

A hybrid fuzzy group ANP–TOPSIS framework for assessment of e-government readiness from a CiRM perspective



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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). 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 these methods suffer from poor data quality and fragmented measurement efforts. 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), to assess a community's overall e-government readiness from a Citizen Relationship Management (CiRM) perspective. For practitioners, we present the results of a pilot study to demonstrate the complexities inherent in e-government readiness assessment.

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1. Introduction

The Internet revolution and advances in information and communication technologies (ICT) have dramatically changed how citizens and businesses interact with their government. Electronic government (e-government) is the delivery of government information and services to citizens, businesses, government employees, and other agencies online through the Internet or other ICT [29,95]. 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 citizens' needs [1,94]. 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, as with e-voting or policy development over the Internet [30]. E-government initiatives of varying scope and complexity have been implemented at the municipal, state, and federal government levels around the world [89]. The advantages of e-government in timeliness, responsiveness, and cost containment are substantial [21]. For

example, e-government allows for interactions with government without the limitations of time and space imposed by office hours and municipal buildings, resulting in reductions in 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 that refers to building stronger relationships between firms and their customers in the private sector [65]. CRM provides opportunities for citizens to participate in government [79], one of the key goals of e-government [37,7,69]. CRM builds on ICT and a variety of channels to enable firms 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 [103]. Although great efforts to build citizen-driven government have been undertaken, in most cases, public sector agencies neither have a fully functional CiRM nor the means to systematically analyze their readiness to implement a fully functional CiRM. In the context of e-government research, both practitioners and academic scholars argue that citizen orientation is still far from being fully exploited [24]. Instead of infusing organizational and institutional change, most e-government projects represent simple transformations of existing government information and services to the citizens through digital means [92].

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We argue that effective CiRM helps public agencies develop and maintain strong relationships with citizens.

E-government readiness is an important measure of a community's overall readiness to utilize opportunities provided by ICT [2,44], and an effective e-government readiness assessment framework is a necessary condition for advancing e-government [4,61]. Over the years, various e-government readiness assessment models and indices have been developed by different organizations, especially for purposes of international benchmarking. These indices implicitly assume different definitions and use a wide range of measures to determine a community's e-government readiness. As one would expect, their outcomes differ markedly.

E-government readiness assessment problems often involve a complex decision-making process in which multiple interdependent criteria and uncertain conditions must simultaneously be considered [4]. 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 usually involve different units of measurement [91]. Zavadskas and Turskis [106] provide an excellent survey of MCDM methods in economics and summarize the pioneering studies that support multiple criteria decisions.

A commonly cited definition of uncertainty, given by Hunter and Goodchild [33], 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." Sources of uncertainty include both vagueness and ambiguity. Vagueness characterizes data that lack clarity, and ambiguity characterizes 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. 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 [100].

ANP is a generalization of the Analytic Hierarchy Process methodology by which hierarchies are replaced by networks to capture outcomes of dependence and feedback within and among elements. ANP is a general framework for a detailed analysis of societal, governmental, and corporate decisions [74]. In recent years, numerous applications of ANP have been published in the literature [49]. ANP consists of two parts. The first part consists of a network of criteria, a network 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. This network captures the influence of elements in the feedback system with respect to each of the criteria. The importance weights of these criteria are obtained through paired comparison judgments of homogeneous elements. The ANP combines all possible outcomes in estimating the relative influence of different criteria from which the overall priorities are derived. The Super Decisions software can be used to perform matrices computation and solve ANP problems [75].

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), to assess a community's overall e-government readiness from a CiRM perspective. TOPSIS has also found broad use in decision-making applications over the past few decades. The reasons for using TOPSIS in this study are that it provides: (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 easily be

programmed into a spreadsheet [40,84,81]. In addition, TOPSIS allows importance weights to be incorporated into the comparison process. However, in 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 [62]. As to which MCDM method(s) we should use, there are no specific rules. Different MCDM methods are introduced for different decision situations ([35], p. 210). There are many MCDM methods and models, but none can be considered the "best" and/or most appropriate in all situations [45].

The motivations for the integration of ANP with TOPSIS in this study are threefold: first, we use the concepts of *positive ideal solution* and *negative ideal solution* in TOPSIS for benchmarking purposes; second, the use of TOPSIS after ANP avoids the predicament that the units under evaluation are of the same value and cannot be appropriately ranked [31]; and third, various successful applications of the integrated ANP–TOPSIS are found in the literature – for example, to commercial off-the-shelf software evaluation [83], personnel selection [17], marketing strategy evaluation [97], hospital location planning [53]; and machine tool evaluation [3].

The purpose of this research is to propose a generic e-government readiness assessment framework that has several distinct characteristics. The proposed framework will (1) utilize a set of suitable e-government readiness indicators that impact e-government readiness in a community; (2) utilize the importance weights 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. In the next section, we present a review of the relevant literature. In Section 3, we present our mathematical notation 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 limitations of our study and future research directions. In Section 6, we present our conclusions.

2. Literature review

2.1. E-government readiness

E-government is a dynamic concept that, over a very short period of time, has had an enormous impact on the efficient and effective delivery of government services to citizens, business partners, and other government entities [18]. E-government has transformed government structures and created opportunities to increase: (1) operational efficiency by reducing costs and increasing productivity and (2) operational effectiveness by enabling delivery of higher quality services. E-government promises better government, including improved services, cost savings, wider political participation, and more effective policies and programs [22].

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 [27,67]. The increase in efficiency has strengthened the quality of government services to citizens and the business sector [57,70]. E-government has also fortified democracy and reduced the distance between citizens and government [56]. E-government services represent different levels of technological sophistication and administrative challenges [30,58,78]. Several empirical studies have identified a dynamic progression in e-government sophistication, from national to state to local governments [19,86,96]. 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 are under the least direct democratic control of citizens, businesses, and other government entities. However, over the last decade, more and more state and local governments have begun to embrace e-government.

The e-government literature has focused predominantly on implementation [9,8,12,28,48,51,60,72,93], security and authentication [38,87,107,109], technology acceptance [32,50,55,82], interoperability and connectivity [13,23,36], project planning and design [6,73,77,80], and procurement and purchasing [16,26,63].

In this paper, we focus on e-government readiness, 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 government functioning [101]. Recently, e-Government readiness research has gained significant recognition [4,25,39,43,59,66], as multiple initiatives have been undertaken by international organizations, consulting firms, and academic researchers to measure and operationalize the various aspects of e-government readiness. Much of the research in this area is motivated and initiated by specific stakeholders and focuses on divergent sets of indicators [61].

