A Hybrid Fuzzy Group ANP-TOPSIS Framework for E-government Readiness Assessment from a CiRM Perspective

INFMAN-D-11-00467R3
Third Revision

Madjid Tavana, Ph.D.
Professor of Business Systems and Analytics
Lindback Distinguished Chair of Information Systems and Decision Sciences
La Salle University
Philadelphia, PA 19141, U.S.A.
Email: tavana@lasalle.edu
URL: http://tavana.us

Faramak Zandi, Ph.D.
Senior Lecturer of Operations and Production Management
La Salle University
Philadelphia, PA 19141, U.S.A.
Email: zandi@lasalle.edu

Michael N. Katehakis, Ph.D.
Professor and Chair
Department of Management Science and Information Systems
Rutgers University
Newark, NJ 07102
Email: mnk@rutgers.edu
A Hybrid Fuzzy Group ANP-TOPSIS Framework for E-government Readiness Assessment from a CiRM Perspective

Abstract
Electronic government (E-government) readiness assessment is a relatively new concept that has been given impetus by the rapid rate of Internet penetration and advances in information and communication technologies (ICT). The e-government readiness assessment of a community provides policy makers with a detailed scorecard of a community’s overall readiness for utilizing the opportunities provided by ICT relative to their counterparts in the digital era. Over the years, various e-government readiness assessment methods have been proposed by different organizations. These methods use a wide range of indicators to assess a community’s e-government readiness. However, most of them suffer from poor data quality and fragmented measurement efforts. In addition, they do not take into consideration the best practices in the assessment process. In this paper we propose a hybrid fuzzy model based on the group Analytic Network Process (ANP) and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) for assessing a community’s overall e-government readiness from a Citizen Relationship Management (CiRM) perspective. The e-government readiness assessment framework proposed in this study is a ranking and benchmarking tool that retrospectively measures the achievements of public agencies in the use of ICT. The results allow government agencies to discern their strengths in areas in which improvement can be made regarding citizen's needs. For practitioners, we present the results of a pilot study to demonstrate the complexities inherent in e-government readiness assessment due to the subjective and objective evaluation of a large number of competing and conflicting indicators provided by multiple experts.

Keywords: E-government Readiness, Fuzzy Group Analytic Network Process, Technique for Order Preference by Similarity to Ideal Solution, Citizen Relationship Management.
1. Introduction

The Internet revolution and advances in information and communication technologies (ICT) has dramatically changed how citizens and businesses interact with their government. Electronic government (e-government) is the delivery of government information and services to the citizens, businesses, government employees, and other agencies online through the Internet or other ICT (Hernon et al., 2002; West, 2004). There are many benefits to transforming traditional public services into e-government services including cost-effective delivery of services, integration of services, reduction in administrative costs, a single integrated view of citizens across all government services, and faster adaptation to meet citizens’ needs (Akman et al., 2005; Venkatesh et al., 2012). E-government capabilities can vary from the provision of simple information via a website, to the ability to conduct financial transactions and participate in e-democracy such as e-voting or policy development over the Internet (Holden et al., 2003). E-government initiatives of varying scope and complexity have been implemented at the municipal, state, and federal governments around the world (Torres et al., 2005). The advantages of e-government in timeliness, responsiveness, and cost containment are tremendous (Evans and Yen, 2006). For example, e-government allows interaction without the limitations of time and space imposed by office hours and municipal buildings, resulting in the reduction of operation inefficiencies, redundant spending, and excessive paperwork. E-government initiatives are deployed not only to enhance citizen services and cost savings in government administration but also to improve transparency and accountability in government functions.

The term Citizen Relationship Management (CiRM) is derived from Customer Relationship Management (CRM), a widely applied concept to build stronger relationships between firms and their customers in the private sector (Peppers and Rogers, 2004). CRM provides opportunities for citizens to participate in government (Schellong, 2008). Involving citizens in government is one of the key visions of e-government advancement (Jones et al., 2007; Caillier, 2009; Reddick, 2011). CRM builds on ICT and a variety of channels to interact with customers with the ultimate goal of increasing sales. Successful CRM requires a customer centric business philosophy, effective business processes, and often dramatic cultural and organizational change at the core of the firm (Zablah et al., 2004). Although there are great efforts to build customer driven governments, in most cases, public sector agencies do neither have a fully functional CiRM, nor do they have the means to systematically analyze their
readiness towards a fully functional CiRM. In the context of e-government research, both practitioners and academic scholars argue that citizen orientation is still far away from being fully exploited (Greitens and Strachan, 2011; Christensen, 2002). Instead of infusing organizational and institutional change, most of the e-government projects represent simple transformation of existing government information and services to the citizens through some digital means (United Nations, 2003). We argue that effective CiRM helps public agencies develop and maintain a strong relationship with their citizens.

E-government readiness is an important measure of a community’s overall readiness to utilize the opportunities provided by ICT (Al-Omari and Al-Omari, 2006; Kovacic, 2005). Providing an effective e-government readiness assessment framework is a necessary condition for advancing e-government (Ayanso et al., 2011; Ojo et al., 2005). Over the years, various e-government readiness assessment models and indices have been developed by different organizations especially for the purpose of international benchmarking. These indices implicitly assume different definitions and use a wide range of measures for determining a community’s e-government readiness. As one would expect, their outcomes differ markedly.

The e-government readiness assessment problems often involve a complex decision-making process in which multiple interdependent criteria and uncertain conditions have to be taken into consideration simultaneously (Ayanso et al. 2011). Measuring and operationalizing the various aspects of readiness is complex and inherently imprecise as it involves subjective conditions and information, linguistic assessments, and multiple and conflicting criteria. The multi-dimensional nature of e-government readiness assessment justifies the use of Multi-Criteria Decision Making (MCDM) methods. The criteria in MCDM can be qualitative and quantitative and they usually have different units of measurement (Turskis et al. 2009). Zavadskas and Turskis (2011) have provided an excellent panorama of MCDM methods in economics and summarized the pioneering studies that support multiple criteria decisions.

