The Analysis of Priorities of ITS Using Analytic Hierarchy Processes

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Abstract. Daegu Metropolitan City is currently in the process of implementing an Intelligent Transportation Systems (ITS) basic plan in order to establish these systems and the foundation of basic services, in addition to setting establishment goals based on the national basic plan of ITS. Some criteria have proven to be very effective at determining the priorities of ITS services, measuring their contribution to solving transportation problems, identifying the services preferred by users, and evaluating ITS systems and related technologies. The purpose of this paper is to analyze priorities of ITS using the Analytic Hierarchy Process (AHP), combining absolute and relative measurement in a hierarchy. This is done by using rating intensities of six sub criteria to determine the priorities of 17 ITS according to how effectively it contributes to solving transportation problems, users' preference of ITS, and its evaluation and related technologies. According to the results of ITS priorities analysis, the Regional Traffic Information Center System was chosen to be the top priority project followed by the Urban Arterial Incident Management System and the Urban Arterial Traffic Signal Control System.

Keywords: Analytic Hierarchy Process (AHP), Intelligent Transportation Systems (ITS), Priorities, Multi Criteria Analysis

1 Introduction

The use of intelligent transportation systems (ITS) is increasing, as further attempts are made to alleviate traffic problems by means other than expanding the physical capacity and size of roadways. ITS field trials have demonstrated various benefits associated with individual applications and integrated systems. In Korea, following the enactment of the ‘Transport System Efficiency Promotion Act’ in 1999, the ‘National ITS Plan 21’ was established in 2000. Since then, ITS projects have begun to be implemented at the city level.

Daegu Metropolitan City, the 3rd largest city in Korea, is also establishing a basic ITS plan and considering the priority for detailed items to be implemented for each field. Before setting priorities for ITS establishment, applicability and timing should be determined in consideration of technologies at home and abroad. In addition, users' preferences must also be considered to maximize the effect of the introduction of ITS services focusing on resolving the transportation problems that the citizens are really experiencing. Any city government with plans to introduce ITS services also intends to resolve the current transportation problems and to consider as much as possible the potential impact of the ITS service on the overall transportation flow, since it is something that can never be neglected.

The Analytic Hierarchy Process (AHP) is recommended as one of the Multi-Criteria Analysis methods to be used for decision making or priority setting in the public and private sectors. The AHP has increased in use and popularity due to the fact that the process reflects the way people think and make decisions by simplifying complex decisions to a series of one-on-one comparisons. In this regard, we conducted a survey of Daegu citizens and experts regarding their perception of traffic issues (traffic conditions) and appropriate ITS. Based on our survey results and technology level (evaluated in the National ITS Plan), we prioritized ITS services by applying the AHP.

It was impossible to prioritize among 17 ITS services with a pairwise comparison method. Thus, we used relative measurement for upper level objects (on ITS services) to derive their weight, and absolute measurement for lower level objects (on purposes) based on rating intensities.

2 Outlines of AHP and Research Trend

2.1 Research Trends of AHP

AHP is a multiple-attribute decision-making tool developed by Thomas Saaty in the early 1970s. AHP is most commonly used as a supporting system for group decision-making as it is easy to apply and highly respected for its process of measurement and weight calculation according to its hierarchical evaluation structure. In Korea, the Korea Development Institute (KDI) used AHP as a multi-criteria analysis method when conducting a comprehensive evaluation of the preliminary feasibility study. And the number of positive studies using AHP is increasing.

Conventional AHP established by Saaty is classified into an inner dependence method and an outer dependence method. When alternatives are dependent on one another, an inner dependence method is suggested. When alternatives and evaluation items are related, an outer dependence method is suggested. Also, the Analytic Network Process(ANP) can represent the dependence between different levels. The development from a conventional AHP hierarchical structure to the recently suggested 4-phase ANP network structure is shown in (Figure 1). As such, its application areas have been expanded (Saaty, 2001). The conventional AHP's relative and absolute measurement correspond to the Dominant AHP's dominant alternative method and dominant evaluation level method.