2.2. Multi-attribute decision-making

MCDM methods are generally categorized as continuous or discrete, depending on the domain of alternatives. Hwang and Yoon [35] have classified MCDM methods into two categories: multi-objective decision-making (MODM) and multi-attribute decision-making (MADM). MODM has been widely studied through mathematical programming methods within well-formulated theoretical frameworks. Under MODM methods, decision variable values are determined in a continuous or integer domain, with either an infinite or a large number of alternative choices, the best of which should satisfy the decision maker (DM) constraints and preference priorities [34,20]. MADM methods, however, have been used to resolve decision-making processes in discrete decision spaces with a predetermined or limited number of alternative choices. The MADM solution process requires inter and intra-attribute comparisons and involves implicit or explicit tradeoffs [35]. Several methods have been proposed for solving MADM problems. The ANP, developed by Saaty [74], and the TOPSIS, proposed by Hwang and Yoon [35], 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 [46,99]. TOPSIS has been one of the most successful MADM methods used to address the rank reversal issue, where the latter refers to the change in the ranking of alternatives when a non-optimal alternative is introduced [105]. This consistency feature is widely appreciated in practical applications. Moreover, the rank reversal in TOPSIS is insensitive to the number of alternatives and exhibits its poorest performance only when there are a very limited number of attributes [105,90]. A relative advantage of TOPSIS is its ability to identify the best alternative quickly [64].

A pitfall of the TOPSIS method is the need for precise measurement of performance ratings and criteria weights [110]. However, in many real-world problems, ratings and weights cannot be measured precisely, as some DMs may express their judgments in linguistic terms [11,88]. Most measures in e-government readiness assessment are described subjectively in ill-defined and vague linguistic terms, and conventional assessment approaches cannot effectively handle such measurements. However, fuzzy logic provides a useful tool in addressing e-government readiness assessment problems in which the

indicators are imprecise and vague [54]. Fuzzy logic and fuzzy sets can represent ambiguous, uncertain or imprecise information in e-government readiness assessments by formalizing inaccuracy in human decision-making [15]. Fuzzy set algebra, developed by Zadeh [104], is the formal body of theory that allows for 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 e-government readiness indicators
m_i	The number of e-government readiness sub-indicators of indicator i
q_{ji}	The number of e-government readiness sub-sub-indicators of sub-indicator j of indicator i
p	The number of e-government readiness committee members
Y_t	The e-government readiness community t
c_i	The e-government readiness indicator i
$e_j(c_i)$	The e-government readiness sub-indicator j of indicator i
$f_h(e_j(c_i))$	The e-government readiness sub-sub-indicator h of sub-indicator j of indicator i
$f_{ii}^k(1)$	The fuzzy individual pair-wise comparison value of indicator i and indicator i'
$f_{jj'}^k(c_i)$	The fuzzy individual pair-wise comparison value of sub-sub-indicator j and sub-indicator j' with respect to indicator i
$f_{hh'}^k(e_j(c_i))$	The fuzzy individual pair-wise comparison value of sub-indicator h and sub-indicator h' with respect to sub-indicator j of indicator i
$\tilde{r}_{ii}(1)$	The fuzzy weighted collective pair-wise comparison value of indicator i and indicator i'
$\tilde{r}_{jj'}(c_i)$	The fuzzy weighted collective pair-wise comparison value of sub-indicator j and sub-indicator j' with respect to indicator i
$\tilde{r}_{hh'}(e_j(c_i))$	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
$\tilde{d}_{ii}^k(1)$	The fuzzy individual pair-wise comparison value of interdependencies for indicator i and indicator i'
$\tilde{d}_{jj'}^k(c_i)$	The fuzzy individual pair-wise comparison value of interdependencies for sub-sub-indicator j and sub-indicator j' with respect to indicator i
$\tilde{d}_{hh'}^k(e_j(c_i))$	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
$\tilde{d}_{ii}(1)$	The fuzzy weighted collective pair-wise comparison value of interdependencies for indicator i and indicator i'
$\tilde{d}_{jj'}(c_i)$	The fuzzy weighted collective pair-wise comparison value of interdependencies for sub-indicator j and sub-indicator j' with respect to indicator i
$\tilde{d}_{hh'}(e_j(c_i))$	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
$\nu(k)$	The voting power of e-government readiness committee member k
$\tilde{a}_{ijh}^k(t)$	The fuzzy individual e-government readiness score of sub-sub-indicator h of sub-indicator j of indicator i for community t
$\tilde{a}_{ijh}(t)$	The fuzzy weighted collective e-government readiness score of sub-sub-indicator h of sub-indicator j of indicator i for community t
$\tilde{a}_{ijh}^+(t)$	The fuzzy ideal e-government readiness score of sub-sub-indicator h of sub-indicator j of indicator i
$\tilde{a}_{ijh}^-(t)$	The fuzzy nadir e-government readiness score of sub-sub-indicator h of sub-indicator j of indicator i
\tilde{w}_{tjh}	The fuzzy importance weight of the e-government readiness sub-sub-indicator h of sub-indicator j of indicator i
\tilde{w}_{ij}	The fuzzy importance weight of the e-government readiness sub-indicator j of indicator i
\tilde{w}_i	The fuzzy importance weight of the e-government readiness indicator i
$D^+(t)$	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 Fig. 1 to calculate an e-government readiness index for each community in order to make such comparisons. 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 the two. Frameworks based on objective and subjective measures tend to attract less criticism [71]. 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.

4.1. Phase 1: define the decision parameters

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

4.1.1. 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:

$$Committee = [CM(1), CM(2), \dots, CM(p)] \tag{1}$$

The committee determines the voting power associated with each committee member. In this paper, we will assign voting power to each committee member as a proportion of total power (where total power is normalized to 1), according to some pre-specified rule(s). Alternatively, the committee can assign equal weights to different committee members as appropriate. Let us assume that the different levels of voting power of the p committee members are as follows:

$$\underline{V} = [v(1), v(2), \dots, v(p)] \tag{2}$$

4.1.2. 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:

$$Candidate\ communities\ Y = [Y_1, Y_2, \dots, Y_t] \tag{3}$$

4.1.3. 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 creation, diffusion, adoption, and utilization of the various components of a networked economy. Let us consider the following n indicators, m_i sub-indicators, and q_i sub-sub-indicators as follows:

$$c = [c_1, c_2, \dots, c_j, \dots, c_n] \tag{4}$$

Table 1

The e-government readiness indicators, sub-indicators, and sub-sub-indicators.

E-government readiness		
Indicator	Sub-indicator	Sub-sub-indicator
c_1	$e_1(c_1)$	$f_1(e_1(c_1))$

	$f_{q_1}(e_1(c_1))$	...

...	$e_{m_1}(c_1)$	$f_1(e_{m_1}(c_1))$
		...
		$f_{q_{m_1}}(e_{m_1}(c_1))$
		...
c_n	$e_1(c_n)$	$f_1(e_1(c_n))$
		...
		$f_{q_1}(e_1(c_n))$
		...
...	$e_{m_n}(c_n)$	$f_1(e_{m_n}(c_n))$
		...
		$f_{q_{m_n}}(e_{m_n}(c_n))$
		...

$$c_i = [e_1(c_i), e_2(c_i), \dots, e_{m_i}(c_i)] \tag{5}$$

$$e_j(c_i) = [f_1(e_j(c_i)), f_2(e_j(c_i)), \dots, f_{q_{m_j}}(e_j(c_i))] \tag{6}$$

4.1.4. Step 1.4. Identify network interdependencies

The committee then identifies the network interdependencies in the e-government readiness hierarchy, using the ANP proposed by Saaty [74]. Interested readers can consult Saaty [74] for further reading on the ANP, its algorithms and explanations of its elements. For example, as shown in Fig. 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).