A commonly cited definition of uncertainty given by Hunter and Goodchild (1993) is “the degree to which the lack of knowledge about the amount of error is responsible for hesitancy in accepting the results and observations without caution.” The source of uncertainty can be vagueness or ambiguity. Vagueness refers to data with lack of clarity and ambiguity refers to data with several overlapping values. While vague data are uncertain because they lack detail or precision, ambiguous data are uncertain because they are subject to multiple
interpretations. The e-government readiness assessment problems involve vagueness and ambiguity and fuzzy sets theory has been widely used to handle imprecise and ambiguous data in MCDM (Yu et al., 2005).

ANP is a generalization of the Analytic Hierarchy Process methodology where hierarchies are replaced by networks to capture the outcome of dependence and feedback within and among the elements. ANP is a general framework for a detailed analysis of societal, governmental and corporate decisions (Saaty, 1996). In recent years, numerous applications of ANP have been published in the literature (Lee et al., 2009). The ANP is comprised of two parts. The first part consists of a network of criteria that controls the interactions in which the criteria are identified, organized and prioritized. The second part consists of a network of influences among the factors that captures the influence of elements in the feedback system with respect to each of these criteria. The importance weight of these criteria is obtained through paired comparison judgments of homogeneous elements. The ANP combines all possible outcomes to estimate the relative influence from which the overall priorities are derived. The Super Decisions software can be used to perform matrices computation and solve ANP problems (Saaty, 2003).

In this paper we propose a hybrid fuzzy model based on the group Analytic Network Process (ANP) and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) for assessing a community’s overall e-government readiness from a CiRM perspective. TOPSIS too has found broad use for decision-making applications over the past few decades. The reasons for using TOPSIS in this study are: (1) a sound logic that represents the rationale of human choice; (2) a unique visualization of the alternatives on a polyhedron; (3) a scalar value that accounts for the best and worst alternative choices simultaneously; and (4) a simple computation process that can be easily programmed into a spreadsheet (Kim et al., 1997; Shyur and Shih, 2006; Shih et al., 2007). Furthermore, TOPSIS allows the importance weights to be incorporated into the comparison process. However, while considering a solution with the shortest distance to the positive ideal solution and the greatest distance to the negative ideal solution, TOPSIS does not consider the relative importance of these distances (Opricovic and Tzend, 2004). As to which MCDM method(s) we should use, there are no specific rules. Different MCDM methods are introduced for different decision situations (Hwang and Yoon, 1981, p. 210). There are many MCDM methods and models, but none can be considered the “best” and/or appropriate for all situations (Kujawski, 2003).
The motivations for the integration of ANP with TOPSIS in this study are threefold: first, we use the concepts of the *positive ideal solution* and *negative ideal solution* in TOPSIS for benchmarking purposes; second, the use of TOPSIS after ANP can avoid the predicament that the units under evaluation are of the same value and cannot be appropriately ranked (Hsieh et al., 2006); and third, various successful applications of the integrated ANP-TOPSIS have been found in the literature for commercial-off-the-shelf software evaluation (Shyur, 2006), personnel selection (Dağdeviren, 2010), marketing strategy evaluation (Wu et al., 2010), hospital Location planning (Lin and Tsai, 2010); and machine tool evaluation (Ayağ and Gürcan Özdemir, 2012).

The purpose of this research is to propose a generic e-government readiness assessment framework with several distinct characteristics. The proposed framework will (1) utilize a set of suitable e-government readiness indicators that impacts e-government readiness in a community; (2) utilize the importance weight of these indicators by considering their interdependencies; and (3) provide an overall e-government readiness score by incorporating these indicators into a comprehensive and fuzzy framework.

This paper is organized into six sections. We present a review of the relevant literature in the next section. In Section 3 we present the mathematical notations and the details of the proposed framework. In Section 4 we present a pilot study to demonstrate the applicability of the proposed framework. In Section 5 we discuss the limitations and future research directions of our study and in Section 6 we present our conclusions.

2. Literature review

2.1. E-government readiness

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 entities in a very short period of time (Davies, 2002; Reylea, 2002). E-government has transformed government structures and provided opportunities to increase: (1) operational efficiency by reducing costs and increasing productivity; and (2) 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).

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 although 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 literature has a predominant focus on implementation (Chan et al., 2008; Chan and Pan, 2008; Chen et al., 2009; Heeks, 2005; Layne and Lee, 2001; Liao and Jeng, 2005; Nagi and Hamdan, 2009; Rose and Grant, 2010; Valdés et al., 2011), security and authentication (Kaliontzoglou et al., 2005; Lambrinoudakis et al., 2005; Tanaka et al., 2005; Zhao et al., 2010; Zissis and Lekkas, 2011), technology acceptance (Hung et al., 2006; Lee et al., 2011; Lin et al., 2011; Shyu and Huang, 2011), interoperability and connectivity (Choi and Whinston, 2000; Gottschalk, 2009; Jaeger et al., 2006), project planning and design (Batini et al., 2009; Ruuska and Teigland, 2009; Sarantis et al., 2011; Sharifi and Manian, 2010), and procurement and purchasing (Concha et al., 2011; Hardy and Williams, 2008; Özbilgin and Imamoğlu, 2011).

In this paper we focus on e-government readiness that represents a particular area of policy-making and research within the field of e-governance. E-government readiness primarily assesses the extent to which government agencies are equipped to deliver various governmental services online and can exploit ICT for internal functioning of the government (Yuan et al., 2012). The e-Government readiness research has gained significant recognition recently (Ayanso et al., 2011; Hanafizadeh et al., 2009; Khalil, 2011; Koh et al., 2008; Mutula and van Brakel, 2006; Potnis, 2010). Multiple initiatives have been undertaken by international organizations, consulting firms, and academic researchers to measure and operationalize the various aspects of readiness. Much of the research in this area is motivated and initiated by specific stakeholders
and focuses on divergent sets of indicators (Ojo et al., 2005).

