A Strategic Benchmarking Process for Identifying the Best Practice Collaborative Electronic Government Architecture

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ABSTRACT

The rapid growth of the Internet has given rise to electronic government (e-government) which enhances communication, coordination, and collaboration between government, business partners, and citizens. An increasing number of national, state, and local government agencies are realizing the benefits of e-government. The transformation of policies, procedures, and people, which is the essence of e-government, cannot happen by accident. An e-government architecture is needed to structure the system, its functions, its processes, and the environment within which it will live. When confronted by the range of e-government architectures, government agencies struggle to identify the one most appropriate to their needs. This paper proposes a novel strategic benchmarking process utilizing the simple additive weighting method (SAW), real options analysis (ROA), and fuzzy sets to benchmark the best practice collaborative e-government architectures based on three perspectives: Government-to-Citizen (G2C), Government-to-Business (G2B), and Government-to-Government (G2G). The contribution of the proposed method is fourfold: (1) it addresses the gaps in the e-government literature on the effective and efficient assessment of the e-government architectures; (2) it provides a comprehensive and systematic framework that combines ROA with SAW; (3) it considers fuzzy logic and fuzzy sets to represent ambiguous, uncertain or imprecise information; and (4) it is applicable to international, national, Regional, state/provincial, and local e-government levels.

Keywords: *Collaborative E-Government Architecture, Fuzzy Sets, Real Options Analysis, Simple Additive Weighting Method, Strategic Benchmarking*

INTRODUCTION

Electronic government (e-government) is "the use of technology, particularly the Internet, to enhance the access to and delivery of government information and services to citizens, businesses, government employees, and other agencies" (Hernon et al., 2002, p. 388). E-government is a dynamic concept that has had an enormous impact on the efficient and effective delivery of government services to citizens, business partners, and other government

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entities in a very short period of time (Davies, 2002; Reylea, 2002). In spite of the newness of the concept, e-government has transformed government structures by providing opportunities to: (1) increase operational efficiency by reducing costs and increasing productivity; and (2) increase operational effectiveness by providing better quality of services. E-government promises better government including improved quality of services, cost savings, wider political participation, and more effective policies and programs (Garson, 2004; Bourquard, 2003; Gartner, 2000).

One of the primary objectives of e-government is to make the government and its policies more effective by providing citizens with efficient access to public information (Heeks, 2003; Prins, 2001). The increase in efficiency has strengthened the quality of government services to citizens and the business sector (Millard, 2006; Relyea, 2002). E-government has also fortified democracy and reduced the distance between citizens and government (Macintosh et al., 2003).

E-governments services represent different levels of technological sophistication and administrative challenges (Holden et al., 2003; Moon, 2002; Schelin, 2003). Several empirical studies have identified a dynamic progression in e-government sophistication from national to state to local governments (Edmiston, 2003; Stowers, 1999; West, 2005). Generally, e-government initiatives at the national level have both the financial resources and the technical expertise to move toward more sophisticated systems while they have the least direct democratic control from citizens, businesses, and other government entities. However, during the past decade, more and more state and local governments have started to embrace e-government.

The e-government architecture could be defined as the structure of what is built, its functions, the environment within which it will live, and the processes by which it will be built and operated (Rechtin, 1991; Maier, 1998). This architecture includes standards, infrastructure components, applications, technologies, business model and guidelines for electronic interactions among and between government organizations, and other consumers (Ebrahim & Irani, 2005). Being a relatively new research area, e-government architecture and adoption strategies have not been widely discussed in the literature (Zarei & Ghapanchi, 2008).

Government operates on three different levels: government to business (G2B), government to citizens (G2C), and government to government (G2G). In these cases, the relationship between the two parties is two-fold. G2B designates interactions that originate with government as well as business. Similarly, G2C designates interactions between government and citizens. G2G comprises all interactions within and between government agencies. Table 1 presents a summary of the three e-government relationship models.

Reddick (2004) has examined the three different government relationship models in U.S. cities. According to Reddick (2004), the G2C relationship shows that e-government is primarily providing an online presence for cities while the e-government is more developed when it comes to G2G use of Intranets for government employees. However, the most advancement has occurred in G2B in the case of online procurement of office supplies and equipment.

Evaluating e-government is an important research agenda and the lack of formal methods for assessing best practice e-government architectures has led to a significant slowdown of e-government development at the national, state, and local levels (Kunstelj & Vintar, 2004). In addition, the current approaches to identifying best practice e-government architectures do not support comprehensive assessment and need to be further improved in order to give policymakers better evaluation frameworks to support their decisions (Kunstelj & Vintar, 2004). The evaluation of the e-government architectures can identify strengths, weaknesses, and best practices for both national and local integration (Esteves & Joseph, 2008).

The evaluation of e-government architectures is conducted either as an ex-ante (before

Table 1. Summary of e-government relationship models

	E-Government Portfolio		
	G2B	**G2C**	**G2G**
Goal	Reduce the burden on businesses by adopting processes that enable collecting data once for multiple uses & streamlining redundant data	Use the web for accessing services such as benefits, loans, recreational sites & educational material	Share & integrate state & local data
Key lines of business	Regulation, economic development, trade, permits/licenses, grants/loans, asset management	Social services, recreation & natural resources, grants/loans, taxes	Economic development, recreation & natural resources, public safety, law enforcement, disaster response management, grants/loans

implementation) or ex-post (after implementation). In this study, we present an ex-ante framework for identifying the best practice e-Government architecture. We propose a strategic benchmarking process that utilizes the simple additive weighting method (SAW), real options analysis (ROA), and fuzzy sets to benchmark the best e-government architecture based on the G2C, G2B, and G2G perspectives.

The remainder of this paper is organized as follows. The next section presents the literature review on ROA analysis and fuzzy sets. We follow this literature review with a presentation of our mathematical notations and definitions. Next, we present the details of the proposed framework. We then present a case study to demonstrate the applicability of the proposed framework and exhibit the efficacy of the procedures and algorithms. The paper will conclude with conclusions and future research directions.

LITERATURE REVIEW OF ROA AND FUZZY SETS

The Fuzzy Logic

The SAW method is one of the best known and the most widely used multi-attribute decision making methods (Hwang & Yoon, 1981). Using the SAW method, a rank-ordered list of alternatives is generated based on the attribute weights (Chen & Hwang, 1992). A pitfall of the SAW method is the need for precise measurement of the performance ratings and criteria weights (Yoon & Hwang, 1995). However, in many real-world problems, ratings and weights cannot be measured precisely as some policy makers may express their judgments using linguistic terms such as low, medium and high (Chen, 2000; Tsaur et al., 2002; Zadeh, 1975). Fuzzy set theory is ideally suited for handling ambiguity encountered in e-government architecture assessment projects. Since Zadeh (1965) introduced fuzzy set theory, and Bellman and Zadeh (1970) described the decision making method in fuzzy environments, an increasing number of studies have dealt with uncertain fuzzy problems by applying fuzzy set theory (Zimmerman, 1991; Yager, 1977). According to Zadeh (1975), it is very difficult for conventional quantification to reasonably express complex situations and it is necessary to use linguistic variables whose values are words or sentences in a natural or artificial language.

The Real Options Analysis

A review of the current literature offers several e-government evaluation methods that provide frameworks for the quantification of risks and benefits. The net present value (NPV), return on investment (ROI), cost benefit analysis (CBA), information economics (IE) and return

on management (ROM) are among most widely used methods to assess the risks and payoffs associated with e-government initiatives. In addition to the above mentioned traditional quantitative approaches, there is a stream of research studies which emphasizes ROA. The ROA differs from the traditional methods in terms of priceability of the underlying project (McGrath, 1997). With the traditional methods, the underlying value of an option is priced as known (Black & Scholes, 1973) while in technology-based investment projects the price of an underlying investment is rarely known (McGrath, 1997). The ROA uses three basic types of data: (1) current and possible future investment options, (2) the desired capabilities sought by the government, and (3) the relative risks and costs of other e-government initiatives that could be used. The method can help assess the risks associated with e-government architectures by taking into consideration the changing nature of government strategies and requirements.

Real options are commonly valued with the Black-scholes option pricing formula (Black & Scholes, 1973). When valuating an e-government initiatives using ROA, it is required to estimate several parameters (i.e. expected payoffs and costs or deferral time). However, the estimation of uncertain parameters in this valuation process is often very challenging. Most traditional methods use probability theory in their treatment of uncertainty. Fuzzy logic and fuzzy sets can represent ambiguous, uncertain or imprecise information in ROA by formalizing inaccuracy in human decision-making (Collan et al., 2009). For example, fuzzy sets allow for graduation of belonging in future cash-flow estimation (i.e. future cash flow at year 5 is about 5000 dollars). Fuzzy set algebra developed by Zadeh (1965) is the formal body of theory that allows the treatment of imprecise estimates in uncertain environments.

In recent years, several researchers have combined fuzzy set theory with ROA. Carlsson and Fullér (2003) introduced a (heuristic) real option rule in a fuzzy setting, where the present values of expected cash flows and expected costs are estimated by trapezoidal fuzzy numbers. Tao et al. (2007) developed a comprehensive but simple methodology to evaluate technology-based investment in a nuclear power station based on fuzzy risk analysis and a real option approach. Frode (2007) used the conceptual real option framework of Dixit and Pindyck (1994) to estimate the value of investment opportunities in the Norwegian hydropower industry. Villani (2008) combined two successful theories, namely real options and game theory, to value the investment opportunity and the value of flexibility as a real option while analyzing the competition with game theory. Collan et al. (2009) presented a new method for real option valuation using fuzzy numbers. Their method considered the dynamic nature of the profitability assessment, that is, the assessment changes when information changes. As cash flows taking place in the future come closer, information changes, and uncertainty is reduced. Chrysafis and Papadopoulos (2009) presented an application of a new method of constructing fuzzy estimators for the parameters of a given probability distribution function using statistical data. Wang and Hwang (2007) developed a fuzzy research and development portfolio selection model to hedge against the environmental uncertainties. They applied fuzzy set theory to model uncertain and flexible project information. Since traditional project valuation methods often underestimate a risky project, a fuzzy compound-options model was used to evaluate the value of each project. Their portfolio selection problem was formulated as a fuzzy zero–one integer programming model that could handle both uncertain and flexible parameters and determine the optimal project portfolio. A new transformation method based on qualitative possibility theory was developed to convert the fuzzy portfolio selection model into a crisp mathematical model from the risk-averse perspective. The transformed model was solved by an optimization technique.

