuzzy logic has been combined with other soft computing techniques to model, simulate, and create advanced dynamic systems [3]. Modeling is a way of representing knowledge and improved modeling techniques continue to be investigated that enable us to incorporate human experience, and work with the imprecision and uncertainty inherent in real world systems [4]. The fields of *Soft Computing* and *Computational Intelligence* offer new theories and approaches to leveraging mature technologies and techniques such as fuzzy logic, neural nets, genetic algorithms, support vector machines, and probabilistic reasoning [5][6]. Engineers use these approaches to develop sophisticated models of complex systems based on representation of extensive, qualitative domain knowledge [7].

FCM modeling is a computational intelligence technique employing fuzzy logic and neural networks [8]. FCM depicts interconnected concepts and the causal links between them [9][10]. The maps depict the causal relationships between concepts, with a direct relationship shown as a positive weight and an inverse relationship shown as a negative weight [11]. FCM have been used to support decision analysis [12], automate human problem-solving [13], model water distribution control systems [14] and perform Failure Mode and Effects Analysis (FMEA) [15]. Soft computing approaches have been studied as a way to improve the modeling of complex systems in the presence of uncertainty [16]. By combining fuzzy logic and neural nets, FCM models have been used in complex hierarchical and supervisory support systems [17][18]. Project management is a complex system. It is highly dependent on external and market factors, with the market acting as a dynamic, complex, chaotic system. Other contributing factors include internal factors including management training, procedures, skills, and experience.

This paper includes this introduction, provides background on the FCM modeling approach (Section II) and introduces the construction project management domain with much attention to risk management (Section III). In Section IV, we describe the specifics of the novel modeling approach and the development of the PM- FCM, and Section V provides results and conclusions.

II. FUZZY COGNITIVE MAPS

Fuzzy Cognitive Maps (FCMs) have been introduced as an extension of cognitive maps –used to model brain inference and cognition- where fuzzy brings the ambiguity and abstraction, characteristics for any rational conclusion process. Learning characteristics have been brought into FCM, either as Hebbian learning algorithms –or other neural network based algorithms. This makes FCM neuro-fuzzy systems that are able to solve real-world, usually complex decision-making problems, with great modeling challenges [19]. FCMs integrating neural networks and fuzzy logic principles belong to neuro-fuzzy systems that capture the benefits of and they are able to incorporate human knowledge and adapt it through learning algorithms so that to efficiently model, design and develop hybrid intelligent systems [20].

The conceptual mechanism behind FCM is better understand and visualized through the graphical representation of FCM. It is designed as a *signed directed graph* permitting feedback, which is consisted of *concepts-nodes* and *weighted interconnections*. The concepts stand for fundamental entities, mainly presenting abstract generalized ideas that model and describe the behavior of the system. The signed and weighted interconnections among concepts represent the cause and effect simplification of the existing relationships among generalized entities (Figure 1). All values in the FCM graph are fuzzy, so concepts take values in the range of [0,1] while weights of the interconnections belong in the range of [-1,1]. The graphical visualization of FCM comprehensively represent the influence from one concept to the other. This visualization facilitates the understanding of the influence mechanism among concepts and encourage restructuring of FCM by adding or deleting either interconnections and/or concepts. In generally, FCMs could be characterized as fuzzy-graph structures that describe systematic causal propagation of any kind either forward and/or backward chaining.

