Construction Industry Pursuit Intel Modeling Insights with FCM

Denise M. Case
Computer Science and Information Systems
Northwest Missouri State University
Maryville, MO USA
dcase@nwmissouri.edu

Ty Blackburn
Strategic Initiatives
Corporate Services
Burns & McDonnell Engineering Company
Kansas City, Missouri
tblackburn@burnsmcd.com

Chrysostomos Stylios
Informatics and Telecommunications
University of Ioannina
Arta, Greece
stylios@uoi.gr

***Abstract*—This paper describes new interactive mental models applied to the pursuit of Construction Management (CM) project opportunities using Fuzzy Cognitive Maps (FCM). The CM-FCM models provide a basis for new decision support tools capable of providing Construction Industry Practitioners (CIP) support throughout the Project Life Cycle (PLC). It presents two novel CM-FCM models based on real-world construction engineering and management experience, specifically designed to support key decisions in the PLC. The interactive CM-FCM validates the application of FCM to this domain and demonstrate a method capable of helping manage the complexity and uncertainty inherent in construction management. The models offer a foundation for interactive intelligent decision support tools to assist with construction management.**

***Index Terms*—construction management, project life cycle, fuzzy cognitive maps, modeling, risk management problems, soft computing.**

I. Introduction

This paper describes how to design and develop an interactive model to assist with construction management. It discusses the main points of Construction Management (CM), Project Life Cycle (PLC) and Fuzzy Cognitive Maps (FCM) and provides the background and related prior work. It describes the research methodology employed to develop the models under investigation and presents the resulting models. This works aims to contribute to construction industry practitioners (CIP) needs and requirements for an advanced tool that makes project execution more simple and allows to avoid costly financial problems. CIP deal in an environment of complexity and uncertainty complicated by human activities and subjective reasoning where the adoption of a mental model based on Fuzzy Cognitive Maps gives new solutions.

A. Construction Management

The construction industry is continuously and widely expanding as it includes major aspects of our transportation backbone, buildings, utilities, facilities, and all other human construction. A comprehensive construction engineering framework is characterized by complexity and uncertainty because it dependents on various internal and external factors often with supplementary, complementary, and potentially conflicting objectives. Construction industry project management could be presented in three mainstreams: project pursuit, project execution and project closeout where each one includes various aspects. Thus there is a high complexity that requires efficient modeling approaches. To address the challenges related to complexity and uncertainty for modeling and decision making in construction industry, there are proposed fuzzy hybrid computing approaches [1]. In construction engineering, Fuzzy Cognitive Maps have been introduced to provide qualitative modeling of construction schedule performance [2] to model construction labor productivity [3] and simulate tunnel construction [3]. FCM have been introduced in construction engineering management problems and used to successfully model and evaluate aspects of various projects. [4].

B. Project Life Cycle

The 2013 PMI ”A Guide to the Project Management Body of Knowledge - Fifth Addition states the following. ”A project life cycle is the series of phases that a project passes through from its initiation to its closure. The phases are generally sequential, and their names and numbers are determined by the management and control needs of the organization or organizations involved in the project, nature of the project itself, and its area of needs application.” A typical Project Life Cycle (PLC) structure can be summarized at a high level in three major phases and broken down into functional tasks within each major phase. Fig. 1 illustrates key aspects of an overall PLC that may execute medium to large heavy industrial projects in a Design Build or EPC project delivery method. Fig. 2 illustrates the integration of CM-FCM into the PLC.