THE MATHEMATICAL NOTATIONS AND DEFINITIONS

Let us introduce the following mathematical notations and definitions:

$c_j(c)$ The jth strategic G2C criterion

$c_j(b)$ The jth strategic G2B criterion

$c_j(g)$ The jth strategic G2G criterion

A_i The ith e-government architecture

p_1 The number of the e-government architecture strategic G2C criteria

p_2 The number of the e-government architecture strategic G2B criteria

p_3 The number of the e-government architecture strategic G2G criteria

l The number of the e-government steering committee (SC) members

n The number of alternative e-government architectures

$\tilde{a}_{ij}^k(c)$ The fuzzy ordinal rank of the ith e-government architecture with respect to the jth strategic G2C criterion evaluated by the e-government SC member $(e-Gv)_k$

$\tilde{a}_{ij}^k(b)$ The fuzzy ordinal rank of the ith e-government architecture with respect to the jth strategic G2B criterion evaluated by the e-government SC member $(e-Gv)_k$

$\tilde{a}_{ij}^k(g)$ The fuzzy ordinal rank of the ith e-government architecture with respect to the jth strategic G2G criterion evaluated by the e-government SC member $(e-Gv)_k$

$Br(E[\tilde{a}_{ij}(c)])$ The Borda score for the possibilistic mean value of the ith e-government architecture with respect to the jth strategic G2C criterion

$Br(E[\tilde{a}_{ij}(b)])$ The Borda score for the possibilistic mean value of the ith e-government architecture with respect to the jth strategic G2B criterion

$Br(E[\tilde{a}_{ij}(g)])$ The Borda score for the possibilistic mean value of the ith e-government architecture with respect to the jth strategic G2G criterion

$w(c)$ The importance weight of the G2C perspective

$w(b)$ The importance weight of the G2B perspective

$w(g)$ The importance weight of the G2G perspective

$w_j(c)$ The importance weight of the jth e-government architecture strategic G2C criterion

$w_j(b)$ The importance weight of the jth e-government architecture strategic G2B criterion

$w_j(g)$ The importance weight of the jth e-government architecture strategic G2G criterion

$w(v)_k$ The voting power of the e-government SC member $(e-GB)_k$ for scoring ($k=1,2,\ldots,l$)

$v_i(c)$ The weight of the ith e-government architecture based on the G2C perspective

$v_i(b)$ The weight of the ith e-government architecture based on the G2B perspective

$v_i(g)$ The weight of the ith e-government architecture based on the G2G perspective

$FROV_i(T_j)$ The fuzzy real option value of the ith e-government architecture at time T_j

$\tilde{A}_{FROV}$ The fuzzy real option value matrix of the e-government architectures

$\tilde{B}_i(T_j)$ The weighted collective fuzzy present value of the expected payoffs of the ith e-government architecture at time T_j

$\tilde{C}_i\left(T_j\right)$ The weighted collective fuzzy present value of the expected cost of the ith e-government architecture at time T_j

$\tilde{B}_i^k$ The individual fuzzy present value of the expected payoffs of the ith e-government architecture at time T_j evaluated by the e-government SC member $\left(e-Gv\right)_k$

$\tilde{C}_i^k$ The individual fuzzy present value of the expected cost of the ith e-government architecture at time T_j evaluated by the e-government SC member $\left(e-Gv\right)_k$

$E\left(\tilde{B}_i\left(T_j\right)\right)$ The possibilistic mean value of the weighted collective present value of expected payoffs of the ith e-government architecture at time T_j

$E\left(\tilde{C}_i\left(T_j\right)\right)$ The possibilistic mean value of the weighted collective expected costs of the ith e-government architecture at time T_j

$\left(\sigma^2\left(T_j\right)\right)_i$ The variance of the weighted collective fuzzy present value of expected payoffs of the ith e-government architecture at time T_j evaluated by the e-government SC member $\left(e-Gv\right)_k$

δ_i The value loss over the duration of the option

r_i The risk-free interest rate

$N\left(D_{1i}\left(T_j\right)\right)$ The e-government architecture i^{th} cumulative normal probability distribution for the D_1

$N\left(D_{2i}\left(T_j\right)\right)$ The e-government architecture i^{th} cumulative normal probability distribution for the D_2

T_m The maximum deferral time of the e-government architectures

T_1 The minimum deferral time of the e-government architectures

THE PROPOSED FRAMEWORK

The framework depicted in Figure 1 is proposed to assess the alternative e-government architectures. The framework consists of several phases, processes and steps.

Phase 1. Prioritizing the e-Government Architectures

In this phase, the SAW method and the fuzzy Borda's approach are used to prioritize the collaborative e-government architectures based on the G2C, G2B, and G2G perspectives. This phase is divided into the following four processes.

Process 1.1. Prioritizing the e-Government Architectures Based on the G2C Perspective

In this process, we evaluate the interactions and transactions between the citizens and the government in the e-government architectures based on the strategic G2C criteria. The goal is to build user-friendly one-stop shop for high-quality government e-service. This process is divided into the following six steps.

Step 1.1.1. Establishing the e-government steering committee

In this step, we establish an e-government SC with l members to participate in the evaluation process.

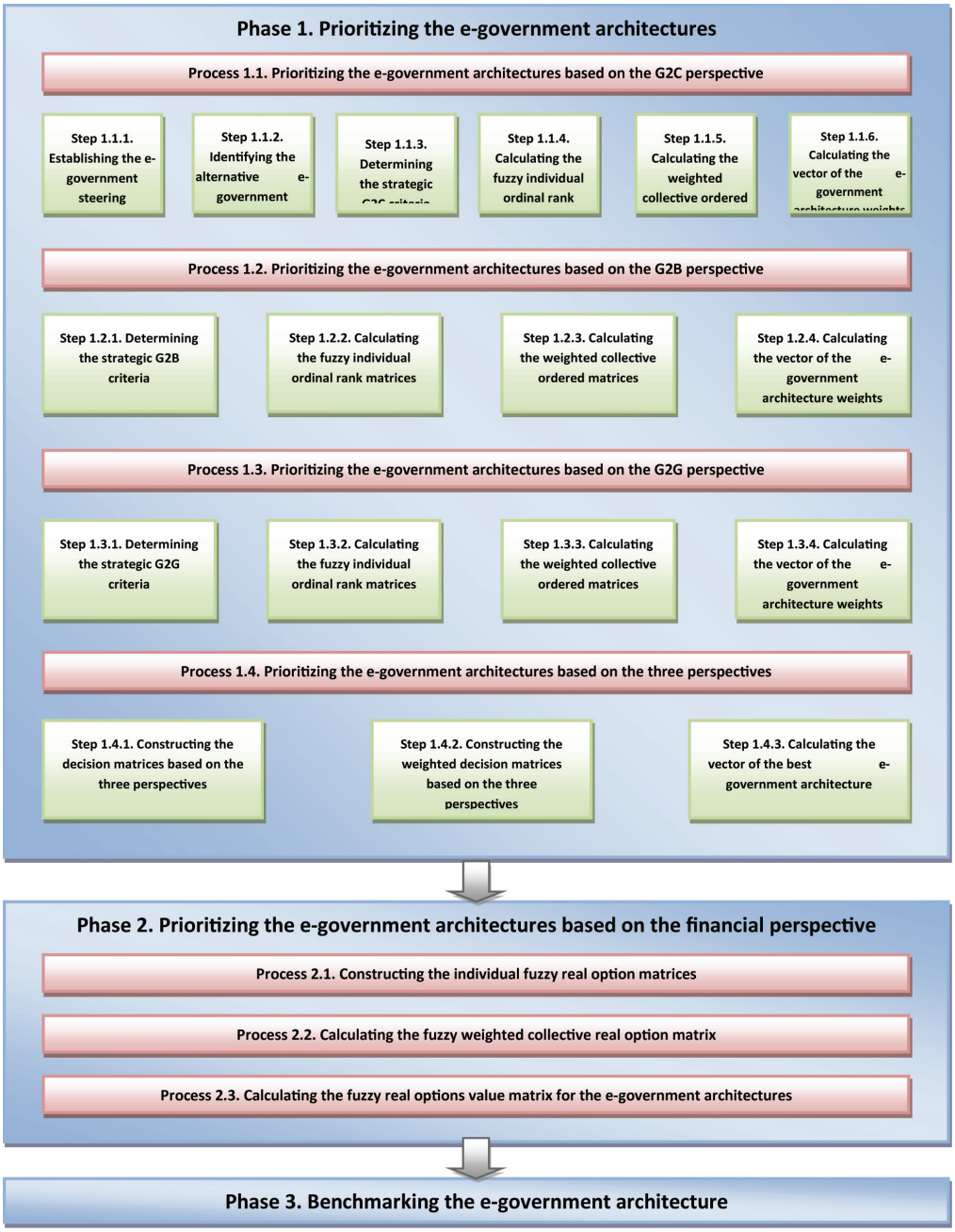
$$\underline{e-Gv}=[(e-Gv)_1,(e-Gv)_2,\ldots,(e-Gv)_l]$$

Step 1.1.2. Identifying the alternative e-government architectures

In this step, the e-government SC identifies *n* alternative e-government architectures with the maximum deferral time of T_m.

$$\underline{A}=[A_1,A_2,\ldots,A_n]$$

Figure 1. The proposed framework



Step 1.1.3. Determining the strategic G2C Criteria

In this step, the e-government SC determines $c_1(c), c_2(c), \ldots, c_{p_1}(c)$ as the strategic G2C criteria.

