Government policy of technology selection for advanced traveler information systems

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Technology selection is widely recognized for its increasing importance in the field of technology management. Different from previous work that only used a single evaluation method, this study uses the grey statistics method with survey techniques and scenario approach to develop a three-stage model for the technology selection issue. An empirical case of the Advanced Traveler Information System (ATIS) technology selection in Taiwan was chosen to illustrate the application of this model on the technology selection problem. The results indicate that GPS/GIS technology is the preferred ATIS technology developed in Taiwan. The application of the model provides an avenue for government policy makers and researchers to deal effectively with the technology selection issue.

1. Introduction

The Advanced Traveler Information System (ATIS) is a system that uses advanced information technologies to make the movement of goods and people more economical and efficient. Evidenced from advanced countries such as the United States and Japan, ATIS is recognized for its contribution in enhancing operational efficiency in the transportation industry (Thomas, 1999). The development of ATIS in new industrial countries such as Taiwan receives the impetus from the experience of the advanced countries (Chen, 2003). In the 5-year policy guideline, ‘Challenge 2008: National Development Plan,’ Taiwan’s government selected the ATIS industry to be one of the strategic industries for development in Taiwan (MOTC, 2004). However, some of the previous pilot projects are overbudget and delayed mainly due to the use of inappropriate technologies. As the resources and time are constrained, the selection of appropriate ATIS technologies is an important issue for Taiwan government in the development of ATIS industries.

A number of prior studies have been conducted on the technology selection issues (Chang and Chen, 1998; Fang, 1998; Mackett and Edwards, 1998; Godet, 2000; Sheu, 2002) due to its increasing importance in the field of technology management. Several evaluation methods, such as questionnaire survey (Fang, 1998; Mackett and Edwards, 1998; Sheu, 2002), scenario analysis (Godet, 2000), and grey statistics method (Chang
and Chen, 1998), were used in the previous research. Different from previous work that only used a single evaluation method, this study uses the grey statistics method with survey techniques and scenario approach to develop a three-stage model for the technology selection issue. An empirical case of the ATIS technology selection in Taiwan was chosen to illustrate the application of this model on the technology selection problem to provide policy recommendation for the Taiwan government.

The rest of the paper is set out as follows: the next section considers the previous literature regarding the evaluation criteria, ATIS technologies, and technology selection approaches. Following that is the methodology illustrating the research model, grey statistics method, and scenario analysis. Then, the paper presents the results of the empirical study in achieving the goals as set out above. Discussion and conclusions are provided in the last section.

2. Literature review

2.1. Evaluation criteria for technology selection

According to previous studies (Calzonetti, 2000; Hsu et al., 2003; Barreto and Kypreos, 2004), evaluation criteria for technology selection can be divided into three main categories including environmental conditions, organizational characteristics, and technology attributes. In the environmental perspective, firms may not urgently develop a specific technology unless the market and political prospects of the technology become clear. Some issues including user needs (Mackett and Edwards, 1998; Mohanty and Deshmukh, 1998; Lowe et al., 2000), stakeholders’ opinion (Jiang and Klein, 1999), infrastructure (Calzonetti, 2000), supporting organization (Zysman et al., 2000), local economic development (Avineri et al., 2000), and local capital source (Lowe et al., 2000) were identified as the critical determinants influencing the decision-making of technology selection.

Secondly, besides outside environmental factors, organizational characteristics play a major role in affecting the selection of a specific technology. Some studies suggested that dense networks of firms (Calzonetti, 2000; Akmanligil and Palvia, 2004), trained workforce (Lowe et al., 2000; Mohanty and Deshmukh, 1998), setting costs (Lowe et al., 2000), existing technology capability (Calzonetti, 2000), and human resource training (Mohanty and Deshmukh, 1998) are the key organizational factors that may affect decision makers’ technology selection behavior. Thirdly, prior literature proposed that the technology attributes should be considered when decision makers need to make choice among several technology alternatives. These technological evaluation criteria for technology selection include emissions (Mackett and Edwards, 1998; Avineri et al., 2000; Barreto and Kypreos, 2004), technological characteristics (Fang, 1998; Thomas, 1999; Hsu et al., 2003; Akmanligil and Palvia, 2004), specific knowledge requirement (Lowe et al., 2000), safety (Avineri et al., 2000), and human resource training (Mackett and Edwards, 1998). The following table summarizes the evaluation criteria for technology selection:

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Evaluation criteria</th>
<th>Literature</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Stakeholders’ opinion</td>
<td>Jiang and Klein (1999)</td>
</tr>
<tr>
<td></td>
<td>Infrastructure</td>
<td>Calzonetti (2000)</td>
</tr>
<tr>
<td></td>
<td>Supporting organization</td>
<td>Zysman et al. (2000)</td>
</tr>
<tr>
<td></td>
<td>Local economic development</td>
<td>Avineri et al. (2000)</td>
</tr>
<tr>
<td></td>
<td>Local capital source</td>
<td>Lowe et al. (2000)</td>
</tr>
<tr>
<td></td>
<td>Trained workforce</td>
<td>Lowe et al. (2000), Mohanty and Deshmukh (1998)</td>
</tr>
<tr>
<td></td>
<td>Setting cost</td>
<td>Lowe et al. (2000)</td>
</tr>
<tr>
<td></td>
<td>Existing technology capability</td>
<td>Calzonetti (2000)</td>
</tr>
<tr>
<td></td>
<td>Human resource training</td>
<td>Mohanty and Deshmukh (1998)</td>
</tr>
<tr>
<td></td>
<td>Specific knowledge requirement</td>
<td>Lowe et al. (2000)</td>
</tr>
<tr>
<td></td>
<td>Safety</td>
<td>Avineri et al. (2000)</td>
</tr>
</tbody>
</table>
2004), specific knowledge requirement (Lowe et al., 2000), and safety (Avineri et al., 2000). Table 1 shows the 15 evaluation criteria for the technology selection.

2.2. ATIS technologies in Taiwan

ATIS technologies in this research refer to the information technologies that can enhance the performance of land transportation networks and alleviate traffic congestion. Through literature review and interview of experienced experts, six technologies were identified as prior-developed alternatives of ATIS technologies for Taiwan. These six technology alternatives, as shown in Table 2, include route guidance systems technology, GPS/GIS technology, integrated services digital network (ISDN) technology, videotex technology, GSM technology, and wideband code division multiple access (WCDMA) technology. Route guidance systems technology is utilized for driver guidance on optimal routes on the basis of real-time traffic information. It can reduce several transportation-related problems including traffic accidents, congestion, and driving-induced stress (Fu, 2001). GPS/GIS technology provides useful information for road users on the scheduling of the fleet as well as safe routing. The integration of GPS/GIS technology can be utilized to various applications for safety and incident management (Mintsis et al., 2004). The ISDN technology allows for simultaneous high-speed transmission of video, data, voice, and image through a single channel, while videotex technology provides information of weather forecast and meteorological advice within the transportation field (Kodama, 2000). The GSM technology is a successful second-generation wireless technology that can be used both in the telecommunications and transportation industry. The evolitional WCDMA technology is a third-generation technology used to transmit video information wirelessly (Bekkers et al., 2002).

2.3. Technology selection approaches

The existing literature suggests that the evaluation methods of technology selection include simulation (Thomas, 1999), linear programming (Barreto and Kypreos, 2004), questionnaire survey (Fang, 1998; Mackett and Edwards, 1998; Sheu, 2002), analytic hierarchy process (Mohanty and Deshmukh, 1998), scenario analysis (Godet, 2000), and grey statistics method (Chang and Chen, 1998). Thomas (1999) used a micro-simulation program to examine the relationship between advanced technology location and travel characteristics. He found that using the simulation method could successfully evaluate technology locations under a large amount of data circumstance. Barreto and Kypreos (2004) used a linear programming model to explore the effects of emissions trading on technology deployment. They found that the emissions constraints might influence the technology choice and emissions profiles of other areas.

Mackett and Edwards (1998) used a survey to investigate the decision-making process of the selection of the most appropriate technology for an urban transportation system. The research results reveal the way in which decisions are made about the new public transportation systems. Fang (1998) used a survey-based statistical model to predict and explain the usage and choice of computer-mediated communication technologies (CMCT). The results indicate the individual and combined effects of user self-efficacy, tech-

<table>
<thead>
<tr>
<th>Table 2. Illustrations of six ATIS technologies</th>
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<tbody>
<tr>
<td>Technology</td>
</tr>
<tr>
<td>Route guidance systems technology (RGS)</td>
</tr>
<tr>
<td>GPS/GIS technology</td>
</tr>
<tr>
<td>ISDN technology</td>
</tr>
<tr>
<td>Videotex technology</td>
</tr>
<tr>
<td>GSM technology</td>
</tr>
<tr>
<td>WCDMA technology</td>
</tr>
</tbody>
</table>