Our interactive CM-FCM ties the Project Life Cycle together and illustrates how CM-FCM can be used to assist with decision making during the various activities:

1) Project Pursuit: This initial activity includes Identification of client/owner requirements; marketing and an opportunity feasibility study to identify a potentially beneficial business opportunity and perform initial analysis, scoping and an Order of Magnitude estimate to determine whether the opportunity is worth further investigation. Completion

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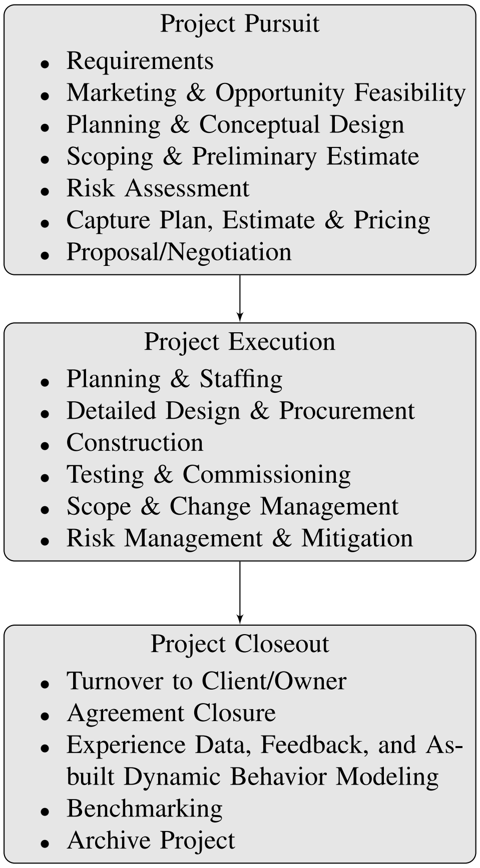

Fig. 1. High-level example of a Construction Management PLC.

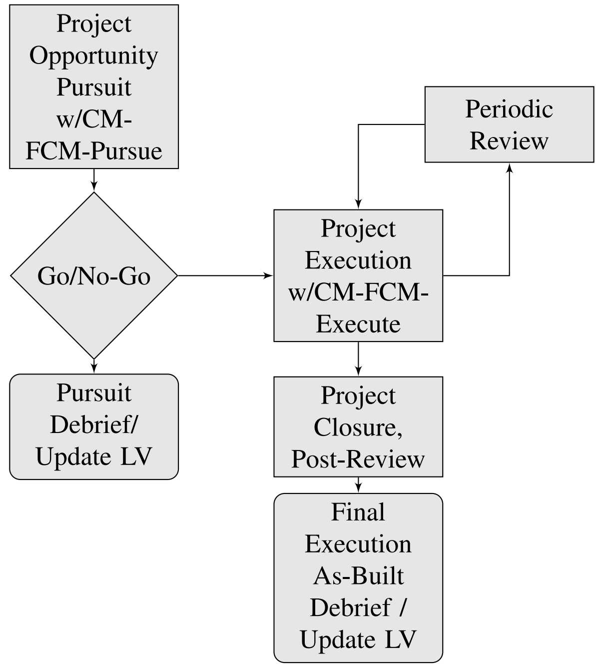

Fig. 2. Integration of CM-FCM into the Construction Management PLC.

of the feasibility phase may or may not result in a capital project. In addition to the preliminary cost estimate, deliverables generally include an initial Project Execution Plan, a preliminary schedule and several preliminary engineering design documents. During this activity, CIP generally finalize technology, project objectives, process and design scope definition, major equipment pricing, and the Project Execution Plan with a summary level schedule timeline to support a Cost Budget Estimate and funding request. Deliverables may include a Detailed Scope Document and the activity typically includes a risk assessment.Negotiations are held to finalize details between the parties and establish a formal contract agreement between the parties. Contract agreement signing by both parties ends the Project Pursuit phase.

2) Project Execution: Project execution begins after a contract agreement is executed by all parties. This starts the detailed design with the Detailed Scope Document as a basis to support performing multiple discipline design activities and produce documents in support of procurement, construction, commissioning and startup. Major deliverables may include issue for construction (IFC) and conformed procurement documents. Documents produced may include Request for Quotes and Bids/Bid Analysis for Labor, Equipment and Materials, Purchase Order Documentation, and Labor Contracts and Subcontracts. The function responsible for the completion of all activities is the Construction Phase. As construction starts to near completion, testing, commissioning and startup begin. This phase may be executed by the Owner, Contractor or by a third party under contract.

