GREY STATISTICS METHOD OF TECHNOLOGY SELECTION FOR ADVANCED PUBLIC TRANSPORTATION SYSTEMS

– The Experience of Taiwan –

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Taiwan is involved in intelligent transportation systems planning, and is now selecting its prior focus areas for investment and development. The high social and economic impact associated with which intelligent transportation systems technology are chosen explains the efforts of various electronics and transportation corporations for developing intelligent transportation systems technology to expand their business opportunities. However, there has been no detailed research conducted with regard to selecting technology for advanced public transportation systems in Taiwan. Thus, the present paper demonstrates a grey statistics method integrated with a scenario method for solving the problem of selecting advanced public transportation systems technology for Taiwan. A comprehensive questionnaire survey was conducted to demonstrate the effectiveness of the grey statistics method. The proposed approach indicated that contactless smart card technology is the appropriate technology for Taiwan to develop in the near future. The significance of our research results implies that the grey statistics method is an effective method for selecting advanced public transportation systems technologies. We feel our information will be beneficial to the private sector for developing an appropriate intelligent transportation systems technology strategy.

Key Words: Intelligent transportation systems, Technology selection, Advanced public transportation systems, Grey statistics, Contactless smart card technology

1. INTRODUCTION

Taiwan is involved in intelligent transportation systems (ITS) planning, and is now selecting its prior focus areas for investment and development. The high social and economic impact associated with which intelligent transportation systems-related technology will be chosen explains the effort allocated by various electronics and transportation corporations for developing ITS-related technology in order to expand their business opportunities. A grey statistics method based on the grey theory is used for technology selection. We feel it is an effective alternative research method[1]. The method is used to analyze unknown or uncertain data that are normally difficult or impossible to measure, such as experts and decision-makers' opinions. This method estimates the information based on given data or strategies.

The grey statistics method has the following characteristics: (1) It involves different actors' decisions, such as transportation managerial agencies, electronics corporations, and transportation operators; (2) It can be effectively designed by using specific current data. It does not require a large amount of information; (3) It deals with the intrinsic uncertainty of experts' evaluations, not the uncertainty caused by group discussions; (4) It does not have a compromise effect, that is, this method concerns all people's opinions, and will not view some of the opinions as an extreme point; (5) It suggests strategic proposals, not final decisions. The characteristics of the technology selection decision-making environment in Taiwan suggest to us that a grey statistics method can help enhance the effectiveness and efficiency of ITS technology selection. Selecting prior developed ITS-related technology considers not only specific information (such as specifications) but also uncertain and unknown information (such as the economic or social situation). Thus, it is fitting to use a grey statistics method to suggest the appropriate ITS-related technology for development.

The objective of the present paper is to develop a grey statistics method for suggestions related to the selection of ITS-related technology in Taiwan. The remainder of present paper is organized as follows: Section 2 presents the literature review, Section 3 presents the methodology, Section 4 and 5 present our data process and research results. Section 6 summarizes our conclusion.

2. LITERATURE REVIEW

Many studies have described technology selection and development. Jackson et al.[2] explored the selection of technologies for landfill waste site remediation in American. The required attributes are found to be total cost and time. Zysman et al.[3] investigated the development and selection of mobile and personal communications. They revealed that technological and research ability, as well as research organization, are important factors. Schimmoller[4] identified the business strategies used in fast-developed power generation project development, and the factors influencing technology selection in that field. He indicated that environmental concerns, such as emissions controls, could be the key factors in selection decisions. From a mass transit service perspective, Cunningham and Young[5] examined public transportation development and service quality from the American managerial viewpoint. In their conclusion, stakeholders' opinions (such as transportation officials' and customers' opinions) were all important determinants of a provider's selection. Zhang[6] described some required success factors in choosing technology using a questionnaire investigation and e-mail messages. She investigated the fast-developed technology use in distance teaching of a graduate course. The critical success factors are user needs, user characteristics and the availability of the technology. Zhang indicated evidence of effectiveness in choosing distance technology, and described important administrative support to distant instructional persons for choosing and utilizing advanced technologies. Other studies have pointed out that the frequent utilization of technology, other technology users, environmental impacts and the effects on technological development are critical influencing factors involved in the choice of technology. They surveyed 108 public transport systems and technologies around the world and described how providing the technology most appropriate to meeting user needs was more effective than spreading the public transport budget over a small number of prestige schemes[7].