ISDN, integrated services digital network; WCDMA, wideband code division multiple access.
nological characteristics, and social-influence perspectives on CMCT choice. Sheu (2002) used a sequential decision methodology for determining the developmental priorities of commercial vehicle operations (CVO) technical packages. The results reveal that the CVO package used for fleet management appears to be the most urgently needed in the short-term plan. Mohanty and Deshmukh (1998) used the analytic hierarchy process to propose a framework for analyzing a firm’s investment in advanced manufacturing technologies. They found that the proposed model has facilitated the process of effective management of knowledge for an Indian electronics-manufacturing firm. Godet (2000) presented a scenario-planning model that effectively solves high-technology planning and choice problem. He indicates that the scenario planning is popular and effective in technology selection, especially among large corporations in the rapidly developed energy sector. Chang and Chen (1998) used the grey statistics method to choose critical evaluation criteria of technology selection for the high-speed rail. They found that the grey statistics method could deal with uncertainty of evaluation process and select appropriate evaluation criteria using the least amount of data.

Prior research often used a single evaluation method to investigate the issues of technology selection. Moreover, some methods, such as linear programming and simulation, need a large amount of data for analysis (Thomas, 1999; Barreto and Kypreos, 2004). The AHP method belongs to the diagrammatic analysis rather than the comprehensive one such as scenario analysis (Yu et al., 2001). In this research, we attempted to use the grey statistics method with survey techniques and scenario approach to build up a three-stage model to deal with the complicated problems of technology selection.

3. Research method

3.1. Research model

This study proposes an integrated model for the evaluation and selection of complicated technologies such as ATIS-related technologies. There are three stages in the model: the first stage is to select critical evaluation criteria for construction of possible scenarios. Evaluation criteria for technology evaluation were identified through extensive literature review. Then, a group of experts were surveyed to determine their familiarity with the ATIS technologies and to obtain their subjective judgments on the importance of the evaluation criteria for technology selection. The authors give weights to the respondents based on their familiarity with the ATIS technologies. Accordingly, a refined grey statistics method is used to decide the critical evaluation criteria of transport technology evaluation. Considering the complexity and integrity in the construction of the following possible scenarios, we selected the three most important evaluation criteria as the critical evaluation criteria.

The next stage is to identify the most likely scenario for the following technology selection. Scenario analysis is used to build up the possible scenarios based on the selected critical evaluation criteria. A group of experts were surveyed to obtain their evaluation of these possible scenarios. Then, the most likely future scenario is identified using the grey statistics method. In the final stage, the ATIS technology candidates are identified from the literature and experts are interviewed to evaluate the ATIS technology alternatives under the most likely future scenario. A refined grey statistics method is used to decide the most appropriate ATIS technology for development. The research model is shown in Figure 1.

3.2. Grey statistics method

Some effective evaluation methods were developed in recent years for evaluating critical alternatives. The fuzzy techniques and grey statistics method are two popular ones among these methods (Li and Lai, 2001; Herrera-Viedma and Peis, 2003; Gheorghe et al., 2004; Hwang et al., 2004). The nature of fuzzy techniques deals with uncer-
tainty from recognition. Fuzzy techniques use fuzzy inference as a mathematical algorithm to represent kennings. Similar to fuzzy theory, the grey theory is a useful alternative method to the traditional approaches of uncertain selection problems (Deng, 1989a, b, 1992; Chang and Chen, 1998). The nature of grey statistics techniques explores uncertainty from the least data. Grey statistics techniques use grey generating as a mathematical algorithm to represent reality law (Deng, 1989b). The grey statistics method solves problems with a smaller amount of data than the fuzzy logic needed (Hsu and Wen, 2000). It has been used in many evaluation problems ranging from construction, education, and transportation (Chang and Chen, 1998; Shih, 2001; Lu and Yu, 2002). In this study, we adopted the grey statistics method to deal with least data as technology selection problems of ATIS technologies are new in Taiwan. The following describes the concepts and applications of the grey statistics method:

### 3.2.1 Decision space of the grey statistics method

In a decision space, the grey statistics method involves a set of decision groups $i$, $i = \{1, 2, \ldots, o\}$, a set of decision categories $k$ (called grey categories), $k = \{1, 2, \ldots, n\}$, and a set of decision candidates $j$, $j = \{1, 2, \ldots, m\}$, where $o$, $n$, and $m$ are the number of elements of the three sets.

### 3.2.2 Whitened value

In grey theory, random variables are regarded as grey numbers. A grey system is defined as a system involving information presented as grey numbers (Deng, 1992). A grey number is transformed into the whitened value through the whitening function. The grey statistics method is on the basis of whitening functions.