3) Project Closeout: Closeout involves completing regulatory, contractual, archival and Owner required activities to close the project in an orderly manner. Once complete, the project turnover and closeout has been fulfilled. The facility turnover may occur early during this phase if a third party under contract executes commissioning and startup.

C. Fuzzy Cognitive Map Modeling

Fuzzy Cognitive Maps have been proposed as an expansion of cognitive models [5] with fuzzy logic. [6]. Researchers further expanded FCM integrated aspects such as training from Neural Networks [7] expert systems and knowledge-based systems [8]. FCM have been supplemented with other soft computing and computational intelligence methodologies to create advanced modeling approaches including advanced decision support systems [9], [10] [11].

FCM may be thought of as a causal graph representation consisting of interconnected concepts assigned fuzzy weights. [12]. [13] each FCM is a fuzzy signed directed graph permitting feedback, where the weighted edge w_{ij} from concept C_i to affected concept C_j describes the degree to which the first concept influences the latter. An important characteristic of FCM is that they permit feedback so they are able to model complex systems such as those encountered in engineering, construction, and management. FCM are structures of interrelated entities similar to the abstract mental model that one builds in their own mind when conceiving of and modeling a complex interacting system, in order to be able to infer decisions. The permitted feedback interconnections combined with the inherent 'if-then' inferencing approach provide the main strength of FCM in modeling complex nonlinear dynamic systems [14]. [10] Thus, FCM have the ability to include hidden nonlinear dynamics and model systems of any complexity.

FCM models consist of concepts, key elements that represent the main characteristics of an abstract mental model. Each concept of the FCM model represents a granular entity representing a state, variable, input, output, event, action, goal, and/or trend of the real system modeled as an FCM. The value of every concept is A_i, and it results from the transformation of the fuzzy real value of the system's variable, for which this concept stands for, in the interval [0,1]. The initial concept values are produced and are then updated as they are computed through the interaction of the interconnected concepts with the corresponding weights. Generally, between two concepts there are three possible types of causal relationships that express the type of influence of one concept to the other. The weight of the arc between concept C_i and concept C_j may be positive ($W_{ij} > 0$), indicating an increase in the value of concept C_i leads to an increase of the value of concept C_j, and a decrease in the value of concept C_i leads to a decrease of the value of concept C_j. When causality is negative, ($W_{ij} < 0$), an increase in the value of concept C_i leads to a decrease of the value of concept C_j. Additionally, there may be no causality between two concepts ($W_{ij} = 0$).

The value A_i of every concept C_i expresses a fuzzy value of its corresponding physical value. FCM are used to model the behavior of systems; during the simulation step, the value A_i of a concept C_i is calculated by computing the influence of the interconnected concepts C_js on C_i following the calculation rule:

$$A_i{}^{(k+1)} = f(A_i{}^k + A_j{}^k * w_{ji}) \tag{1}$$

where $A_i{}^{k+1}$ is the value of concept C_i at simulation step k+1, A_j is the value of concept C_j at simulation step k_i, w_{ji} is the weight of the interconnection from concept C_j to concept C_i and f is the hyperbolic tangent function: $f(x) = tanh(\lambda x)$ where $\lambda > 0$ is a parameter that determines its steepness. In this approach, the value $\lambda = 1$ has been used. This function is selected since the values A_i of the concepts must lie in the interval [0,1]. FCM modelers employ symbolic representation for the description and modeling of systems [15], [16].