4.2. Phase 2: calculate the importance weights of e-government readiness elements

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

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

In this step, each committee member compares pairs of indicators in terms of their importance to the overall objective. Similarly, pairs of sub-indicators and sub-sub-indicators in each cluster are also compared in terms of their importance to their control indicators and sub-indicators, respectively. Each committee member is asked to respond to a series of pair-wise comparisons of two indicators in which indicators are compared 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 contributions to their respective indicators (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 [74], is used to represent the pair-wise comparisons. In this study, trapezoidal fuzzy numbers, proposed by Zheng et al. [108], are used to represent subjective pair-wise comparisons. The scales of

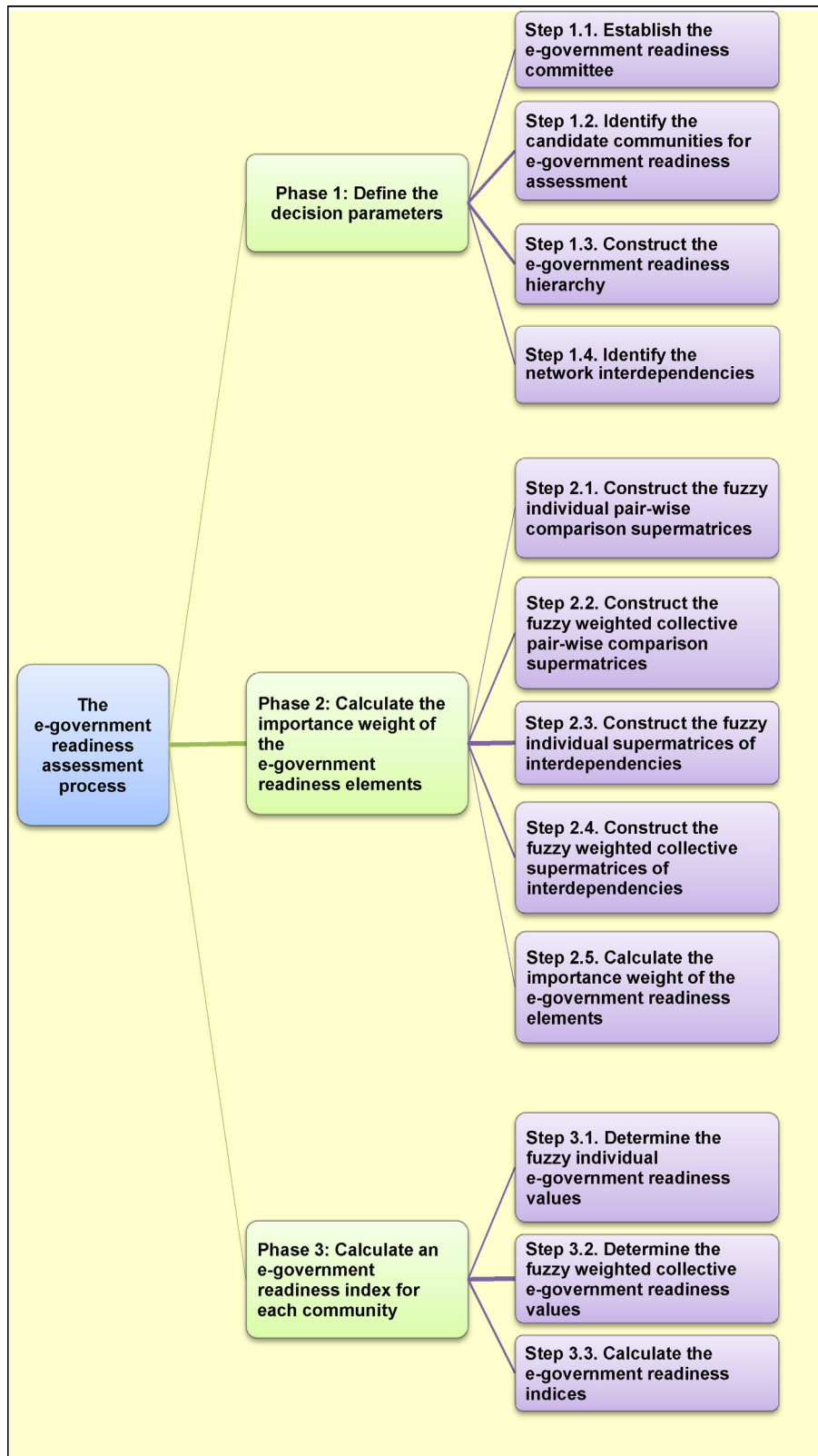


Fig. 1. The proposed framework.

relative importance used to represent pair-wise comparisons and the corresponding trapezoidal fuzzy numbers are given in Table 2. Reciprocal values are assigned to the inverse comparisons.

Among the various types of fuzzy numbers, triangular and trapezoidal fuzzy numbers are the most important. We choose

trapezoidal fuzzy numbers for the present case study because they are used most often in practical applications in characterizing imprecise, vague, and ambiguous information [41,98]. The common use of trapezoidal fuzzy numbers is mainly attributed to their simplicity in both concept and computation. Chen [10]

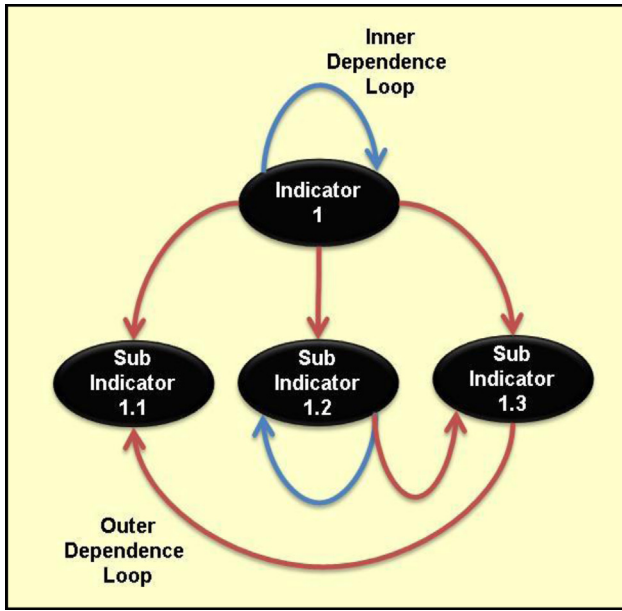


Fig. 2. ANP network interdependencies.

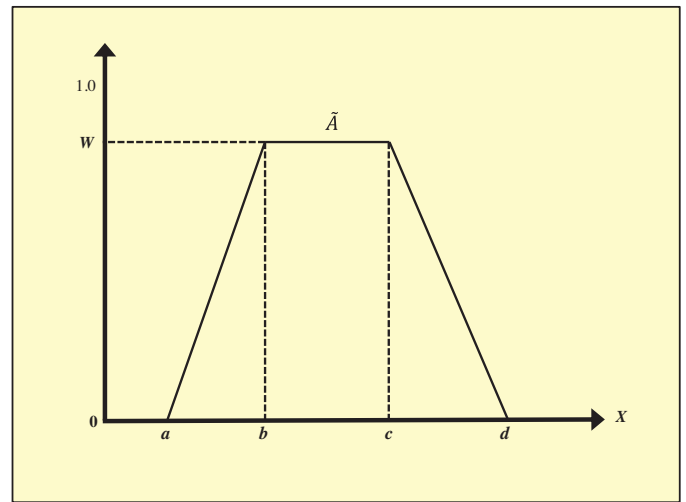


Fig. 3. Trapezoidal fuzzy number.

represents 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 Fig. 3.