Many scholars have focused on the development of evaluation methodology ranging from AHP to ANP. As a result, diverse AHP theories were established through the International Symposium on the Analytic Hierarchy Process (which was first held in Tianjing, China, in 1988), and, accordingly, empirical studies are being conducted across a wide range of areas including education, transportation, regional development, business, and labor.

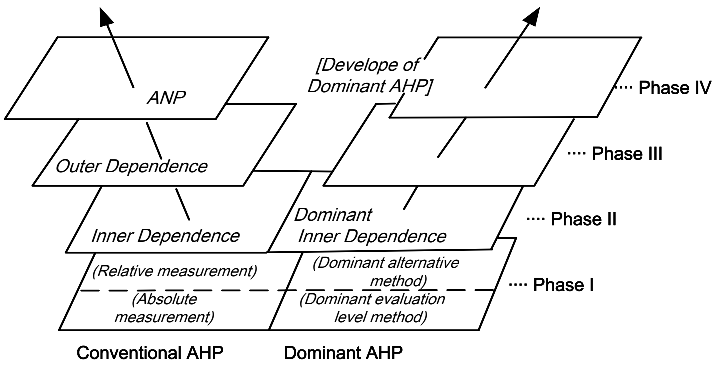


Fig. 1. Theoretical Development of AHP

2.2 Summery of AHP Analysis Method

AHP analysis process is divided into five steps: 1) brainstorming; 2) structuring; 3) weighting; 4) measurement; and 5) feedback. Evaluation items should be carefully prepared in consideration of a variety of factors such as different views, and evaluation index should be able to objectively grade the lowest questionnaires.

We derived relative weight based on answers (scores from one to nine) of our questionnaires. As shown in the <Table 1>, we calculated the eigenvalue of N × N matrix via pairwise comparison.

Table 1. Pairwise Comparison Scale

Definition	Intensity of Importance: a_{ij}
Equal Important	1
Moderate Important	3
Important	5
Very Important	7
Extremely Important	9

	$a_{ii} = 1, \quad a_{ji} = 1/a_{ij}$

'a_{ij}' the relative weight (pairwise comparison figure) of the evaluation items of i and j represents 'w_i/w_j', the weight ratio of respective evaluation items.

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a_{21} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & 1 \end{bmatrix} = \begin{bmatrix} 1 & w_1/w_2 & \cdots & w_1/w_n \\ w_2/w_1 & 1 & \cdots & w_2/w_n \\ \vdots & \vdots & \ddots & \vdots \\ w_n/w_1 & w_n/w_2 & \cdots & 1 \end{bmatrix} \quad (1)$$

Matrix A times the vector obtained from evaluation item weight becomes the eigenvector of matrix A. By doing so, the weight of each evaluation item is derived.

$$Aw = \begin{bmatrix} 1 & w_1/w_2 & \cdots & w_1/w_n \\ w_2/w_1 & 1 & \cdots & w_2/w_n \\ \vdots & \vdots & \ddots & \vdots \\ w_n/w_1 & w_n/w_2 & \cdots & 1 \end{bmatrix} \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} = nW \quad (2)$$

The formulation can be applied only in the case of '$a_{ik} = a_{ij} \times a_{ik}$'. Therefore, when it is difficult to have consistent answers, Consistency Index (CI) can be derived as follows.

$$C.I. = \frac{\lambda_{\max} - n}{n-1} \quad (3)$$

where, $\lambda_{\max}$ is maximum eigenvalue.

And if C.I. <0.1, the comparison matrix is consistent. In a perfet consistence case, the element of comparison matrix is represented by ratio of the alternative's weights, that is any alternatives i and j we have $a_{ij} = w_i / w_j$..

3 Survey on the preference among the ITS Services

3.1 Outline

The subject of the survey was categorized into two groups: 1) general group (citizens and employees in transportation business); and 2) expert group (transportation related government officials and experts).

The questionnaire includes personal attributes, perceptions of transport, and preference of ITS. Additionally, we asked the expert group pairwise comparison type of questions (relative importance and preference among evaluation items) for AHP analysis.