FCM models critical concepts and illustrates different aspects of the behavior of the system. Concepts interact dynamically through fuzzy weights. Experts are actively involved in the creation of FCM models, and as they interact with the models and their understanding of the benefits of the models increases, the quality of FCM models and the knowledge inherent in the models increases, and the models are more likely to be accepted and employed on a regular basis. In addition to this, learning algorithms may also be applied to enhance the performance of FCM [7]. One role of FCM is to create an abstract mental model with the common interconnected aspects and actors of the simple models, so that to extend the range of application of the conventional local view of each system by using more abstract representation and general knowledge and adaptation heuristics and enhance the performance of the whole system. FCM replicates some of the knowledge and skills of the management team as it is built using a combination of knowledge representation techniques as causal models, logistics rules, and object hierarchies, and it is used to perform more demanding procedures, such as decision-making and planning, which are tasks that are usually performed by the management team [17], [18].

D. New Case Study

In this effort, enhanced models have been developed and illustrate how an FCM can be used to enhance project pursuit.

II. Methodology

Fuzzy cognitive mapping applied to the Opportunity Pursuit Process typically utilized by an Architect, Engineer, Constructor (AEC) in the heavy industrial construction industry can facilitate decision-making support. The two CM-FCM models we have developed for this paper to assist in opportunity pursuit assessment and capture execution are two examples of many that may be developed. There are numerous pursuit processes deployed throughout the heavy industrial construction industry by numerous organizations, however, we believe CM-FCM can be tailored to any pursuit process.

The CM-FCM-Pursuit model is designed to assist in screening or assessing opportunities in the early stages of the pursuit. The goal is to assist decision-makers with determining which possible pursuits should pass the first GO/NO-GO stage gate. Best Case and Worst Case Scenarios were generated to properly calibrate the model with linguistic variables (causal relationships) being set at 1 and -1, respectively. The confidence rating was then set to 100% for each linguistic variable. The linguistic variables used are displayed in Table I.

TABLE I
Linguistic Variables

LID	Relationship	Linguistic variables	central Weight
1	direct	fully positive	1.0
2	direct	highly positive	0.7
3	direct	positive	0.5
4	direct	weakly positive	0.1
5	none	neutral	0.0
6	inverse	weakly negative	-0.1
7	inverse	negative	-0.5
8	inverse	highly negative	-0.7
9	inverse	fully negative	-1.0

The new CM-FCM models build on the FCM for CM developed and presented earlier [4]. CM-FCM-Pursuit concepts are presented in Table II. Subject matter experts and experienced model developers developed the relationship assessments presented in Table III. Three scenarios were generated and reviewed with this model as described below.

- Scenario S01 - Familiar client and project technology type with experienced Project Manager and Construction Manager available for staffing the project

- Scenario S02 Familiar client and project technology type, however, the Contractor is so busy with work that an inexperienced Project Manager and an inexperienced Construction Manager are the only available resources for staffing the project
- Scenario S03 - New client and new project technology type with inexperienced Project Manager and inexperienced Construction Manager only available for staffing the project.

TABLE II
CM-FCM-PURSUIT CONCEPTS

CID	Concept
1	C01 - Client RFP Overall Rating
2	C10 - Client RFP Commercial Agreement T&C Rating
3	C20 - Client RFP Technical Information Assessment
4	E01 - PM Experience Rating
5	E02 - CM Experience Rating
6	E03 - Client Experience Rating
7	E04 - Client Experience Rating
8	E07 - Contractor Experience with Major Equipment
9	E99 - Overall Client Experience Rating
10	S99 - Likelihood of Project Success & Contract Award

TABLE III
CM-FCM-PURSUIT RELATIONSHIPS

CID_{in}	CID_o	Linguistic Variable
1	10	fully positive
2	1	fully positive
3	1	fully positive
4	10	fully positive
5	10	fully positive
6	9	fully positive
7	9	fully positive
8	1	fully positive
8	9	fully positive
8	10	fully positive
9	10	fully positive

The CM-FCM-Execute model assists in assessing opportunities in the later stages of the process. We focus on the capture execution phase after the opportunity passes the early stage gates performing screening and assessment. Best Case and Worst Case Scenarios were generated to properly calibrate the model with linguistic variables (causal relationships). The confidence ratings were all set to 83% for each linguistic variable. CM-FCM-Execute concepts are presented in Table IV. Subject matter experts and experienced model developers developed the relationship assessments presented in Table V. Three scenarios were generated and reviewed for the CM-FCM-Execute model as described below.