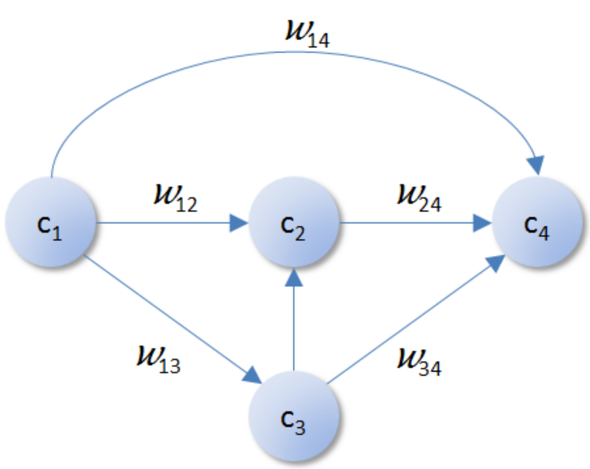

Fig. 1 Fuzzy Cognitive Map model

FCMs are used as generalized modeling approaches suitable for symbolic and conceptual representation of any system [10][19]. The most essential and critical entities describing the behavior of a system and being able to include different aspects, are selected to represent the concepts of the FCM. The kind of interactions and interactions among concepts describe the dynamics of the system. FCMs initially are described and constructed by experts who have experience by observing the operation and instances of the system based on which the empirical concepts are arisen out. Experts have to have extensive knowledge and understanding on the models , so that the quality of FCM models and the inherited mentality in the models increases[20].

III. CONSTRUCTION ENGINEERING & PROJECT MANAGEMENT

Construction engineering deals with the design, construction, and management of infrastructure systems including roads, bridges, utilities, and many other facilities. Project management is both a required part of construction engineering and a complex discipline on its own. Project management involves the planning, executing, and controlling activities and teams of people to achieve a specific outcome. Projects, and in particular construction projects, are impacted by a variety of factors both internal to the managing organization and external to the organization, including potentially high-uncertainty factors as commodity costs, inflation, availability of resources and materials, and regulations. Projects are often evaluated in terms of cost, schedule, and risk. Previously, FCM modeling has been already introduced to develop and provide a qualitative model for construction schedule performance, which is presented at Figure 2 [3]. At that particular case Dissananyake, et.al., designed and developed a to include and evaluate effects of various project occurrences so that to estimate a construction project duration.

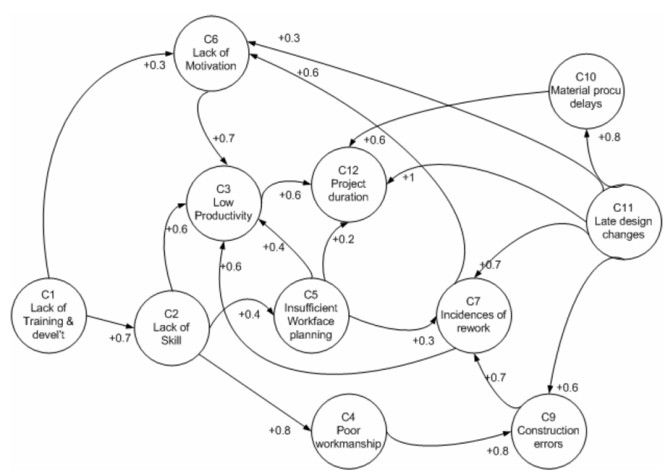

Fig. 2 Dissanayake's schedule performance FCM [3]

In this work, we develop and present a FCM model based on published literature [3] and [21], which is used to select and infer the concepts that consist the FCM. Actually, Zou, et.al [21] presented all the key risks factors that influence a construction project success. Project success is impacted by duration by costs and other factors. The top ten ranked risk factors are referring for risks that affected by cost, time, quality, environment, and safety. Table 1, gathers the key risk factors proposed by Zou, et.al [21], which are used as concepts C12-C30 at the Project Management Fuzzy Cognitive Map (PM-FCM). These risks are ranked relative to multiple and various project objectives and so different risks would affect different project objectives, which could be examined by running different scenarios at the PM-FCM model.

Table 1. 20 Key Risk factors in construction projects [21].

20 Key Risks	Abbreviations
Tight project schedule	TPS
Design variations	DV
Excessive approval procedures in administrative government departments	EAP
High performance/quality expectations	HPQE
Inadequate program scheduling	IPS
Unsuitable construction program planning	UCPP
Variations of construction programs	VCP
Low management competency of subcontractors	LMCS
Variations by the client	VC
Incomplete approval and other documents	IAD
Incomplete or inaccurate cost estimate	ICE
Lack of coordination between project participants	LCP
Unavailability of sufficient professionals and managers	UPM
Unavailability of sufficient amount of skilled labour	USL
Bureaucracy of government	BG
General safety accident occurrence	GSAO
Inadequate or insufficient site information (soil test and survey report)	ISI
Occurrence of dispute	OD
Price inflation of construction materials	PICM
Serious noise pollution caused by construction	SNP

