Analytic Hierarchy Approach for Transport Project Appraisal

An Application to Korea

by

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The candidate confirms that the work submitted is his own
and that appropriate credit has been given where
reference has been made to the work of others

For lovely Jin and cute Moon

Abstract

Transport evaluation methodology in Korea has remained largely unchanged even though the evolution of the transport planning process has changed in its nature and circumstances. The economic analysis has played an important role as a decision-making method, and the Government has the leading role as a single decision maker. As a result, there are so many debates on most of transport investment projects by other interest groups and by the fact that other non-economic attributes are not properly considered in the evaluation process.

Therefore, it is necessary to avoid this costly indecision and incomplete evaluation. As a result, the recent work has focused on improving public participation and evaluation methods utilising multiple criteria decision making methods which are able to reflect diverse interests of multiple actors involved in the project, environmental issues, socio-economic concerns and public discontent in evaluation process, and to respond to the changed nature of transport planning.

In this research, the analytic hierarchy approach which enables to combine the advantages in quantifying the tangible factors from CBA and in deriving weights of the factors from the AHP was attempted to evaluate the transport investment project in Korea as the methodology through reviewing and assessing many multiple criteria decision making methods. The case for application was chosen from the real project implemented by Korean government so as to compare the current evaluation method with the analytic hierarchy approach, one of multiple criteria decision making methods. The project is to develop a high speed rail network passing through/by a historic city with many cultural assets, so there are many conflicting debates between transport efficiency and cultural conservation among the stakeholders affected by this project, supplier, user and community.

For the application and evaluation of the project, a model with five levels of hierarchical structure with three stakeholders, six objectives, seven elements and three alternatives was developed. A total of 615 respondents from transport experts, government officials and the general public answered the survey questionnaire to find out the degree of importance for each stakeholder's role on this project investment from transport experts, and a relative preference for each attribute as main factor from all stakeholders. With the evaluation process and results (including alternative ranking) from both methods, they were compared with each other. In addition to this, the applicability and suitability of the analytic hierarchy approach method for the evaluation of transport investment project in Korea were assessed by several assessment criteria.

The analytic hierarchy approach (through its application) provided much wider scope than the current evaluation method. It showed a systematic framework for the evaluation in which all possible factors should be judged with the distribution of weights on all stakeholders incorporating qualitative and quantitative information. In addition, it showed the applicability of the analytic hierarchy approach to the transport project due to its ability to deal with complex problems with conflicting attributes and to elicit the preferences of many stakeholders affected by the project into the evaluation process. However, it also showed some drawbacks to be overcome such as a large amount of data and information requirement, inherent difficulty in survey implementation, difficulty in structuring a hierarchy, especially in checking the homogeneity.

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Table of Contents

Chapter 1 : Introduction 1

1.1 Introduction 1

1.2 Aims of The Research 4

1.3 Thesis Outline 5

1,4 Research Framework 6

Chapter 2 : The Transport Sector in Korea 9

2.1 Introduction 9

2.2 The Transport Sector in Korea 9

2.2.1 Transport Trends and Modal Shares 9

2.2.2 Transport Investment and Source 14

2.2.3 Transport Policy for Investment 15

2.3 Transport Investment Evaluation Techniques in Korea 19

2.3.1 Evaluation Criteria 22

2.3.2 Examples of The Transport Investment Evaluation 22

2.3.2.1 Example 1: Seoul-Pusan High Speed Rail Feasibility Study 22

2.3.2.2 Example 2: Urban Rail Construction Feasibility Study 24

2.3.2.3 Example 3: New Highway Construction Evaluation 24

2.4 High Speed Rail Network Development in Korea 25

2.4.1 Background 25

2.4.2 HSR 27

2.4.2.1 HSR Scheme 27

2.4.2.2 HSR Process 28

2.4.3 Kyongju Line 28
2.4.3.1 Background 28
2.4.3.2 Evaluation of Kyongju Line Alternatives by KOTI 32
2.5 Conclusion 33

Chapter 3 : Transport Appraisal Methods 35

3.1 Introduction 35
3.2 Transport Appraisal Methods 35
3.2.1 Cost-Benefit Analysis 35
3.2.2 Financial Analysis 44
3.2.3 Cost-Effectiveness Analysis 44
3.2.4 Multiple Criteria Evaluation Method 46
3.3 The classification of Multiple Criteria Evaluation Methods 50
3.3.1 Goals-Achievement Method 52
3.3.2 Multiattribute Utility Theory (MAUT) 57
3.3.3 Simple Additive Weighting Method (SAW) 60
3.3.4 Outranking Method 62
3.3.5 Analytic Hierarchy Process Analysis (AHP) 68
3.4 Conclusion 71

Chapter 4 : Comparison and Selection of A Method for Application 73

4.1 Introduction 73
4.2 Comparison of Appraisal Methods 74
4.2.1 CBA vs. MCDM 74
4.2.2 MCDM vs. MCDM 76
4.3 Selection of A Method for Application 85

4.3.1 Background of The Project 85
4.3.2 Selection of A Method for Application 86
4.4 Conclusion 87

Chapter 5 : Analytic Hierarchy Process 89

5.1 Introduction 89
5.2 Overview of the AHP 89
5.2.1 Background of the AHP 89
5.2.2 Principles and Axioms of the AHP theory 91
5.3 Application procedure of the AHP 95
5.3.1 Design of a Hierarchy (Decomposition) 98
5.3.2 Determining the Priorities (Prioritisation) 100
5.3.3 Composition of Priorities (Synthesis) 112
5.4 Consistency Analysis 115
5.5 Conclusion 116

Chapter 6 : Model Development for Application 118

6.1 Introduction 118
6.2 Model development 119
6.2.1 Model Development Procedure 119
6.2.2 Selection of Alternatives 124
6.2.2.1 Background 124
6.2.2.2 Alternatives for Application 126
6.2.3 Definition of Overall goal 130
6.2.4 Identification of Stakeholders 130
6.2.5 Definition of Objectives and Attributes 131

6.2.6 Design of a Hierarchy 133
6.3 Questionnaire Survey and Derivation of Weights 134
6.3.1 Expert Survey 134
6.3.2 Questionnaire Survey and Derivation of Weights 135
6.3.2.1 Collecting Data 137
6.3.2.2 Deriving Group Judgement Data 137
6.3.3 Derivation of Weights 138
6.3.4 Consistency Analysis 138
6.3.5 Project survey 139
6.3.5.1 Urban Travel Cost of Kyongju city 140
6.3.5.2 Project Cost 141
6.3.5.3 Travel Cost of Rail Passengers 141
6.3.5.4 Households Replacement 142
6.3.5.5 Noise 143
6.4 Composition of Priorities 144
6.5 Sensitivity Analysis 144
6.6 Comparison of the Results 146