- Scenario S01 - The Request for Proposal (RFP) is provided to the contractor with a very compressed execution time line for the perspective project.
- Scenario S02 The RFP Contract Terms and Conditions (T&C) are rigorous even after negotiations. In this scenario, the execution time line was acceptable for the perspective project.

TABLE IV
CM-FCM-EXECUTE CONCEPTS

CID	Concept
1	P1.1 - Client Request For Proposal
2	P1.2 - Client RFP Commercial Agreement T&C
3	P1.3 - Client RFP Technical Information
4	P2.1 - Pre-Bid Site Visitation
5	P2.2 - Contractor Preliminary Conceptual Design
6	P2.3 - Contractor Experience Assessment with Client
7	P2.3.1 - Scoring of Past Project Experience with Client
8	P2.3.2 - Financial Review of Client
9	P2.4 - Contractor Project Manager Experience
10	P2.5 - Contractor Construction Manager Experience
11	P3.5 - Contractor Risk Assessment scoring 'go/no-go' decision
12	P4.1 - Direct Pricing
13	P4.2 - Indirect & GC Pricing
14	P4.3 - Favorable Contingency & Profit
15	P4.4 - Favorable Project Schedule
16	P5.1 - Negotiate High Risk Terms & Conditions
17	P5.2 - Negotiate Moderate Risk Terms & Conditions
18	P5.3 - Parties Success in Negotiation & Finalizing T&C

- Scenario S03 - The RFP Contract T&C are rigorous even after negotiation. In this scenario, the execution time line is compressed and the client relationship is found to be unacceptable for the perspective project.

TABLE V
CM-FCM-EXECUTE RELATIONSHIPS

CID_{in}	CID_o	Linguistic Variable
1	2	weakly positive
1	3	weakly positive
2	16	fully positive
2	17	fully positive
3	4	fully positive
4	5	fully positive
5	12	fully positive
5	15	fully positive
6	11	fully positive
7	6	fully positive
8	6	fully positive
9	11	highly positive
10	11	highly positive
12	11	fully positive
13	11	fully positive
14	11	fully positive
15	11	fully positive
16	11	fully positive
16	18	fully positive
17	11	fully positive
17	18	fully positive
18	11	fully positive
18	14	fully positive

III. RESULTS

Our results improved the analysis of the Pursuit process using the FCM-enhanced process and stage gates represented as GO/NO GO decision points. Mental Modeler software was utilized to analyze the FCM. Analysis in all cases was performed using hyperbolic tangent function setting. The resulting CM-FCM-Pursuit model is presented in Fig. 3. The resulting CM-FCM-Execute model is presented in Fig. 4.

