A Model for Enterprise Architecture Scenario Analysis Based on Fuzzy Cognitive Maps and OWA Operators

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Abstract*—Enterprise architecture makes the connection between enterprise goals, processes and IT systems. These connections represented in causal models can be used to enhance decision making on enterprise-wide issues. This paper describes a new framework for enterprise architecture decision making based on enterprise modeling, fuzzy cognitive mapping and the ordered weighted averaging (OWA) operators. The proposal makes use of causal relations modeling using fuzzy cognitive maps. An OWA operator based on distance are used to rank the scenarios dependent upon the decision makers risk preferences. The model aims to extend the enterprise architecture analysis toolbox, enabling more powerful tools for scenario analysis. A case study showing information systems selection is provided in conjunction with future research directions.

Keywords*: enterprise architecture, enterprise modeling, fuzzy cognitive maps, OWA operator, scenario analysis.***

I. INTRODUCTION

Enterprise Architecture (EA) [1] has received much attention recently in the information systems community. Decisions in EA are difficult due to the interdependencies among the many organizational components. These links expressed in models could be used for decision making purposes.

This paper presents a framework that integrates enterprise modeling, fuzzy cognitive maps and ordered weighted averaging (OWA) operators based on distance [2]. The proposal allows identification, analysis, and ranking of EA future scenarios.

The outline of this paper is as follows: Section II is dedicated to enterprise architecture and enterprise modeling, Section III to fuzzy cognitive maps and Section IV to OWA operators. The proposed framework is presented in Section V. A case study is discussed in Section VI. The paper closes with concluding remarks, and discussion of future work in Section VII.

II. ENTERPRISE ARCHITECTURE AND ENTERPRISE MODELLING

EA promotes the use of models for decision making on enterprise-wide issues [3]. A number of EA frameworks have been proposed, such as the Zachman Framework [4] and TOGAF [1]. EA makes the connection between enterprise goals and the business functions, processes, people, IT systems and infrastructure required to reach these goals.

Enterprise modeling (EM) is a central topic in EA. The first approaches to EM were focused on software development, but recently have been more widely applied [5], for example in business intelligence [6], organizational transformation [7], and knowledge management [8].

Enterprise models should permit the deployment of advanced analysis methods to facilitate rational decision making. However, EA models typically provide only visual and qualitative decision support [9].

For enterprise modeling, an abstract model is an EA metamodel containing entities and entity relations, augmented with attributes and causal relations between attributes [10]. A concrete model is an instantiation of an abstract model, much in the same way that an object model is an instantiation of a class model in object-oriented modeling [11]. This way causal modeling can be integrated in EM [12, 13].

III. FUZZY COGNITIVE MAPS

A fuzzy cognitive map(FCM) [14] is a cognitive map that can be used to model and simulate complex systems. It incorporates ideas from artificial neural networks and fuzzy logic [15]. In FCMs causal relationships between nodes are fuzzy numbers.

There are three possible types of causal relationships between concepts:

$W_{ij} > 0$, which indicates positive causality between concepts C_i and C_j. That is, the increase (decrease) in the value of C_i leads to the increase (decrease) in the value of C_j.

$W_{ij} < 0$, which indicates negative causality between concepts C_i and C_j. That is, the increase (decrease) in the value of C_i leads to the decrease (increase) in the value of C_j.

$W_{ij} = 0$, which indicates no relationship between C_i and C_j

The value of a concept is calculated at each simulation step, computing the influence of the interconnected concepts to the specific concept according to the following calculation rule:

$$A_i^{(K+1)} = f\left(A_i^{(K)} + \sum_{j=1, j\neq i}^{n} A_i^{(K)} \cdot W_{ji}\right) \quad (1)$$

where $A_i^{(K+1)}$ is the state of the node i at the instant K+1, W_{ji} is the weight of the influence of j node over the i node, and f(x) is the activation function. The calculation halts if an equilibrium state is reached. The final vector reflects the state of the FCM nodes after system intervention [16]. After the inference process, the FCM will reach three possible states; a fixed point attractor, when a repeating state occur; a limit cycle, when a few states keep repeating forming a cycle; and a chaotic attractor when the states have different values with each step [17].