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 monotonically increasing in $[a,b]$;
- $\mu_{\tilde{A}}(x) = w$, where $b \leq x \leq c$;
- $\mu_{\tilde{A}}(x)$ is monotonically 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 by $\tilde{A} = (a, b, c, d)$. 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 $\tilde{A} = (a_1, a_2, a_3, a_4; \hat{w}_{\tilde{A}})$ and $\tilde{B} = (b_1, b_2, b_3, b_4; \hat{w}_{\tilde{B}})$. The arithmetical operations between the two generalized trapezoidal fuzzy numbers \tilde{A} and \tilde{B} are reviewed in Chen [10] as follows:

- Generalized fuzzy numbers addition \oplus :

$$\tilde{A}_1 \oplus \tilde{A}_2 = (a_1, b_1, c_1, d_1; \hat{w}_1) \oplus (a_2, b_2, c_2, d_2; \hat{w}_2) = (a_1 + a_2, b_1 + b_2, c_1 + c_2, d_1 + d_2; \min(w_1, w_2)) \quad (7)$$

where $a_1, b_1, c_1, d_1, a_2, b_2, c_2$ and d_2 are real numbers.

Table 2
The scale of relative importance used in the pair-wise comparisons.

Scale of relative importance (crisp number)	Trapezoidal fuzzy number	Linguistic variable
1	(1,1,1,1)	Equally important
3	(2,5/2,7/2,4)	Weakly important
5	(4,9/2,11/2,6)	Essentially important
7	(6,13/2,15/2,8)	Very strongly important
9	(8,17/2,9,9)	Absolutely important

- Generalized fuzzy numbers subtraction \ominus :

$$\tilde{A}_1 \ominus \tilde{A}_2 = (a_1, b_1, c_1, d_1; \hat{w}_1) \ominus (a_2, b_2, c_2, d_2; \hat{w}_2) = (a_1 - a_2, b_1 - b_2, c_1 - c_2, d_1 - d_2; \min(w_1, w_2)) \quad (8)$$

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 :

$$\tilde{A}_1 \otimes \tilde{A}_2 = (a, b, c, d; \min(w_1, w_2)) \quad (9)$$

where $a = \text{Min}(a_1 \times a_2, a_1 \times d_2, d_1 \times a_2, d_1 \times d_2)$, $b = \text{Min}(b_1 \times b_2, b_1 \times c_2, c_1 \times b_2, c_1 \times c_2)$, $c = \text{Max}(b_1 \times b_2, b_1 \times c_2, c_1 \times b_2, c_1 \times c_2)$, 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:

$$\tilde{A}_1 \otimes \tilde{A}_2 = (a_1 \times a_2, b_1 \times b_2, c_1 \times c_2, d_1 \times d_2; \min(w_1, w_2)). \quad (10)$$

- Generalized fuzzy numbers division \oslash :

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

$$\tilde{A}_1 \oslash \tilde{A}_2 = (a_1, b_1, c_1, d_1; w_1) \oslash (a_2, b_2, c_2, d_2; w_2) = (a_1/d_2, b_1/c_2, c_1/b_2, d_1/a_2; \min(w_1, w_2)) \quad (11)$$

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 of the indicators, sub-indicators, and sub-sub-indicators. The influences of each indicator on other indicators, of each sub-indicator on other sub-indicators, and of each sub-sub-indicator on other sub-sub-indicators are represented by eigenvectors. Saaty and Takizawa [76] propose several algorithms to approximate the eigenvectors. In this paper, Super Decisions [75], employing the algorithms proposed by Saaty [74], is used to compute the eigenvectors from the pair-wise comparison matrices and to determine the consistency ratios. We convert the trapezoidal fuzzy numbers into matching crisp values before use of the Super Decisions software. Defuzzification is an inverse transformation that maps the output from the fuzzy numbers back into the crisp numbers. Assume that the trapezoid fuzzy number is $\tilde{A} = (a, b, c, d)$. Then, the matching crisp value can be obtained by using Equation (12), as proposed by Lin and Lee [52]:

$$N = \frac{(B + c)}{2} + \frac{[(d - c) - (b - a)]}{6} = \frac{(a + 2b + 2c + d)}{6} \quad (12)$$

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 members of e-government readiness committees, is shown in Table 3. Similarly, the fuzzy individual pair-wise comparison supermatrices of the sub-indicators and sub-sub-indicators are constructed.

Next, the Super Decisions software [75] is used to perform all the necessary calculations in Steps 2.2, 2.3, and 2.4 as follows:

4.2.2. 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. The fuzzy weighted collective supermatrices of the sub-indicators and sub-sub-indicators are constructed similarly. Where

$$\tilde{r}_{ii'}(1) = \frac{\sum_{k=1}^m (v(k)) [r_{ii'}^k(1)]}{\sum_{k=1}^m v(k)} \tag{13}$$

$$\tilde{r}_{jj'}(c_i) = \frac{\sum_{k=1}^m (v(k)) [r_{jj'}^k(c_i)]}{\sum_{k=1}^m v(k)} \tag{14}$$

$$\tilde{r}_{hh'}(e_j(c_i)) = \frac{\sum_{k=1}^m (v(k)) [r_{hh'}^k(e_j(c_i))]}{\sum_{k=1}^m v(k)} \tag{15}$$

4.2.3. 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. The fuzzy individual supermatrices of interdependencies

Table 3
The fuzzy individual pair-wise comparison supermatrix of the indicators.

		E-government readiness indicators		
		c ₁	...	c _n
E-government readiness indicators	c ₁	$\tilde{r}_{11}^k(1)$	...	$\tilde{r}_{1n}^k(1)$
	⋮	⋮	...	⋮
	c _n	$\tilde{r}_{n1}^k(1)$	...	$\tilde{r}_{nn}^k(1)$

Table 4
The fuzzy weighted collective pair-wise comparison supermatrix of the indicators.

		E-government readiness indicators		
		c ₁	...	c _n
E-government readiness indicators	c ₁	$\tilde{r}_{11}(1)$	...	$\tilde{r}_{1n}(1)$
	⋮	⋮	...	⋮
	c _n	$\tilde{r}_{n1}(1)$	...	$\tilde{r}_{nn}(1)$

for the sub-indicators and sub-sub-indicators are constructed similarly.

4.2.4. 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. The fuzzy weighted collective supermatrices of interdependencies among the sub-indicators and sub-sub-indicators are constructed similarly. Where

$$\tilde{d}_{ii'}(1) = \frac{\sum_{k=1}^m (v(k)) [d_{ii'}^k(1)]}{\sum_{k=1}^m v(k)} \tag{16}$$

$$\tilde{d}_{jj'}(c_i) = \frac{\sum_{k=1}^m (v(k)) [d_{jj'}^k(c_i)]}{\sum_{k=1}^m v(k)} \tag{17}$$

$$\tilde{d}_{hh'}(e_j(c_i)) = \frac{\sum_{k=1}^m (v(k)) [d_{hh'}^k(e_j(c_i))]}{\sum_{k=1}^m v(k)} \tag{18}$$

4.2.5. Step 2.5. Calculate the importance weights 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 $\tilde{A} = (a, b, c, d)$, we use Equation (12), proposed by Lin and Lee [52], 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 [75].