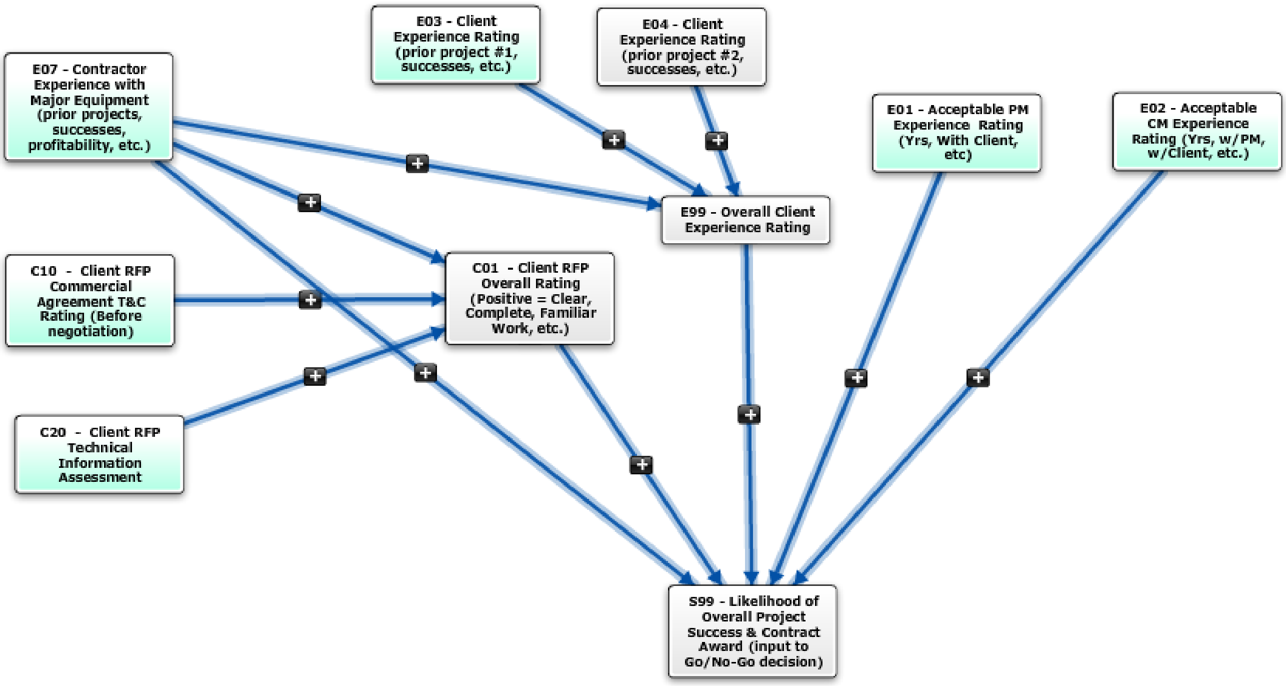

Fig. 3. CM-FCM Pursuit Model

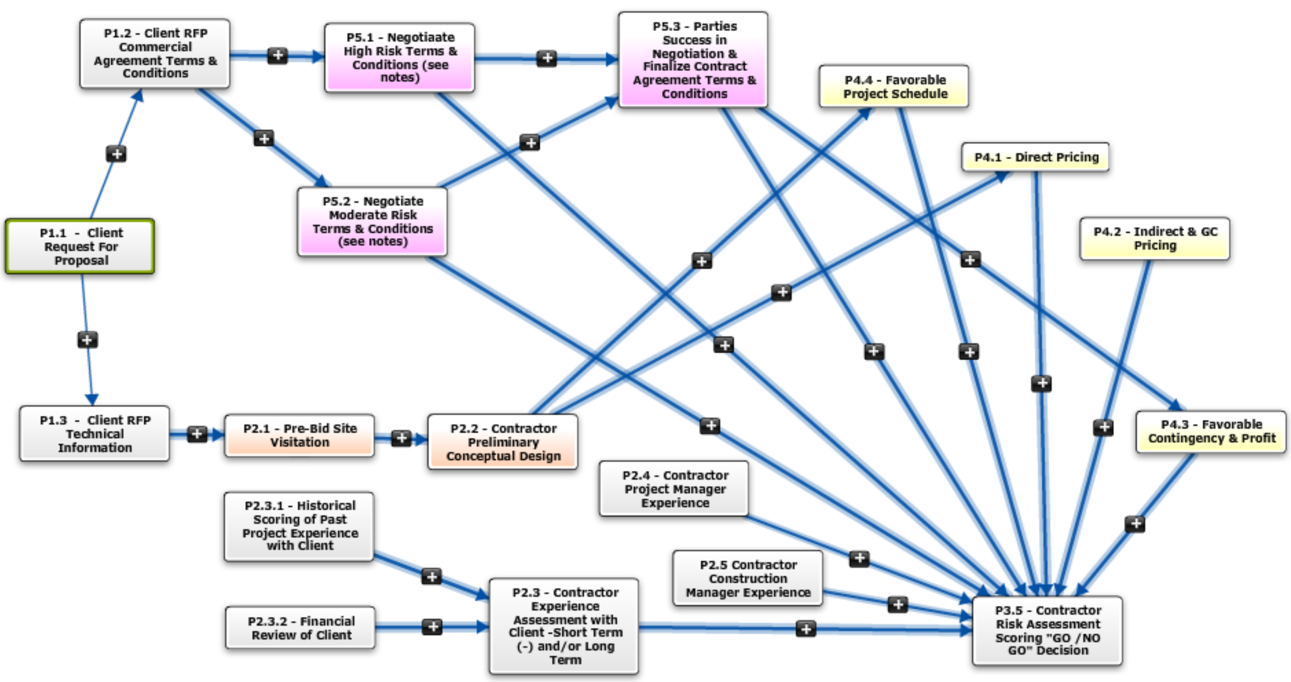

Fig. 4. CM-FCM Execute Model

Scenarios for CM-FCM-Pursuit						
Scenario ID (SID)	Familiar Client Concept E03 & E04	Acceptable PM Experience Level Concept E01	Acceptable CM Experience Level Concept E02	Overall Client Experience Rating Concept E99	Likelihood of Success Concept S99	Decision GO/NO-GO
S01	Yes	Yes	Yes	0.85	**0.97**	**GO**
S02	Yes	No	No	0.83	**0.74**	**GO**
S03	No	No	No	-0.84	-0.61	NO-GO

Notes:
1.) Concepts not mentioned in this table remained unchanged through each scenario.
2.) Confidence Ratings are set at 100%.

Fig. 5. Example CM-FCM Pursuit Scenarios

The CM-FCM-Pursuit model scenario results are shown in Fig. 5. The decision to push forward on an opportunity into the detailed capture execution stage was determined by concept S99, 'Likelihood of Success'. If concept S99 scored above a zero in the positive range a GO was decided. On the contrary, if concept S99 scored less than zero in the negative range a NO-GO would be decided and the opportunity would be abandoned.

Example execute scenarios are shown in Fig. 6. The decision to push forward into a contract agreement is supported by concept P3.5, 'Contractor Risk Assessment Scoring'. If concept P3.5 scored above a zero in the positive range a GO was decided. On the contrary, if concept P3.5 scored less than zero in the negative range a NO-GO would be decided and the opportunity would be abandoned.

The insights gained during the review of these two models provided clarity and statistical analysis to support the CIP in their decision process.

Scenarios for CM-FCM-Execute							