IV. PROJECT MANAGEMENT-FCM MODELING APPROACH

As it has already presented, we are going to develop an integrated Project Management Fuzzy Cognitive Map (PM-FCM) model, which takes advantage of the FCM ability to incorporate various complementary and contradictory factors/ concepts. The PM-FCM model incorporates the factors identified in a set of concepts, which has been selected combinatory by factors suggested at [3] and [21] and more generic factors. For every node of the PM-FCM, it is assigned a unique Concept Identifier (CID) and it is also presented the published work (reference), which proposed the corresponding factor. (see Table 2).

Most of the identified factors are related to risk factors making the PM-FCM model more focused on risk management. But there are also included construction performance factors providing a model broader than the risk management. Thus the proposed Project Management Fuzzy Cognitive Map (PM-FCM) model aims to develop a model, which could be used to evaluate the overall project success but also estimating other essential construction project and risk related factors.

Table 2. Model concepts.

CID	Ref	RCID	Label
1	[3]	1	C1 Lack of training/development
2	[3]	2	C2 Lack of skill
3	[3]	3	C3 Low productivity
4	[3]	4	C4 Poor workmanship
5	[3]	5	C5 Insufficient workface planning
6	[3]	6	C6 Lack of motivation
7	[3]	7	C7 Incidences of rework
8	[3]	9	C9 Construction errors
9	[3]	10	C10 Procurement delays
10	[3]	11	C11 Late design changes
11	[3]	12	C12 Extended project duration (goal)
12	[21]	TPS	Tight schedule
13	[21]	DV	Design variations
14	[21]	VC	Variations by client
15	[21]	UCPP	Unsuitable construction program planning
16	[21]	OD	Occurrence of dispute
17	[21]	PICM	Price inflation of construction materials
18	[21]	EAP	Excessive approval procedures in administrative government departments
19	[21]	IAD	Incomplete approval and other documents
20	[21]	ICE	Incomplete or inaccurate cost estimate
21	[21]	IPS	Inadequate program scheduling
22	[21]	BG	Bureaucracy of government
23	[21]	HPQE	High performance or quality expectations
24	[21]	VCP	Variations of construction programs
25	[21]	LMCS	Low management competency of subcontractors
26	[21]	USL	Unavailability of sufficient amount of skilled labor, professionals, and managers
27	[21]	LCP	Lack of coordination between project participants
28	[21]	ISI	Inadequate or insufficient site information (soil test and survey report)
29	[21]	SNP	Serious noise pollution caused by construction
30	[21]	GSAO	General safety accident occurrence
31		B	Overall schedule risk
32		A	Overall Expenses risk
33		C	Overall qual-related risks
34		D	Overall environmental related risk
35		E	Overall safety related risk
36			Increased labor costs
37			Increased project procurement costs and expenses
38			Increased project overhead costs
39			Increased project costs
40			Increased project risk
41			Overall project success

The causal relationships among concepts have declared with a fuzzy variable *T(influence)* that codifies both the direction and the intensity of the relationship as shown in Table 3. The fuzzy membership functions are incorporated to reflect the influence information acquired at studies [3] and [21]. The relationships among the concepts along with their fuzzy membership functions described in linguistic format are gathered Table 3 where it is described to express the direction and degree to which a change in one concept influences another concept.

Table 3. The T(influence) options

TID	Relation-ship	T(influence)	Membership function
1	direct	very strongly positive	PPPPP
2	direct	quite strongly positive	PPPP
3	direct	strongly positive	PPP
4	direct	somewhat strongly positive	PP
5	direct	moderately positive	P
6	direct	lightly moderately positive	+++++
7	direct	weakly positive	++++
8	direct	quite weakly positive	+++
9	direct	very weakly positive	++
10	direct	barely weakly positive	+
11	none	no influence	
12	inverse	barely weakly negative	-
13	inverse	very weakly negative	--
14	inverse	quite weakly negative	---
15	inverse	weakly negative	----
16	inverse	lightly moderately negative	-----
17	inverse	moderately negative	N
18	inverse	somewhat strongly negative	NN
19	inverse	strongly negative	NNN
20	inverse	quite strongly negative	NNNN
21	inverse	very strongly negative	NNNNN

Each active relationship is identified in terms of both the direction of the relationship, either direct or inverse, and a qualitative assessment of direction is provided selecting one of the T(influence) options at Table 3. Any kind of relationship between a concept CID_i and a resulting concept CID_o is permitted.