Chapter 7 : Model Implementation and Analysis 147

7.1 Introduction 147
7.2 Pilot Survey 148
7.3 Conduct of the Questionnaire 153
7.3.1 Expert Survey 155
7.3.2 Questionnaire Survey 155
7.4 Derivation of Weights 156
7.4.1 Expert Survey 158
7.4.1.1 The Comparison of Stakeholder's Role 158
7.4.1.2 The Preference for Objectives 162

7.4.2 Questionnaire Survey 165

7.4.2.1 Overview of Survey Questionnaire 165

7.4.2.2 Derivation of Weights 166

7.4.3 Project Survey 180

7.5 Synthesis 181

7.5.1 Local Priorities 181

7.5.1.1 Supplier 182

7.5.1.2 User 183

7.5.1.3 Community 185

7.5.2 Global Priority 186

7.6 Conclusion 188

Chapter 8 : Sensitivity Analysis & Comparison 193

8.1 Introduction 193

8.2 Sensitivity Analysis 194

8.2.1 Sensitivity Analysis on stakeholder's role 195

8.2.1.1 Sensitivity on Supplier's Role 196

8.2.1.2 Sensitivity on User's Role 197

8.2.1.3 Sensitivity on Community's Role 199

8.2.2 Sensitivity Analysis on the Importance of Objectives 200

8.3 Comparison 203

8.3.1 Comparison of the Results of Both Techniques 203

8.3.2 Assessment of the Analytic Hierarchy Approach 206

8.4 Conclusion 211

Chapter 9 : Conclusions and Recommendations 215

9.1 Conclusions 215
9.2 Contributions 221
9.3 Recommendations for Further Research 223

REFERENCES **224**

APPENDICES **234**

1. Pilot Survey Questionnaire 235
    1. Survey Scheme 236
    2. Alternatives 237
    3. Stakeholders and Objectives 240
    4. Assessment 242
        1. Expert Survey 243
        2. Questionnaire Survey 245

2. Main Survey Questionnaire 250
    1. Survey Scheme 251
    2. Alternatives 252
    3. Assessment 258
        1. Expert Survey 259
        2. Questionnaire Survey 263

3. Sensitivity Test Results of Objectives 269
    1. Supplier 269
    2. User 270
    3. Community 271

List of Tables

Tables		Page
2.1	Modal Shares (Domestic Freight & Passenger Transport)	10
2.2	Trends in Automobile, Road Budget, Capacity and Congestion	12
2.3	Railway Investment and Rail Demand	13
2.4	Trend of KR Facilities	13
2.5	Modal Share of Investment	14
2.6	Investment in Transport Sector In Korea by Source	15
2.7	Investment Rate over Transport Sector	16
2.8	Investment in Transport Infrastructure	19
2.9	Concentration of Seoul-Pusan Corridor for Passenger & Freight	25
2.10	Details of HSR Scheme	27
2.11	Evaluation Items and its Attributes	32
3.1	An Example of NPV and B/C Ratio	37
3.2	The Balance Sheet of Development	42
3.3	General Inputs-Outputs Tables for Cost-Effectiveness Analysis	45
3.4	Conceptual Product of Analysis	54
3.5	Data for Evaluation of Fighter Selection	62
3.6	Scale of Verbal Measurement	70
5.1	Scale of Verbal Measurement for AHP	104
5.2	Pairwise Comparison Matrix for Level 2	106
5.3	Pairwise Comparison Matrix for Level 3	106
5.4	Derivation of Eigenvector	111
5.5	Local and Global Priorities	114

5.6	Random Consistency Index	116
6.1	Brief Descriptions of Each Alternative	128
6.2	The Objectives	133
6.3	Urban Travel Cost of Kyongju Area	140
6.4	Project Cost	141
6.5	Travel Cost	142
6.6	House Replacement	142
6.7	Number of House exposed to Noise	143
6.8	Summary of Relative Priorities for Tangible Objectives	143
7.1	Expert Survey Respondents	155
7.2	Questionnaire Survey Respondents	156
7.3	Comparison Matrix of Stakeholder's Role	159
7.4	The Relative Priority of Stakeholder's Role: ≥ 7 yrs	162
7.5	The Relative Priority of Stakeholder's Role: < 7 yrs	162
7.6	The Relative Priority of Stakeholder's Role: Summary	162
7.7	Statistics of Expert Survey for Preference of Objectives	163
7.8	The Objectives and The Reasons & Measurement	164
7.9	The Comparison Matrix for Objectives: Supplier	168
7.10	Comparison of Objectives by Supplier's Career	168
7.11	The Comparison Matrix for Objectives: User	169
7.12	Comparison of Objectives by Frequency	169
7.13	The Comparison Matrix for Objectives: Community	171
7.14	Comparison of Objectives by Area	171
7.15	Comparison of The Priority of Objectives between Groups	173
7.16	Kullback-Leibler Statistics	173
7.17	Comparison of The Priority of Socio-economic Factors	174
7.18	Comparison of The Priority of Environmental Factors	176
7.19	Comparison of Alternatives with respect to Factors	179
7.20	Summary of Relative Priorities for Tangible Factors	180

7.21	Composite Priority under Socio-economic Benefits: Supplier	182
7.22	Composite Priority under Environmental Factors: Supplier	183
7.23	Composite Priority of Supplier	183
7.24	Composite Priority under Socio-economic Benefits: User	184
7.25	Composite Priority under Environmental Factors: User	184
7.26	Composite Priority of User	184
7.27	Composite Priority under Socio-economic Benefits: Community	185
7.28	Composite Priority under Environmental Factors: Community	186
7.29	Composite Priority of Community	186
7.30	Global Priority of Alternative	187
8.1	Sensitivity Analysis on Supplier's Role	197
8.2	Sensitivity Analysis on User's Role	198
8.3	Sensitivity Analysis on Community's Role	199
8.4	Sensitivity Analysis of Supplier's Preference for Objectives	201
8.5	Sensitivity Analysis of User's Preference for Objectives	202
8.6	Sensitivity Analysis of Community's Preference for Objectives	202
8.7	Alternative Modification	203
8.8	The Results of KOTI Project Evaluation	204
8.9	The Results of The Application of Analytic Hierarchy Approach	204