Step 1.1.4. Calculating the fuzzy individual ordinal rank matrices

The fuzzy individual rank matrix of the e-government architectures evaluated by the e-government SC member $(e-Gv)_k$ will be as follows: (See Box 1).

or:

$$(\tilde{D}(C))^k = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_n \end{array} \begin{array}{c} \begin{array}{cccc} c_1(c) & c_2(c) & \cdots & c_{p_1}(c) \end{array} \\ \begin{bmatrix} \tilde{a}^k_{11}(c) & \tilde{a}^k_{12}(c) & \cdots & \tilde{a}^k_{1p_1}(c) \\ \tilde{a}^k_{21}(c) & \tilde{a}^k_{22}(c) & \cdots & \tilde{a}^k_{2p_1}(c) \\ \vdots & \vdots & \cdots & \vdots \\ \tilde{a}^k_{n1}(c) & \tilde{a}^k_{n2}(c) & \cdots & \tilde{a}^k_{np_1}(c) \end{bmatrix} \end{array} \tag{2}$$

Consequently, we have the following matrix for each strategic G2C criterion, $c_j(c)$:

$$\tilde{D}_j(C) = \begin{array}{c} A_1 \\ A_2 \\ \vdots \\ A_n \end{array} \begin{bmatrix} \tilde{a}^1_{1j}(c) & \tilde{a}^2_{1j}(c) & \cdots & \tilde{a}^l_{1j}(c) \\ \tilde{a}^1_{2j}(c) & \tilde{a}^2_{2j}(c) & \cdots & \tilde{a}^l_{2j}(c) \\ \vdots & \vdots & \cdots & \vdots \\ \tilde{a}^1_{nj}(c) & \tilde{a}^2_{nj}(c) & \cdots & \tilde{a}^l_{nj}(c) \end{bmatrix} \tag{3}$$

Step 1.1.5. Calculating the weighted collective ordered matrix

Next, we determine the Borda's score with respect to p_1 strategic G2C criteria:

$$\tilde{B}r(C) = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_n \end{array} \begin{array}{c} \begin{array}{cccc} c_1(c) & c_2(c) & \cdots & c_{p_1}(c) \end{array} \\ \begin{bmatrix} Br(E[\tilde{a}_{11}(c)]) & Br(E[\tilde{a}_{12}(c)]) & \cdots & Br(E[\tilde{a}_{1p_1}(c)]) \\ Br(E[\tilde{a}_{21}(c)]) & Br(E[\tilde{a}_{22}(c)]) & \cdots & Br(E[\tilde{a}_{2p_1}(c)]) \\ \vdots & \vdots & \cdots & \vdots \\ Br(E[\tilde{a}_{n1}(c)]) & Br(E[\tilde{a}_{n2}(c)]) & \cdots & Br(E[\tilde{a}_{np_1}(c)]) \end{bmatrix} \end{array} \tag{4}$$

where:

$$Br(E[\tilde{a}_{ij}(c)]) = Br\left(E\left[\frac{\sum_{k=1}^{l} (w(v)_k)\left[\tilde{a}^k_{ij}(c)\right]}{\sum_{k=1}^{l} w(v)_k} \right] \right) \tag{5}$$

Box 1.

$$(\tilde{D}(C))^k = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_n \end{array} \begin{array}{c} \begin{array}{cccc} c_1(c) & c_2(c) & \cdots & c_{p_1}(c) \end{array} \\ \begin{bmatrix} \left\{\left(a^k_{11}(c)\right)^o, \left(a^k_{11}(c)\right)^\alpha, \left(a^k_{11}(c)\right)^\beta, \left(a^k_{11}(c)\right)^\gamma\right\} & \left\{\left(a^k_{12}(c)\right)^o, \left(a^k_{12}(c)\right)^\alpha, \left(a^k_{12}(c)\right)^\beta, \left(a^k_{12}(c)\right)^\gamma\right\} & \cdots & \left\{\left(a^k_{1p_1}(c)\right)^o, \left(a^k_{1p_1}(c)\right)^\alpha, \left(a^k_{1p_1}(c)\right)^\beta, \left(a^k_{1p_1}(c)\right)^\gamma\right\} \\ \left\{\left(a^k_{21}(c)\right)^o, \left(a^k_{21}(c)\right)^\alpha, \left(a^k_{21}(c)\right)^\beta, \left(a^k_{21}(c)\right)^\gamma\right\} & \left\{\left(a^k_{22}(c)\right)^o, \left(a^k_{22}(c)\right)^\alpha, \left(a^k_{22}(c)\right)^\beta, \left(a^k_{22}(c)\right)^\gamma\right\} & \cdots & \left\{\left(a^k_{2p_1}(c)\right)^o, \left(a^k_{2p_1}(c)\right)^\alpha, \left(a^k_{2p_1}(c)\right)^\beta, \left(a^k_{2p_1}(c)\right)^\gamma\right\} \\ \vdots & \vdots & \cdots & \vdots \\ \left\{\left(a^k_{n1}(c)\right)^o, \left(a^k_{n1}(c)\right)^\alpha, \left(a^k_{n1}(c)\right)^\beta, \left(a^k_{n1}(c)\right)^\gamma\right\} & \left\{\left(a^k_{n2}(c)\right)^o, \left(a^k_{n2}(c)\right)^\alpha, \left(a^k_{n2}(c)\right)^\beta, \left(a^k_{n2}(c)\right)^\gamma\right\} & \cdots & \left\{\left(a^k_{np_1}(c)\right)^o, \left(a^k_{np_1}(c)\right)^\alpha, \left(a^k_{np_1}(c)\right)^\beta, \left(a^k_{np_1}(c)\right)^\gamma\right\} \end{bmatrix} \end{array} \tag{1}$$

Step 1.1.6. Calculating the vector of the e-government architecture weights

Next, we calculate the weights vector of the e-government architectures for matrix (4) based on the Borda score as follows:

$$\underline{V(C)} = \begin{bmatrix} v_1(c) & v_2(c) & \cdots & v_n(c) \end{bmatrix}^T \tag{6}$$

where:

$$v_i(c) = \frac{\sum_{j=1}^{p_1} w_j \left[Br\left(E[\tilde{a}_{ij}(c)] \right) \right]}{\sum_{i=1}^{n} \sum_{j=1}^{p_1} w_j \left[Br\left(E[\tilde{a}_{ij}(c)] \right) \right]} \tag{7}$$

Process 1.2. Prioritizing the e-Government Architectures Based on the G2B Perspective

In this process, we evaluate the interactions and transactions between the businesses and the government in the e-government architectures based on the strategic G2B criteria. The goal is to reduce the government's burden on businesses by eliminating redundant collection of data. This process is divided into the following four steps.

Step 1.2.1. Determining the Strategic G2B Criteria

In this step, the e-government SC determines $c_1(b), c_2(b), \ldots, c_{p_2}(b)$ as the strategic G2B criteria.

Step 1.2.2. Calculating the Fuzzy Individual Ordinal Rank Matrices

The fuzzy individual rank matrix of the e-government architectures evaluated by the e-government SC member $\left(e - Gv\right)_k$ will be as follows: (See Box 2.) or:

$$(\tilde{D}(B))^k = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_n \end{array} \begin{array}{c} \begin{array}{cccc} c_1(b) & c_2(b) & \cdots & c_{p_2}(b) \end{array} \\ \begin{bmatrix} \tilde{a}_{11}^k(b) & \tilde{a}_{12}^k(b) & \cdots & \tilde{a}_{1p_2}^k(b) \\ \tilde{a}_{21}^k(b) & \tilde{a}_{22}^k(b) & \cdots & \tilde{a}_{2p_2}^k(b) \\ \vdots & \vdots & \cdots & \vdots \\ \tilde{a}_{n1}^k(b) & \tilde{a}_{n2}^k(b) & \cdots & \tilde{a}_{np_2}^k(b) \end{bmatrix} \end{array} \tag{9}$$

Consequently, we have the following matrix for each strategic G2B criterion, $c_j(b)$:

Box 2.