Recently, Calzonetti's research investigated technology planning and selection in West Virginia, U.S.A. The results of his research indicated that the essential influencing factors in technology selection are: research infrastructure, specialized workforce, existing technical ability, strong research universities, dense networks of firms, supporting technology organizations, existing local sources of capital and technological characteristics[8].

After summarizing the review of previous research, fifteen factors were chose for use for the present investigation questionnaire. They are listed as follows:

• User needs	• Specific knowledge	• Infrastructure
• Regional growth	• Local sources of capital	• Emissions
• Dense networks of firms	• Stakeholders' opinions	• Technological characteristics
• Supporting organizations	• Trained workforce	• Setting cost
• Workforce training	• Existing technical capability	• Safety

3. METHOD AND PROCEDURE

This research develops a grey statistics method and a scenario method for solving technology selection problems. In the present section are outlined two methods.

Cotter[9] shows that scenario analysis is very useful in evaluating fast-developed e-marketing initiatives and plan appropriate systems and technologies effectively. Godet[10] indicates that a scenario-planning model effectively solves high technology planning and selection problems. He demonstrated that scenario planning is an effective and popular method in choosing technology, especially among large companies in the fast-developed energy sector. The scenario model is used for solving systems and technologies selection problems that suffer from a lack of historical data for reference. Since technology selection problems of advanced public transportation systems (APTS) are new in Taiwan, we feel it can be throughly explored using scenario analysis. The grey statistics method, a part of grey system theory, is an evaluation method different from fuzzy theory. The grey statistics focus on problems with uncertain or "least" data, and thus allows the data to be distributed arbitrarily rather than distributed typically. The difference between grey statistics and fuzzy theory is shown in Table 1. The pilot projects such as transit smart card ticketing systems in Taiwan are important projects in the development of national projects. The purpose of this project was to implement and integrate smart card systems for most of the transportation modes in Taiwan[12]. However, problems in technology selection have delayed it. Based on the aforementioned analysis, the authors use a conceptual scenario model integrated with a grey statistics method for technology choice problem of APTS, as shown in Figure 1.

Table 1 The difference between grey statistics and fuzzy theory

Item	Fuzzy theory	Grey statistics
Nature	Uncertainty from recognition	Uncertainty from least data
Mathematical foundation	Fuzzy set	Grey hazy set
Data characteristics	Experiential data	Least data
Data distribution	Functional distribution	Arbitrary distribution
Objective	Representation of kenning	Reality law

Source: The authors and [11]

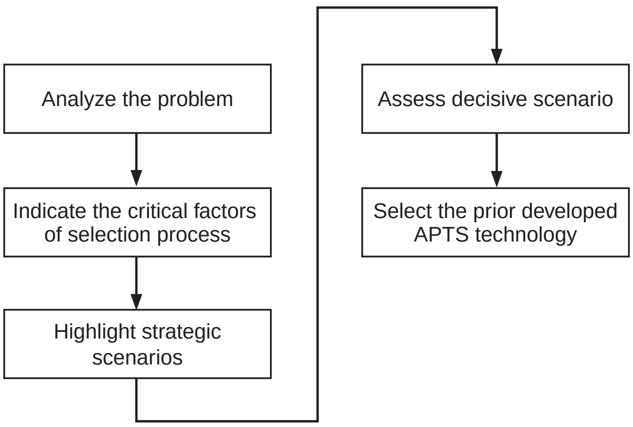

Fig. 1 The conceptual model of selecting APTS-related technology

4. SURVEY DESIGN AND DATA PROCESS

In order to establish the APTS developmental strategy, a comprehensive questionnaire mail survey was conducted. The contents of the questionnaire were designed on the basis of the proposed grey statistics method for determining the developmental priority of APTS-related technology such that the proposed strategy can meet the needs of both the supply and the demand markets. Some sections covered in the questionnaire, are briefly described below.