In grey statistics, the whitening function value is denoted by $f_k$. It serves as a criterion for judging category level. A typical linear function is generally used as the whitening function to perform the analysis. The whitening functions generally represent three types of meaning, e.g. larger than a certain number, smaller than a certain number, and approximate a certain number. The values of whitening functions are maintained within the close interval $[0, 1]$ for all $f_k$. The critical values and upper limit of whitening functions could be designed by the planners (Hsu and Wen, 2000; Lu and Yu, 2002). The typical whitening functions are shown in Equations (1)–(3) and Figures 2–4, where $d_k$, $\oplus d_k$, and $\Theta d_k$ indicate the critical value, the upper, and lower limit of the values $x$, respectively.

1. Smaller than a certain number $d_k$:
   \[
   f_k(x) = \begin{cases} 
   1, & x \leq d_k, \\
   \frac{1}{d_k - d_k}(\oplus d_k - x), & d_k < x < \oplus d_k, \\
   0, & x \geq \oplus d_k.
   \end{cases}
   \]  
   (1)

2. Approximate a certain number $d_k$:
   \[
   f_k(x) = \begin{cases} 
   1, & x = d_k, \\
   \frac{1}{d_k - d_k}(x - \Theta d_k), & \Theta d_k < x < d_k, \\
   0, & d_k < x < \oplus d_k, \\
   \frac{1}{\oplus d_k - d_k}(\oplus d_k - x), & x \geq \oplus d_k, x \leq \Theta d_k.
   \end{cases}
   \]  
   (2)

3. Larger than a certain number $d_k$:
   \[
   f_k(x) = \begin{cases} 
   1, & x \geq d_k, \\
   \frac{1}{d_k - d_k}(x - \Theta d_k), & \Theta d_k < x < d_k, \\
   0, & x \leq \Theta d_k.
   \end{cases}
   \]  
   (3)
3.2.3. **Evaluation of the alternatives**

The grey statistics method usually involves four steps. The first step is to measure the sample data for each of the respondents for all decision candidates. In this research, the respondents were asked to rate the alternative candidates according to their potential importance. The rated numbers are from 1 to 9. Let \( d_{ij} \) be the rated value of the respondents in decision group \( i \) toward decision candidate \( j \). When the rules for judging the decision category for a respondent are uncertain, the whitening functions can be utilized to obtain the whitening function value and to indicate the decision rules.

The second step is to calculate the decision weight parameters. Let \( \sigma_{jk} \) denote the decision weight parameter of grey statistics with category \( k \) and candidate \( j \). It can be calculated by the weighted summation of whitening function values for all respondents, i.e. \( \sigma_{jk} = \sum_{i=1}^{n} f_k(d_{ij})w_i/p_i \), where \( w_i \) and \( p_i \) denote the weight and the number of respondents in the decision group \( i \), respectively. For category \( k = 1–5 \) (e.g. high \((k = 1)\), high–intermediate \((k = 2)\), intermediate \((k = 3)\), intermediate–low \((k = 4)\), low \((k = 5)\)), we have \( \sigma_j = (\sigma_{j1}, \sigma_{j2}, \sigma_{j3}, \sigma_{j4}, \sigma_{j5}) \). It is called the grey statistics series.

The third step is to classify the decision alternatives. The grey statistics method classifies the decision candidate \( j \) into a certain decision category by ranking the decision weight parameters of candidate \( j \) and choosing the highest among all categories \( k \); i.e. candidate \( j \) belongs to category \( k^* \), if \( \sigma_{jk^*} = \max_k \sigma_{jk} \).

The final step is to select the final alternative. The selection priority depends on the category that the candidates are assigned and the value of the decision weight parameter. The rank of the categories can be high, high–intermediate, intermediate, intermediate–low, and low. The candidate that is in the prior category with higher values will be selected as the final alternative (Chang and Chen, 1998).

### 3.3. Scenario analysis

Scenario analysis is an approach to realize present environment and future possible phenomena. This method is effective for dealing with the problems under a highly complicated, uncertain environment as well as the deficiency of historical data that can be referenced (Van der Heijden, 1996; Ringland, 1998; Godet, 2000; Yu et al., 2001).

The operational process of scenario analysis is as follows (Godet, 2000): firstly, the analysts need to define the decision focus. It is the foundation of the continuity in the scenarios. The analysts need to find the important contexts such as in political, economic, and social aspects. As such, the deep realization can be developed of how the system posed and worked. The second step is to identify important variables. The analysts need to identify critical trends and analyze external driving forces. These moves will lead to the concrete concepts of key variables.

The third step is to select uncertain axes (critical evaluation criteria) and develop scenario logics. The analysts need to find the critical evaluation criteria from external and organizational environments using reasonable methods and analysis. Accordingly, a limited number of scenarios are developed by the critical evaluation criteria. Finally, the last step is to identify the most likely future scenario using a systematic analysis. Under this scenario, the analysts can further analyze the decision of the research.