List of Figures

Figures		Page
1.1	Overall Research Flow Scheme	8
2.1	High Speed Rail Route Plan and its Circumstances	29
2.2	Kyongju HSR Line Alternatives by Government	31
3.1	A Hierarchy for Fighter Evaluation	61
3.2	Structural Diagram of Outranking Method	66
3.3	A Pairwise Comparison Matrix	70
4.1	Hierarchy Samples for 3 and 4 Levels and its Number of Comparisons	80
5.1	Advantages of The Analytic Hierarchy Process	93
5.2	A hierarchy for House Choice Example	100
5.3	Example of Survey Questionnaire	102
5.4	Composition of Priorities of The Example	113
6.1	Model Development and Application Procedure	123
6.2	Route Alternatives and its Circumstances	129
6.3	Structuring A Hierarchy	134
7.1	Example of Group Judgement Data Calculation and Comparison Matrix Structuring	158
7.2	Stakeholder's Role by Expert Survey	160
7.3	Comparison of The Priority of Objectives between Groups	172

7.4	Comparison of The Priority of Socio-economic Factors	175
7.5	Comparison of the Priority of Environmental Factors	177
7.6	Composition of Priorities: Supplier Group	182
7.7	Composition of Priorities: User Group	183
7.8	Composition of Priorities: Community Group	185
7.9	Composition of Priorities for All	186
7.10	Global Priority of Alternatives	187
8.1	Sensitivity Analysis on Supplier's Role	197
8.2	Sensitivity Analysis on User's Role	198
8.3	Sensitivity Analysis on Community's Role	200

Chapter One

Introduction

1.1 Introduction

The evolution of the transport planning process has been characterised by complexity. The narrow focus on economic efficiency prevalent in the past has given way to a consideration of many diverse and conflicting economic, environmental and social objectives due to changing circumstances. In addition, the ever increasing range of possible solutions for each problem considered has widened and the number of participants in the planning process has increased. Therefore, in order to make the transport investment plans, it should encompass explicit considerations of various factors, tangible and intangible, economic and otherwise.

Despite fundamental changes in the decision-making environment since the mid 1980s, the evaluation process for transport investment planning has remained largely unchanged in Korea. As with most developing countries, South Korea faces a strong demand for better transport services. The country's socio-economic status has been changing rapidly over the last two decades due to rapid urbanisation, continuous growth of household income, upgrading of the industrial structure, and concerns on the environment. Accordingly people's concerns have shifted from the economic issues to other aspects such as environmental and social circumstances.

However, cost-benefit analysis and financial analysis as evaluation methods for the transport investment projects have been widely used in Korea because economic efficiency has been considered as the most important factor for evaluation. Moreover governmental officials as the decision maker still play a leading role without enough

consideration of many other various interests groups whose quality of life are affected directly or indirectly by the transport investment projects.

Therefore, many conflicts have occurred in investment planning especially with regard to large projects which potentially had a great impact on a society socially and environmentally. As a result, many transport investment projects have been faced with strong objections by reasons such as regional socio-economic disadvantages or adverse environmental impacts so that the projects had to be reconsidered or cancelled.

In the transport evaluation process focused on economic efficiency, a whole range of impacts needed to be taken into account in project evaluation have not been considered. Accordingly it has failed to respond wholly to the changing nature of transport planning such as the increasing demands of socio-economic and environmental concerns since the mid 1980s. Therefore, it is necessary to avoid this costly indecision of the iterative project evaluation (objection → reconsideration → replanning) and also to avoid incomplete evaluation in which a whole range of impacts and various interests groups could not be involved.

For this, the recent work is focused on improving public participation, and the most important aspect which appears in all the studies relates to data concerning estimated costs and benefits, and especially their distribution and accuracy. Regarding this, it is necessary that many diverse factors such as environmental and social welfare should be considered from the narrow focus on economic efficiency in the past, and various interests groups are to be involved from the first step of many transport investment.

Evaluation methods such as Multiple Criteria Decision Making (MCDM) have been proposed for evaluating these investments so as to reflect and measure diverse interests such as environmental and socio-economic concerns involved in the project. It is caused by the fact that the MCDM methods are applicable to a wide variety of problems and are especially capable of including multiple criteria and of the preference

of multiple stakeholders in an evaluation process so that decision makers are presented with useful and understandable information for appropriate decisions.

The tools of MCDM are quite useful for guiding decisions because there are three advantageous devices that make evaluations more likely to be used in decisions. Ward Edwards & Newman (1982) summarised these advantages as follows:
The first and most important is to involve the decision makers heavily in the evaluation process. The second is to make the evaluation as directly relevant to the decision as possible, preferably by making sure that the options available to the decision maker are the objects of evaluation. The third is to make the product of the evaluation useful- which primarily means making it readable and short.

There are a number of MCDM techniques available for transport investment evaluation according to the type and salient features of information and application process. Multiple Criteria Decision Making methods serve to enhance the quality of planning and decision-making by providing both a sound methodological platform for decision analysis and an operational framework for actual decision-making that incorporates the opinions of various interest groups. A wide variety of theoretical and empirical contributions can be found in the field of regional, urban and transport economics.

In this research, through the reviewing and assessing of several principal MCDM methods widely and popularly used, the AHP method which is relatively advantageous in terms of rating decision alternatives for evaluation, selection and handling both quantitative and qualitative parameters systematically within a framework is selected as the main method. The basic concepts of CBA are blended with the AHP to evaluate the whole range of impacts and select the best one amongst the complicated transport project alternatives with multiple attributes and multiple stakeholders in this analytic hierarchy approach.

The proposed project for the application with the analytic hierarchy approach in this research is to develop the railway network passing through/by the historic city of

Kyongju, with many cultural assets which has many conflicts between transport efficiency maximisation and cultural assets conservation among stakeholders affected by the project.

From the application of this method to the project in which the best one among complicated alternatives in a situation involving multiple criteria and stakeholders is to be chosen, the advantages and disadvantages of using MCDM are to be examined focusing on the analytic hierarchy approach through the comparison with the current evaluation methods as a case study.