Scenario analysis helps to identify different alternatives to attain a future state. It is a strategic planning method to make flexible planning, often used in enterprise-wide technology management. FCM have been recently used for scenario analysis [18-20]. One of the main shortcomings in scenario analysis with FCM is the lack of quantitative analysis of results for ranking of alternatives [20]. Salmeron, Vidal y Mena propose a methodology integrating FCM and multicriteria (TOPSIS) techniques [16], but it lacks the possibilities to model the degree of risk acceptance, an important topics in decision making [21] .

Bayesian networks have been used for causal inference in EA [12], but FCM provides a more flexible and more realistic representation scheme for dealing with knowledge [22]. By using FCMs we get also the benefits of visual modeling simulation and prediction [23]. FCM also offers the modeling mechanism for linking the strategic goals with the Object Oriented models [24].

IV.OWA OPERATOR.

The OWA operators were introduced by R.R. Yager [25] as a conceptually simple, however extremely powerful general aggregation operator. An OWA operator of dimension n is a mapping OWA: $R^n \rightarrow R$ that have an associated weighting vector W of dimension n, having the properties: $w_{ij} \in [0, 1]$, $\sum_{j=1}^{n} w_j = 1$, and such that,

$$OWA(a_1, a_2, \ldots, a_n) = \sum_{j=1}^{n} w_j b_j \quad (2)$$

where b_j es el jth largest of the a_i

The ordered weighted averaging distance (OWAD) [2] is an extension of the distances measures by using OWA operators. The main difference is the reordering of the individual distances according to their values.

An OWAD operator of dimension n is a mapping: OWAD: $R^n \rightarrow R$ that has an associated weighting vector, such that $\sum_j^n w_j = 1$ and $w_j \in [0,1]$. Then, the distance between two sets A and B,

$$OWAD(A, B) = \sum_{j=1}^{n} w_j D_j \quad (3)$$

where D_j is the j th largest of the d_i and d_i is the individual distance between A and B.

Yager introduced a measure of orness, associated with any weight vector [26]. Orness can be formulated in two different forms depending on the type of ordering used for descending form:

$$orness(W) = \sum_{j=1}^{n} \frac{(n-j)w_j}{n-1} \quad (4)$$

and for the ascending form :

$$orness(W) = \sum_{j=1}^{n} \frac{(j-1)w_j}{n-1} \quad (5)$$

The Yager‘s definition of the orness measure for OWA [27], can be interpreted as a degree of risk acceptance. Decision maker risk attitudes can be then encoded in the form of OWA operators.

V.PROPOSED FRAMEWORK

The following three steps will be used to establish a framework for EA scenario analysis (Fig. 1).

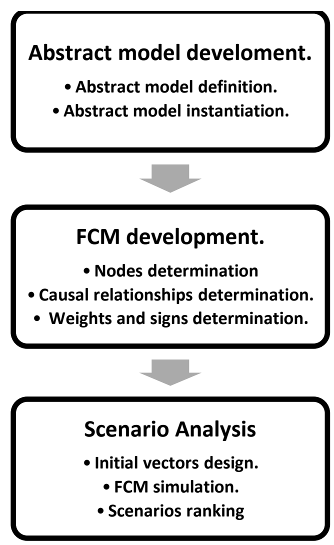

Figure 1. Proposed framework

5.1 Abstract model development.

An abstract model suitable for modeling the aspects of the interest is defined. The purpose is to create EA models that can be used for the analysis of the enterprise. Instantiating the abstract model in a concrete model is the second step. The concrete models contain the EA scenarios with visual information suitable for human consumption.