1. Critical factors in the selection of transportation technology for the private sector

This section identifies the comparative significance among the pre-specified key factors of selecting transportation technologies for the private sector on the basis of the given literature. Survey respondents were asked to present their opinions about the key factors of selecting technology. Transferred positive integers are bounded by 1 and 5, corresponding to “strongly disagreeable” and “strongly agreeable” respectively. The positive integer obtained here is referred to as “the degree of comparative significance of factors”.

2. Formulation of the strategic scenarios

The objective of the section is to formulate some types of strategic scenarios for further use and to select the likely future scenario (one representing a structurally different but plausible scenario). Given the possible scenarios formulated by critical factors in choosing transportation technology, survey respondents were asked to denote the base case scenario, the optimistic scenario, the pessimistic scenario and the likely future scenario.

3. Developmental priority of APTS-related technology

The questions written for this section were designed to explore the potential usefulness of APTS-related technologies. In this section, six APTS-related technologies, either currently used or being developed, can be classified into several groups: (1) communications technology: short-range communications systems technology, (2) positioning technology: automatic vehicle location technology and (3) others: route guidance systems technology, automatic vehicle monitoring technology, combi card and contactless smart card technology. The groups are predetermined based on the consideration in the potentialities of APTS to the markets of passenger service and freight transportation[11, 13-18]. Given the likely future scenario, survey respondents were requested to rate the technologies on a nine-point scale to denote numerically the developmental priority of the technologies to the APTS-related technologies.

The comprehensive questionnaire mail survey was conducted during the spring of 2003 in Taiwan. Considering the comprehensiveness of the samples surveyed, the authors included four groups in this survey. They are (1) government representatives, (2) researchers and professors in this field, (3) public transportation business operators (the APTS demander), and (4) APTS-related hardware/software providers (the APTS technical supplier). The sample for the present research was selected on the basis of the Directory of ITS Taiwan Website, which is renewed about every six months. The corporations selected includes air transport corporations, bus companies, mass rapid transit corporations, the Taiwan railway administration and electronics corporations. In the present survey, a total of 66 samples were identified. Of these, 33 were valid. Sample characteristics in the aspect of sample familiarity with ITS and APTS are worth noting. They are summarized in Table 2. The information with respect to the respondents' familiarity with ITS may help to enhance the acceptability of the investigation's results. It is notable that as many as 94% and 88% of the respondents were to a certain extent familiar with ITS and APTS respectively.

Table 2 Sample familiarity with ITS and APTS

Familiarity with ITS	Number of respondents	Percentage (%)
Very familiar	4	12
Familiar	14	43
Somewhat familiar	13	39
Slightly unfamiliar	2	6
Rather unfamiliar	0	0
Familiarity with APTS		
Very familiar	3	9
Familiar	13	39.5
Somewhat familiar	13	39.5
Slightly unfamiliar	4	12
Rather unfamiliar	0	0

The authors processed the raw data and developed the scenarios using the 33 experts' opinions. We analyzed the experts' opinions with the grey statistics method, and formulated the final scenario. In order to process the unclear characteristics contained within expert opinions, the grey statistics approach was employed. It first uses grey numbers to classify influencing factors into different categories. Critical factors can be identified to construct the strategic scenarios. The process is briefly presented below.

4.1 Definition of critical uncertainties

We developed a new questionnaire survey method in this section. In the questionnaire, we first asked experts to assess the factors according to their potential importance. Although the number intervals are ranked from 1 to 5, the numbers can be given unlimited rank after the decimal point, becoming, for example, 1.10 or 2.112. Using this method, we can analyze generalized trapezoid grey numbers and special triangular grey numbers. Thus, the results can precisely represent experts' opinions. We have converted the rank numbers into grey numbers (or sample values) from 9 to 1, such that the higher value represents greater importance. The rankings were all identified by the experts' professional background. We collected the sample values for analysis according to their five degrees of importance (or grey group). The details about data processing are described as follows.

Establishment of conversion scales

We categorized factor importance into five linguistic terms. The conversion scale of each linguistic term is shown in Figure 2[12,19].