2.2. Multi-attribute decision making

MCDM methods are generally categorized as continuous or discrete, depending on the domain of alternatives. Hwang and Yoon (1981) have classified the MCDM methods into two categories: multi-objective decision making (MODM) and multi-attribute decision making (MADM). MODM has been widely studied by means of mathematical programming methods with well-formulated theoretical frameworks. MODM methods have decision variable values that are determined in a continuous or integer domain with either an infinitive or a large number of alternative choices, the best of which should satisfy the decision maker (DM) constraints and preference priorities (Hwang and Masud, 1979; Ehrgott and Wiecek, 2005). MADM methods, on the other hand, have been used to resolve the decision making process with discrete decision spaces and a predetermined or a limited number of alternative choices. The MADM solution process requires inter and intra-attribute comparisons and involves implicit or explicit tradeoffs (Hwang and Yoon, 1981). Several methods have been proposed for solving MADM problems. The ANP developed by Saaty (1996) and the TOPSIS proposed by Hwang and Yoon (1981) are two well-known MADM methods used in this study.

The basic principle of TOPSIS is that the chosen alternatives should have the shortest distance from the ideal solution and the farthest distance from the nadir (negative-ideal) solution (Lai et al., 1994; Yoon and Hwang, 1995). TOPSIS has been one of the best MADM methods in addressing the rank reversal issue, which is the change in the ranking of alternatives when a non-optimal alternative is introduced (Zanakis et al., 1998). This consistency feature is largely appreciated in practical applications. Moreover, the rank reversal in TOPSIS is insensitive to the number of alternatives and has its worst performance only in the case of a very limited number of attributes (Zanakis et al., 1998; Triantaphyllou and Lin, 1996). A relative advantage of TOPSIS is its ability to identify the best alternative quickly (Paxkan and Wu, 1997).

A pitfall of the TOPSIS method is the need for precise measurement of the performance ratings and criteria weights (Yurdakul and Tansel, 2009). However, in many real-world problems, ratings and weights cannot be measured precisely as some DMs may express their judgments using linguistic terms (Chen, 2000; Torabi and Hassini, 2009). Most measures in e-government readiness assessment are described subjectively by ill-defined and vague linguistic terms and the conventional assessment approaches cannot effectively handle such measurement.
However, fuzzy logic provides a useful tool for dealing with e-government readiness assessment problems in which the indicators are imprecise and vague (Lin et al., 2006). Fuzzy logic and fuzzy sets can represent ambiguous, uncertain or imprecise information in e-government readiness assessment by formalizing inaccuracy in human decision-making (Collan et al. 2009). Fuzzy set algebra developed by Zadeh (1965) is the formal body of theory that allows the treatment of imprecise estimates in uncertain environments.

3. Mathematical Notations and Definitions

Let us introduce the following mathematical notations and definitions:

- $n$: The number of the e-government readiness indicators
- $m_i$: The number of the e-government readiness sub-indicators of indicator $i$
- $q_{ji}$: The number of the e-government readiness sub-sub-indicators of sub-indicator $j$ of indicator $i$
- $p$: The number of the e-government readiness committee members
- $Y_i$: The e-government readiness community $t$
- $c_i$: The e-government readiness indicator $i$
- $e_{ji}(c_i)$: The e-government readiness sub-indicator $j$ of indicator $i$
- $f_h(e_{ji}(c_i))$: The e-government readiness sub-sub-indicator $h$ of sub-indicator $j$ of indicator $i$
- $\rho_{i,i'}(1)$: The fuzzy individual pair-wise comparison value of indicator $i$ and indicator $i'$
- $\rho_{j,j'}(c_i)$: The fuzzy individual pair-wise comparison value of sub-sub-indicator $j$ and sub-indicator $j'$ with respect to indicator $i$
- $\rho_{hh'}(e_{ji}(c_i))$: The fuzzy individual pair-wise comparison value of sub-indicator $h$ and sub-indicator $h'$ with respect to sub-indicator $j$ of indicator $i$
- $\rho_{i,i'}(1)$: The fuzzy weighted collective pair-wise comparison value of indicator $i$ and indicator $i'$
- $\rho_{j,j'}(c_i)$: The fuzzy weighted collective pair-wise comparison value of sub-indicator $j$ and sub-indicator $j'$ with respect to indicator $i$
- $\rho_{hh'}(e_{ji}(c_i))$: The fuzzy individual pair-wise comparison value of sub-sub-indicator $h$ and sub-sub-indicator $h'$ with respect to sub-indicator $j$ of indicator $i$
The fuzzy individual pair-wise comparison value of interdependencies for indicator $i$ and indicator $i'$

The fuzzy individual pair-wise comparison value of interdependencies for sub-sub-indicator $j$ and sub-sub-indicator $j'$ with respect to indicator $i$

The fuzzy weighted collective pair-wise comparison value of interdependencies for sub-sub-indicator $h$ and sub-sub-indicator $h'$ with respect to sub-indicator $j$ of indicator $i$

The fuzzy weighted collective pair-wise comparison value of interdependencies for sub-sub-indicator $i$ and indicator $i'$

The fuzzy weighted collective pair-wise comparison value of interdependencies for sub-sub-indicator $j$ and sub-sub-indicator $j'$ with respect to indicator $i$

The fuzzy weighted collective pair-wise comparison value of interdependencies for sub-sub-indicator $h$ and sub-sub-indicator $h'$ with respect to sub-indicator $j$ of indicator $i$

The voting power of the e-government readiness committee member $k$

The fuzzy individual e-government readiness score of sub-sub-indicator $h$ of sub-indicator $j$ of indicator $i$ for community $t$

The fuzzy weighted collective e-government readiness score of sub-sub-indicator $h$ of sub-indicator $j$ of indicator $i$ for community $t$

The fuzzy ideal e-government readiness score of sub-sub-indicator $h$ of sub-indicator $j$ of indicator $i$

The fuzzy nadir e-government readiness score of sub-sub-indicator $h$ of sub-indicator $j$ of indicator $i$

The fuzzy importance weight of the e-government readiness sub-sub-indicator $h$ of sub-indicator $j$ of indicator $i$

The fuzzy importance weight of the e-government readiness sub-indicator $j$ of indicator $i$

The fuzzy importance weight of the e-government readiness indicator $i$

The ideal e-government readiness score of community $t$
$D^*(t)$ The nadir (negative ideal) e-government readiness score of community $t$

$G(t)$ The relative closeness of community $t$ representing a simultaneous consideration of the distances from the ideal e-government readiness score of community $t$ (to be minimized) and the distance from the nadir e-government readiness score of community $t$ (to be maximized)

4. **Proposed Framework**

An e-government readiness assessment provides policy makers with a detailed scorecard of their community’s competitiveness relative to its local, regional or national counterparts. We propose the framework depicted in Figure 1 to calculate an e-government readiness index for each community in order to make this comparison. The proposed framework consists of three main phases modularized into a series of steps and procedures.