1.2. Aims of The Research

The aims of research are, therefore, as follows;

1. To review and assess the existing Multiple Criteria Decision Making (MCDM) methods
2. To select the methodology suitable for evaluating transport projects considered in this research through the comparison of several methods, then to combine the advantages from evaluation methods for setting up a methodology for the application
3. To apply the proposed methodology for the transport investment project in Korea as a case study
4. To analyse the degree of importance of the stakeholder's role and their preference of objectives, and to find the major factors which have an impact on decisions of rail network development investment in Kyongju
5. To compare the results with the current evaluation of the project to check the advantages and disadvantages of using the analytic hierarchy approach
6. To examine the applicability of the analytic hierarchy approach to the transport investment projects for the evaluation, and suggest the use of the appropriate

transport evaluation method with the logical, comprehensive framework suitable for the needs of the efficient transport investment planning in Korea

1.3 Thesis Outline

This research consists of three parts.

In part one (Chapter 1 to 4), which includes this chapter, the various transport investment appraisal techniques widely used will be reviewed as well as a brief description of the transport sector and high speed rail development in Korea. The current transport system and evaluation techniques being used in Korea for the transport project appraisal will be reviewed in chapter two. Past and present transport investment and policy trends are also included in this chapter. In addition, the current situation of the high speed rail development project and the Kyongju line (as part of a whole line) is described.

In chapter three, the various transport investment evaluation techniques will be reviewed in detail. In this chapter, the advantages and disadvantages of those techniques will be discussed and assessed. Through the assessment in chapter three, the suitability to the case of this research will be evaluated and the most appropriate method for the project will be chosen in chapter four.

In part two (Chapter 5 to 6), the method selected from the comparison of many methods will be examined in detail and then the model for the application will be developed. In chapter five, the proposed methodology will be reviewed in detail and modified for the application to the project. In chapter six, the model for application will be developed based on the selected method.

The third part (Chapter 7 to 9) of the thesis consists of application and conclusions. In chapter seven, the results of the survey implementation will be described and analysed.

The degree of the importance of the stakeholder's role and their preference of the objectives will be derived and analysed. With the results of the analysis, the best alternative is selected in this chapter. In chapter eight, sensitivity analysis to see how it is changed by the stakeholder's role and their preference for objectives will be done, and so the major factors which have an impacts on the decision will be found. In addition, the results for the application of the proposed methodology will be compared with the current evaluation of the project by several assessment criteria.

In the final chapter, a series of conclusions will be drawn to both theoretical and empirical findings as well as the policy implications of this research, and then some recommendations for further research will follow the conclusions.

1.4 Research Framework

There are four main stages of this research.

The first stage is to identify the problems and issues of current transport evaluation methods. At this stage, current transport investment trends, transport policy and evaluation methods for the transport investment projects are reviewed to establish research issues.

At the second stage, through reviewing future transport demand and public needs in Korea and principles of existing transport evaluation techniques, the methodology suitable for solving the problems, especially complex transport projects such as the case of the Kyongju high speed rail route and station selection project with multiple criteria and many stakeholders, will be selected by the comparison and assessment of various evaluation techniques.

In the third stage, the model for the project appraisal will be developed based on the proposed method in the case of Kyongju, and the project survey to collect the related

data with the evaluation of this project is to be carried out in advance of model development. Then according to the evaluation process, the proposed methodology is applied to the project of the best railway route and station alternative selection. Finally with the results of analysis, a series of conclusions will be drawn through the analysis of the application of the proposed methodology and sensitivity analysis, and the comparison with evaluation results from the real project using cost-benefit analysis with some subjective judgement. In addition, the adaptability and suitability of multiple criteria evaluation methods, especially the analytic hierarchy approach, will also be examined.

The research is carried out as shown in the following Figure 1.1.

Figure 1.1 Overall Research Flow Scheme

Chapter Two

The Transport Sector in Korea

2.1 Introduction

This chapter reviews the current situation of the transport sector in Korea. This includes three parts, the first one is trends in transport sector which include modal share, investment trend and source, and planned transport investment. In addition the transport policy for implementing this transport investment is reviewed. In the second part, transport appraisal methods for evaluating transport projects in Korea are described with several examples. Finally the scheme of high speed rail development project is briefly described, and the Kyongju line as part of the whole high speed rail line is also discussed in detail as a case study to be considered.

2.2 The Transport Sector in Korea

2.2.1 Transport Trends and Modal Shares

Since the early 1960s, Korea has experienced remarkable economic growth, which has led to a huge increase in the number of automobiles owned and a rapid increase in the demand for transport. In order to cope with the ever increasing transport demand, to pursue industrialisation and economic development more efficiently, the Government has invested in expanding economic infrastructure.

In the early stage of infrastructure investment, public investments were focused on industrialisation such as large scale industrial complexes, expanding transport

communication networks, and ensuring water and energy supplies, and since the late 1970s, the transport infrastructure has been expanded continuously even though this expansion has not been able to keep up with the increase in transport demand.

During the period from 1971-1996, the total number of passenger trips rose about four and half times. The largest mode share is for the road although its share fell from 95.7% in 1971 to 83.2% by 1996. Inter-city rail also experienced substantial growth in passengers carried, but its modal share is still very low (6%). Aviation also grew substantially although it still has less than 1% of the total passengers.

Table 2.1 Modal Shares (Domestic Freight & Passenger Transport)

unit: Million (percent)

	Year	Inter city Rail	Subway	Road (commercial buses)	Coastal Maritime	Aviation
Passenger	1971	128.2 (4.1)	- (0.00)	3024 (95.7)	6.4 (0.2)	1.1 (0.03)
	1981	444.1 (4.8)	88.3 (0.96)	8683 (94.1)	9.3 (0.1)	1.6 (0.02)
	1991	579.3 (3.9)	1249.1 (8.5)	12854.2 (87.4)	8.5 (0.06)	12.2 (0.08)
	1996	819.5 (6.0)	1470.7 (10.6)	11480.4 (83.2)	9.4 (0.1)	23.6 (0.1)

unit: Million ton (percent)

	Year	Rail	Road (commercial)	Coastal Maritime	Aviation
Freight	1971	32 (27.3)	73.9 (63.1)	11.3 (9.6)	0 (0.0)
	1981	48.8 (27.8)	104.3 (59.5)	22.2 (12.7)	0.0176 (0.0)
	1991	61.2 (15.6)	245.1 (62.5)	85.9 (21.9)	0.2 (0.0)
	1996	53.5 (8.7)	426.4 (69.4)	132.0 (21.8)	0.351 (0.1)

Source: MOT, statistical yearbook of transportation, 1987-97

Freight traffic has grown substantially following major industrialisation. Total tonnage increased over five times from 1971-1996 except non-commercial freight traffic. Of the total, road transport accounts for the largest share in terms of tonnage. As the share of tonnage carried by private fleets on road has grown rapidly and the total demand is similar to commercial traffic demand by road, actual increase in freight traffic and road share may be greater than the actual figures in the table, while the share by the other modes may be less than shown. The rail share of tonnage fell

dramatically although total tonnage almost doubled. Air and maritime cargo grew continuously.