Table 5
The fuzzy individual supermatrix of interdependencies among the indicators.

		E-government readiness indicators		
		c ₁	...	c _n
E-government readiness indicators	c ₁	$\tilde{d}_{11}^k(1)$	...	$\tilde{d}_{1n}^k(1)$
	⋮	⋮	...	⋮
	c _n	$\tilde{d}_{n1}^k(1)$	...	$\tilde{d}_{nn}^k(1)$

Table 6
The fuzzy weighted collective supermatrix of interdependencies among the indicators.

		E-government readiness indicators		
		c ₁	...	c _n
E-government readiness indicators	c ₁	$\tilde{d}_{11}(1)$	...	$\tilde{d}_{1n}(1)$
	⋮	⋮	...	⋮
	c _n	$\tilde{d}_{n1}(1)$	...	$\tilde{d}_{nn}(1)$

4.3. 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:

4.3.1. 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, show to what extent each community has created, diffused, adopted, and used the various components of a networked economy.

4.3.2. 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

$$\tilde{a}_{ijh}(t) = \frac{\sum_{k=1}^m (v(k)) [\tilde{a}_{ijh}^k(t)]}{\sum_{k=1}^m v(k)} \tag{19}$$

and $1 \leq \tilde{a}_{ijh}(t) \leq 9$.

4.3.3. 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

Table 7
The linguistic variables and trapezoidal fuzzy numbers for the evaluation.

Linguistic variables	Trapezoidal fuzzy numbers
Very poor	(0,1,2,3)
Poor	(1,2,3,4)
Medium	(3,4,5,6)
Good	(5,6,7,8)
Very good	(7,8,9,10)

Table 8
The fuzzy individual e-government readiness scores.

Importance weight			Fuzzy individual e-government readiness scores
Indicator	Sub-indicator	Sub-sub-indicator	
\tilde{w}_1	\tilde{w}_{11}	\tilde{w}_{111}	$\tilde{a}_{111}^k(t)$
		$\tilde{w}_{11q_{11}}$	$\tilde{a}_{11q_{11}}^k(t)$
	\tilde{w}_{1m_1}	\tilde{w}_{1m_11}	$\tilde{a}_{1m_11}^k(t)$
		$\tilde{w}_{1m_1q_{11}}$	$\tilde{a}_{1m_1q_{11}}^k(t)$
\tilde{w}_n	\tilde{w}_{n1}	\tilde{w}_{n11}	$\tilde{a}_{n11}^k(t)$
		$\tilde{w}_{n1q_{1n}}$	$\tilde{a}_{n1q_{1n}}^k(t)$
	\tilde{w}_{nm_n}	\tilde{w}_{nm_n1}	$\tilde{a}_{nm_n1}^k(t)$
		$\tilde{w}_{nm_nq_{m_n}}$	$\tilde{a}_{nm_nq_{m_n}}^k(t)$

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):

$$G(t) = \frac{D^-(t)}{D^*(t) + D^-(t)} \tag{20}$$

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

$$D^*(t) = \sqrt{E(\tilde{w}_1) \cdot E(\tilde{w}_{11}) \cdot E(\tilde{w}_{111}) \cdot E[\tilde{a}_{111}(t) - \tilde{a}_{111}^*]^2 + \dots + E(\tilde{w}_n) \cdot E(\tilde{w}_{nm_n}) \cdot E(\tilde{w}_{nm_nq_{m_n}}) \cdot E[\tilde{a}_{nm_nq_{m_n}}(t) - \tilde{a}_{nm_nq_{m_n}}^*]^2} \tag{21}$$

$$D^-(t) = \sqrt{E(\tilde{w}_1) \cdot E(\tilde{w}_{11}) \cdot E(\tilde{w}_{111}) \cdot E[\tilde{a}_{111}(t) - \tilde{a}_{111}^-]^2 + \dots + E(\tilde{w}_n) \cdot E(\tilde{w}_{nm_n}) \cdot E(\tilde{w}_{nm_nq_{m_n}}) \cdot E[\tilde{a}_{nm_nq_{m_n}}(t) - \tilde{a}_{nm_nq_{m_n}}^-]^2} \tag{22}$$

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

5. Pilot study

Over the last decade, the State of East Virginia¹ has sought to introduce e-government infrastructure, with a view to creating an integrated and networked government structure and thereby increasing the quality of public services and enhance citizen participation. The state Information Technology Services Division (ITSD) chief was charged to conduct a pilot study to assess 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 assist the information services division in this assessment process. The ITSD in the five cities selected for this pilot study provides a series of services that include integrating computer systems, negotiating and managing information technology-related contracts, coordinating and providing training, and providing 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 across the five cities in 2010–2011 was \$3,625,750, and the average number of full-time equivalent employees during that period was 25. 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 that of 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 of 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.

¹ The state and city names in this case study are changed to protect their anonymity.

Table 9
The fuzzy weighted collective e-government readiness scores.

E-government readiness			Fuzzy weighted collective e-government readiness score
Indicator	Sub-indicator	Sub-sub-indicator	
1	1	1	$\tilde{a}_{111}(t)$
		\vdots	\vdots
	\vdots	q_{1_1}	$\tilde{a}_{11q_{1_1}}(t)$
		\vdots	\vdots
	m_1	1	$\tilde{a}_{1m_1}(t)$
		\vdots	\vdots
	\vdots	q_{m_1}	$\tilde{a}_{1m_1q_{1_1}}(t)$
		\vdots	\vdots
\vdots	\vdots	\vdots	\vdots
		\vdots	\vdots
n	1	1	$\tilde{a}_{n11}(t)$
		\vdots	\vdots
	\vdots	q_{1_n}	$\tilde{a}_{n1q_{1n}}(t)$
		\vdots	\vdots
	m_n	1	$\tilde{a}_{nmn}(t)$
		\vdots	\vdots
	\vdots	q_{m_n}	$\tilde{a}_{nmnq_{m_n}}(t)$
		\vdots	\vdots

- 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 of the five cities ranged from Reactive to Managed. The above 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 use of the framework proposed in this study, and the ITSD chief agreed. Initially, the ITSD chief and the authors formed a committee of 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:

$$Committee = [CM(1), CM(2), CM(3), CM(4), CM(5), CM(6), CM(7), CM(8)]$$

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:

$$V = [v(1), v(2), v(3), v(4), v(5), v(6), v(7), v(8)]$$

The committee then agreed to use a set of e-government readiness functions called readiness indicators. Readiness indicators and their sub-indicators are used to compare communities in terms of creation, diffusion, adoption, and utilization of the various components of a networked economy. Koh and Balthazard [42] propose an intuitive yet comprehensive three-ring framework, outlining three primary functions by which to categorize the 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 services and transfer value.
- Operational function: where government agencies provide a new mechanism by integrating various business operations into synergistic networks.