### 3.4. Research design

#### 3.4.1. Survey design

A comprehensive three-stage questionnaire survey was conducted during late 2003 in Taiwan to collect data for selecting the ATIS technologies. The first-stage survey was conducted to identify three out of 15 evaluation criteria as the critical factors for constructing the possible scenarios of transport technology development. These 15 evaluation criteria, as shown in Table 1, are user needs, stakeholders' opinion, infrastructure, supporting organization, local economic development, local capital source, dense networks of firms, trained workforce, setting cost, existing technology capability, human resource training,
emissions, technological characteristics, specific knowledge requirement, and safety. The respondents were asked to indicate the relative importance of each evaluation criterion.

The second-stage survey was implemented to determine the most likely future scenario. The respondents were asked to indicate the most likely future scenario among the eight scenario logics. The last-stage survey was conducted to decide the prior-developed ATIS technology for Taiwan from six candidates. These six candidates are route guidance systems technology, GPS/GIS technology, ISDN technologies, videotex technology, GSM technology, and WCDMA technology. The respondents were asked to compare the ATIS technologies in the most likely future scenario.

3.4.2. Sample collection

Considering the comprehensiveness of the samples to be surveyed, we include government officials, industry analysts, academic researchers, and industry experts, who are experienced in the development of ATIS in Taiwan, as the respondents in this study. The government officials are in the agencies for the planning and development of ATIS technologies such as Ministry of Transportation and Communications. Industry analysts and academic researchers are from institutes and universities such as Institute of Transportation and National Cheng Kung University. Industry experts are experienced in the development of ATIS in the private sector such as transportation business operators (the ATIS demander) and the ATIS hardware/software providers (the ATIS technical supplier).

The survey was conducted in three stages. One hundred questionnaires in each stage were sent to the targeted experts. Twenty usable responses were received in the first- and second-stage survey, respectively, and 29 usable responses were collected in the final-stage survey. The experts were asked in each of the three stages to evaluate their familiarity with ATIS technologies using a four-point scale ranging from ‘not familiar’, ‘somewhat familiar’, ‘familiar’, to ‘very familiar’. We assigned the weights 0 to ‘not familiar’, 1 to ‘somewhat familiar’, 3 to ‘familiar’, and 5 to ‘very familiar’. The number of respondents in terms of the degree of their familiarity with ATIS technologies is shown in Table 3. Also, the experts were asked to rate the importance of the 15 evaluation criteria, to obtain their evaluation of the possible scenarios, and to evaluate the ATIS technology alternatives under the most likely future scenario in the three stages, respectively. The rated number is from 1 to 9. The values of weights and rated numbers are used in calculating the decision weight parameters.

4. Research results

In this research, we followed Lu and Yu (2002) and Chang and Chen’s (1998) studies and used five types of whitening functions as shown in equations (4)–(8) and Figure 5.

1. ‘Low’ grey category:

\[ f_2(x) = \begin{cases} 1, & x \leq 0, \\ \frac{1}{3}(3 - x), & 0 < x < 3, \\ 0, & x \geq 3. \end{cases} \] (4)

2. ‘Intermediate-low’ grey category:

\[ f_4(x) = \begin{cases} 1, & x = 2.5, \\ \frac{1}{2}(5 - x), & 2.5 < x < 5, \\ 0, & x \geq 5, x \leq 0. \end{cases} \] (5)

3. ‘Intermediate’ grey category:

\[ f_3(x) = \begin{cases} 1, & x = 5, \\ \frac{1}{2}(x - 3), & 3 < x \leq 5, \\ \frac{1}{2}(7 - x), & 5 < x < 7, \\ 0, & x \geq 7, \ x \leq 3. \end{cases} \] (6)

4. ‘High-intermediate’ grey category:

\[ f_2(x) = \begin{cases} 1, & x = 7.5, \\ \frac{1}{2}(x - 5), & 5 < x \leq 7.5, \\ \frac{1}{2}(10 - x), & 7.5 < x \leq 10, \\ 0, & x \geq 10, \ x \leq 5. \end{cases} \] (7)

<table>
<thead>
<tr>
<th>Stage</th>
<th>Degree of familiarity</th>
<th>Number of respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Very familiar</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Familiar</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Somewhat familiar</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>Very familiar</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Familiar</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Somewhat familiar</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>Very familiar</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Familiar</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>Somewhat familiar</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 3. Number of respondents in terms of their familiarity with ATIS technologies in the three stages.
the decision weight parameters were calculated to obtain the grey statistics series methodology, the decision weight parameters technology selection. Following the grey statistics rate the importance of the 15 evaluation criteria of their familiarity with the ATIS technologies and to survey, the respondents were asked to determine possible scenarios. In the first-stage questionnaire We first selected three critical evaluation criteria 4.1. Selection of critical evaluation criteria