In order to cope with huge increases of both domestic and international transport demands in all modes, the transport infrastructure has been expanded along with the demand for services based on the six national economic development plans. Nonetheless, the rapid growth of demand is straining the capacity of the existing infrastructure in freight, inter-city passenger and urban transport.

In terms of freight transport, the cargo terminal capacities of the major airports may become constrained: two of the three largest Korean airports (Kimpo, Kimhae), which handle two-thirds or more of all domestic and international air traffic, were approaching or already exceeding full utilisation of their air cargo capacity. In the case of port freight, overall congestion still persists although port infrastructure and the vessel fleet have been rapidly expanded to meet growing demands. Container traffic is of special interest. Pusan port handles 95% of all container traffic, with around 4000 vessels annually, but the numbers have declined slightly since 1990. At the peak in 1991, 1096 container vessels, or more than every fourth ship had to wait an average of 28.5 hours even though its figure declined in 1992.

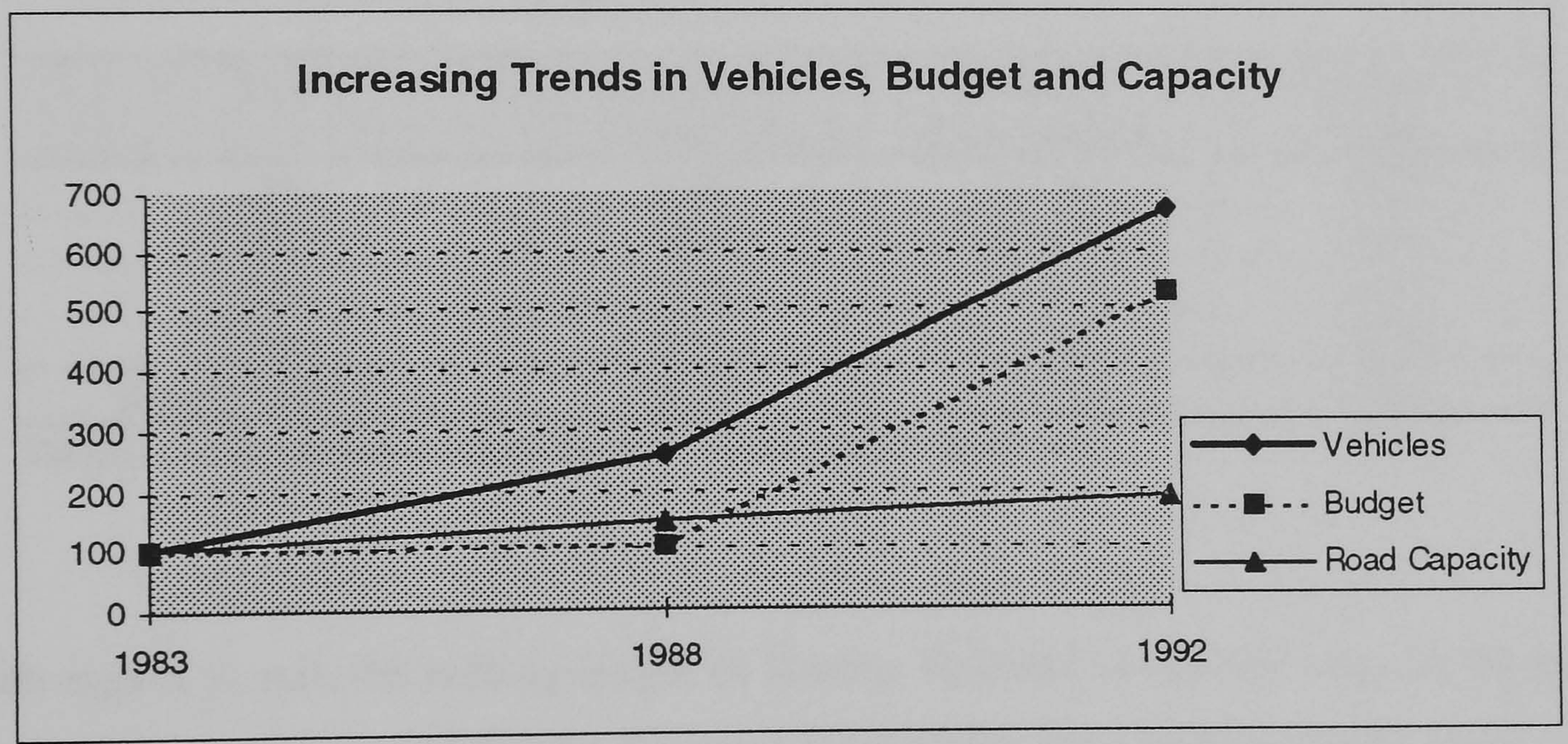
Regarding passenger transport capacity, investments have grown along with the growth in demand, but transport demand has outstripped the available capacity, causing congestion in road and rail infrastructure. The road building budget of the central Government increased at an annual average rate of 20.3% from 1983-92, but due to the increasing cost of road construction and land acquisition and the predominance of road widening work, the length of motorway and national trunk roads only increased by 7.4% during the same period as Table 2.2 shown below.

Despite the relatively large investments, capacity of the tolled motorway, national and provincial road networks has not increased enough to meet the capacity required by rapid motorisation over the last decade.

Accordingly the congested sections of trunk roads increased from 814 km in 1988 to 3880 km in 1992. Data on motorways indicates that travel times nearly doubled on the Seoul-Pusan corridor. Since the Seoul-Pusan motorway serves almost half the total motorway system traffic, congestion is mainly concentrated along this corridor.