Koh et al. [43] further categorize 31 Internet functions (indicators) in terms of the three-ring framework proposed by Koh and Balthazard [42]. Although the model proposed in this study is generic and can be used in a wide range of hierarchical and non-hierarchical structures, the hierarchical structure with three indicators, seven sub-indicators, and 31 sub-sub-indicators,

Table 10
Overall maturity level in comparison to the best-in-class city in the State of East Virginia.

City	2010–2011 budget	2010–2011 full time equivalent employees	Overall maturity level				
			Ad Hoc	Reactive	Challenged	Managed	Optimized
Little Heaven	4,536,000	26			↙		
Egg Harbor	3,841,000	28				↙	
Radium Springs	2,842,000	22		↘			
Slippery Rock	3,693,000	24		↘			
Windy Falls	4,127,000	25			↙		

Table 11
TOPSS maturity level in comparison to the best-in-class city in the State of East Virginia.

Dimension	City				
	Little Heaven	Egg Harbor	Radium Springs	Slippery Rock	Windy Falls
Technology	Managed	Challenged	Challenged	Reactive	Challenged
Organization	Challenged	Managed	Reactive	Challenged	Reactive
Process	Managed	Managed	Reactive	Reactive	Reactive
Strategy	Challenged	Challenged	Challenged	Reactive	Challenged
Service Level	Challenged	Managed	Challenged	Reactive	Reactive

Table 12

The e-government readiness indicators, sub-indicators, and sub-sub-indicators used for the State of East Virginia.

E-government readiness		
Indicator	Sub-indicator	Sub-sub-indicator
1. Informational uses	1.1. Online publishing	1.1.1. City information 1.1.2. GIS data 1.1.3. City budget 1.1.4. Employee manuals 1.1.5. Online tour of city 1.1.6. Minutes of meetings
	Broadcasting	1.2.1. Video broadcast of meetings 1.2.2. Audio broadcast of meetings 1.2.3. Live traffic cams
2. Transactional uses	2.1. Online procurement	2.1.1. Calls for bids or proposals 2.1.2. Bidder applications
	2.2. Online payments	2.2.1. Utility payments 2.2.2. Collection of fees 2.2.3. Collection of fines 2.2.4. Tax collection 2.2.5. Payments to service providers
3. Operational uses	3.1. Online customer service	3.1.1. Requests for service 3.1.2. Permit application and renewal 3.1.3. License application and renewal 3.1.4. Voter registration 3.1.5. Requests for records 3.1.6. Property registration 3.1.7. Surveys & polls 3.1.8. Forums & discussions
	3.2. Operational support for employees	3.2.1. E-mail access 3.2.2. Online calendar 3.2.3. Scheduling meetings online 3.2.4. Online document management 3.2.5. Video conferencing
	3.3. Miscellaneous	3.3.1. Online job applications 3.3.2. Emergency management

Table 13

The importance weights of the e-government readiness indicators, sub-indicators, and sub-sub-indicators.

E-government readiness indicator	Importance weight		
	Indicator	Sub-indicator	Sub-sub-indicator
1	(0.17,0.23,0.03,0.03)	(0.56,0.59,0.03,0.03)	(0.18,0.20,0.02,0.02) (0.70,0.09,0.03,0.03) (0.19,0.21,0.01,0.01) (0.11,0.13,0.04,0.04) (0.13,0.15,0.02,0.02) (0.19,0.21,0.01,0.01)
		(0.40,0.40,0.01,0.01)	(0.30,0.30,0.03,0.03) (0.30,0.30,0.02,0.02) (0.35,0.37,0.05,0.05)
2	(0.34,0.36,0.01,0.01)	(0.30,0.30,0.02,0.02)	(0.47,0.49,0.03,0.03) (0.49,0.51,0.01,0.01) (0.21,0.23,0.02,0.02) (0.14,0.16,0.02,0.02) (0.12,0.14,0.03,0.03) (0.23,0.25,0.01,0.01) (0.20,0.22,0.02,0.02)
		(0.66,0.68,0.04,0.04)	
3	(0.42,0.48,0.05,0.05)	(0.34,0.36,0.03,0.03)	(0.12,0.14,0.05,0.05) (0.09,0.11,0.02,0.02) (0.09,0.11,0.03,0.03) (0.09,0.11,0.04,0.04) (0.12,0.14,0.01,0.01) (0.10,0.12,0.02,0.02) (0.10,0.12,0.01,0.01) (0.07,0.09,0.03,0.03)
		(0.23,0.25,0.02,0.02)	(0.17,0.19,0.05,0.05) (0.18,0.20,0.02,0.02) (0.18,0.20,0.03,0.03) (0.17,0.19,0.05,0.05) (0.14,0.16,0.01,0.01)
		(0.36,0.39,0.01,0.01)	(0.39,0.41,0.01,0.01) (0.59,0.61,0.01,0.01)

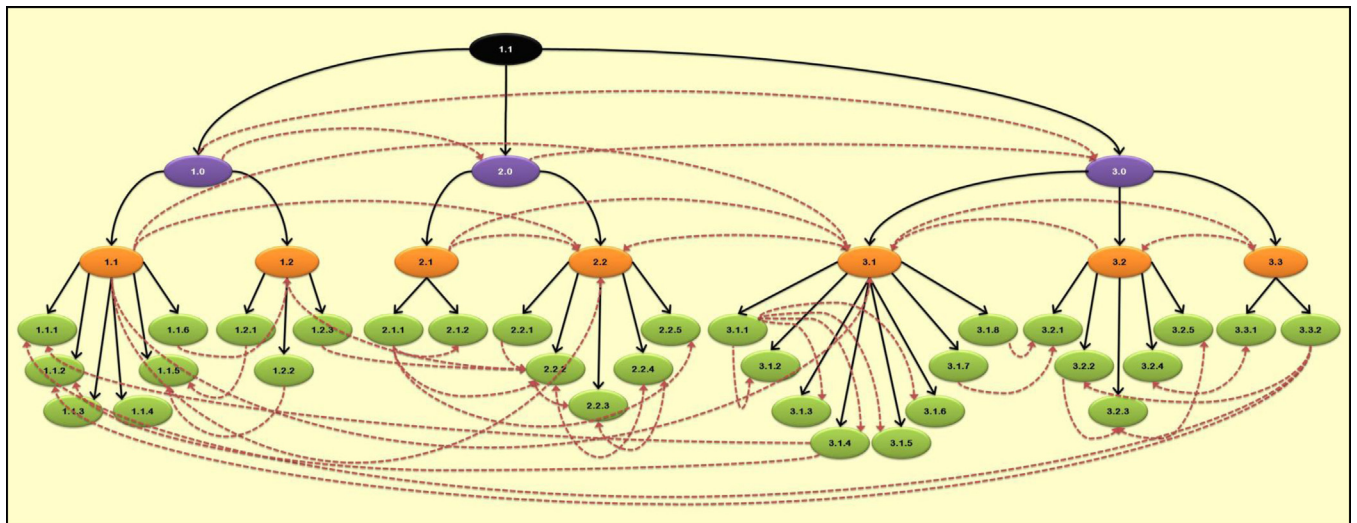


Fig. 4. Network interdependencies in the hierarchical structure of the State of East Virginia.

proposed by Koh et al. [43], 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 Fig. 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 [74] 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:

Table 14

The fuzzy weighted collective e-government readiness scores of the three indicators for the five cities in the State of East Virginia.