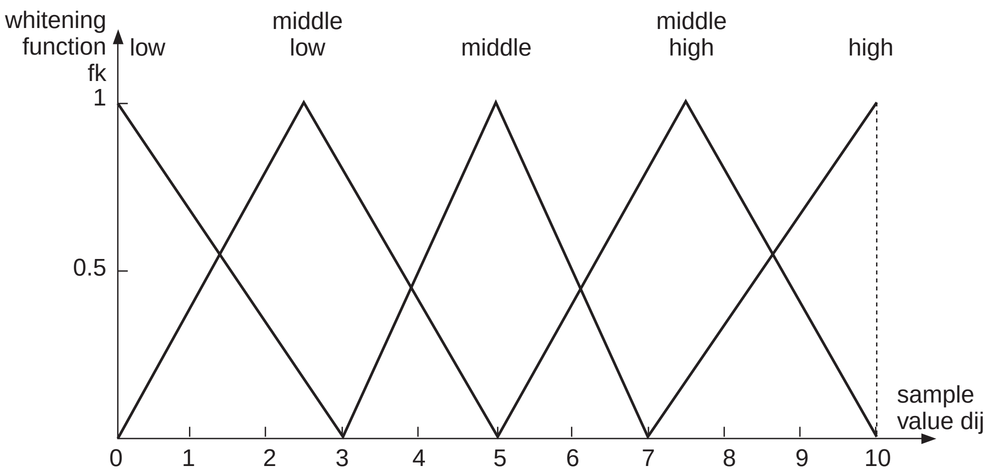

Fig. 2 Five grey groups

Establishment of white value

In the data process, our final objective was to calculate the values of the APTS-related technology associated with each sample. The authors first obtained a specific element 'd_{ij}' representing the degree of comparative significance associated with the factor j and identified by survey respondent i. Then we obtained the element 'f_k' to represent the whitening function of grey group k, and $ó_{jk}$ is the white value of the factor j belonging to grey group k. The value is given by $ó_{jk}$ =(Óf_k d_{ij})/ (Ó$^n{}_{k=1}$ Óf_k d_{ij}), k∈{1,2,…,n}, i∈{1,2,…,w}, j∈{1,2,…,m}. For k, the grey statistics series of factor j is $ó_j$ =[$ó_{j1}$,…, $ó_{jk}$]. Also, the authors defined factor j as belonging to grey group k*, then $ó_{jk*}$ =max$_k$ $ó_{jk}$.

For example, when we take the factor “user needs”, its grey statistics series [high, middle-high, middle, middle-low, low] is calculated as [9.38,8.64,0,0,0]. According to the results, the authors categorized "user needs" into “high” conversion scale.

Establishment of grey group

We appointed each factor’s grey statistics series as [high, middle-high, middle, middle-low, low]. Table 3 summarizes the relative grey group of each factor.

Table 3 Relative grey group of each factor

Influencing factor	Grey statistics series	Grey group
User needs	[9.38,8.64, 0, 0,0]	High
Specific knowledge demand	[2.01,8.36,5.00,0.67,0]	Middle-high
Infrastructure	[6.03,7.66,4.00, 0,0]	Middle-high
Local economic development	[4.02,6.67,6.00,0.67,0]	Middle-high
Dense networks of firms	[2.68,8.02,4.00,0.67,0]	Middle-high
Supporting organization	[5.34,5.36,1.00,0.67,0]	Middle-high
Local capital source	[3.35,5.67,7.00,1.34,0]	Middle
Stakeholders’ opinions	[2.01,7.02,8.00, 0,0]	Middle
Professional worker	[6.70,9.33,1.00, 0,0]	Middle-high
Existing technical ability	[5.36,8.00,3.00,0.67,0]	Middle-high
Human resources training	[2.68,6.68,5.00,2.01,0]	Middle-high
Emissions	[0,8.71,7.00, 0,0]	Middle-high
Technological characteristics	[2.01,9.70,2.00,1.34,0]	Middle-high
Setting cost	[9.38,7.30,1.00,0.67,0]	High
Safety	[6.70,8.66,2.00, 0,0]	Middle-high

According to the aforementioned analysis, the authors used factors belonging to “high grey group” and “middle-high grey group with highest white value” in constructing the strategic scenarios. However, these factors have uncertainties and, following the literature[20], we chose the independent factors to be “user needs”, “setting cost”, and “technological characteristics”.