Table 2.2 Trends in Automobile, Road Budget, Capacity and Congestion

Item	1983	1988	1992	Annual Average Increase 1983-1992
Vehicles (000's)	784	2035	5231	23.5%
Central Govt. Budget (100m won)	4978	5394	26195	20.3%
Road Capacity (Motorways, National & Provincial roads in km)	13416	19713	25411	7.4%



Item		1988	1989	1990	1991	1992	Annual Average Increase 1988-1992
Congested Road Length in km	Motorways	151	279	417	576	652	44.2%
	Nat'l Trunk Road	663	945	1559	2287	3238	48.7%
	Provincial Roads	106	194	263	380	508	48.0%
	Total	920	1418	2239	3243	4398	47.9%

Source: Transportation Section Financial Plan Report, 1993, KOTI

Similarly, rail investments grew by an annual average of 26% over the decade, but total rail mileage changed little (0.7%) as a large share of the investment was directed to equipment and related facilities. During 1976 to 1992, passenger and freight ton-km increased at an annual average rate of 4.5% and 2.3% respectively. Accordingly most of the rail trunk lines have reached saturation. On the Seoul-Pusan line, 136 trains operate daily in each direction, and the line's maximum capacity is 136 trains per day.

Table 2.3 Railway Investment and Rail Demand

Item	1983	1988	1992	Annual Average Increase
Railway Length (km)	6128	6456	6496	0.7%
Railway Investment Budget (100m won)	1283	2175	10637	26.5%
Demand for 1st Class Train (Thousand Passengers)	1883	5317	10253	20.7%

Source: Transportation Section Financial Plan Report, 1993, KOTI
Statistical Yearbook of Transportation, 1993, MOT

Year	Commercial Route: km	Passenger Passenger-km	Freight Ton-km
1976	3144.3	14305	9728
1983	3120.7	21688	11629
1988	3148.8	25978	13784
1992	3092.4	32218	14256
Annual Growth, %	-0.10%	5.21%	2.42%

Source: Statistical Yearbook of Railroad, 1993, Korean Railroad

With regard to rail, the railway length of Korean Railroad is still the same as 20 years ago and those investments in the Korean railroad have been comparatively inactive as Table 2.4 shows below. This situation is caused by the fact that roads have gained an advantage over railways in the transport investments in Korea in response to increasing numbers of private vehicles.

Table 2.4 Trend of KR Facilities

Year	'71	'93	1993/ 1971
Railway Length (km)	5582	6517	117
Motorway Length (km)	641	1602	250

Source: High Speed Rail and National Development, KOTI, 1995

The railway has to play an important role in connecting the large cities, ports and industrial complexes as a massive, high speed, time reliable public transport mode because severe road congestion these days results in inefficiency, environmental pollution, energy waste and reduced competitiveness in industry. Therefore, there is an increasing demand for rail, but the construction of the rail network has not been satisfactory as shown in the Tables above.

2.2.2 Transport Investment and Source

The sector investment data in Table 2.5 shows that, as a share of GDP, transport investments were actually higher than in the past. However, two other factors may contribute to falling investment. One is the lack of improvement in travel conditions because growth in demand has offset the expansions and the other one is that land prices absorb a larger amount of expenditure on roads. So investment expenditure has increased less than in previous years.

Table 2.5 Modal Share of Investment (percent)

	'78-'82	'83-'87	'88-'92	1992
roads	59.2	52.6	64.8	57.6
motorway(trunk roads)		32.5	35.9	33.8
local road		20.1	28.9	23.8
rail	25.2	10.3	11.2	13.7
port	14.3	12.2	9.1	8.0
airport	1.2	3.5	2.5	3.2
subway		21.5	12.6	17.5
total percentage (/GDP)	2.1	1.9	2.6	3.3

Source: World Bank (1995)

In the 1980s, the Government strategy on the transport sector was focused on expanding capacity, and most of the investments were directed to roads accounting for over half of transport investment since 1978. Moreover, its share in 1988-92 rose relative to the preceding five years. This increase occurred primarily at the expense of subways, reflecting the slowdown in subway construction immediately following the

completion of the new subway lines in Seoul and Pusan. However, since 1992, capital expenditure on subways has risen again because of the expansion of the Pusan system and commencement of the Taegu system. The share of investment in ports has also declined. The share of rail investment has slightly increased since 1988, and this trend was particularly marked during the past few years.

Regarding the investment source, nearly all investment in transport infrastructure was undertaken by the central and local Governments or by public corporations, but since the late 1980s, investment was shifted from the central Government toward local Governments, public corporations and the private sector. However, most investments, especially in transport fields, are still implemented by the Government. The expansion in local Governments share reflects both the expansion of capital expenditure on local roads as well as a significant share of subway investments. The Government share in road investments remained relatively stable between 1980 and 1990. However, its share of rail investments appears to have fallen sharply over the decade.

Table 2.6 Investment in Transport Sector in Korea by Source
(percent of total investment: current prices))

	1980	1985	1991
Central	73.1	61.0	33.4
Road (Motorway & Trunk roads)	20.8	30.8	21.5
Rail	27.1	10.5	4.8
Port & Airport	20.0	12.9	4.7
Subway	5.2	10.7	2.4
Local	22.7	31.5	46.7
Road	22.7	25.2	35.0
Subway		6.3	11.7
Other (including public corp.)	4.2	7.5	19.9
Total (billion won)	580.7	1604.8	5747.6

Source: World Bank, 1995

2.2.3 Transport Policy for Investment

In order to pursue industrialisation and economic development continuously, and to allocate the resource efficiently, the Government came to realise the necessity of a

comprehensive plan for national land development, and so the first national comprehensive land development plan as a long-term project has been established since 1972. On the other hand, a 5 year economic and social development plan as a mid-term plan has also been established since 1962.

The comprehensive national land development plan is formulated every 10 years and devised based upon requests regarding national-scale projects submitted by central administrative agencies. The transport programme is a sub plan concerning the arrangement and plan of main public transport facilities which form the basis of industrial development and covers transport facilities such as highways, railways, ports and airports. However, the plan is not a concrete action plan but a plan of the spatial location and arrangement of the transport facilities, J. Rhee (1995).

Its counterpart, the five year economic and social development plan contains more concrete and detailed measures than the long-term plan, and it consists of appraisal of past results, circumstantial prospects, demand supply projects, objects, basic strategies and courses, executing measures and prospects.

Therefore, the past transport policies can be reviewed by "The Five-Year Economic and Social Development Plan" from 1962-1996 and the investment rate over the period of Table 2.7 reflects its policies. The summary and the statistics of the five year plans are useful for understanding the changed transport policy and its investments.