$$(\tilde{D}(B))^k = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_n \end{array} \begin{array}{c} \begin{array}{cccc} c_1(b) & c_2(b) & \cdots & c_{p_2}(b) \end{array} \\ \begin{bmatrix} \left(\left(a_{11}^k(b)\right)^o, \left(a_{11}^k(b)\right)^\alpha, \left(a_{11}^k(b)\right)^\beta, \left(a_{11}^k(b)\right)^\gamma\right) & \left(\left(a_{12}^k(b)\right)^o, \left(a_{12}^k(b)\right)^\alpha, \left(a_{12}^k(b)\right)^\beta, \left(a_{12}^k(b)\right)^\gamma\right) & \cdots & \left(\left(a_{1p_2}^k(b)\right)^o, \left(a_{1p_2}^k(b)\right)^\alpha, \left(a_{1p_2}^k(b)\right)^\beta, \left(a_{1p_2}^k(b)\right)^\gamma\right) \\ \left(\left(a_{21}^k(b)\right)^o, \left(a_{21}^k(b)\right)^\alpha, \left(a_{21}^k(b)\right)^\beta, \left(a_{21}^k(b)\right)^\gamma\right) & \left(\left(a_{22}^k(b)\right)^o, \left(a_{22}^k(b)\right)^\alpha, \left(a_{22}^k(b)\right)^\beta, \left(a_{22}^k(b)\right)^\gamma\right) & \cdots & \left(\left(a_{2p_2}^k(b)\right)^o, \left(a_{2p_2}^k(b)\right)^\alpha, \left(a_{2p_2}^k(b)\right)^\beta, \left(a_{2p_2}^k(b)\right)^\gamma\right) \\ \vdots & \vdots & \cdots & \vdots \\ \left(\left(a_{n1}^k(b)\right)^o, \left(a_{n1}^k(b)\right)^\alpha, \left(a_{n1}^k(b)\right)^\beta, \left(a_{n1}^k(b)\right)^\gamma\right) & \left(\left(a_{n2}^k(b)\right)^o, \left(a_{n2}^k(b)\right)^\alpha, \left(a_{n2}^k(b)\right)^\beta, \left(a_{n2}^k(b)\right)^\gamma\right) & \cdots & \left(\left(a_{np_2}^k(b)\right)^o, \left(a_{np_2}^k(b)\right)^\alpha, \left(a_{np_2}^k(b)\right)^\beta, \left(a_{np_2}^k(b)\right)^\gamma\right) \end{bmatrix} \end{array} \tag{8}$$

$$\tilde{D}_j(B) = \begin{array}{c} A_1 \\ A_2 \\ \vdots \\ A_n \end{array} \begin{bmatrix} \tilde{a}^1_{1j}(b) & \tilde{a}^2_{1j}(b) & \cdots & \tilde{a}^l_{1j}(b) \\ \tilde{a}^1_{2j}(b) & \tilde{a}^2_{2j}(b) & \cdots & \tilde{a}^l_{2j}(b) \\ \vdots & \vdots & \cdots & \vdots \\ \tilde{a}^1_{nj}(b) & \tilde{a}^2_{nj}(b) & \cdots & \tilde{a}^l_{nj}(b) \end{bmatrix} \tag{10}$$

Step 1.2.3. Calculating the weighted collective ordered matrices

Next, we determine the Borda's score with respect to p_2 strategic G2B criteria.

$$\tilde{B}r(B) = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_n \end{array} \begin{array}{c} \begin{array}{cccc} c_1(b) & c_2(b) & \cdots & c_{p_2}(b) \end{array} \\ \begin{bmatrix} Br(E[\tilde{a}_{11}(b)]) & Br(E[\tilde{a}_{12}(b)]) & \cdots & Br(E[\tilde{a}_{1p_2}(b)]) \\ Br(E[\tilde{a}_{21}(b)]) & Br(E[\tilde{a}_{22}(b)]) & \cdots & Br(E[\tilde{a}_{2p_2}(b)]) \\ \vdots & \vdots & \cdots & \vdots \\ Br(E[\tilde{a}_{n1}(b)]) & Br(E[\tilde{a}_{n2}(b)]) & \cdots & Br(E[\tilde{a}_{np_2}(b)]) \end{bmatrix} \end{array} \tag{11}$$

where:

$$Br(E[\tilde{a}_{ij}(b)]) = Br\left(E\left[\frac{\sum_{k=1}^{l}\left(w(v)_k\right)\left[\tilde{a}^k_{ij}(b)\right]}{\sum_{k=1}^{l} w(v)_k}\right]\right) \tag{12}$$

Step 1.2.4. Calculating the vector of the e-government architecture weights

Next, we calculate the weights vector of the e-government architectures for matrix (11) based on the Borda score as follows:

$$\underline{V(B)} = \begin{bmatrix} v_1(b) & v_2(b) & \cdots & v_n(b) \end{bmatrix}^T \tag{13}$$

where:

$$v_i(b) = \frac{\sum_{j=1}^{p_2} w_j\left[Br\left(E\left[\tilde{a}_{ij}(b)\right]\right)\right]}{\sum_{i=1}^{n}\sum_{j=1}^{p_2} w_j\left[Br\left(E\left[\tilde{a}_{ij}(b)\right]\right)\right]} \tag{14}$$

Process 1.3. Prioritizing the e-Government Architectures Based on the G2G Perspective

In this process, we evaluate the internal interactions and transactions within the government agencies in the e-government architectures based on the strategic G2G criteria. The goal is to streamline the channels of communication and reporting between the state and local governments and between the state agencies. This process is divided into the following four steps.

Step 1.3.1. Determining the Strategic G2G Criteria

In this step, the e-government SC determines $c_1(g), c_2(g), \ldots, c_{p_3}(g)$ as the strategic G2G criteria.

Step 1.3.2. Calculating the Fuzzy Individual Ordinal Rank Matrices

The fuzzy individual rank matrix of the e-government architectures evaluated by the e-government SC member $(e-Gv)_k$ will be as follows: (See Box 3.)
or:

$$(\tilde{D}(G))^k = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_n \end{array} \begin{array}{c} \begin{array}{cccc} c_1(g) & c_2(g) & \cdots & c_{p_3}(g) \end{array} \\ \begin{bmatrix} \tilde{a}^k_{11}(g) & \tilde{a}^k_{12}(g) & \cdots & \tilde{a}^k_{1p_3}(g) \\ \tilde{a}^k_{21}(g) & \tilde{a}^k_{22}(g) & \cdots & \tilde{a}^k_{2p_3}(g) \\ \vdots & \vdots & \cdots & \vdots \\ \tilde{a}^k_{n1}(g) & \tilde{a}^k_{n2}(g) & \cdots & \tilde{a}^k_{np_3}(g) \end{bmatrix} \end{array} \tag{16}$$

Consequently, we have the following matrix for each strategic G2G criterion, $c_j(g)$:

Box 3.

$$(\tilde{D}(G))^k = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_n \end{array} \begin{array}{c} \begin{array}{cccc} c_1(g) & c_2(g) & \cdots & c_{p_3}(g) \end{array} \\ \begin{bmatrix} \left(\left(a_{11}^k(g)\right)^o, \left(a_{11}^k(g)\right)^\alpha, \left(a_{11}^k(g)\right)^\beta, \left(a_{11}^k(g)\right)^\gamma\right) & \left(\left(a_{12}^k(g)\right)^o, \left(a_{12}^k(g)\right)^\alpha, \left(a_{12}^k(g)\right)^\beta, \left(a_{12}^k(g)\right)^\gamma\right) & \cdots & \left(\left(a_{1p_3}^k(g)\right)^o, \left(a_{1p_3}^k(g)\right)^\alpha, \left(a_{1p_3}^k(g)\right)^\beta, \left(a_{1p_3}^k(g)\right)^\gamma\right) \\ \left(\left(a_{21}^k(g)\right)^o, \left(a_{21}^k(g)\right)^\alpha, \left(a_{21}^k(g)\right)^\beta, \left(a_{21}^k(g)\right)^\gamma\right) & \left(\left(a_{22}^k(g)\right)^o, \left(a_{22}^k(g)\right)^\alpha, \left(a_{22}^k(g)\right)^\beta, \left(a_{22}^k(g)\right)^\gamma\right) & \cdots & \left(\left(a_{2p_3}^k(g)\right)^o, \left(a_{2p_3}^k(g)\right)^\alpha, \left(a_{2p_3}^k(g)\right)^\beta, \left(a_{2p_3}^k(g)\right)^\gamma\right) \\ \vdots & \vdots & \cdots & \vdots \\ \left(\left(a_{n1}^k(g)\right)^o, \left(a_{n1}^k(g)\right)^\alpha, \left(a_{n1}^k(g)\right)^\beta, \left(a_{n1}^k(g)\right)^\gamma\right) & \left(\left(a_{n2}^k(g)\right)^o, \left(a_{n2}^k(g)\right)^\alpha, \left(a_{n2}^k(g)\right)^\beta, \left(a_{n2}^k(g)\right)^\gamma\right) & \cdots & \left(\left(a_{np_3}^k(g)\right)^o, \left(a_{np_3}^k(g)\right)^\alpha, \left(a_{np_3}^k(g)\right)^\beta, \left(a_{np_3}^k(g)\right)^\gamma\right) \end{bmatrix} \end{array} \tag{15}$$

$$\tilde{D}_j(G) = \begin{array}{c} A_1 \\ A_2 \\ \vdots \\ A_n \end{array} \begin{bmatrix} \tilde{a}_{1j}^1(g) & \tilde{a}_{1j}^2(g) & \cdots & \tilde{a}_{1j}^l(g) \\ \tilde{a}_{2j}^1(g) & \tilde{a}_{2j}^2(g) & \cdots & \tilde{a}_{2j}^l(g) \\ \vdots & \vdots & \cdots & \vdots \\ \tilde{a}_{nj}^1(g) & \tilde{a}_{nj}^2(g) & \cdots & \tilde{a}_{nj}^l(g) \end{bmatrix} \tag{17}$$

Step 1.3.3. Calculating the Weighted Collective Ordered Matrices

Next, we determine the Borda's score with respect to p_3 strategic G2G criteria.

$$\tilde{B}r(G) = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_n \end{array} \begin{array}{c} \begin{array}{cccc} c_1(g) & c_2(g) & \cdots & c_{p_3}(g) \end{array} \\ \begin{bmatrix} Br(E[\tilde{a}_{11}(g)]) & Br(E[\tilde{a}_{12}(g)]) & \cdots & Br(E[\tilde{a}_{1p_3}(g)]) \\ Br(E[\tilde{a}_{21}(g)]) & Br(E[\tilde{a}_{22}(g)]) & \cdots & Br(E[\tilde{a}_{2p_3}(g)]) \\ \vdots & \vdots & \cdots & \vdots \\ Br(E[\tilde{a}_{n1}(g)]) & Br(E[\tilde{a}_{n2}(g)]) & \cdots & Br(E[\tilde{a}_{np_3}(g)]) \end{bmatrix} \end{array} \tag{18}$$

where:

$$Br(E[\tilde{a}_{ij}(g)]) = Br\left(E\left[\frac{\sum_{k=1}^{l}\left(w(v)_k\right)\left[\tilde{a}_{ij}^k(g)\right]}{\sum_{k=1}^{l} w(v)_k}\right]\right) \tag{19}$$

Step 1.3.4. Calculating the Vector of the e-Government Architecture Weights

Next, we calculate the weights vector of the e-government architectures for matrix (18) based on the Borda score as follows:

$$\underline{V(G)} = \left[v_1(g) \quad v_2(g) \quad \cdots \quad v_n(g)\right]^T \tag{20}$$

where:

$$v_i(g) = \frac{\sum_{j=1}^{p_3} w_j\left[Br\left(E[\tilde{a}_{ij}(g)]\right)\right]}{\sum_{i=1}^{n}\sum_{j=1}^{p_3} w_j\left[Br\left(E[\tilde{a}_{ij}(g)]\right)\right]} \tag{21}$$

Process 1.4. Prioritizing the e-Government Architectures Based on the Three Perspectives

In this process, the SAW method is used to prioritize the collaborative e-government architectures based on the G2C, G2B, and G2G perspectives. This phase is divided into the following three steps.