We first selected three critical evaluation criteria among the 15 possible criteria for construction of possible scenarios. In the first-stage questionnaire survey, the respondents were asked to determine their familiarity with the ATIS technologies and to rate the importance of the 15 evaluation criteria of technology selection. Following the grey statistics methodology, the decision weight parameters \( \sigma_{jk} \) were calculated to obtain the grey statistics series for each of the 15 evaluation criteria. For example, the decision weight parameters \( \sigma_{jk} \) of the evaluation criterion ‘user needs’ were calculated as follows:

\[
\sigma_{11} = \sum_{i=1}^{20} f_1(d_{i1}) w_i p_i
\]

\[
= 0.67 \times (1 \times 2 + 3 \times 8 + 5 \times 4) + 0.00 \times (1 \times 1 + 3 \times 2 + 5 \times 1) + 0.00 \times (1 \times 1 + 3 \times 0 + 5 \times 1)
\]

\[
= 30.82,
\]

\[
\sigma_{12} = \sum_{i=1}^{20} f_2(d_{i2}) w_i p_i
\]

\[
= 0.40 \times (1 \times 2 + 3 \times 8 + 5 \times 4) + 0.80 \times (1 \times 1 + 3 \times 2 + 5 \times 1) + 0.00 \times (1 \times 1 + 3 \times 0 + 5 \times 1)
\]

\[
= 28.00,
\]

\[
\sigma_{13} = \sum_{i=1}^{20} f_3(d_{i3}) w_i p_i
\]

\[
= 0.00 \times (1 \times 2 + 3 \times 8 + 5 \times 4) + 0.00 \times (1 \times 1 + 3 \times 2 + 5 \times 1) + 1.00 \times (1 \times 1 + 3 \times 0 + 5 \times 1)
\]

\[
= 6.00,
\]

\[
\sigma_{14} = \sum_{i=1}^{20} f_4(d_{i4}) w_i p_i
\]

\[
= 0.00 \times (1 \times 2 + 3 \times 8 + 5 \times 4) + 0.00 \times (1 \times 1 + 3 \times 2 + 5 \times 1) + 0.00 \times (1 \times 1 + 3 \times 0 + 5 \times 1)
\]

\[
= 0.00,
\]

\[
\sigma_{15} = \sum_{i=1}^{20} f_5(d_{i5}) w_i p_i
\]

\[
= 0.00 \times (1 \times 2 + 3 \times 8 + 5 \times 4) + 0.00 \times (1 \times 1 + 3 \times 2 + 5 \times 1) + 0.00 \times (1 \times 1 + 3 \times 0 + 5 \times 1)
\]

\[
= 0.00.
\]

Therefore, the grey statistics series of the evaluation criterion ‘user needs’ are [30.82, 28.00, 6.00, 0.00, 0.00]. As ‘30.82’ is the largest value among the series, the grey category of ‘user needs’ is assigned into the ‘high’ category. The grey statistics series and grey categories for the 15 evaluation criteria are shown in Table 4. The results indicate that only the criterion ‘user needs’ is categorized into a ‘high’ category and the other fourteen evaluation criteria are assigned into ‘high-intermediate’ categories. Among the 14 criteria, ‘existing technology ability’ and ‘technological characteristics’ have the
Table 4. Grey statistics series and grey category of evaluation criteria