Table 2.7 Investment Rate over Transport Sector

Planning period		First '62-66	Second '67-'71	Third '72-76	Fourth '77-'81	Fifth '82-'86	Sixth '87-91	Seventh* '92-'96
Investment Rate	Railway	48.4	18.5	15.3	15.8	16.9	20.9	18.0
	Road	30.6	54.0	46.9	54.8	47.2	57.8	55.0
	Seaport/ Airport	21.0	27.5	35.2	16.4	15.1	20.2	10.4
	Subway	-	-	2.6	13.2	20.8	1.1	16.6

Source: KOTI, HSR and National Development, 1995, *: estimated

1. *First Five-Year Economic Plan (1962-1966):*
   - first step years to economic development
   - so transport investment was limited to basic transport facilities for industry
   - so rail's portion of transport investment for industry was large
2. *Second plan (1967-1971):*
   - the period of rapid vehicle increase
   - so demand for roads was dominant and investment was focused on roads
3. *Third plan (1972-1976):*
   - road investment also continued to be dominant
   - subway construction started
4. *Fourth plan (1977-1981):*
   - balanced investment among modes was considered
   - so rail share increased slightly and subway investment increased according to the main period of construction
   - but road investment was still dominant
5. *Fifth plan (1982-1986):*
   - urban transport facilities improvement against traffic congestion by rapid vehicle increase in urban area
   - international transport and tourism facilities improvement
   - necessity of continuous consideration over comprehensive investment plan and policy for the changing circumstances made rail and subway's share increase continuously
6. *Sixth plan (1987-1991):*
   - multi-objective transport policy is considered
   - improvement of urban transport problem and accessibility of the whole area by transport
   - enlargement of inter-regional transport, and improvement of transport safety
7. *Seventh Plan (1992-1996):*
   - balanced transport modal split and intermodal network development

- international transport network development such as new hub airport construction
- continuous enlargement of inter-regional transport, especially Seoul-Pusan HSR line construction

Despite remarkable development from the first (1972-1981) and second (1982-1991) comprehensive national land development plans, the results of these plans were not satisfactory. Most cities had been suffering from traffic congestion, environmental pollution, and a huge increase of land and housing prices. In addition, although urban and industrial infrastructure has been expanded continuously, this expansion has not been able to keep up with the increases in demand, and also rapid industrialisation has deteriorated the natural environment.

Therefore, the third (1992-2001) national land development plan was intended to cope with these problems, and this long-term plan indicates the prospects for the future transport plans and policies. The basic goals of the third plan are, firstly, to form a decentralised spatial structure, secondly to establish a productive and resource conserving land use system, thirdly to improve social welfare and environmental quality. Balanced regional development and a safe environment are the ultimate goals.

To achieve these goals, physical investment targets had been set for all transport modes. For example, all highways are to be paved and the length of the national and provincial road network is to be expanded by 10%. On the railways, the proportion of electrified trains and double track rails is to be doubled, and a high speed rail will operate between Seoul and Pusan. New commuter rails links are to be built and subway lines are to be added in many cities. A new international airport is being constructed, and container handling facilities are to be added at major ports. These concrete goals are also shown in 7th five year plan.

The total investment in transport infrastructure 1995-1997 is shown in the table below: it involves substantial increases in total investments to 6% by 1997. The scale of the

increases can be seen by comparing these levels with the average ratio of transport investments to GDP during 1988-92, which was about 2.6%. This also shows the substantial increases in the investments on each of the individual modes as well as in the total investment.

Table 2.8 Investment in Transport Infrastructure
(percent : current prices)

Mode	1988-92	1995	1996	1997	1993 - 97
Roads	64.8	54.4	54.2	58.1	55.6
Motorway/Trunk Roads	35.9	25.4	27.3	32.3	27.5
Local Roads	28.9	29.0	26.9	25.8	28.1
Rail	11.2	20.7	21.4	18.8	18.6
Port	9.1	5.4	4.9	4.1	4.9
Airport	2.5	5.4	4.8	3.6	4.7
Subway	12.6	14.0	14.9	15.5	16.2
Total Investment (%/GDP)	2.6	5.3	5.7	5.9	5.2

Source: World Bank (1995)

However, as in the past, road investments account for the largest share and have grown sharply even though there is a shift away from local roads toward motorway and national roads. Nonetheless, there is an increase in the railway's share of investment, continuing the trend that began in the mid-1980s towards balanced investment under comprehensive transport planning. In addition, about 40% of total infrastructure spending will be directed to a limited number of mega-projects, including the new Seoul international airport, urban subways, the Seoul-Pusan High Speed Rail projects and motorway for future comprehensive national development with balanced and improved transport facilities.

2.3 Transport Investment Evaluation Techniques in Korea

In order to assess the transport investments, give them priority and allocate the limited budget more efficiently, it is necessary for the evaluation method which enables to

decide the investment priority and implement. Therefore, some Ministries have their own investment assessment manual. Among these the Economic Planning Bureau issued a handbook on public investment evaluation (transport section) in 1982, and this has been widely used since on the evaluation of public transport investment projects. It provides the appraisal methods for specific investment projects. In the case of local Government of Seoul, there is another instruction manual for self assessment with the central Government's manual, which was prepared by the local Government itself in 1992.

- Central Government (MOFE)

Central Government, Ministry of Finance and Economy (renamed from EPB), has an instruction manual for transport evaluation. It is called "The manual for transport investment assessment" and it was prepared by EPB in 1982. In the manual, the identification and definition of evaluation items and their measurement, evaluation process for road and rail for economic evaluation, and financial analysis are described in detail as methodologies for evaluation.

- Local Government (Seoul)

According to this manual, weighted scoring is used as the measure of evaluation methodology including qualitative criteria such as technical and social impacts. For the evaluation, each weight for 4 large categories (transport, economic, social and political factors: 30%, 25%, 20%, 25% respectively in the case of road project evaluation) and sub-categories (among several elements in transport category, congestion relief 40%, capacity increase 30%, traffic distribution 30%) were already fixed by the Government. The score is given according to the type of project to be evaluated. Therefore, transport project alternatives are prioritised according to the multiplication of weights to score.