The e-government readiness indices are generally quantitative in nature. Some frameworks are based on measurable characteristics while others use one or more subjective measures. A few employ a combination of both. Frameworks based on objective and subjective measures tend to attract fewer criticisms (Rorissa et al., 2011). The proposed framework is a comprehensive and structured framework designed to capture the subjective and objective judgments associated with qualitative and quantitative indicators in multi-criteria multi-actor e-government readiness assessment problems.

**Phase 1: Define the decision parameters**

In this phase we identify the decision makers, candidate communities, the e-government readiness hierarchy and their interdependencies as follows:

**Step 1.1. Establish the e-government readiness committee**

We begin the assessment process by establishing an e-government readiness committee. Let us assume that we form an e-government readiness committee with $p$ members as follows:

$$Committee = [CM(1), CM(2), \ldots, CM(p)]$$

(1)

The committee then determines the voting power associated with each committee member. In this paper we will assign a voting power to each committee member as the proportion of the total power (where the total power is normalized to 1) according to some pre-specified rule(s). In contrast, the committee can give equal weights where appropriate. Let us
assume that the voting powers of the p committee members are as follows:
\( \mathcal{V} = [v(1), v(2), \ldots, v(p)] \)  

(2)

**Step 1.2. Identify the candidate communities for e-government readiness assessment**

The e-government readiness committee then identifies the candidate communities to be considered in the assessment process. Let us consider \( t \) communities as follows:

*Candidate communities* \( Y = [Y_1, Y_2, \ldots, Y_t] \)  

(3)

**Step 1.3. Construct the e-government readiness hierarchy**

In this step the committee identifies a set of e-government readiness functions called e-government readiness indicators. Each indicator is further categorized into several sub-indicators and each sub-indicator is further categorized into several sub-sub-indicators. This hierarchical structure presented in Table 1 is intended to capture how communities compare in terms of creating, diffusing, adopting and using the various components of a networked economy. Let us consider the following \( n \) indicators, \( m \) sub-indicators, and \( q \) sub-sub-indicators as follows:

\[
c_i = [c_1, c_2, \ldots, c_j, \ldots, c_n]
\]

(4)

\[
c_i = [e_1(c_i), e_2(c_i), \ldots, e_m(c_i)]
\]

(5)

\[
e_j(c_i) = [f_1(e_j(c_i)), f_2(e_j(c_i)), \ldots, f_{q_{i,j}}(e_j(c_i))]
\]

(6)

**Step 1.4. Identify the network interdependencies**

The committee then identifies the network interdependencies in the e-government readiness hierarchy using the ANP proposed by Saaty (1996). Interested readers may consult Saaty (1996) for further reading on the ANP and its algorithms and the explanation of its elements. For example, as shown in Figure 2 sub-indicator 1.2 may influence itself (inner-dependence loop) or influence sub-indicator 1.3 (outer-dependence loop). In addition, dependence can occur within a cluster (sub-indicators of indicator 1) or between clusters (a sub-indicator of indicator 1 and a sub-indicator of indicator 2).

**Phase 2: Calculate the importance weight of the e-government readiness elements**

In this phase, the proposed approach is used to calculate the importance weight of the e-
government readiness elements (indicators, sub-indicators and sub-sub-indicators) according to the following steps:

**Step 2.1. Construct the fuzzy individual pair-wise comparison supermatrices**

In this step, each committee member compares pairs of indicators with respect to their importance towards the overall objective. Similarly, pairs of sub-indicators and sub-sub-indicators in each cluster are also compared with respect to their importance towards their control indicator and sub-indicator, respectively. Each committee member is asked to respond to a series of pair-wise comparisons of two indicators in terms of their contribution to the overall objective. Similarly, each committee member conducts a series of pair-wise comparisons of two sub-indicators (or sub-sub-indicators) in terms of their contribution to their respective indicator (or sub-indicator). In addition, interdependencies among indicators, sub-indicators and sub-sub-indicators of a cluster are examined pair-wise.

In the conventional AHP, a 9-point scale proposed by Saaty (1996) is used to represent the pair-wise comparisons. In this study, trapezoidal fuzzy numbers proposed by Zheng et al. (2012) are used to represent subjective pair-wise comparisons. The scale of the relative importance to measure comparison and the corresponding trapezoidal fuzzy numbers are given in Table 2. A reciprocal value is assigned to the inverse comparisons.

| Insert Table 2 Here |

Among the various types of fuzzy numbers, triangular and trapezoidal fuzzy numbers are most important. We chose trapezoidal fuzzy numbers for the case study because they are used most often for characterizing imprecise, vague and ambiguous information in practical applications (Klir and Yuan, 1995; Yeh and Deng, 2004). The common use of trapezoidal fuzzy numbers is mainly attributed to their simplicity in both concept and computation. Chen (1985) represent a generalized trapezoidal fuzzy number \( \tilde{A} \) as \( \tilde{A} = (a, b, c, d; w) \) where a, b, c, and d are real values and \( 0 < w \leq 1 \), as shown in Figure 3.

| Insert Figure 3 Here |

The membership function \( \mu_{\tilde{A}} \) of a generalized fuzzy number \( \tilde{A} \) satisfies the following conditions:

- \( \mu_{\tilde{A}} \) is a continuous mapping from the universe of discourse \( X \) to the closed interval \( [0,1] \);
• \( \mu_{\tilde{A}}(x) = 0 \), where \( -\infty < x \leq a \);

• \( \mu_{\tilde{A}}(x) \) is monotonical increasing in \([a,b]\);

• \( \mu_{\tilde{A}}(x) = w \), where \( b \leq x \leq c \);

• \( \mu_{\tilde{A}}(x) \) is monotonical decreasing in \([c,d]\);

• \( \mu_{\tilde{A}}(x) = 0 \), where \( d \leq x \leq \infty \).