5.2 FCM development.

This activity aims to aggregate the causal knowledge acquired from various sources to develop a comprehensive FCM, which will represent the understanding about causal relations between EA elements depicted in the concrete model. These elements become FCM nodes. There are basically three sources of knowledge to construct the causal model: scientific literature, experts and empirical data. More about FCM construction from these sources of knowledge can be found in [28]. This activity includes steps for the determination of nodes, causal relationship, and its weights and signs.

5.3 Scenario Analysis.

A Stimulus vector (E), is designed for each EA scenario. It represents the initial value of each node in the scenario. The simulation of the scenarios with the FCM are run with the outcome in the form of concepts being 'activated' at different levels after reaching equilibrium. The suitability of each scenario is evaluated through a distance calculation based in OWAD operator between the vector (R), with the values of the nodes of the output layer [29] in the fixed-point attractor, and the ideal vector (I) . The ideal vector is denoted as:

$$\mathrm{I} = \left\{\left(v_j = 1 \middle| j \in \mathrm{I}^+\right), \left(v_j = -1 \middle| j \in \mathrm{I}^-\right)\right\} \\ =[v_1, v_2, \ldots, v_m] \quad (6)$$

I^+ and I^- are the node sets of the benefit and cost type, respectively of the output layer nodes. The alternatives are ranked based in the value of this distance.

VI. CASE STUDY

The case study is based in an information technologies consulting organization. Archimate 1.0 [30] was the modeling language chosen for the concrete model because of its simplicity, expressive power and tool support. Archimate 1.0 lacks concepts for representing goals, but the concept Business Object is used, to represent it.

The abstract model proposed is shown in Fig 2. It represents the goals, business processes, and IS options of the organization.

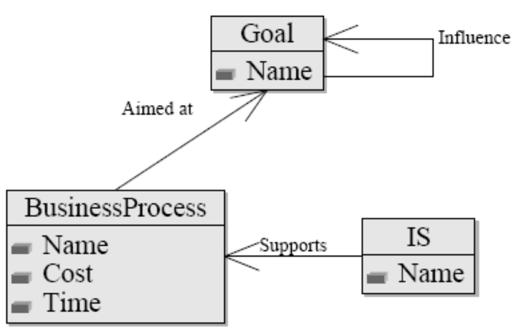

Figure 2. Abstract model.

The abstract model is then instanced in the concrete model (Fig. 3). The concrete model represents the relation among goals, process and IS options.

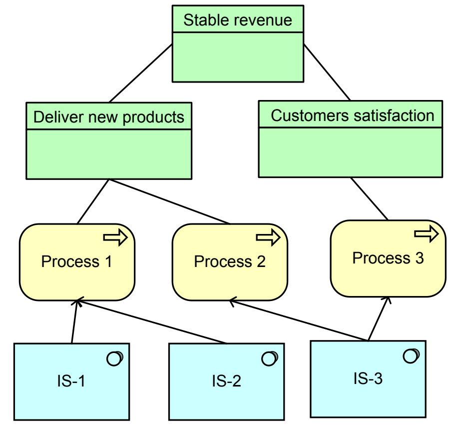

Figure 3. Concrete model example

In this case study it is considered that the goals, process attributes and information systems options correspond to nodes. The FCM in this case is composed of 12 nodes, which are shown in Table I.

TABLE I. FCM NODES

Node	Description
X_1	Increase profit
X_2	Increase market share
X_3	Increase customer satisfaction
X_4	Process 1 cost
X_5	Process 1 time
X_6	Process 2 cost
X_7	Process 2 time
X_8	Process 3 cost
X_9	Process 3 time
X_{10}	Information system 1.
X_{11}	Information system 2
X_{12}	Information system 3

The FCM is developed integrating knowledge from experts. The FCM with weighs and the output layer is represented in Fig. 4.