Table 2. Outline of Survey

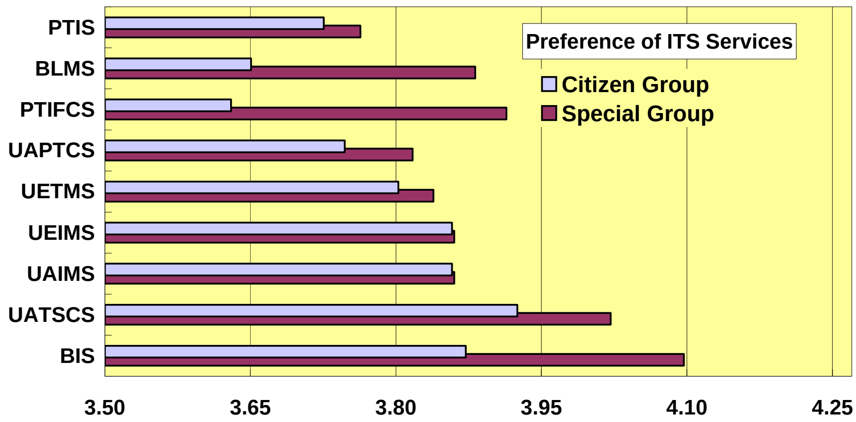
The Subject of Survey (No. of questionnaires)	Contents	Survey Method
· Citizen Group(920) : general citizen and traffic service workers · Special Group(93) : transportation specialists and government officials	· Attributes of individual · Perceptions of transport (i.e., Transportation problems, Traffic Information) ·Preferences of ITS - AHP Survey	Workplace/personal interview, mail back survey

3.2 Satisfaction with Transport Status and Preference of ITS

According to the result of survey on the satisfaction with transportation, parking and traffic congestion are the most serious issues. Illegal parking and stoppage received 4.43 points, parking lot issue 3.99, and intersection congestion 3.86. Therefore, ITS services to be implemented should be able to directly or indirectly contribute to addressing such transportation problems.

As to the preference of ITS, "Urban Arterial Traffic Information Service System(UATISS)" was the most preferred with 3.84 points. "Urban Arterial Traffic Signal Control System" was the second most preferred with 3.84 points, and "Bus Information System" was the next with 3.74 points, as shown in the <Figure 2>.

Fig. 2. Preference of ITS



These outcomes evidence that people consider those services for traffic conditions and efficient public transportation is very important. Meanwhile, they did not fully understand ITS services given the relative low 3.51 points to "Regional Traffic Information Center System", which should be established in the first place. The services given below 3.5 points on average include "Speed Violation Enforcement System" and "Reversible Lane Control System".

Combined our survey results and sub systems indicated by the National ITS Plan, we listed a total of 17 ITS services that Daegu Metropolitan City could establish in the short and medium term. Then, taking into consideration technology level and benefits, we prioritized the 17 ITS services based on AHP.

4 Decision of ITS Services Priorities

4.1 Analysis Procedure

As mentioned above, making pairwise comparisons is not appropriate in a model that has a large number of alternatives, as numerous comparisons should be performed for every sub-object up to N×(N-1)/2 (N: number of alternatives).

Instead, therefore, comprehensive evaluation was conducted in this paper by using "Data Grid" function of Expert Choice 2000 Program, which includes rating intensities and weight by extending the scope of the original AHP.

(1) Calculation of Evaluation Item Weight

Upper level items for this study were set as 1) Solving Transportation Problems, 2) Preference of ITS Services, 3) Evaluation of ITS Technologies by the National ITS Plan. As sub-items of Solving Transportation Problems, six evaluation items were prepared as follows: traffic management (smooth traffic), public transport management, security and emergency management, and traffic and travel information.