Step 1.4.1. Constructing the Decision Matrices Based on the Three Perspectives

Initially, we construct the following matrix based on three perspectives reflected by the vectors (6), (13), and (20):

$$P = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_n \end{array} \begin{array}{c} \begin{array}{ccc} c(c) & c(b) & c(g) \end{array} \\ \begin{bmatrix} v_1(c) & v_1(b) & v_1(g) \\ v_2(c) & v_2(b) & v_2(g) \\ \vdots & \vdots & \vdots \\ v_n(c) & v_n(b) & v_n(g) \end{bmatrix} \end{array} \tag{22}$$

Step 1.4.2. Constructing the Weighted Decision Matrices Based on the Three Perspectives

Next, we construct the weighted decision matrix by multiplying each column of the matrix (22) with its associated importance weight for each perspective:

$$R = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_n \end{array} \begin{array}{c} \begin{array}{ccc} c(c) & c(b) & c(g) \end{array} \\ \begin{bmatrix} r_1(c) & r_1(b) & r_1(g) \\ r_2(c) & r_2(b) & r_2(g) \\ \vdots & \vdots & \vdots \\ r_n(c) & r_n(b) & r_n(g) \end{bmatrix} \end{array} \tag{23}$$

where:

$$\begin{aligned} r_i(c) &= w(c)v_i(c) \\ r_i(b) &= w(b)v_i(b) \\ r_i(g) &= w(g)v_i(g) \end{aligned} \tag{24}$$

Step 1.4.3. Calculating the Vector of the Best e-Government Architecture

We then calculate the weight vector of the e-government architectures based on the weighted average values as follows:

$$\underline{V} = \begin{bmatrix} v_1 & v_2 & \cdots & v_n \end{bmatrix}^T \tag{25}$$

where:

$$v_i = \frac{r_i(c) + r_i(b) + r_i(g)}{w(c) + w(b) + w(g)} \tag{26}$$

Phase 2. Prioritizing the e-Government Architectures Based on the Financial Perspective

In this phase, the Dos Santos (1994) real options equations are used to prioritize the e-government architectures. This phase is divided into the following three processes:

Process 2.1. Constructing the Individual Fuzzy Real Option Matrices

First, we construct the following individual real option matrices based on the judgments pro-

Box 4.

$$\tilde{A}_{RO}^k = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_n \end{array} \begin{array}{c} \begin{array}{cccccccc} \tilde{B}(T_1) & \tilde{B}(T_2) & \cdots & \tilde{B}(T_m) & \tilde{C}(T_1) & \tilde{C}(T_2) & \cdots & \tilde{C}(T_m) \end{array} \\ \begin{bmatrix} \tilde{B}_1^k(T_1) & \tilde{B}_1^K(T_2) & \cdots & \tilde{B}_1^k(T_m) & \tilde{C}_1^k(T_1) & \tilde{C}_1^k(T_2) & \cdots & \tilde{C}_1^k(T_m) \\ \tilde{B}_2^k(T_1) & \tilde{B}_2^k(T_2) & \cdots & \tilde{B}_2^k(T_m) & \tilde{C}_2^k(T_1) & \tilde{C}_2^k(T_2) & \cdots & \tilde{C}_2^k(T_m) \\ \vdots & \vdots & \cdots & \vdots & \vdots & \vdots & \cdots & \vdots \\ \tilde{B}_n^k(T_1) & B_n^K(T_2) & \cdots & B_n^K(T_m) & \tilde{C}_n^k(T_1) & C_n^k(T_2) & \cdots & C_n^k(T_m) \end{bmatrix} \end{array}$$

$$(k = 1, 2, \ldots, l) \tag{27}$$

vided by each e-government SC member:(see Box 3).

The following trapezoidal fuzzy numbers are used to find the individual fuzzy present values of the expected benefits and costs of the ith e-government architecture at time T_j by the e-government SC member $\left(e-Gv\right)_k$:

$$\tilde{B}_i^k\left(T_j\right)=\left(\left(B_i^k\left(T_j\right)\right)^o,\left(B_i^k\left(T_j\right)\right)^\alpha,\left(B_i^k\left(T_j\right)\right)^\beta,\left(B_i^k\left(T_j\right)\right)^\gamma\right)$$
$$\tilde{C}_i^k=\left(\left(C_i^k\left(T_j\right)\right)^o,\left(C_i^k\left(T_j\right)\right)^\alpha,\left(C_i^k\left(T_j\right)\right)^\beta,\left(C_i^k\left(T_j\right)\right)^\gamma\right)$$
$$j=1,2,\ldots,m \tag{28}$$

where:

$\left(\left(B_i^k(T_j)\right)^o,\left(B_i^k(T_j)\right)^\alpha\right)$: The most possible values of the expected benefit of the ith e-government architecture at time T_j evaluated by the e-government SC member $\left(e-Gv\right)_k$

$\left(\left(B_i^k(T_j)\right)^o+\left(B_i^k(T_j)\right)^\gamma\right)$: The upward potential for the expected benefit of the ith e-government architecture at time T_j evaluated by the e-government SC member $\left(e-Gv\right)_k$

$\left(\left(B_i^k(T_j)\right)^o-\left(B_i^k(T_j)\right)^\beta\right)$: The downward potential for the expected benefit of the ith e-government architecture at time T_j evaluated by the e-government SC member $\left(e-Gv\right)_k$

$\left(\left(C_i^k(T_j)\right)^o,\left(C_i^k(T_j)\right)^\alpha\right)$: The most possible values of the expected cost of the ith e-government architecture at time T_j evaluated by the e-government SC member $\left(e-Gv\right)_k$

$\left(\left(C_i^k(T_j)\right)^o+\left(C_i^k(T_j)\right)^\gamma\right)$: The upward potential for the expected cost of the ith e-government architecture at time T_j evaluated by the e-government SC member $\left(e-Gv\right)_k$

$\left(\left(C_i^k(T_j)\right)^o-\left(C_i^k(T_j)\right)^\beta\right)$: The downward potential for the expected payoffs of the ith e-government architecture at time T_j evaluated by the e-government SC member $\left(e-Gv\right)_k$

Consequently, by substituting equation (28) into matrix (27), the individual real option matrices can be rewritten as: (Box 5).

Process 2.2. Calculating the Fuzzy Weighted Collective Real Option Matrix

The proposed method also allows for assigning different voting power weights to each e-government SC member.

Box 5.

$$\tilde{A}_{RO}^k\left(T_i\right)=\begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_n \end{array}\begin{array}{cc} \tilde{B}\left(T_i\right) & \tilde{C}\left(T_i\right) \\ \left[\left(B_1^k\left(T_i\right)\right)^o,\left(B_1^k\left(T_i\right)\right)^\alpha,\left(B_1^k\left(T_i\right)\right)^\beta,\left(B_1^k\left(T_i\right)\right)^\gamma\right] & \left[\left(C_1^k\left(T_i\right)\right)^o,\left(C_1^k\left(T_i\right)\right)^\alpha,\left(C_1^k\left(T_i\right)\right)^\beta,\left(C_1^k\left(T_i\right)\right)^\gamma\right] \\ \left[\left(B_2^k\left(T_i\right)\right)^o,\left(B_2^k\left(T_i\right)\right)^\alpha,\left(B_2^k\left(T_i\right)\right)^\beta,\left(B_2^k\left(T_i\right)\right)^\gamma\right] & \left[\left(C_2^k\left(T_i\right)\right)^o,\left(C_2^k\left(T_i\right)\right)^\alpha,\left(C_2^k\left(T_i\right)\right)^\beta,\left(C_2^k\left(T_i\right)\right)^\gamma\right] \\ \vdots & \vdots \\ \left[\left(B_n^k\left(T_i\right)\right)^o,\left(B_n^k\left(T_i\right)\right)^\alpha,\left(B_n^k\left(T_i\right)\right)^\beta,\left(B_n^k\left(T_i\right)\right)^\gamma\right] & \left[\left(C_n^k\left(T_i\right)\right)^o,\left(C_n^k\left(T_i\right)\right)^\alpha,\left(C_n^k\left(T_i\right)\right)^\beta,\left(C_n^k\left(T_i\right)\right)^\gamma\right] \end{array} \tag{29}$$

$$\underline{W}\left(vf\right) = [w(vf)_1, w(vf)_2, ..., w(vf)_j, ..., w(vf)_l] \tag{30}$$