The current PM-FCM model includes 41 concepts and over 100 interconnections and it has been developed by asking three senior industry domain experts who incorporate their expertise with the published prior work [3] and [21]. Thus they identified the concepts provided at Table 2 and the assessments of relationships between concepts, provided in Table 4. The PM-FCM model construction approach is based on [16]. Weight among concepts are assigned using the μz fuzzy membership function of Table 3.

Table 4. Interconnection weights between concepts (non-μz)

CID 1	CID1 Description	CID 2	CID2 Description	Influence function
1	Lack of training/devmt	2	Lack of skill	PPPP
1	Lack of training/devmt	6	Lack of motivation	+++
2	Lack of skill	3	Low productivity	PPP
2	Lack of skill	4	Poor workmanship	PPPPP
2	Lack of skill	5	Insufficient planning	+++++
3	Low productivity	11	Extended project duration (goal)	PPP
3	Low productivity	36	Incr labor costs	+
4	Poor workmanship	8	Construction errors	PPPPP
5	Insufficient planning	3	Low productivity	+++++
5	Insufficient planning	7	Incidences of rework	+++
5	Insufficient planning	11	Extended project duration (goal)	+
6	Lack of motivation	3	Low productivity	PPPP
7	Incidences of rework	3	Low productivity	PPP
7	Incidences of rework	6	Lack of motivation	PPP
8	Construction errors	7	Incidences of rework	PPPP
9	Procurement delays	11	Extended project duration (goal)	PPP
9	Procurement delays	36	Incr labor costs	+
9	Procurement delays	37	Increased proc costs	+
9	Procurement delays	38	Increased OH costs	+
10	Late design changes	6	Lack of motivation	+++
10	Late design changes	7	Incidences of rework	PPPP
10	Late design changes	8	Construction errors	PPP
10	Late design changes	9	Procurement delays	PPPPP
10	Late design changes	11	Extended project duration (goal)	PPPPP
10	Late design changes	36	Incr labor costs	+
11	Extended project duration (goal)	31	Overall schedule risk	+
11	Extended project duration (goal)	32	Overall Expenses risk	+
11	Extended project duration (goal)	33	Overall qual-related risks	+
11	Extended project duration (goal)	38	Increased OH costs	+
12	Tight schedule	31	Overall schedule risk	PPP
12	Tight schedule	32	Overall Expenses risk	PPPP
12	Tight schedule	33	Overall qual-related risks	PPP
12	Tight schedule	34	Overall env-rel risk	+++++
12	Tight schedule	35	Overall safety related risk	P
13	Design variations	31	Overall schedule risk	PP
13	Design variations	32	Overall Expenses risk	PP
13	Design variations	33	Overall qual-related risks	+++
13	Design variations	36	Incr labor costs	+
13	Design variations	37	Increased proc costs	+
13	Design variations	38	Increased OH costs	+
14	Variations by client	31	Overall schedule risk	PP
14	Variations by client	32	Overall Expenses risk	PP
14	Variations by client	34	Overall env-rel risk	+++
14	Variations by client	36	Incr labor costs	+
14	Variations by client	37	Increased proc costs	+
14	Variations by client	38	Increased OH costs	+
15	Unsuitable planning	31	Overall schedule risk	P
15	Unsuitable planning	32	Overall Expenses risk	P
15	Unsuitable planning	33	Overall qual-related risks	+++++
15	Unsuitable planning	35	Overall safety related risk	++++
16	Dispute occurrences	32	Overall Expenses risk	P
16	Dispute occurrences	38	Increased OH costs	+
17	Materials inflation	32	Overall Expenses risk	P
17	Materials inflation	37	Increased proc costs	+
18	Excessive approval	31	Overall schedule risk	PP
18	Excessive approval	32	Overall Expenses risk	+++++
18	Excessive approval	34	Overall env-rel risk	+++
18	Excessive approval	38	Increased OH costs	+
19	Incomplete approval and other documents	31	Overall schedule risk	P
19	Incomplete approval and other documents	32	Overall Expenses risk	+++++
19	Incomplete approval and other documents	36	Incr labor costs	+
20	Inaccurate estimates	32	Overall Expenses risk	+++++
20	Inaccurate estimates	33	Overall qual-related risks	+++++
20	Inaccurate estimates	37	Increased proc costs	+
21	Inadequate scheduling	31	Overall schedule risk	P
21	Inadequate scheduling	32	Overall Expenses risk	+++++
21	Inadequate scheduling	33	Overall qual-related risks	P
21	Inadequate scheduling	34	Overall env-rel risk	++
21	Inadequate scheduling	36	Incr labor costs	+