4.2 Construction of scenarios

The construction of scenarios can first combine two factors to both construct possible scenarios and analyze consistency. For example, one can first construct scenarios using two factors: “user needs” and “technological characteristics” shown in Figure 3.

		User needs	
		High	**Low**
Technological	**Simple**	Situation 1	Situation 3
Characteristics	**Complicated**	Situation 2	Situation 4

Fig. 3 Possible situations for technology choice scenario structures (part 1)

From Figure 3, we understand that Situations 1 to 4 are all possible situations, thus we retain them all. Then a third factor (Setting cost) is added to the matrix to form another figure, as shown in Figure 4.

In Figure 4 we finally simulate eight reasonable scenarios for the private sector. After constructing possible scenarios for the private sector in Taiwan, the next round of the questionnaire survey was conducted by interviewing experts and asking them to rate each scenario by the possibility of its occurrence in a strategic situation. As the replies came back, we analyzed every scenario under the “likely future” situation using grey statistics method to determine the final decisive future scenario. Based on the aforementioned analysis, the structurally different but plausible scenario is Scenario 1, *it represents that under a slower economic development environment together with urgent user needs for efficient and safe transportation, the setting cost of APTS-related technology is high for developing effective products. Government agencies pursue business and infrastructure with a reasonable return for economic development and industrial advancement. On the other hand, the technological characteristics of APTS-related technology are fully utilized by manufacturers. Thus, public sectors cooperate with private operators in the development of transport technology industry*. It can be found that the prior-developed technology of APTS is contactless smart card technology based on the same aforementioned analysis, too. Tables 4 and 5 summarize the grey groups of each scenario and technology respectively.

		User needs/Technological characteristics			
		High/Simple	High/Complicated	Low/Simple	Low/Complicated
Setting cost	High	Scenario 1	Scenario 2	Scenario 3	Scenario 4
	Low	Scenario 5	Scenario 6	Scenario 7	Scenario 8

Fig. 4 Possible situations for technology choice scenario structures (part 2)

Table 4 Grey group of each scenario

Scenario	Grey statistics series	Grey group
Scenario 1	[5.69,4.80,3.50,0.40, 0]	High
Scenario 2	[5.00,7.20,2.50,1.60, 0]	Middle-high
Scenario 3	[1.67,2.40,3.00,3.20,0.33]	Middle-low
Scenario 4	[0.33,1.20,1.50,4.80,0.99]	Middle-low
Scenario 5	[4.68,7.20, 0,0.80, 0]	Middle-high
Scenario 6	[2.00,4.40,1.50,0.80,0.33]	Middle-high
Scenario 7	[0.33,2.80,2.50,1.60, 0]	Middle-high
Scenario 8	[0,2.40,1.50,2.80,0.66]	Middle-low

Table 5 Grey group of each technology

Technology	Grey statistics series	Grey group
Short-range communications	[2.64,14.40,10.50,2.40,0]	Middle-high
Route guidance systems	[1.65,10.40, 6.00,7.20,0]	Middle-high
Automatic vehicle location systems	[3.63,14.00, 8.00,1.20,0]	Middle-high
Automatic vehicle monitoring systems	[0.99, 8.80,10.00,4.80,0]	Middle
Contactless smart card	[3.630,15.20, 6.00,2.40,0]	Middle-high
Combi card	[0.33, 8.40, 7.00,6.00,0]	Middle-high

5. RESULTS AND DISCUSSION

There are several generalizations indicated by our research results. First, contactless smart card technology would seem to be the best choice of relative required technology from among the other APTS-related technologies in the near future in Taiwan. Second, route guidance systems are commonly agreed to be significant technologies in APTS. In our present results they drew less concern than we anticipated. The reason seems to be the complication of systems and infrastructure needed. In general, systems will not be established in a short time, thus appropriate education is an effective way in supporting current ITS development.

Transportation service providers in Taiwan understand that the need for security and convenience is a growing social need. The basic values of contactless smart cards have the capability of storing personal information with a high degree of security and portability[21]. Therefore companies are willing to do research and develop the kind of technology which can gain profit for sustainable development.