In order to form a fuzzy weighted collective real option matrix, we aggregate the individual fuzzy real option matrices with the voting powers as follows:

$$\tilde{A}_{RO2}(T_i) = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_n \end{array} \begin{array}{c} \begin{array}{cc} \tilde{B}\left(T_i\right) & \tilde{C}\left(T_i\right) \end{array} \\ \begin{bmatrix} \tilde{B}_1(T_i) & \tilde{C}_1(T_i) \\ \tilde{B}_2(T_i) & \tilde{C}_2(T_i) \\ \vdots & \vdots \\ \tilde{B}_n(T_i) & \tilde{C}_n(T_i) \end{bmatrix} \end{array} \tag{31}$$

where:

$$\tilde{B}_i\left(T_i\right) = \frac{\sum_{k=1}^{l}\left(w\ (vf)_k\right)\left(\tilde{B}_i^k(T_i)\right)}{\sum_{k=1}^{l} w(vf)_k} \tag{32}$$

$$\tilde{C}_i\left(T_i\right) = \frac{\sum_{k=1}^{l}\left(w\ (vf)_k\right)\left(\tilde{C}_i^k\left(T_i\right)\right)}{\sum_{k=1}^{l} w\left(vf\right)_k} \tag{33}$$

Process 2.3. Calculating the Fuzzy Real Options Value Matrix for the e-Government Architectures

In this process, we determine the real options values of the e-government architectures at times $T_1, T_2, \ldots, T_m$ with the following fuzzy real options value matrix:

$$\tilde{A}_{FROV} = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_n \end{array} \begin{array}{c} \begin{array}{cccc} T_1 & T_2 & \cdots & T_m \end{array} \\ \begin{bmatrix} FROV_1(T_1) & FROV_1(T_2) & \cdots & FROV_1(T_m) \\ FROV_2(T_1) & FROV_2(T_2) & \cdots & FROV_2(T_m) \\ \vdots & \vdots & \cdots & \vdots \\ FROV_n(T_1) & FROV_n(T_2) & \cdots & FROV_n(T_m) \end{bmatrix} \end{array} \tag{34}$$

or: (see Box 6.) where the best e-government architecture i^{th} cumulative normal probability distribution for D_1 and D_2 are as follows:

$$A_{RO}\left(T_i\right) = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_n \end{array} \begin{array}{c} \begin{array}{cc} N\left(D_1(T_i)\right) & N\left(D_2(T_i)\right) \end{array} \\ \begin{bmatrix} N\left(D_{11}(T_i)\right) & N\left(D_{21}(T_i)\right) \\ N\left(D_{12}(T_i)\right) & N\left(D_{22}(T_i)\right) \\ \vdots & \vdots \\ N\left(D_{1n}(T_i)\right) & N\left(D_{2n}(T_i)\right) \end{bmatrix} \end{array} \tag{36}$$

$$A_{RO}\left(T\right) = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_n \end{array} \begin{array}{c} \begin{array}{cc} D_1(T_i) & D_2(T_i) \end{array} \\ \begin{bmatrix} D_{11}(T_i) & D_{21}(T_i) \\ D_{12}(T_i) & D_{22}(T_i) \\ \vdots & \vdots \\ D_{1n}(T_i) & D_{2n}(T_i) \end{bmatrix} \end{array} \tag{37}$$

Box 6.

$$\tilde{A}_{FROV}\left(T_i\right) = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_n \end{array} \begin{bmatrix} \tilde{B}_1\left(T_i\right).e^{-\delta T_i}.N\left(D_{11}\left(T_i\right)\right) - \tilde{C}_1\left(T_i\right).e^{-rT_i}.N\left(D_{21}\left(T_i\right)\right) \\ \tilde{B}_2\left(T_i\right).e^{-\delta T_i}.N\left(D_{12}\left(T_i\right)\right) - \tilde{C}_2\left(T_i\right).e^{-rT_i}.N\left(D_{22}\left(T_i\right)\right) \\ \vdots \\ \tilde{B}_n\left(T_i\right).e^{-\delta T_i}.N\left(D_{1n}\left(T_i\right)\right) - \tilde{C}_n\left(T_i\right).e^{-rT_i}.N\left(D_{2n}\left(T_i\right)\right) \end{bmatrix} = \begin{bmatrix} \tilde{F}ROV_1\left(T_i\right) \\ \tilde{F}ROV_2\left(T_i\right) \\ \vdots \\ \tilde{F}ROV_n\left(T_i\right) \end{bmatrix} \tag{35}$$

or equivalently: (see Box 7.) where E and σ^2 denote the possibilistic mean value and possibilistic variance operators as follows:

$$A_{RO}(T_i) = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_n \end{array} \begin{array}{c} \begin{array}{ccc} E\left(\tilde{B}(T_i)\right) & E\left(\tilde{C}(T_i)\right) & \sigma^2(T_i) \end{array} \\ \begin{bmatrix} E\left(\tilde{B}_1(T_i)\right) & E\left(\tilde{C}_1(T_i)\right) & \sigma_1^2(T_i) \\ E\left(\tilde{B}_2(T_i)\right) & E\left(\tilde{C}_2(T_i)\right) & \sigma_2^2(T_i) \\ \vdots & \vdots & \vdots \\ E\left(\tilde{B}_n(T_i)\right) & E\left(\tilde{C}_n(T_i)\right) & \sigma_n^2(T_i) \end{bmatrix} \end{array} \tag{39}$$

Next, the formulas proposed by Carlsson et al. (2007) are used to calculate the expected payoffs and costs as well as the variance of $\tilde{B}_i$ as follows seen in Box 8

Phase 3: Benchmarking the e-Government Architecture

$$Max\, Z_1 = \frac{E[\tilde{F}ROV_1(T_1)]}{E[\tilde{F}ROV_1(T_1)] + \cdots + E[\tilde{F}ROV_n(T_1)]}.x_1 + \frac{E[\tilde{F}ROV_1(T_2)]}{E[\tilde{F}ROV_1(T_2)] + \cdots + E[\tilde{F}ROV_n(T_2)]}.x_2 + \cdots + \frac{E[\tilde{F}ROV_n]\,(T_m)}{E[\tilde{F}ROV_1(T_m) + \cdots + E[\tilde{F}ROV_n(T_m)]]}.x_n \tag{Model P}$$

Box 7.

$$A_{RO}(T_i) = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_n \end{array} \begin{array}{c} \begin{array}{cc} D_1(T_i) & D_2(T_i) \end{array} \\ \begin{bmatrix} \dfrac{Ln\left(E\left(\tilde{B}_1(T_i)\right)/E\left(\tilde{C}_1(T_i)\right)\right) + \left(r_1 - \delta_1 + \sigma_1^2(T_i)/2\right).T_i}{\sigma_1(T_i)\sqrt{T_i}} & \dfrac{Ln\left(E\left(\tilde{B}_1(T_i)\right)/E\left(\tilde{C}_1(T_i)\right)\right) + \left(r_1 - \delta_1 - \sigma_1^2(T_i)/2\right).T_i}{\sigma_1^2(T_i)\sqrt{T_i}} \\ \dfrac{Ln\left(E\left(\tilde{B}_2(T_i)\right)/E\left(\tilde{C}_2(T_i)\right)\right) + \left(r_2 - \delta_2 + \sigma_2^2(T_i)/2\right).T_i}{\sigma_2(T_i)\sqrt{T_i}} & \dfrac{Ln\left(E\left(\tilde{B}_2(T_i)\right)/E\left(\tilde{C}_2(T_i)\right)\right) + \left(r_2 - \delta_2 - \sigma_2^2(T_i)/2\right).T_i}{\sigma_2(T_i)\sqrt{T}} \\ \vdots & \vdots \\ \dfrac{Ln\left(E\left(\tilde{B}_n(T_i)\right)/E\left(\tilde{C}_n(T_i)\right)\right) + \left(r_n - \delta_n + \sigma_n^2(T_i)/2\right).T_i}{\sigma_n(T_i)\sqrt{T_i}} & \dfrac{Ln\left(E\left(\tilde{B}_n(T_i)\right)/E\left(\tilde{C}_n(T_i)\right)\right) + \left(r_n - \delta_n - \sigma_n^2(T_i)/2\right).T_i}{\sigma_n(T_i)\sqrt{T_i}} \end{bmatrix} \end{array} \tag{38}$$

Box 8.

$$E\left(\tilde{B}_i(T_j)\right) = \frac{\left(B(T_j)\right)^o + \left(B(T_j)\right)^\alpha}{2} + \frac{\left(B(T_j)\right)^\gamma - \left(B(T_j)\right)^\beta}{6}$$

$$E\left(\tilde{C}_i(T_j)\right) = \frac{\left(C(T_j)\right)^o + \left(C(T_j)\right)^\alpha}{2} + \frac{\left(C(T_j)\right)^\gamma - \left(C(T_j)\right)^\beta}{6}$$

$$\sigma_i^2(T_j) = \frac{\left(\left(B(T_j)\right)^\alpha - \left(B(T_j)\right)^o\right)^2}{4} + \frac{\left(\left(B(T_j)\right)^\alpha - \left(B(T_j)\right)^o\right)\left(\left(B(T_j)\right)^\beta + \left(B(T_j)\right)^\gamma\right)}{6} + \frac{\left(\left(B(T_j)\right)^\beta + \left(B(T_j)\right)^\gamma\right)^2}{24} \tag{40}$$

$$Max\ Z_2 = v_1.x_1 + v_2.x_2 + \cdots + v_n.x_n$$

Subject to:

$$\begin{aligned}
&f_1\left(x_1, x_2, \ldots, x_n\right) \le 0 \\
&f_2\left(x_1, x_2, \ldots, x_n\right) \le 0 \\
&\vdots \\
&f_r\left(x_1, x_2, \ldots, x_n\right) \le 0 \\
&x_1 + x_2 + \cdots + x_n \le 1 \\
&x_i = 0,1\ (i = 1,2,\ldots,n)
\end{aligned}$$

where $f_i\left(x_1, x_2, \ldots, x_n\right)$ is a given function of the n e-government architectures. The optimal solution for model (P) is the best e-government architecture. Next, we present a case study to demonstrate the applicability of the proposed framework and exhibit the efficacy of the procedures and algorithms.