If \( w = 1 \), then the generalized fuzzy number \( \tilde{A} \) is a normal fuzzy number denoted as \( \tilde{A} = (a,b,c,d) \). If \( a = b \) and \( c = d \), then the generalized fuzzy number \( \tilde{A} \) is a crisp interval. If \( a < b = c < d \), then \( \tilde{A} \) is a triangular fuzzy number. If \( a < b < c < d \), then \( \tilde{A} \) is a generalized trapezoidal fuzzy number. If \( a = b = c = d \) and \( w = 1 \), then \( \tilde{A} \) is a crisp value.

Assume that there are two generalized trapezoidal fuzzy numbers \( \tilde{A} \) and \( \tilde{B} \), where \( \tilde{A} = (a_1,a_2,a_3,a_4;\hat{w}_A) \) and \( \tilde{B} = (b_1,b_2,b_3,b_4;\hat{w}_B) \). The arithmetic operations between the two generalized trapezoidal fuzzy numbers \( \tilde{A} \) and \( \tilde{B} \) are reviewed from Chen (1985) as follows:

• Generalized fuzzy numbers addition \( \oplus \):

\[
\tilde{A}_1 \oplus \tilde{A}_2 = (a_1,b_1,c_1,d_1;\hat{w}_1) \oplus (a_2,b_2,c_2,d_2;\hat{w}_2) = (a_1 + a_2, b_1 + b_2, c_1 + c_2, d_1 + d_2; \min(w_1,w_2))
\]  

(7)

where \( a_1, b_1, c_1, d_1, a_2, b_2, c_2 \) and \( d_2 \) are real numbers.

• Generalized fuzzy numbers subtraction \( \ominus \):

\[
\tilde{A}_1 \ominus \tilde{A}_2 = (a_1,b_1,c_1,d_1;\hat{w}_1) \ominus (a_2,b_2,c_2,d_2;\hat{w}_2) = (a_1 - a_2, b_1 - b_2, c_1 - c_2, d_1 - d_2; \min(w_1,w_2))
\]  

(8)

where \( a_1, b_1, c_1, d_1, a_2, b_2, c_2 \) and \( d_2 \) are real numbers.

• Generalized fuzzy numbers multiplication \( \otimes \):

\[
\tilde{A}_1 \otimes \tilde{A}_2 = (a,b,c,d; \min(w_1,w_2))
\]  

(9)

where \( a = \text{Min}(a_1 \times a_2, a_1 \times d_2, d_1 \times a_2, d_1 \times d_2) \),

\[
b = \text{Min}(b_1 \times b_2, b_1 \times c_2, b_2 \times c_1, c_1 \times c_2) ,
\]

\[
c = \text{Max}(b_1 \times b_2, b_1 \times c_2, b_2 \times c_1, c_1 \times c_2) , \text{ and}
\]

\[
d = \text{Max}(a_1 \times a_2, a_1 \times d_2, d_1 \times a_2, d_1 \times d_2).
\]

It is obvious that if \( a_1, b_1, c_1, d_1, a_2, b_2, c_2 \) and \( d_2 \) are positive real numbers, then:
\[ \widetilde{A}_1 \otimes \widetilde{A}_2 = (a_1 \times a_2, b_1 \times b_2, c_1 \times c_2, d_1 \times d_2; \ \min (w_1, w_2)) \]  

(10)

• Generalized fuzzy numbers division \( \otimes \):

Let \( \widetilde{A}_1 \) and \( \widetilde{A}_2 \) be two generalized trapezoidal fuzzy numbers, where \( \widetilde{A}_1 = (a_1, b_1, c_1, d_1; w_1) \), \( \widetilde{A}_2 = (a_2, b_2, c_2, d_2; w_2) \), \( a_1, b_1, c_1, d_1, a_2, b_2, c_2 \) and \( d_2 \) are non-zero positive real numbers, \( w_1 \in [0,1] \) and \( w_2 \in [0,1] \). Then, the division between \( \widetilde{A}_1 \) and \( \widetilde{A}_2 \) is defined as follows:

\[ \widetilde{A}_1 \otimes \widetilde{A}_2 = (a_1 / d_2, b_1 / c_2, c_1 / b_2, d_1 / a_2; \ \min (w_1, w_2)) \]  

(11)

The pair-wise comparisons in ANP are performed in the framework of a matrix and a local priority vector is derived as an estimate of the relative importance associated with the indicators, sub-indicators and sub-sub-indicators. The influence of each indicator on other indicators, each sub-indicator on other sub-indicators and each sub-sub-indicator on other sub-sub-indicators are represented by eigenvectors. Saaty and Takizawa (1986) have proposed several algorithms to approximate the eigenvector. In this paper, Super Decisions (Saaty, 2003) is used to compute the eigenvectors from the pair-wise comparison matrices and to determine the consistency ratios using the algorithms proposed by Saaty (1996). We convert the trapezoidal fuzzy numbers into matching crisp values before using the Super Decisions software. Defuzzification is an inverse transformation which maps the output from the fuzzy numbers back into the crisp numbers. Assume that the trapezoid fuzzy number is \( \widetilde{A} = (a, b, c, d) \), then the matching crisp value can be obtained by using Equation (12) proposed by Lin and Lee (2006):

\[ N = \frac{(B + c)}{2} + \frac{[(d - c) - (b - a)]}{6} = \frac{(a + 2b + 2c + d)}{6} \]  

(12)

To obtain global priorities in a problem with interdependent influences, the local priority vectors are entered in the appropriate columns of a supermatrix (a partitioned matrix where each matrix segment represents a relationship between two indicators, sub-indicators or sub-sub-indicators). The fuzzy individual pair-wise comparison supermatrix of the indicators evaluated by the members of the e-government readiness committees are shown in Table 3. Similarly, the fuzzy individual pair-wise comparison supermatrices of the sub-indicators and sub-sub-indicators are constructed.