SID	Favorable Project Schedule	Reasonable Contract Agreement Terms & Conditions	Bad Client Rating and Relationship	Contractor Experience Assessment Concept P2.3	Parties Success in Negotiations Concept P5.3	Contractor Risk Assessment Scoring Concept P3.5	Decision GO/NO-GO
S01	No	Yes	No	0.49	-0.18	**0.49**	**GO**
S02	Yes	No	No	0.91	-0.85	**0.99**	**GO**
S03	No	No	Yes	-0.15	-0.81	-0.39	NO-GO

Notes:
1.) All confidence levels on causal relationships are set at 83%.
2.) All linguistic values on causal relationships are set at a value of 1 to establish the best case.

Fig. 6. Example CM-FCM Execute Scenarios

IV. Conclusion

Fuzzy Cognitive Map modeling has great potential within the construction industry for modeling complex and uncertain aspects of project opportunities. Here two fuzzy cognitive map models were developed to assist in construction management, one modeling the pursuit process and one modeling the execute process. Various scenarios were run for both processes that proved the efficacy of the proposed CM-FCM modeling to provide decision support. Proposed models include cycles of interactions for simplicity reasons and we are planning to further expand the modes so that to include feedback loops that create dynamic models. Construction industry practitioners need more robust tools to put into practice but this will requires further investigation and it remains an open field. In our short term investigations, we will develop additional scenarios and test the proposed models against a range of situations and provide additional results. Our later future work will focus on integrating the CM-FCM models with the financial forecasting of the pursuit and the on-going project execution phase.

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