CASE STUDY

The Office of Information Technology (OIT) for the State of East Virginia[1] wants to better serve the constituents by delivering government services over the World Wide Web. There are a number of factors that will need to be considered as the state moves forward with the selection of an e-government architecture. Citizens and businesses operating in East Virginia should be able to access a number of basic government services through a single convenient point of access. The OIT has indicated that requiring a constituent to visit a government agency during normal business hours would not be acceptable in the near future. The state wants to remove barriers of time and distance so that the constituents can interact and perform the business of government when and where they want.

The majority of state services are currently delivered through fifteen agencies with distinct missions within the executive branch of the State of East Virginia. These agencies interact with businesses and/or with one another, sometimes dealing with the same constituent. This compounds the complexity perceived by citizens and businesses interacting with state agencies. Another key requirement for East Virginia's e-government architecture is compatibility with the current information technology environment.

Initially, the OIT held a two-week workshop to review the e-government performance in 10 top ranking states identified by West (2007). The OIT workshop reviewed the e-government initiatives in Delaware, Michigan, Maine, Kentucky, Tennessee, Massachusetts, Maryland, Texas, New Jersey, and Utah. The three most promising e-government architectures of Massachusetts, Texas, and Kentucky were selected for further evaluation on the basis of value to citizens, potential improvement in agency efficiency and likelihood of deploying within 18 to 24 months.

In Massachusetts, the Information Technology Division (ITD) coordinates e-government initiatives within the executive department via the Mass.Gov portal and other means.

Massachusetts Best Practices

- Facilitation: The ITD enables citizens and businesses to work with several different government organizations at the same time from within a single web page efficiently and effectively.
- Open Standards: The ITD uses an open standards policy for an interchangeability of solutions and coordination across the entire enterprise.
- Streamlining Government and Cost Effectiveness: The ITD searches for efficient solutions ranging from private vendors to the possibility of open source software for flexibility in meeting changing circumstances.
- In-house Decision Making: The ITD maintains the core-competency of government by not outsourcing its management workload.
- Easy Access to Services: The ITD includes all state government services within the portal by providing ease of access to ser-

vices most frequently requested through a short-list on the portal's home page.
- Cross-Agency Coordination: The ITD maintains a highly mobile exchange across jurisdictions.

In Texas, the Department of Information Resources (DIR) directs and implements e-government initiatives that assist the state government in reaching constituencies and efficiently performing governmental operations.

Texas Best Practices

- DIR Board of Directors: The DIR Board is an appointed body that provides leadership through input from the public, private, non-profits, and academic sectors.
- Limited Control of Other Agencies: The DIR allows state agencies to pursue their core mission objectives by providing them with adequate technical support.
- Division of Labor: The DIR delegates responsibility to smaller internal groups in order to create a more precise focus on the Board's initiatives.
- Public-Private Partnership: The DIR achieves cost minimization and profit maximization through its public-private partnership initiatives.
- Securing Property Rights: The DIR outsources some of the labor but the department maintains control over intellectual property rights.
- Understanding of Cost Savings in E-Government: The DIR has completed a number of studies of online services to identify potential savings.

In Kentucky, the Commonwealth Office of Technology (COT) develops e-government services and encourages its citizens to use computers whenever possible.

Kentucky Best Practices

- Public-Private Partnership: The COT keeps up with technology through an efficient and effective private business model while avoiding traditionally slow bureaucratic decision models.
- Existing Infrastructure: The COT has the basic technology infrastructure in place for expanding e-government.
- Secure Systems and Widespread Access: The COT is committed to provide and maintain a high-speed and secured Internet access for most citizens.
- All-inclusive Strategy: The COT has a far-reaching strategy that includes a wide range of interested parties including local and state government, universities, private businesses, and citizens.
- Regional Approach: The COT has adopted a regional approach that is opposed to top-down.
- Target Marketing: The COT promotes applications for agencies to help them drive the adoption of their online services.

The OIT formed a SC with 15 members (one from each state agency) and charged them with the task of evaluating the e-government architectures for the states of Massachusetts, Texas, and Kentucky.

Phase 1. In this phase, the fuzzy Borda's function approach and the SAW method were used to prioritize the e-government architectures of Massachusetts, Texas, and Kentucky based on G2C, G2B, and G2G perspectives.

Process 1.1. In this process, the group ordinal approach was used to determine the importance of the e-government architectures with respect to the strategic G2C criteria as follows:

Step 1.1.1. and 1.1.2. These two steps involved the appointment of the 15 member SC and the identification of the three e-government architectures of Massachusetts, Texas and Kentucky for further consideration.

Step 1.1.3. In this step, the e-government SC identified the strategic G2C criteria presented in Table 2:

Table 2. Strategic G2C criteria

No.	Strategic G2C criteria	Description
1	Recreation one stop	To provide recreation information, reservations, searchable maps, etc. online
2	Eligibility assistance online	Online information on benefit programs
3	Online access for loans	Online information of loans
4	Citizen services	Personalized citizen services; provision of single-window services
5	EZ tax filing	Internet-based tax filing and refund

Table 3. The fuzzy weighted collective ordered matrices with respect to the five strategic G2C criteria

Strategic G2C criteria	E-government architecture		
	E-government architecture of Massachusetts	E-government architecture of Texas	E-government architecture of Kentucky
Recreation one stop	$Br\left(E\left[\left(0.5,1.5,0.5,0.5\right)\right]\right)=2$	$Br\left(E\left[\left(1.5,2.5,0.5,0.5\right)\right]\right)=1$	$Br\left(E\left[\left(2.5,3.5,0.5,0.5\right)\right]\right)=0$
Eligibility assistance online	$Br\left(E\left[\left(1,2,0.5,0.5\right)\right]\right)=1.5$	$Br\left(E\left[\left(1,2,0.5,0.5\right)\right]\right)=1.5$	$Br\left(E\left[\left(2.5,3.5,0.5,0.5\right)\right]\right)=0$
Online access for loans	$Br\left(E\left[\left(1,2,0.5,0.5\right)\right]\right)=1.5$	$Br\left(E\left[\left(1,2,0.5,0.5\right)\right]\right)=1.5$	$Br\left(E\left[\left(2.5,3.5,0.5,0.5\right)\right]\right)=0$
Citizen services	$Br\left(E\left[\left(0.5,1.5,0.5,0.5\right)\right]\right)=2$	$Br\left(E\left[\left(2.5,3.5,0.5,0.5\right)\right]\right)=0$	$Br\left(E\left[\left(1.5,2.5,0.5,0.5\right)\right]\right)=1$
EZ tax filing	$Br\left(E\left[\left(1.5,2.5,0.5,0.5\right)\right]\right)=1$	$Br\left(E\left[\left(2.5,3.5,0.5,0.5\right)\right]\right)=0$	$Br\left(E\left[\left(0.5,1.5,0.5,0.5\right)\right]\right)=2$

Steps 1.1.4. and 1.1.5. In these two steps, we first used equations (1) to (3) to determine the fuzzy individual rank matrix of the e-government architectures evaluated by the e-government SC members with respect to the G2C criteria and then used equations (4) and (5) to calculate the weighted collective ordered matrix presented in Table 3.

Step 1.1.6. In this step, we used equations (6) and (7) and calculated the fuzzy vector for the three e-government architectures of Massachusetts, Texas and Kentucky with respect to the importance weight vector of the G2C perspective, $\underline{W(c)}=(0.15,0.25,0.1,0.25,0.25)$, and the five strategic G2C criteria. The fuzzy vector for the three e-government architectures with respect to the G2C perspective will be shown later in Table 8.

Process 1.2. In this process, the importance of the e-government architectures was determined with regard to the strategic G2B criteria as follows:

Step 1.2.1. In this step, the e-government SC identified five strategic G2B criteria as shown in Table 4:

Steps 1.2.2. and 1.2.3. In these two steps, we first used equations (8) to (10) to determine the fuzzy individual rank matrix of

Table 4. Strategic G2B criteria

No.	Strategic G2B criteria	Description
1	Online rulemaking management	Creation of online rulemaking system with facility for receiving public comments
2	Electronic tax products or businesses	T o create capabilities for an end-to-end tax administration online
3	State asset sales	Online asset sales integrated with business
4	Streamlining international trade process	Simplify export-import procedures and provide online services
5	One stop business compliance information	To help business to comply with relevant regulations in the sectors like environment, health and safety, employment, and taxes

Table 5. The fuzzy weighted collective ordered matrices with respect to the five strategic G2B criteria

Strategic G2C criteria	E-government architecture		
	E-government architecture of Massachusetts	E-government architecture of Texas	E-government architecture of Kentucky
Online rulemaking management	$Br\left(E\left[\left(0.5,1.5,0.5,0.5\right)\right]\right)=2$	$Br\left(E\left[\left(1.5,2.5,0.5,0.5\right)\right]\right)=1$	$Br\left(E\left[\left(2.5,3.5,0.5,0.5\right)\right]\right)=0$
Electronic tax products or businesses	$Br\left(E\left[\left(0.5,1.5,0.5,0.5\right)\right]\right)=2$	$Br\left(E\left[\left(2.5,3.5,0.5,0.5\right)\right]\right)=0$	$Br\left(E\left[\left(1.5,2.5,0.5,0.5\right)\right]\right)=1$
State asset sales	$Br\left(E\left[\left(0.5,1.5,0.5,0.5\right)\right]\right)=2$	$Br\left(E\left[\left(2.5,3.5,0.5,0.5\right)\right]\right)=0$	$Br\left(E\left[\left(1.5,2.5,0.5,0.5\right)\right]\right)=1$
Streamlining international trade process	$Br\left(E\left[\left(0.5,1.5,0.5,0.5\right)\right]\right)=2$	$Br\left(E\left[\left(2.5,3.5,0.5,0.5\right)\right]\right)=0$	$Br\left(E\left[\left(1.5,2.5,0.5,0.5\right)\right]\right)=1$
One stop business compliance information	$Br\left(E\left[\left(1.5,2.5,0.5,0.5\right)\right]\right)=1$	$Br\left(E\left[\left(0.5,1.5,0.5,0.5\right)\right]\right)=2$	$Br\left(E\left[\left(2.5,3.5,0.5,0.5\right)\right]\right)=0$

the e-government architectures evaluated by the e-government SC members with respect to the G2B criteria and then used equations (11) and (12) to calculate the weighted collective ordered matrix presented in Table 5.