Insert Table 3 Here
Next, the Super Decisions software (Saaty, 2003) is used to perform all the necessary calculations in Steps 2.2, 2.3, and 2.4 as follows:

**Step 2.2. Construct the fuzzy weighted collective pair-wise comparison supermatrices**

The committee then aggregates the fuzzy individual pair-wise comparison supermatrix into the fuzzy weighted collective supermatrix of the indicators shown in Table 4. Similarly, the fuzzy weighted collective supermatrices of the sub-indicators and sub-sub-indicators are constructed.

\[
\text{Insert Table 4 Here}
\]

where

\[
\rho_{ij}(1) = \frac{\sum_{k=1}^{m} (v(k)) \left[ \rho_{ij}(1) \right]}{\sum_{k=1}^{m} v(k)}
\]

(13)

\[
\rho_{ij}(c_i) = \frac{\sum_{k=1}^{m} (v(k)) \left[ \rho_{ij}(c_i) \right]}{\sum_{k=1}^{m} v(k)}
\]

(14)

\[
\rho_{ij}(e_j(c_i)) = \frac{\sum_{k=1}^{m} (v(k)) \left[ \rho_{ij}(e_j(c_i)) \right]}{\sum_{k=1}^{m} v(k)}
\]

(15)

**Step 2.3. Construct the fuzzy individual supermatrices of interdependencies**

In this step, the committee constructs the fuzzy individual supermatrix of interdependencies for the indicators as shown in Table 5. Similarly, the fuzzy individual supermatrices of interdependencies for the sub-indicators and sub-sub-indicators are constructed.

\[
\text{Insert Table 5 Here}
\]

**Step 2.4. Construct the fuzzy weighted collective supermatrices of interdependencies**

The committee then aggregates the fuzzy individual supermatrix of interdependencies to form the fuzzy weighted collective supermatrix of interdependencies among the indicators as shown in Table 6. Similarly, the fuzzy weighted collective supermatrices of interdependencies among the sub-indicators and sub-sub-indicators are constructed.

\[
\text{Insert Table 6 Here}
\]

where
Step 2.5. Calculate the importance weight of the e-government readiness elements

We first convert the trapezoidal fuzzy weighted scores calculated in Step 2.4 into matching crisp values. This defuzzification process maps the trapezoidal fuzzy weighted scores back into crisp weighted scores. Assuming that the trapezoid fuzzy number is $\bar{A} = (a, b, c, d)$, we use Equation (12) proposed by Lin and Lee (2006) to obtain the matching crisp values. These matching crisp values are then used to calculate the importance weight vector of the e-government readiness indicators, sub-indicators and sub-sub-indicators using the limit matrix calculation in the Super Decisions software (Saaty, 2003).

Phase 3: Calculate an e-government readiness index for each community

In this phase, the committee uses the proposed fuzzy group TOPSIS approach to calculate the relative closeness of the e-government readiness of a community to the ideal e-government readiness index according to the following three steps:

Step 3.1. Determine the fuzzy individual e-government readiness values

In this step, each committee member individually evaluates all sub-sub-indicators with respect to each community using the linguistic variables and trapezoidal fuzzy numbers presented in Table 7. The scores presented in Table 8 shows how much each community has created, diffused, adopted and used the various components of a networked economy.

Step 3.2. Determine the fuzzy weighted collective e-government readiness values

The committee then aggregates the fuzzy individual e-government readiness values to calculate
the fuzzy weighted collective e-government readiness scores presented in Table 9.

where

\[
\delta_{ijh}(t) = \frac{\sum_{k=1}^{m} (v(k)) \left[ \delta_{ijh}(t) \right]}{\sum_{k=1}^{m} v(k)}
\]  

(19)

where \(1 \leq \delta_{ijh}(t) \leq 9\).

**Step 3.3. Calculate the e-government readiness indices**

The basic principle of TOPSIS is that the chosen alternatives should have the shortest distance from the ideal solution and the farthest distance from the nadir (negative-ideal) solution. In this step, we calculate an e-government readiness index for each community based on its ideal and nadir scores. This index simultaneously measures the relative closeness or distance of a community from \(D^+(t)\) (the ideal e-government readiness score to be minimized) and from \(D^-(t)\) (the nadir e-government readiness score to be maximized) through the TOPSIS Equation (20) given below:

\[
G(t) = \frac{D^-(t)}{D^+(t) + D^-(t)}
\]

where \(0 \leq G(t) \leq 1\) and

\[
D^+(t) = \sqrt{E(\varphi_0)E(\varphi_{\Phi_1})E(\varphi_{\Phi_1})E\left[\delta_{\delta_1}(t) - \delta_{\delta_1}\right] + \frac{E(\varphi_\Phi)E(\varphi_{\Phi_1})E(\varphi_{\Phi_1})E\left[\delta_{\delta_1}(t) - \delta_{\delta_1}\right]}{\sum_{k=1}^{n} v(k)}}
\]

(21)

\[
D^-(t) = \sqrt{E(\varphi_0)E(\varphi_{\Phi_1})E(\varphi_{\Phi_1})E\left[\delta_{\delta_1}(t) - \delta_{\delta_1}\right] + \frac{E(\varphi_\Phi)E(\varphi_{\Phi_1})E(\varphi_{\Phi_1})E\left[\delta_{\delta_1}(t) - \delta_{\delta_1}\right]}{\sum_{k=1}^{n} v(k)}}
\]

(22)

The higher relative closeness scores are preferred to the lower scores. The most attainable e-government readiness index is 1 when \(D^+(t) = 0\) and \(D^-(t) = 8\). In contrast, the least attainable e-government readiness index is zero when \(D^+(t) = 8\) and \(D^-(t) = 0\).