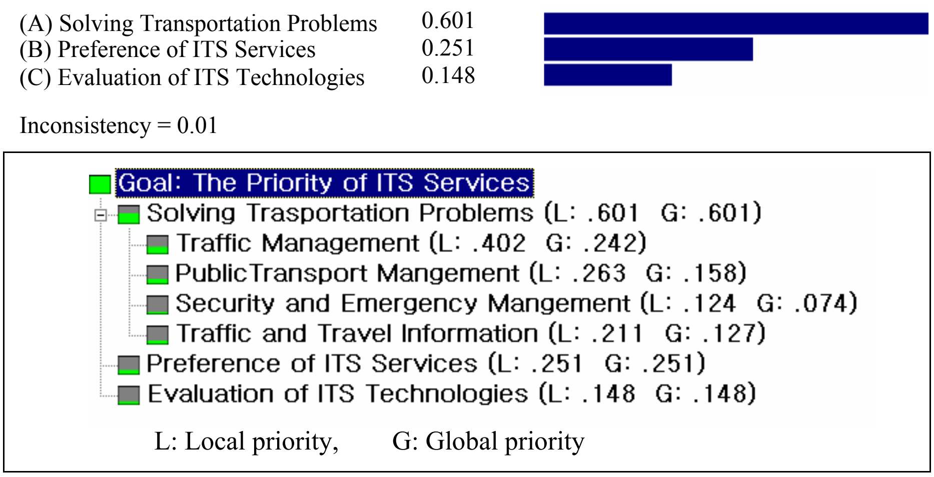


Fig. 3. Weighting of Evaluation Items

For more reasonable group decision-making (weighting) on ITS service priorities, survey with comparative questions (e. g. “In introducing ITS to Daegu, which is more important to solving transportation problems, either traffic management or public transport management?”) was carried out on traffic service workers and government officials participated in the National ITS Plan development. Then, the weight of 6 evaluation items were calculated for the final priority vector of each group based on the geometric means of the survey result.

The global priority result shows that Preference of ITS Services is 0.251, the highest, Transportation Management (smooth traffic), 0.242, Public Transport Management, 0.158, and Evaluation of ITS Technologies, 0.148.

(2) Analysis of Prioritization Results

For the evaluation of 17 ITS services selected above, the following four sub-categories were created under the first item of Solving Transportation Problems: 1) Traffic Management (smooth traffic), 2) Public Transport Management, 3) Security and Emergency Management, and 4) Traffic and Travel Information. To look at how much a system helps addressing traffic problems in Daegu, three rating intensities of A (High benefit), B (Moderate benefit), C (Low benefit) were graded (Table 3).

The second item of Preference of ITS Services was evaluated by reflecting the lowest and the highest values of the analyzed 5-grade ratings by citizen and expert groups. Then, the priority by system is calculated by applying Data Grid Increasing Utility Curves (min.3.0, max4.2) of Expert Choice. For the last item of Evaluation of ITS Technologies, rating intensities are marked as 4 levels of A (Highest level), B (High level), C (Moderate), D (Low level). The rating is based on the National ITS Plan assessment on the standards about the following conditions: if the country has required technologies; other system requirements are met; sub-systems are proven effective; and initial cost for system establishment is reasonable. The Priority analysis result is as shown in the <Table 3> below.