Sub-sub-indicator	City				
	Little Heaven	Egg Harbor	Radium Springs	Slippery Rock	Windy Falls
1.1.1. City information	(4.25,5.75,0.75,0.75)	(6.80,7.20,0.02,0.02)	(2.70,3.30,0.30,0.30)	(4.25,5.75,0.75,0.75)	(4.25,5.75,0.75,0.75)
1.1.2. GIS data	(4.35,5.65,0.65,0.65)	(4.40,5.60,0.06,0.06)	(4.25,5.75,0.75,0.75)	(4.25,5.75,0.75,0.75)	(4.25,5.75,0.75,0.75)
1.1.3. City budget	(4.40,5.60,0.06,0.06)	(8.25,8.50,0.75,0.75)	(4.25,5.75,0.75,0.75)	(6.80,7.20,0.02,0.02)	(6.80,7.20,0.02,0.02)
1.1.4. Employee manuals	(4.25,5.75,0.75,0.75)	(4.40,5.60,0.06,0.06)	(4.25,5.75,0.75,0.75)	(4.25,5.75,0.75,0.75)	(4.25,5.75,0.75,0.75)
1.1.5. Online tour of city	(6.80,7.20,0.02,0.02)	(6.80,7.20,0.02,0.02)	(4.40,5.60,0.06,0.06)	(4.25,5.75,0.75,0.75)	(4.25,5.75,0.75,0.75)
1.1.6. Minutes of meetings	(2.70,3.30,0.30,0.30)	(4.25,5.75,0.75,0.75)	(4.25,5.75,0.75,0.75)	(6.80,7.20,0.02,0.02)	(2.70,3.30,0.30,0.30)
1.2.1. Video broadcast of meetings	(4.25,5.75,0.75,0.75)	(6.80,7.20,0.02,0.02)	(4.25,5.75,0.75,0.75)	(4.35,5.65,0.65,0.65)	(4.25,5.75,0.75,0.75)
1.2.2. Audio broadcast of meetings	(4.40,5.60,0.06,0.06)	(4.25,5.75,0.75,0.75)	(4.40,5.60,0.06,0.06)	(2.70,3.30,0.30,0.30)	(4.35,5.65,0.65,0.65)
1.2.3. Live traffic cams	(6.80,7.20,0.02,0.02)	(6.80,7.20,0.02,0.02)	(6.80,7.20,0.02,0.02)	(4.40,5.60,0.06,0.06)	(4.25,5.75,0.75,0.75)
2.1.1. Calls for bids or proposals	(4.25,5.75,0.75,0.75)	(4.40,5.60,0.06,0.06)	(4.25,5.75,0.75,0.75)	(4.25,5.75,0.75,0.75)	(4.25,5.75,0.75,0.75)
2.1.2. Bidder applications	(4.40,5.60,0.06,0.06)	(6.80,7.20,0.02,0.02)	(6.80,7.20,0.02,0.02)	(6.80,7.20,0.02,0.02)	(6.80,7.20,0.02,0.02)
2.2.1. Utility payments	(4.25,5.75,0.75,0.75)	(4.40,5.60,0.06,0.06)	(6.80,7.20,0.02,0.02)	(4.25,5.75,0.75,0.75)	(4.35,5.65,0.65,0.65)
2.2.2. Collection of fees	(6.80,7.20,0.02,0.02)	(6.80,7.20,0.02,0.02)	(6.80,7.20,0.02,0.02)	(4.40,5.60,0.06,0.06)	(4.40,5.60,0.06,0.06)
2.2.3. Collection of fines	(8.25,8.50,0.75,0.75)	(8.25,8.50,0.75,0.75)	(6.80,7.20,0.02,0.02)	(6.80,7.20,0.02,0.02)	(6.80,7.20,0.02,0.02)
2.2.4. Tax collection	(6.80,7.20,0.02,0.02)	(6.80,7.20,0.02,0.02)	(4.25,5.75,0.75,0.75)	(4.25,5.75,0.75,0.75)	(4.25,5.75,0.75,0.75)
2.2.5. Payments to service providers	(4.40,5.60,0.06,0.06)	(6.80,7.20,0.02,0.02)	(4.40,5.60,0.06,0.06)	(4.35,5.65,0.65,0.65)	(2.70,3.30,0.30,0.30)
3.1.1. Requests for service	(4.25,5.75,0.75,0.75)	(4.40,5.60,0.06,0.06)	(6.80,7.20,0.02,0.02)	(4.25,5.75,0.75,0.75)	(2.70,3.30,0.30,0.30)
3.1.2. Permit application and renewal	(6.80,7.20,0.02,0.02)	(6.9,7.1,0.625,0.625)	(4.25,5.75,0.75,0.75)	(6.80,7.20,0.02,0.02)	(4.40,5.60,0.06,0.06)
3.1.3. License application and renewal	(6.80,7.20,0.02,0.02)	(6.9,7.1,0.625,0.625)	(6.80,7.20,0.02,0.02)	(4.25,5.75,0.75,0.75)	(6.80,7.20,0.02,0.02)
3.1.4. Voter registration	(4.25,5.75,0.75,0.75)	(4.40,5.60,0.06,0.06)	(4.25,5.75,0.75,0.75)	(2.70,3.30,0.30,0.30)	(4.35,5.65,0.65,0.65)
3.1.5. Requests for records	(4.25,5.75,0.75,0.75)	(6.80,7.20,0.02,0.02)	(4.25,5.75,0.75,0.75)	(4.25,5.75,0.75,0.75)	(4.25,5.75,0.75,0.75)
3.1.6. Property registration	(4.25,5.75,0.75,0.75)	(6.80,7.20,0.02,0.02)	(4.25,5.75,0.75,0.75)	(4.25,5.75,0.75,0.75)	(4.25,5.75,0.75,0.75)
3.1.7. Surveys & polls	(4.40,5.60,0.06,0.06)	(4.25,5.75,0.75,0.75)	(6.80,7.20,0.02,0.02)	(4.25,5.75,0.75,0.75)	(4.25,5.75,0.75,0.75)
3.1.8. Forums & discussions	(6.80,7.20,0.02,0.02)	(6.80,7.20,0.02,0.02)	(4.25,5.75,0.75,0.75)	(4.40,5.60,0.06,0.06)	(4.40,5.60,0.06,0.06)
3.2.1. E-mail access	(8.25,8.50,0.75,0.75)	(8.25,8.50,0.75,0.75)	(6.80,7.20,0.02,0.02)	(6.80,7.20,0.02,0.02)	(6.80,7.20,0.02,0.02)
3.2.2. Online calendar	(6.80,7.20,0.02,0.02)	(6.80,7.20,0.02,0.02)	(4.40,5.60,0.06,0.06)	(4.25,5.75,0.75,0.75)	(4.25,5.75,0.75,0.75)
3.2.3. Scheduling meetings online	(6.80,7.20,0.02,0.02)	(6.80,7.20,0.02,0.02)	(6.80,7.20,0.02,0.02)	(6.80,7.20,0.02,0.02)	(6.80,7.20,0.02,0.02)
3.2.4. Online document management	(6.80,7.20,0.02,0.02)	(6.80,7.20,0.02,0.02)	(4.40,5.60,0.06,0.06)	(4.25,5.75,0.75,0.75)	(4.25,5.75,0.75,0.75)
3.2.5. Video conferencing	(4.40,5.60,0.06,0.06)	(4.25,5.75,0.75,0.75)	(4.25,5.75,0.75,0.75)	(2.70,3.30,0.30,0.30)	(2.70,3.30,0.30,0.30)
3.3.1. Online job applications	(4.25,5.75,0.75,0.75)	(4.40,5.60,0.06,0.06)	(4.25,5.75,0.75,0.75)	(4.35,5.65,0.65,0.65)	(4.25,5.75,0.75,0.75)
3.3.2. Emergency management	(4.40,5.60,0.06,0.06)	(4.25,5.75,0.75,0.75)	(4.25,5.75,0.75,0.75)	(2.70,3.30,0.30,0.30)	(4.25,5.75,0.75,0.75)

Table 15
The e-government readiness scores of the five cities in the State of East Virginia.