**5. Pilot Study**

The State of East Virginia\(^1\) has been pursuing policies for the last decade to introduce e-government infrastructure in order to increase the quality of public services and enhance

\(^1\) The state and city names in this case study are changed to protect their anonymity.
citizens’ participation with a view to create an integrated and networked government structure. The state Information Technology Services Division (ITSD) chief was charged with a pilot study to assess the e-government readiness in the cities of Little Heaven, Egg Harbor, Radium Springs, Slippery Rock, and Windy Falls from a CiRM perspective. The ITSD chief invited the authors to help the information services division with this assessment process. The ITSD in the five cities selected for this pilot study provides a series of services that includes integrating computer systems, negotiating and managing information technology-related contracts, coordinating and providing training, and technology assistance and support. The department also creates the technology environment that enables City employees to quickly access vital information using the most efficient and cost effective system hardware and software. The average ITSD budget for the five cities in 2010-11 was $3,625,750 and the average full-time equivalent employees for the five cities were 25 in 2010-11. The individual budget and full-time equivalent data for the five cities are presented in Table 10.

This table also shows the overall maturity level of each city ITSD in comparison to the best-in-class city in the State of East Virginia. The State ITSD used the following maturity scale to evaluate the ITSD maturity level for each city throughout the State:

- **Ad Hoc**: No or limited ITSD systems or tools in place to support the role.
- **Reactive**: ITSD systems and tools are present to support the role; however, there is no coordination or standardization across the enterprise.
- **Challenged**: ITSD systems and tools are in place to support the role but have been procured without suitable alignment to user and operational requirements.
- **Managed**: ITSD support systems are in place to support the IT role across the enterprise and are consistently used.
- **Optimized**: ITSD support systems are in place and support the enterprise’s ability to improve and optimize operational performance.

As shown in Table 10, the overall maturity level for the five cities ranged from Reactive to Managed. The above mentioned scale was also used by the State ITSD to assess the Technology, Organization, Process, Strategy, and Service (TOPSS) maturity level of each city in comparison to the best-in-class city in the State of East Virginia. The results are presented in Table 11.
After a careful analysis of the problem, the authors suggested to use the framework proposed in this study and the ITSD chief agreed. Initially, the ITSD chief and the authors formed a committee with eight members to participate in the evaluation process. The eight-member committee included five Information Technology Services Department Directors from the five cities and three chief executive officers from three well-established e-government watchdog groups and foundations in the State of East Virginia as follows:

\[ \text{Committee} = [CM(1), CM(2), CM(3), CM(4), CM(5), CM(6), CM(7), CM(8)] \]

Next, the committee assigned the following voting power weights to the e-government readiness committee members based on their tenure and seniority in the state government. The three members of the committee selected from the watchdog groups and foundations were assigned equal weights as follows:

\[ \nu = [\nu(1), \nu(2), \nu(3), \nu(4), \nu(5), \nu(6), \nu(7), \nu(8)] \]

The committee then agreed to use a set of e-government readiness functions called readiness indicators. The readiness indicators and their sub-indicators were intended to capture how communities compare in terms of creating, diffusing, adopting and using the various components of a networked economy. Koh and Balthazard (1997) proposed an intuitive and yet comprehensive three-ring framework with three primary functions of Internet for organizing ever-increasing capabilities of the Internet:

- **Informational function:** where government agencies disseminate information to educate, entertain, influence, or reach their citizens.
- **Transactional function:** where government agencies support a coordinated sequence of user and system activities to provide service and transfer value.
- **Operational function:** where government agencies provide a new mechanism by integrating various business operations into synergistic networks.

Koh et al. (2008) further categorized 31 Internet functions (indicators) according to the three-ring framework proposed by Koh and Balthazard (1997). Although the model proposed in this study is generic and can be used for a wide range of hierarchical and non-hierarchical structures, the hierarchical structure with three indicators, seven sub-indicators, and 31 sub-sub-indicators proposed by Koh et al. (2008) was selected by the committee to be used in the
evaluation process (see Table 12).

Next, the committee carefully examined the hierarchical structure presented in Table 12 for interdependencies and feedback among the indicators, sub-indicators, and sub-sub-indicators shown by broken arrows in Figure 4.

In phase 2, we first constructed the fuzzy individual and the fuzzy weighted collective pair-wise comparison supermatrices (According to Steps 2.1 and 2.2). We then constructed the fuzzy individual and the fuzzy weighted collective supermatrices of interdependencies (According to Steps 2.3 and 2.4). We then converted these trapezoidal fuzzy weighted scores into matching crisp values using Equation (12). Finally, the eigenvector method proposed by Saaty (1996) was utilized to calculate the importance weight of the e-government readiness indicators, sub-indicators and sub-sub-indicators presented in Table 13 for e-government readiness assessment from a CiRM perspective:

In phase 3, the fuzzy individual e-government readiness assessment values of the eight committee members were collected in Step 3.1. These individual scores were then integrated using Equation (19) in Step 3.2 to compute the fuzzy weighted collective e-government readiness assessment scores presented in Table 14:

In Step 3.3 we use the TOPSIS concepts of the positive ideal solution and negative ideal solution for benchmarking purposes. We first find the ideal e-government readiness score ($D^+(t)$) and the nadir e-government readiness score ($D^-(t)$) of the cities using Equations (21) and (22), respectively. We then use Equation (20) to calculate the relative closeness of e-government readiness ($G(t)$) for the cities under consideration. Table 15 present the relative closeness of the five cities under evaluation.

As shown in Table 15, the City of Egg Harbor has the lowest ideal e-government readiness score ($D^+(t) = 2.881$) and the highest nadir e-government readiness score
\(D^-(t) = 5.537\) compared to its counterpart cities of Little Heaven, Radium Springs, Slippery Rock, and Windy Falls. In other words, City of Egg Harbor is the closest city to the ideal city and the farthest city from the nadir city. In summary, the City of Egg Harbor has the best (highest) e-government readiness index \(G(t) = 0.658\) reflecting the success of the city in increasing the quality of public services and enhancing citizens’ participation. The final e-government readiness ranking of the five cities in the State of East Virginia from a CiRM perspective is as follows:

Egg Harbor > Little Heaven > Radium Springs > Windy Falls > Slippery Rock

Finally, we developed a plan of action for each city under consideration by plotting each sub-sub-indicator across two dimensions: Implementation Time Frame and Implementation Impact. As shown in Figure 5, using these two dimensions, the sub-sub-indicators were assigned to one of the four following planning quadrants: Top Priorities, Key Investments, Quick Wins, and Future Improvements.