CID 1	CID1 Description	CID 2	CID2 Description	Influence function
21	Inadequate scheduling	38	Increased OH costs	+
22	Bureaucracy of government	31	Overall schedule risk	+++++
22	Bureaucracy of government	36	Incr labor costs	+
22	Bureaucracy of government	38	Increased OH costs	+
23	High performance or quality expectations	31	Overall schedule risk	+++++
23	High performance or quality expectations	33	Overall qual-related risks	++++
23	High performance or quality expectations	34	Overall env-rel risk	++
24	Variations of construction programs	31	Overall schedule risk	+++++
24	Variations of construction programs	33	Overall qual-related risks	++++
24	Variations of construction programs	34	Overall env-rel risk	+++
24	Variations of construction programs	35	Overall safety related risk	+++
24	Variations of construction programs	38	Increased OH costs	+
25	Low sub competency	33	Overall qual-related risks	+++++
25	Low sub competency	34	Overall env-rel risk	++
25	Low sub competency	35	Overall safety related risk	+++++
25	Low sub competency	36	Incr labor costs	+
25	Low sub competency	38	Increased OH costs	+
26	Unavailability of suf. Skilled labor	33	Overall qual-related risks	++++
26	Unavailability of suf. Skilled labor	34	Overall env-rel risk	+++
26	Unavailability of suf. Skilled labor	36	Incr labor costs	+
27	Lack of coordination betw participants	33	Overall qual-related risks	+++
27	Lack of coordination betw participants	36	Incr labor costs	+
28	Insufficient site info	34	Overall env-rel risk	++
28	Insufficient site info	37	Increased proc costs	+
29	Noise pollution by construction	34	Overall env-rel risk	++
29	Noise pollution by construction	38	Increased OH costs	+
30	Gen accident occur.	35	Overall safety-rel risk	+++
30	Gen accident occur.	36	Incr labor costs	+
30	Gen accident occur.	38	Increased OH costs	+
31	Overall schedule risk	40	Increased project risk	PPPPP
32	Overall Expenses risk	40	Increased project risk	PPPPP
33	Overall qual-related risks	40	Increased project risk	PPPPP
34	Overall env-rel risk	40	Increased project risk	PPPPP
35	Overall safety related risk	40	Increased project risk	PPPPP
36	Incr labor costs	39	Increased project costs	+++++
37	Increased proc costs	39	Increased project costs	+++
38	Increased OH costs	39	Increased project costs	+
39	Increased project costs	41	Overall project success	NNN
40	Increased project risk	41	Overall project success	NNN