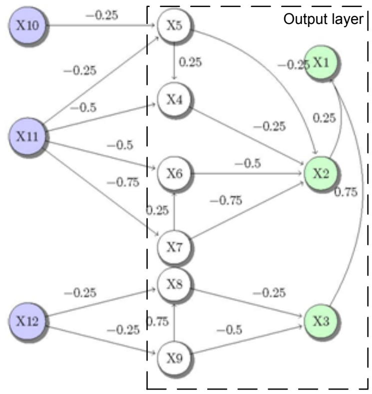

Figure 4. Fuzzy Cognitive Map with Weights

The activation function chosen in this case is hyperbolic tangent function,

$$F(x) = \tanh(\lambda X), \lambda = 1 \quad (7)$$

The hyperbolic tangent function, makes possible that components of the vector acquire negative values [31]. The ideal vector is defined in this case study as follow: I = [1, 1, 1, −1, −1, −1, −1, −1, −1]. The distance measurements are calculated with the OWAD operator (3) using the Euclidian distance between vectors R and I. The weight vector of the OWA operator is W=[0.001, 0.01, 0.026, 0.051, 0.084, 0.125, 0.174, 0.232, 0.298], with orness= 0.778.

Scenario with project 1 active is represented by de initial vector C = [0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0]. The scenarios represent different combinations of IS, with the restriction that we could not invest in the three IS at period of time analyzed. Different scenarios simulated and the $OWAD(R, I)$ (3) for each of them is calculated (Table III).

TABLE II. FCM SCENARIOS

Scenario	Stimulus Vector	OWAD(R, I)
S_1	[0,0,0,0,0,0,0,0,0,0,0,1]	0.9289
S_2	[0,0,0,0,0,0,0,0,0,0,1,0]	0.7928
S_3	[0,0,0,0,0,0,0,0,0,0,1,1]	0.2642
S_4	[0,0,0,0,0,0,0,0,0,1,0,0]	0.979
S_5	[0,0,0,0,0,0,0,0,0,1,0,1]	0.8022
S_6	[0,0,0,0,0,0,0,0,0,1,1,0]	0.7927

The ranking of the scenarios is as follow: $S_3 \succ S_6 \succ S_2 \succ S_5 \succ S_1 \succ S_4$. According this the result scenario 3 (S3) is the closest to the ideal vector. The result shows as the best scenario is to invest in information systems 2 and 3. Recommended EA future state is shown in Fig 5.

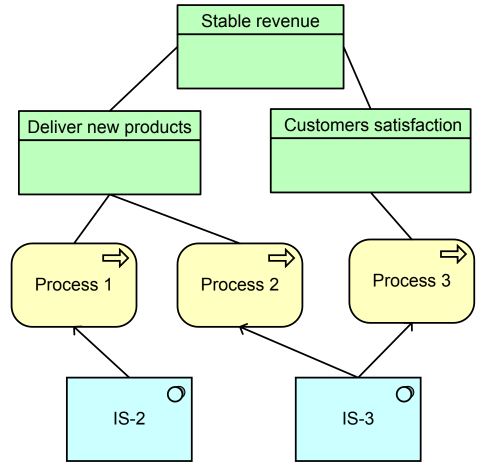

Figure 5. EA future state

The case study showed the aplicability of the proposal. The experts found that FCM offers great flexibility for representing causality. The interpretavility of the models compared with Bayesian networks aproaches [32] is another strength detected. Additionally The causal model obtained can be usefull for future decision suppor systems and knowedge management sytem develoment .

VII. CONCLUSIONS

Interdependency among the many organizational components makes decisions difficult. This paper shows a new framework for EA scenario analysis based on enterprise modeling, FCM and OWA operators. It allows decision makers to rank EA scenarios in a flexible way. A case study confirms that it is a worthy proposal.

Future research will focus on conducting further real life experiments to test and promote the proposed framework. Other areas of future work are the combination with genetic algorithm when the search space is large, and the development of a tool to automate the process. The use of the computing with words (CWW) paradigm is another area of future research.

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