**Top Priorities:** Represent those sub-sub-indicators that have a short implementation time frame and a high improvement impact. These are the sub-sub-indicators that ITSDs should act upon immediately.

**Key Investments:** Represent those sub-sub-indicators that have a high improvement impact and a long implementation time frame. ITSDs should begin investing in these sub-sub-indicators now so that they can be realized subsequent to the implementation of the top priorities.

**Quick Wins:** Represent those sub-sub-indicators that have a short implementation time frame and a low improvement impact. Quick Wins should also be pursued as soon as possible but should not interfere with the implementation of the top priorities and key investments.

**Future Improvements:** Represent those sub-sub-indicators that have a long implementation time frame and a low improvement impact. ITSDs should focus on these sub-sub-indicators after implementing the top priorities, key investments and quick wins.

The plan of actions for the ITSDs in the cities of Little Heaven, Egg Harbor, Radium Springs, Slippery Rock, and Windy Falls are presented in Table 16.

6. **Limitations and future research directions**
This study, like any other study, has several limitations. First, the results depend on the qualitative judgments and quantitative data. The e-government readiness index developed for a community could be developed with some bias in the weights of the various indicators. Another limitation of the proposed model is that it ignores the behavioral and political factors that may influence the weight determination process. Second, we only applied the evaluation framework to a handful of small cities. As many local, provincial, and national governments provide more and more e-government initiatives, one interesting direction for future research would be to apply our framework to different size cities and better understand the implications of the size on the index composition and application proposed in this study. Third, we evaluated the e-government readiness with respect to three indicators: informational uses, transactional uses, and operational uses. It would be a valuable research direction to include more indicators which can reflect the nature of e-government in larger cities.

Furthermore, more and more citizens are discussing their observations and opinions about public administration in online social network sites such as Facebook and Twitter. One interesting direction for future research in this area is to investigate the influence of social network sites in the development of e-government. How should governments make use of social network sites to serve their citizens better? Should governments also provide social network sites platforms to improve interactivity and collect public opinions regarding to new services and policies? Finally, public agencies follow an evolutionary path in utilizing ICT. Initially, they use ICT primarily for informational purposes because it is simple and inexpensive and the return on investment is relatively large and quick (Introduction Phase). As public agencies become more familiar with the technology, they expand their ICT applications to provide more services (Expansion Phase). Eventually public agencies realize the true value of ICT and all of their e-government applications are tightly integrated into a cohesive system (Integration Phase). The paradigm shift from a government-centric to a citizen-centric view of public service delivery is a reality and the relationship between the overall readiness index proposed in this study and the introduction, expansion, and integration phases of e-government evolution will need to be explored further in future research.

7. Conclusions
E-government is not a simple online information provision. It reflects the ultimate visions for policy makers and public administrators to build a comprehensive architecture for integrating
disparate processes and avoiding unnecessary duplication. The aim of e-government is to rethink ways the government functions are performed to improve processes and promote cohesiveness and not simply transform traditional information into bits and bytes and making it available on the Internet. Focusing solely on technological solutions will not change the mentality of bureaucrats who view citizens as neither customers of government nor the participants in the decision-making process. E-government should foster transparency, eliminate distance and other barriers, and empower citizens to participate in the political processes that affect their lives.

The framework proposed in this study assesses the e-government readiness in communities at the municipal, state, and federal governments according to a flexible but systematic structure. Benchmarking and rankings are commonly used to determine the relative standing of the e-government readiness and to monitor the progress of communities with respect to a characteristic or achievement goal (Rorissa et al., 2011). The proposed framework is a hybrid fuzzy model that can assess a community’s overall e-government readiness from a CiRM perspective based on group ANP and TOPSIS. The results allow policy makers and public administrators to discern their strengths and areas in which improvement can be made regarding citizen's needs. We also presented a real-life pilot study and demonstrated the complexities inherent in e-government readiness assessment due to the subjective and objective evaluation of a large number of competing and conflicting indicators provided by multiple experts.

The proposed framework provides a structured and methodical approach rather than relying on intuition and risky conjecture in e-government readiness assessment. The detailed indicators used in this study can help government agencies analyze their community’s unique needs and develop customized action plans to improve e-government readiness through an optimum allocation of resources.

The contribution of the proposed e-government assessment framework is fivefold: (1) it addresses several gaps in the efficacious and effective assessment of e-government readiness; (2) it provides a comprehensive and customized framework that combines ANP and TOPSIS for structuring e-government readiness assessment problems; (3) it considers fuzzy logic and fuzzy sets to represent ambiguous, uncertain or imprecise information; (4) it synthesizes a representative outcome based on qualitative judgments and quantitative data; and (5) it produces an overall e-government readiness index that is tailored for a specific government agency that could be used as a ranking or benchmarking tool.
References


The e-government readiness assessment process

Phase 1: Define the decision parameters
- Step 1.1. Establish the e-government readiness committee
- Step 1.2. Identify the candidate communities for e-government readiness assessment
- Step 1.3. Construct the e-government readiness hierarchy
- Step 1.4. Identify the network interdependencies

Phase 2: Calculate the importance weight of the e-government readiness elements
- Step 2.1. Construct the fuzzy individual pair-wise comparison supermatrices
- Step 2.2. Construct the fuzzy weighted collective pair-wise comparison supermatrices
- Step 2.3. Construct the fuzzy individual supermatrices of interdependencies
- Step 2.4. Construct the fuzzy weighted collective supermatrices of interdependencies
- Step 2.5. Calculate the importance weight of the e-government readiness elements

Phase 3: Calculate an e-government readiness index for each community
- Step 3.1. Determine the fuzzy individual e-government readiness values
- Step 3.2. Determine the fuzzy weighted collective e-government readiness values
- Step 3.3. Calculate the e-government readiness indices

Figure 1: The proposed framework
Figure 2: ANP network interdependencies
Figure 3: Trapezoidal fuzzy number