	City				
	Little Heaven	Egg Harbor	Radium Springs	Slippery Rock	Windy Falls
$D^+(t)$	3.526	2.881	3.778	4.301	4.096
$D^-(t)$	4.902	5.537	4.403	4.057	4.145
$G(t)$	0.582	0.658	0.538	0.485	0.503

In Step 3.3, we use the TOPSIS concepts of the *positive ideal solution* and *negative ideal solution* for benchmarking purposes. We first determine 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 presents 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, the 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 Fig. 5, using these two dimensions, sub-sub-indicators were assigned to one of the four following planning quadrants: *Top Priorities*, *Key Investments*, *Quick Wins*, and *Future Improvements*.

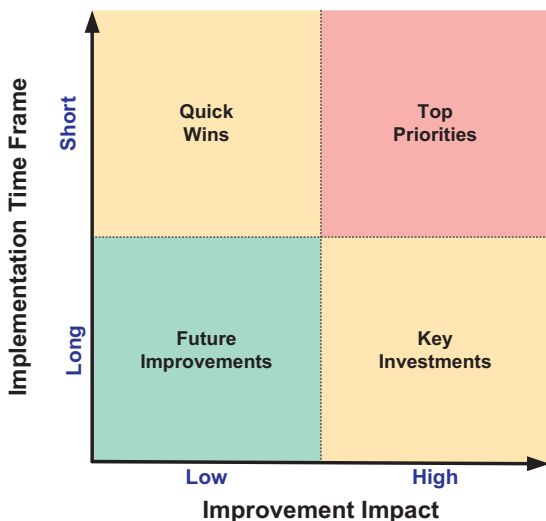


Fig. 5. Plan of actions.

5.1. *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.

5.2. *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 their effects can be realized following implementation of the top priorities.

5.3. *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.

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

Furthermore, more and more citizens are discussing their observations and opinions of public administration in online social network sites such as Facebook and Twitter. One interesting direction for future research would be to investigate the influence of social network sites on the development of e-government. How could governments make use of social network sites to better serve

Table 16

Plan of actions for the five cities in the State of East Virginia.

Sub-sub-indicator	Little Heaven	Egg Harbor	Radium Springs	Slippery Rock	Windy Falls
1.1.1. City information	Key investment	Quick win	Key investment	Key investment	Key investment
1.1.2. GIS data	Key investment	Key investment	Key investment	Key investment	Key investment
1.1.3. City budget	Key investment	Future improvement	Key investment	Quick win	Quick win
1.1.4. Employee manuals	Key investment	Key investment	Key investment	Key investment	Key investment
1.1.5. Online tour of city	Quick win	Quick win	Key investment	Key investment	Key investment
1.1.6. Minutes of meetings	Top priority	Key investment	Key investment	Quick win	Top priority
1.2.1. Video broadcast of meetings	Key investment	Quick win	Key investment	Key investment	Key investment
1.2.2. Audio broadcast of meetings	Key investment	Key investment	Key investment	Key investment	Key investment
1.2.3. Live traffic cams	Quick win	Quick win	Quick win	Key investment	Key investment
2.1.1. Calls for bids or proposals	Key investment	Key investment	Key investment	Key investment	Key investment
2.1.2. Bidder applications	Key investment	Quick win	Quick win	Quick win	Quick win
2.2.1. Utility payments	Key investment	Key investment	Quick win	Key investment	Key investment
2.2.2. Collection of fees	Quick win	Quick win	Quick win	Key investment	Key investment
2.2.3. Collection of fines	Future improvement	Future improvement	Quick win	Quick win	Quick win
2.2.4. Tax collection	Quick win	Quick win	Key investment	Key investment	Key investment
2.2.5. Payments to service providers	Key investment	Quick win	Key investment	Key investment	Top priority
3.1.1. Requests for service	Key investment	Key investment	Quick win	Key investment	Top priority
3.1.2. Permit application and renewal	Quick win	Quick win	Key investment	Quick win	Key investment
3.1.3. License application and renewal	Quick win	Quick win	Quick win	Key investment	Quick win
3.1.4. Voter registration	Key investment	Key investment	Key investment	Key investment	Key investment
3.1.5. Requests for records	Key investment	Quick win	Key investment	Key investment	Key investment
3.1.6. Property registration	Key investment	Quick win	Key investment	Key investment	Key investment
3.1.7. Surveys & polls	Key investment	Key investment	Key investment	Key investment	Key investment
3.1.8. Forums & discussions	Quick win	Quick win	Key investment	Key investment	Key investment
3.2.1. E-mail access	Future improvement	Future improvement	Quick win	Quick win	Quick win
3.2.2. Online calendar	Quick win	Quick win	Key investment	Key investment	Key investment
3.2.3. Scheduling meetings online	Quick win	Quick win	Quick win	Quick win	Quick win
3.2.4. Online document management	Quick win	Quick win	Key investment	Key investment	Key investment
3.2.5. Video conferencing	Key investment	Key investment	Key investment	Top priority	Top priority
3.3.1. Online job applications	Key investment	Key investment	Key investment	Key investment	Key investment
3.3.2. Emergency management	Key investment	Key investment	Key investment	Top priority	Key investment

their citizens? Should governments also provide social network site platforms to improve interactivity and collect public opinions regarding 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 become 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 must be further explored 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 in which government functions are performed so as to improve processes and promote cohesiveness, not simply to transform traditional information into bits and bytes to make it available through the Internet. Focusing solely on technological solutions will not change the mentality of bureaucrats who view citizens as neither customers of government nor participants in decision-making processes. 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 can be used to assess e-government readiness of communities at the municipal, state, and federal government levels, by way of a flexible but systematic structure. Benchmarking and rankings are commonly used to determine the relative standing of e-government readiness and to monitor the progress of communities with respect to a characteristic or achievement goal [71]. The proposed framework is a hybrid fuzzy model that can be used to 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 improvements can be made in meeting citizens' 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 evaluations 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 communities' unique needs and develop customized action plans to improve e-government readiness through an optimal allocation of resources.

The contributions of the proposed e-government assessment framework are 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, tailored to a specific government agency, that could be used as a ranking or benchmarking tool.

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