Table 3. Analysis Results of Priorities of ITS

ITS		Traffic Problems-solving				Pref. of ITS	ITS Tech.	Total	Ranks	Period
		1)TM	2) PTM	3) SM	4) TI					
S1	Urban Arterial Traffic Signal Control System (UATSCS)	0.582	0.109	0.109	0.309	0.808	0.467	0.477	3	S
S2	Urban Arterial Priority Vehicle TreatmentControl System (UAPTCS)	0.582	0.109	0.109	0.309	0.65	0.095	0.383	10	L
S3	Urban Arterial Reversible Lane Control System (UARLCS)	0.582	0.109	0.109	0.109	0.4	0.277	0.321	15	L
S4	Urban Arterial Traffic Information Service System (UATISS)	0.309	0.109	0.109	0.582	0.867	0.16	0.415	8	S
S5	Urban Arterial Incident Management System (UAIMS)	0.582	0.109	0.582	0.582	0.717	0.16	0.479	2	S
S6	Urban Expressway Traffic Management System (UETMS)	0.582	0.109	0.109	0.309	0.683	0.467	0.446	5	S
S7	Urban Expressway Incident Management System (UEIMS)	0.582	0.109	0.582	0.309	0.717	0.16	0.444	6	S
S8	Speed Violation Enforcement System (SVES)	0.109	0.109	0.582	0.109	0.275	0.467	0.239	17	L
S9	Heavy Vehicle Management System (HVMS)	0.109	0.109	0.582	0.109	0.508	0.16	0.252	16	L
S10	Pre-trip Traveler Information System (PTIS)	0.109	0.309	0.109	0.582	0.617	0.277	0.353	13	L
S11	En-route Traveler Information System (ETIS)	0.309	0.309	0.109	0.582	0.617	0.16	0.384	9	L
S12	Electronic Toll Collection System (ETCS)	0.582	0.109	0.109	0.109	0.608	0.277	0.374	11	L
S13	Public Transportation Integrated Fare Collection System (PIFCS)	0.109	0.582	0.109	0.109	0.642	0.277	0.342	14	L
S14	Bus Information System (BIS)	0.109	0.582	0.109	0.582	0.817	0.277	0.446	4	S
S15	Bus Lane Management System (BLMS)	0.309	0.582	0.109	0.109	0.642	0.16	0.373	12	L
S16	Regional Traffic Information Center System (RTICS)	0.582	0.582	0.309	0.582	0.525	0.467	0.530	1	S
S17	Basic Information Broadcasting System (BIBS)	0.309	0.582	0.309	0.582	0.525	0.16	0.419	7	S

Notes: 1) TM: Traffic Management, 2) PTM: Public Transport Management, 3) SM: Security and Emergency Management, 4) TI: Traffic and Travel Information, Period (S) short-terms, (L) long-terms

4.2 Results of ITS Priorities Analysis

As displayed in the <Table 4>, the analysis result shows that the top priority is Regional Traffic Information Center System (S16), followed by Urban Arterial Incident Management System (S5), Urban Arterial Traffic Signal Control System (S1), Urban Expressway Traffic Management System (S6), and Bus Information System (S14) in the order of urgency.

On the other hand, systems with the lowest priorities include Speed Violation Enforcement System (S8), Heavy Vehicle Management System (S9), and Urban Arterial Reversible Lane Control System (S3), relatively well reflecting citizens' preference and contribution to solving transportation problems.

On the basis of this comprehensive evaluation result using AHP, ITS Service Priorities in Daegu were set to make eight systems with 0.4 or above to be established in the short-term and the rest nine in the mid-term.

Table 4. Priority Analysis Results

(A) Solving Transportation Problems

Intensity Name	Priority
A : High benefit	.582
B : Moderate benefit	.309
C : Low benefit	.109

(B) Evaluation of ITS Technologies

Intensity Name	Priority
A : Highest level	.467
B : High level	.277
C : Moderate	.160
D : Low level	.095

4.3 Sensitivity Analysis

Sensitivity analysis shows whether a certain change in weight excessively influences evaluation results. In particular, five sensitivity modules including Performance, Dynamics, and Gradient are provided to easily analyze through graphs how a certain amount of weight change in the upper level objects alters priorities.

The sensitivity analysis of ITS performance for the eight systems with the highest priorities is displayed in the following (Figure 4). The left Y axis shows objective's priority, and the right one represents alternative priorities of each system.

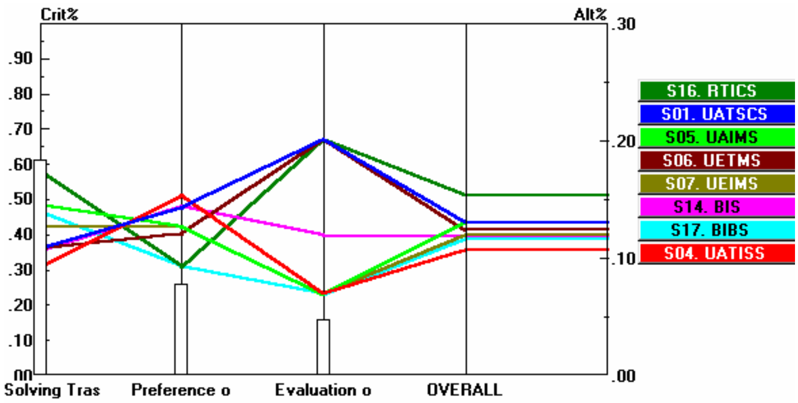


Fig. 4. Sensitivity Analysis of ITS Performance

Although the priorities of evaluation items well reflect ITS experts' views in this study, dynamic analysis was conducted to find out how a little weight change influences priorities as shown in the <Table 5> below. The analysis was done by increasing or decreasing 10% of the initial weight for each item (Solving