<table>
<thead>
<tr>
<th>Critical uncertainty</th>
<th>Grey statistics series</th>
<th>Grey category</th>
</tr>
</thead>
<tbody>
<tr>
<td>User needs</td>
<td>30.82, 28.00, 6.00, 0.00, 0.00</td>
<td>High</td>
</tr>
<tr>
<td>Specific knowledge requirement</td>
<td>6.87, 33.17, 10.26, 2.29, 0.00</td>
<td>High–intermediate</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>27.49, 31.87, 0.00, 0.00, 0.00</td>
<td>High–intermediate</td>
</tr>
<tr>
<td>Local economic development</td>
<td>13.74, 29.41, 10.26, 2.05, 0.00</td>
<td>High–intermediate</td>
</tr>
<tr>
<td>Dense networks of firms</td>
<td>2.05, 30.78, 13.68, 4.44, 0.00</td>
<td>High–intermediate</td>
</tr>
<tr>
<td>Supporting organization</td>
<td>8.89, 34.20, 6.84, 2.05, 0.00</td>
<td>High–intermediate</td>
</tr>
<tr>
<td>Local capital source</td>
<td>6.84, 33.17, 0.00, 0.00, 0.00</td>
<td>High–intermediate</td>
</tr>
<tr>
<td>Stakeholders’ opinion</td>
<td>2.05, 28.38, 17.10, 4.44, 0.00</td>
<td>High–intermediate</td>
</tr>
<tr>
<td>Trained workforce</td>
<td>20.52, 35.22, 0.00, 0.00, 0.00</td>
<td>High–intermediate</td>
</tr>
<tr>
<td>Existing technology ability</td>
<td>12.73, 42.80, 1.00, 0.00, 0.00</td>
<td>High–intermediate</td>
</tr>
<tr>
<td>Human resource training</td>
<td>11.28, 32.83, 13.68, 0.00, 0.00</td>
<td>High–intermediate</td>
</tr>
<tr>
<td>Emissions</td>
<td>4.44, 31.80, 17.10, 0.00, 0.00</td>
<td>High–intermediate</td>
</tr>
<tr>
<td>Technological characteristics</td>
<td>8.04, 41.60, 6.00, 0.00, 0.00</td>
<td>High–intermediate</td>
</tr>
<tr>
<td>Setting cost</td>
<td>20.52, 32.83, 3.42, 0.00, 0.00</td>
<td>High–intermediate</td>
</tr>
<tr>
<td>Safety</td>
<td>31.80, 33.85, 0.00, 0.00, 0.00</td>
<td>High–intermediate</td>
</tr>
</tbody>
</table>

largest values of the decision weight parameters $\sigma_p$: ‘42.80’ and ‘41.60’. Accordingly, these three criteria, ‘user needs’, ‘existing technology ability’, and ‘technological characteristics’, were selected as the critical criteria for construction of the scenarios.

4.2. Identification of the most likely future scenario

Next, we built up the eight possible scenarios, as shown in Figure 6, based on the three critical evaluation criteria and identified the most likely scenario for the following technology selection. In the second-stage questionnaire survey, the respondents were surveyed to determine their familiarity with the ATIS technologies and to obtain their evaluation of these possible scenarios. The decision weight parameters $\sigma_{jk}$ were calculated to obtain the grey statistics series for each of the eight scenarios. For example, the decision weight parameters $\sigma_{jk}$ of the scenario 1 were calculated as follows:

$$\sigma_{14} = \sum_{i=1}^{20} f_4(d_{ij})w_{pi}$$

$$= 0.00 \times (5 \times 5 + 3 \times 7) + 0.00 \times (3 \times 1)$$

$$+ 0.40 \times (5 \times 1 + 3 \times 2 + 1 \times 4)$$

$$= 6.00,$$

$$\sigma_{15} = \sum_{i=1}^{20} f_5(d_{ij})w_{pi}$$

$$= 0.00 \times (5 \times 5 + 3 \times 7) + 0.00 \times (3 \times 1)$$

$$+ 0.67 \times (5 \times 1 + 3 \times 2 + 1 \times 4)$$

$$= 10.05.$$  

Therefore, the grey statistics series of the ‘scenario 1’ are [30.82, 19.60, 1.50, 6.00, 10.05]. As ‘30.82’ is the largest value among the series, the grey category of ‘scenario 1’ is assigned into the ‘high’ category. The grey statistics series and grey categories for the eight scenarios are shown in Table 5. The results indicate that ‘scenario 1’ is categorized into the ‘high’ category while the other seven scenarios are assigned into either ‘high-intermediate’ or ‘intermediate’ categories. Accordingly, ‘scenario 1’ was selected as the most likely scenario for the following technology selection. It represents a higher level of user needs and existing technological capabilities as well as a simpler level of technological characteristics.

4.3. Selection of the prior-developed ATIS technology

Finally, we identified the prior-developed ATIS technology from the six candidates. The experts are surveyed to determine their familiarity with the ATIS technologies and to evaluate the ATIS technology alternatives under the most likely future scenario. The decision weight parameters $\sigma_{jk}$ were calculated to obtain the grey statistics series for each of the six technology candidates.
For example, the decision weight parameters \( \sigma_{jk} \) of the GPS/GIS technology were calculated as follows:

\[
\sigma_{11} = \sum_{i=1}^{29} f_1(d_{ij}) w_i p_i \\
= 0.67 \times (1 \times 5 + 3 \times 6 + 5 \times 1) \\
+ 0.00 \times (1 \times 0 + 3 \times 6) \\
+ 0.00 \times (1 \times 0 + 3 \times 4 + 5 \times 1) \\
+ 0.00 \times (1 \times 0 + 3 \times 5) + 0.00 \times (3 \times 1) \\
= 18.76,
\]