Step 1.2.4. In this step, we used equations (13) and (14) and calculated the fuzzy vector for the three e-government architectures of Massachusetts, Texas and Kentucky with respect to the importance weight vector of the G2B perspective, $\underline{W(b)} = (0.2, 0.2, 0.2, 0.2, 0.2)$, and the five strategic G2B criteria. The fuzzy vector for the three e-government architectures with respect to the G2C perspective will be shown later in Table 8.

Process 1.3. In this process, the importance of the e-government architectures was determined with regard to the strategic G2G criteria as follows:

Step 1.2.1. In this step, the e-government SC identified five strategic G2G criteria as shown in Table 6:

Steps 1.3.2. and 1.3.3. In these two steps, we first used equations (15) to (17) to determine the fuzzy individual rank matrix of the e-government architectures evaluated

Table 6. Strategic G2G criteria

No.	Strategic G2G criteria	Description
1	Geospatial information one-stop	To prescribe standards for core geospatial data and create one-stop site for all GIS needs
2	E-grants	To create a unified state grant management system
3	Disaster assistance and response	To create a unified portal for disaster and crisis management
4	Wireless public safety interoperable communications	Management of public safety wireless communication systems at state and local levels
5	E-vital	On line management of birth and death information

Table 7. The fuzzy weighted collective ordered matrices with respect to the five strategic G2G criteria

Strategic G2C criteria	E-government architecture		
	E-government architecture of Massachusetts	E-government architecture of Texas	E-government architecture of Kentucky
Geospatial information one-stop	$Br\left(E\left[\left(1,2,0.5,0.5\right)\right]\right)=1.5$	$Br\left(E\left[\left(1,2,0.5,0.5\right)\right]\right)=1.5$	$Br\left(E\left[\left(2.5,3.5,0.5,0.5\right)\right]\right)=0$
E-grants	$Br\left(E\left[\left(1,2,0.5,0.5\right)\right]\right)=1.5$	$Br\left(E\left[\left(1,2,0.5,0.5\right)\right]\right)=1.5$	$Br\left(E\left[\left(2.5,3.5,0.5,0.5\right)\right]\right)=0$
Disaster assistance and response	$Br\left(E\left[\left(0.5,1.5,0.5,0.5\right)\right]\right)=2$	$Br\left(E\left[\left(1.5,2.5,0.5,0.5\right)\right]\right)=1$	$Br\left(E\left[\left(2.5,3.5,0.5,0.5\right)\right]\right)=0$
Wireless public safety interoperable communications	$Br\left(E\left[\left(0.5,1.5,0.5,0.5\right)\right]\right)=2$	$Br\left(E\left[\left(2,3,0.5,0.5\right)\right]\right)=.5$	$Br\left(E\left[\left(2,3,0.5,0.5\right)\right]\right)=.5$
E-vital	$Br\left(E\left[\left(2.5,3.5,0.5,0.5\right)\right]\right)=0$	$Br\left(E\left[\left(1.5,2.5,0.5,0.5\right)\right]\right)=1$	$Br\left(E\left[\left(0.5,1.5,0.5,0.5\right)\right]\right)=2$

Table 8. The fuzzy decision matrix based on the G2C, G2B and G2G perspectives

E-government architecture	Perspectives		
	$c(c)$	$c(b)$	$c(g)$
E-government architecture of Massachusetts	1.575	1.8	1.6
E-government architecture of Texas	0.675	0.6	1.01
E-government architecture of Kentucky	0.75	0.6	0.21

by the e-government SC members with respect to the G2G criteria and then used equations (18) and (19) to calculate the weighted collective ordered matrix presented in Table 7.

Step 1.3.4. In this step, we used equations (20) and (21) and calculated the fuzzy vector for the three e-government architectures of Massachusetts, Texas and Kentucky with respect to the importance weight vector of the G2G perspective, $\underline{W(g)} = (0.25, 0.15, 0.3, 0.2, 0.1)$,andthe five strategic G2G criteria. The fuzzy vector for the three e-government architectures with respect to the G2C perspective will be shown later in Table 8.***Process 1.4.*** In this process, the three e-government architectures of Massachusetts, Texas and Kentucky are prioritized based on the SAW method in the three perspectives as follows:***Step 1.4.1.*** Initially, the decision matrix presented was constructed using equation (22) based on the three perspectives of G2C, G2B, and G2G as follows:

Step 1.4.2. In this step, we used equations (23) and (24) and constructed a weighted decision matrix presented in Table 9 for the three e-government architectures of Massachusetts, Texas and Kentucky with respect to the importance weight vector of the three perspectives, $\underline{W} = (0.35, 0.3, 0.35)$.

Step 1.4.3. In this step, we used equations (25) and (26) and calculated a weighted average value for each of the three e-government architectures of Massachusetts, Texas and Kentucky as follows: $\underline{V} = (1.65, 0.77, 0.51)$.

Phase 2. In this phase, equations (27) to (40) were used to prioritize the e-government architectures with respect to the financial

Table 9. The fuzzy weighted decision matrix based on the G2C, G2B and G2G perspectives

E-government architecture	Perspectives		
	$c(c)$	$c(b)$	$c(g)$
E-government architecture of Massachusetts	0.55	0.54	0.56
E-government architecture of Texas	0.24	0.18	0.35
E-government architecture of Kentucky	0.26	0.18	0.07

Table 10. The normalized mean value of the fuzzy real options for three e-government architectures with respect to the financial perspective

Deferral time	E-government architecture		
	E-government architecture of Massachusetts	**E-government architecture of Texas**	**E-government architecture of Kentucky**
0	0.35	0.35	0.29
1	0.37	0.40	0.36
2	0.28	0.25	0.35

normalized mean value of the fuzzy real options for the three e-government architectures of Massachusetts, Texas and Kentucky with respect to the financial perspective are shown in Table 10.

Phase 3. In this phase, we used the following two-objective decision making model (P) and the values obtained in phases (2) and (3) to determine the best e-government architectures:

$$Max\ z_1 = 0.35x_{10} + 0.37x_{11} + 0.28x_{12} + 0.35x_{20} + 0.40x_{21} + 0.25x_{22} + 0.29x_{30} + 0.36x_{31} + 0.35x_{32} \quad \text{(Model } P\text{)}$$

$$Max\ Z_2 = 1.65y_1 + 0.77y_2 + 0.51y_3$$

Subject to:

$$y_1 + y_2 + \cdots + y_n \leq 1$$

$$y_1 = x_{10} + x_{11} + x_{12}$$

$$y_2 = x_{20} + x_{21} + x_{22}$$

$$y_3 = x_{30} + x_{31} + x_{32}$$

$$x_{10}, x_{11}, x_{12}, x_{20}, x_{21}, x_{22}, x_{30}, x_{31}, x_{32} = 0,1$$

The optimal solution for model (P) indicated that the e-government architecture of Massachusetts must be implemented in the first year as the best-practice e-government architecture. The SC communicated its finding to the OIT which in turn communicated this recommendation to the governor and the state legislators for approval.

CONCLUSION AND FUTURE RESEARCH DIRECTION

Government agencies are increasingly using information and communication technologies to deliver government services to citizens, business partners, employees, and other agencies. As a result, the study of e-government has increased in recent years and researchers are developing new theoretical and conceptual models to better understand different aspects of e-government (Cresswell & Pardo, 2001; Dawes et al., 2004; Gil-García & Pardo, 2005; Gupta & Jana, 2003; Moon, 2002).

When confronted by the range of e-government architectures, government agencies struggle to identify the one most appropriate to their needs. The current evaluation methods used to benchmark the best practice e-government architecture do not support comprehensive assessment and need to be further improved in order to give policymakers better evaluation frameworks (Kunstelj & Vintar, 2004). In this study, we proposed a strategic benchmarking process that utilized SAW, ROA, and fuzzy sets to identify the best practice collaborative e-government architecture based on the G2C, G2B, and G2G perspectives. We proposed a strategic benchmarking process that it is applicable to the international, national, regional, state/provincial, and local e-government levels; we addressed the gaps in the e-government literature on the effective and efficient evaluation of the e-government architectures; we provided a comprehensive and systematic framework that combined ROA with SAW; and we used fuzzy logic and fuzzy sets to represent ambiguous, uncertain or imprecise information.

Nevertheless, we stress that our contribution addresses yet a small part of the issues that are involved with e-government evaluation. It is safe to say that ex-ante e-government evaluation as a discipline is at its infancy. Therefore, we hope that the study presented here can inspire others to pursue further research in this area. Additional future research that is being considered is to investigate other drivers that influence the ex-ante and ex-post e-government evaluation decisions. These value drivers could also be incorporated into the model proposed in this study.

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ENDNOTE

1 The name of the state is changed to protect its anonymity.

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