Transportation Problems: 0.601, Preference of ITS Services: 0.251, Evaluation of ITS Technologies: 0.148).

The result explains that BIS (Bus Information System) priority drops significantly from 4 to 7 when imposing 10% more weight to Solving Transportation Problems, which means BIS contributes little to Solving Transportation Problems. Other systems mark only slight changes within a one rating intensity of priority.

Table 5. Results of Sensitivity Analysis for short-term 8 ITS Services

ITS		%MAX (Ranks)	Transportation Problems-solving		Preference of ITS Service		Effects of ITS Technologies	
			+10%	-10%	+10%	-10%	+10%	-10%
S1	Urban Arterial Traffic Signal Control System (UATSCS)	0.90 (3)	12.7 (3)	13.4 (2)	13.1 (2)	13.0 (2)	13.2 (2)	12.9 (3)
S4	Urban Arterial Traffic Information Service System (UATISS)	0.783 (8)	10.4 (8)	10.9 (8)	10.8 (8)	10.5 (8)	10.6 (8)	10.7 (8)
S5	Urban Arterial Incident Management System (UAIMS)	0.903 (2)	13.2 (2)	12.8 (3)	13.0 (3)	13.0 (2)	12.9 (3)	13.1 (2)
S6	Urban Expressway Traffic Management System (UETMS)	0.841 (5)	12.2 (4)	12.6 (4)	12.4 (4)	12.4 (4)	12.6 (4)	12.3 (4)
S7	Urban Expressway Incident Management System (UEIMS)	0.838 (6)	12.1 (5)	11.8 (6)	12.0 (5)	11.9 (5)	11.8 (5)	12.0 (5)
S14	Bus Information System (BIS)	0.842 (4)	**11.7 (7)**	12.1 (5)	12 (5)	**11.8 (6)**	**11.9 (6)**	**11.9 (6)**
S16	Regional Traffic Information Center System (RTICS)	1.000 (1)	15.7 (1)	15.1 (1)	15.2 (1)	15.6 (1)	15.1 (1)	15.3 (1)
S17	Basic Information Broadcasting System (BIBS)	0.790 (7)	12.0 (6)	11.3 (7)	11.6 (7)	11.7 (7)	11.6 (7)	11.7 (7)

Note 1) Priority by system for the highest value of comprehensive evaluation results
2) Priority (%) by system for the overall dynamic sensitivity analysis results

5. Conclusions and Further Research

AHP used in this research is Multi Criteria Analysis (MCA). It is easy to apply and has clear theoretical backgrounds, and its hierarchy structure supports decision-making process. Thanks to these merits, it is widely used as a supporting system of group decision-making, but few case examples are found in Korea’s transportation area. However, in 1999, preliminary feasibility study was mandated for large-scale development projects worth of 50 billion KRW or higher (Art. 9.2, Budget and Accounting Act Enforcement Ordinance), and Public and Private Infrastructure Investment Management Center of Korea Development Institute (KDI) is actively promoting to introduce AHP for MCA evaluation in pre-feasibility study analysis, signaling that empirical research and case studies are gradually spreading.

This paper especially suggests practical result of comprehensive evaluation that combines absolute measurement with relative measurement of the original AHP in setting priorities for a large number of alternatives. This new methodology is expected to be widely applied to other similar MCA in the future. For the further research, validity of priorities and rating intensities should be re-verified for objective and multifaceted evaluation and application of different groups' opinion in priority setting, and the 2nd feedback procedure is also required.

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