6. CONCLUSIONS

This paper investigated choosing technology for advanced public transportation systems with reference to Taiwanese corporations. First, our approach in selecting appropriate technology was to use the grey statistics method and scenario analysis. The technology of APTS was found to be the most appropriate prior developed technology in Taiwan. It is the contactless smart card technology. Second, in using a grey statistics method to select appropriate technology, we found that this method was an effective method both for transportation research and to analyze technology selection strategies quantitatively and successfully. Finally, future research should aim at exploring the relationship between technological characteristics and technology sourcing. The technology-sourcing decision is a significant technology strategy, thus further study concerning this topic is suggested.

REFERENCES

1. Lee, C. M. and Hu, M. H. Gray decision-making analysis in new generation of naval warship evaluation. “Naval Officer” 20(2): pp. 82-92. (2001).
2. Jackson, J. A. et al. Selecting a portfolio of technologies: An application of decision analysis. “Decision Sciences” 30(1): pp. 217-238. (1999).
3. Zysman, G. I. et al. Technology evolution for mobile and personal communications. “Bell Labs Technical Journal” 5(1): pp. 107-130. (2000).
4. Schimmoller, B. K. Evolving power markets challenge project developers. “Power Engineering” 104(9): pp. 57-65. (2000).
5. Cunningham, L. et al. Methodological triangulation in measuring public transportation service quality. “Transportation Journal” 40(1): pp. 35-47. (2000).
6. Zhang, P. A case study on technology use in distance learning. “Journal of Research on Computing in Education” 30(4): pp. 398-420. (1998).
7. Mackett, R. L. and Edwards, M. The impact of new urban public transport systems: will the expectations be met? “Transportation Research Part A” 32(4): pp. 231-245. (1998).
8. Calzonetti, F. J. State science and technology planning in West Virginia: Challenges facing practitioners. “Economic Development Quarterly” 14(4): pp. 360-376. (2000).
9. Cotter, S. Taking the measure of e-marketing success. “The Journal of Business Strategy” 23(2): pp. 30-37. (2002).

10. Godet, M. The art of scenarios and strategic planning: tools and pitfalls. “Technological Forecasting and Social Change” 65: pp. 3-22. (2000).
11. Deng, J. L. The Theory and Application of Gray System. 1 st edition, Gau Lih Books Company, Taipei. (2000).
12. Institute of Transportation. The Program of Developing Intelligent Transportation Systems in Taiwan. Institute of Transportation, Taiwan. (2000).
13. Huang, T. H. The Analysis of Route Choice Behavior with Real Time Information. Ph. D. Dissertation, Institute of Traffic and Transportation, National Chiao Tung University, Hsin Chu, Taiwan, (in Chinese).(2000).
14. Institute of Transportation. Transportation Policy White Paper. Institute of Transportation, Taiwan. (2001).
15. ITS Taiwan. NICI team of Executive Yuan establishes Intelligent Transportation Department and Fourth Flagship Program. “ITS Newsletter” 93. (2002).
16. Lee, Y. N. A Design of An Advanced Web Automatic Vehicle Location System. Master Thesis, Department of Transportation Engineering and Management, National Chiao Tung University, Hsin Chu, Taiwan, (in Chinese). (2000).
17. Wang, H. D. A Study and Comparison of Wireless Communication Techniques for An Integrated Vehicle Navigation System. Master Thesis, Institute of Resource Management, National Defense Management College, Taipei County, Taiwan, (in Chinese). (1999).
18. Yang, B. W. Estimation of Passengers' Benefits for Advanced Dynamic Bus Information System. Master Thesis, Department of Transportation Management, Tamkang University, Taipei County, Taiwan, (in Chinese). (2001).
19. Chen, S. J. and Hwang, C. L. Fuzzy Multiple Attribute Decision Making: Methods and Application. Springer Verlag, New York. (1992).
20. Chang, W. J. The Scenario Analysis of Taiwan's Automobile Repair Industry. Master Thesis, Department of Business Management, National Sun Yat Sen University, Kaohsiung, Taiwan, (in Chinese). (1993).
21. Leung, A. Smart cards seem a sure bet. “InfoWorld” 21(10): pp. 37-40. (1999).

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