\[
\sigma_{12} = \sum_{i=1}^{29} f_2(d_{ij}) w_i p_i \\
= 0.40 \times (1 \times 5 + 3 \times 6 + 5 \times 1) \\
+ 0.80 \times (1 \times 0 + 3 \times 6) \\
+ 0.00 \times (1 \times 0 + 3 \times 4 + 5 \times 1) \\
+ 0.00 \times (1 \times 0 + 3 \times 5) + 0.00 \times (3 \times 1) \\
= 25.60,
\]

\[
\sigma_{13} = \sum_{i=1}^{29} f_3(d_{ij}) w_i p_i \\
= 0.00 \times (1 \times 5 + 3 \times 6 + 5 \times 1) \\
+ 0.00 \times (1 \times 0 + 3 \times 6) \\
+ 1.00 \times (1 \times 0 + 3 \times 4 + 5 \times 1) \\
+ 0.00 \times (1 \times 0 + 3 \times 5) + 0.00 \times (3 \times 1) \\
= 17.00,
\]

\[
\sigma_{14} = \sum_{i=1}^{29} f_4(d_{ij}) w_i p_i \\
= 0.00 \times (1 \times 5 + 3 \times 6 + 5 \times 1) \\
+ 0.00 \times (1 \times 0 + 3 \times 6) \\
+ 0.00 \times (1 \times 0 + 3 \times 4 + 5 \times 1) \\
+ 0.80 \times (1 \times 0 + 3 \times 5) + 0.40 \times (3 \times 1) \\
= 13.2,
\]

\[
\sigma_{15} = \sum_{i=1}^{29} f_5(d_{ij}) w_i p_i \\
= 0.00 \times (1 \times 5 + 3 \times 6 + 5 \times 1) \\
+ 0.00 \times (1 \times 0 + 3 \times 6) \\
+ 0.00 \times (1 \times 0 + 3 \times 4 + 5 \times 1) \\
+ 0.00 \times (1 \times 0 + 3 \times 5) + 0.67 \times (3 \times 1) \\
= 2.01.
\]

Therefore, the grey statistics series of the ‘GPS/GIS technology’ are \([18.76, 25.60, 17.00, 13.20, 2.01]\). As ‘25.60’ is the largest value among the series, the grey category of ‘GPS/GIS technology’ is assigned into ‘high–intermediate’ category. The grey statistics series and grey categories for the six technology candidates are shown in Table 6. The results indicate that all the six technology candidates are assigned into the ‘high–intermediate’ categories. However, ‘GPS/GIS technology’ has the largest value of the decision weight parameters \( \sigma_{14} \) : ‘25.60’. Accordingly, ‘GPS/GIS technology’ was selected as the prior-developed technology among the six candidates.
5. Conclusions

This study attempted to develop a three-stage model by using the grey statistics method with survey techniques and scenario approach. A case of ATIS technology selection in Taiwan was used as an example to illustrate the application of this model on the issue of technology selection. The results indicate that GPS/GIS technology is the preferred ATIS technology developed in Taiwan. The model developed in this paper effectively solves the selection problem of ATIS technology with least referenced data and relevant experts. By using the proposed methodologies developed in this research, the strategic choice of the ATIS technology is quantitatively and effectively analyzed. The approach that we proposed here is effective, as evidenced by comparing the view of prior literature that a good selection model is to select an appropriate technology for development, through effective communication among different groups. The application of the model provided an avenue for government policy makers and researchers to evaluate the alternatives for technology development.

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References


Table 6. Grey statistics series and grey category of ATIS technologies

<table>
<thead>
<tr>
<th>ATIS technology</th>
<th>Grey statistics series</th>
<th>Grey category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Route guidance systems technology</td>
<td>[7.75, 17.76, 6.00, 5.28, 0.00]</td>
<td>High–intermediate</td>
</tr>
<tr>
<td>GPS/GIS technology</td>
<td>[18.76, 25.60, 17.00, 13.20, 2.01]</td>
<td>High–intermediate</td>
</tr>
<tr>
<td>ISDN technology</td>
<td>[6.20, 11.52, 10.20, 4.32, 0.00]</td>
<td>High–intermediate</td>
</tr>
<tr>
<td>Videotex technology</td>
<td>[9.38, 11.66, 10.20, 7.68, 0.00]</td>
<td>High–intermediate</td>
</tr>
<tr>
<td>GSM technology</td>
<td>[2.37, 17.28, 7.80, 2.40, 0.00]</td>
<td>High–intermediate</td>
</tr>
<tr>
<td>WCDMA technology</td>
<td>[9.30, 6.72, 14.40, 4.80, 0.00]</td>
<td>Intermediate</td>
</tr>
</tbody>
</table>


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