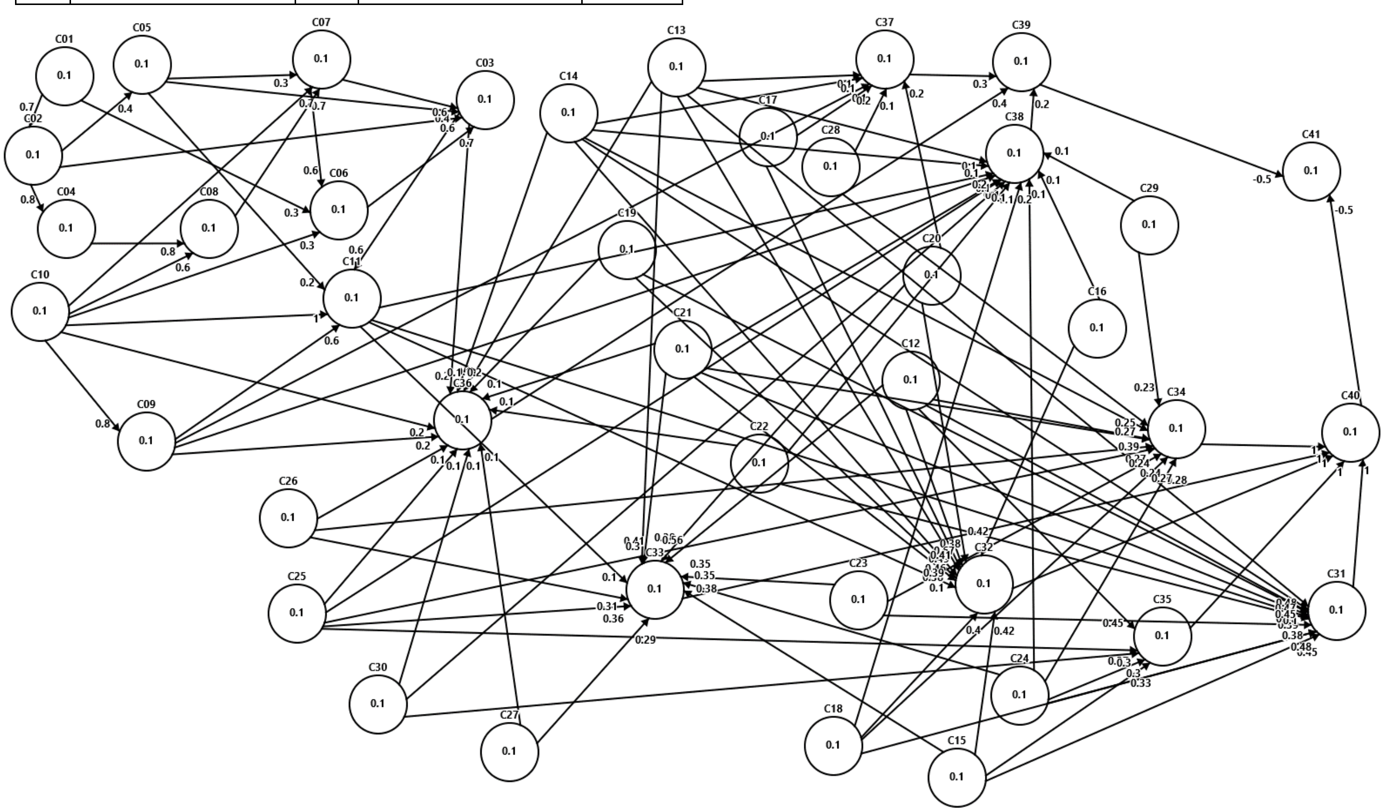

Fig.3 The PM-FCM model for construction problems

The resulting PM-FCM model is shown in Figure 3. It is a visual model illustrating the relationships among concepts, so that to provide an overview and draw appropriate inferences about the final values of the entities and how they are influenced. Based on these observations, there will be running scenarios so that to identify the values of input concept CID_i that convergence the values of output concepts CID_o to desired values.

V. Conclusions and Future Work

In this work, we presented a soft computing approach for forming an Project Management Fuzzy Cognitive Map (PM-FCM) model. It has been presented how the PM-FCM is created so that to be a supporting tool when dealing with complex project management. Fuzzy aspects provide support for managing and incorporating the variety of complex internal and external uncertainties required when developing a dynamic, responsive project management plan. The resulting PM-FCM incorporated concepts related to project schedule, costs, and risks, and offers a way to assist project managers with estimating and managing complex projects in uncertain, dynamic environments.

Future work will further investigate the proposed model, running various scenarios to evaluate its performance and propose possible updates, it will also compare it with other similar approaches.

Acknowledgment

This work was supported by the National funds allocated by the Greek General Secretarial of Research and Development project 2006SE01330025 as continuation of FP7–PEOPLE–IAPP–2009, Grant Agreement No. 251589, Acronym: SAIL

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