As in the manual for the evaluation of the projects in central and local Governments, the cost-benefit analysis, financial analysis and subjectively weighted scoring method have played an important role in decision making methods for transport investment

evaluation and priority setting focused so far on the following reasons without any radical change:

- easy to explain and understand for decision maker
- easy to collect data
- deals with monetary factors
- easy to follow the evaluation procedure
- familiar with this technique for the major groups of analysts

Some of these projects, however, cannot be justified by only executing economic feasibility analysis because of changed nature and circumstances, and the fixed weights for each attribute in the case of local Government is sometimes not valid as the investment circumstances and people's preferences are changing. The evaluation process has remained largely unchanged even though many investments (new construction and improvement) have been made and planned in Korea, so many controversies have occurred around the investment between the supplier and the public. The typical institutional framework for evaluation of investment in Korea was not efficient due to the following reasons.

- not enough inclusion of the socio-economical and political changes in investment circumstances
- a lack of a conceptual or theoretical evaluation framework which is able to organise multiple factors and multiple interest groups
- criteria other than main quantifiable factors such as travel time and investment cost are still considered to be of less importance both to transport analysts and decision makers
- difficulty in obtaining suitable data on more than a restricted set of criteria
- many controversies resulted from transport investment and priority setting

As you can see in the examples in section 2.3.2, under the current method, benefit items are limited to direct benefits such as decreases in vehicle operating costs and in travelling time, and indirect benefits such as social and economic development are

often ignored during consideration. The intangible factors such as those above have simply been regarded as just qualitative secondary factors for decision making to be considered, but not within a framework.

Therefore, it has been proposed that a new paradigm for evaluating these investments to reflect diverse interests such as direct cost, environmental concerns and public dissatisfaction in achieving the goals set up in the long-term national land plan is required.

The main methodology and its criteria for the current evaluation method used for most of evaluations are as follows. Summarising the transport project evaluation, it is said that the evaluation is still focused on economic efficiency, and the other factors such as socio-economic and environmental factors are considered relatively less important. Subjective consideration of qualitative factors is incorporated into an overall evaluation of schemes combined with quantitative evaluation but not in any systematic manner.

2.3.1 Evaluation Criteria

- discount rate: social discount rate commonly used for public investment, and sensitivity analysis within some range
- priority decision method: NPV, IRR
- optimum investment timing: NPV, FYRR

2.3.2 Examples of The Transport Project Evaluation

2.3.2.1 Example 1: Seoul-Pusan High Speed Rail Feasibility Study

- Evaluation of the preliminary route alternatives

- items: cost - construction cost, maintenance cost, operating cost
  energy cost
  benefits - time savings, operating cost savings

- Evaluation of the preliminary station location alternatives

- criteria: 1) easiness of obtaining land, 2) connection to the regional transport network, 3) accessibility inside the city, 4) joint development, 5) alignment criteria 6) contribution to the development of the city
- method: subjectively weighted score

- Evaluation of the final alternatives

- items: cost - civil construction cost, rolling stock purchase, operating cost
  benefit - operating cost savings, time savings, residual value
- criteria: discount rate - 13, 18%
- methods: cost-benefit analysis, B/C, NPV and IRR
- sensitivity analysis: for travel demand, construction and operating cost and rolling stock cost

- Financing analysis

- financial return analysis: FIRR
- financial source and balance analysis

- Evaluation of socio-economic effects

- items: traffic accident reduction, air pollution reduction, fuel savings, local industrial development, national balance, regional development, social structure change, efficient use of the whole land
- method: subjective judgement

- Evaluation of environmental impacts

- items: water quality, air quality, noise and vibration, cultural assets, ecology, visual impacts, waste materials
- methods: qualitative judgement based on a general field survey, data analysis and literature review.

- summary

1. evaluation methodology		- cost-benefit analysis, - financial analysis - subjective judgements
2. evaluation criteria		- discount rate: 13%, 18% - quantitative criteria : economic efficiency - qualitative criteria: socio-economic impacts, environmental impacts
3. main evaluation items	cost	- construction, operating cost - rolling stock cost
	benefit	- operating cost savings - travel time savings

2.3.2.2 Example 2: Urban Rail Construction Feasibility Study

1. project		- Urban Rail Construction - evaluation for route selection
2. methodology		cost-benefit analysis
3. evaluation criteria		- quantitative criteria : economic efficiency, noise, air pollution - qualitative criteria: cultural assets, visual impacts
4. criteria classification for comprehensive evaluation		1) transport efficiency: voc, time savings 2) investment cost: construction, operating cost 3) environmental impact: noise, pollution, etc. 4) economic efficiency: NPV, IRR, B/C
3. evaluation items	cost	- construction cost - operating cost
	benefit	- vehicle operating cost savings - time savings
4. comprehensive evaluation		subjective judgement

2.3.2.3 Example 3: New Highway Construction Evaluation

1. project		- 2 lane highway construction over 4 years - evaluation for economic efficiency about fixed route
2. methodology		cost-benefit analysis
3. evaluation items	cost	- construction cost - operating cost
	benefit	- vehicle operating cost savings - time savings
4. evaluation criteria		- NPV, IRR, FYRR

2.4 High Speed Rail (HSR) Network Development in Korea

2.4.1 Background

In the 1960's to 70's, rail played a very important role in carrying passengers as well as freight transport, but since then, as car ownership has increased rapidly and so demand for roads became dominant. Most of the transport investments were focused on the roads because rail is less suitable to time-sensitive movements and because of the rapid increase of car ownership. This trend continued to the middle of 1980's.

However, despite the huge investment in roads, the road construction could not cope with the rapid vehicle increase and so road congestion resulted in huge loss of passenger's time and the deterioration of industrial competitiveness. From the beginning of the 80's, balanced transport investment among modes was intended in order to encourage better and more efficient transport modes, and this was heavily concentrated in the Seoul-Pusan corridor because the corridor is the major arterial road in Korea as the major transport axis (65.3% for passenger travel, 67.2% freight) and the most developed area (71% of the national population, 75% of the gross national products, 1992).

Table 2.9 Concentration of Seoul-Pusan Corridor for Passenger & Freight

Area	Passenger (thousand pas/day)	Freight (thousand ton/day)
Nation	4007	789
Seoul-Pusan corridor	2617	530
Share of total traffic (%)	65.3	67.2

Source : KOTI, 1992

Past investments in transport infrastructure have been inadequate to meet the ever increasing transport demand. They also showed a bias toward highways resulting in the relative down grading of the rail system in Korea. Future increases in the level of transport demand will still be substantial. Investment in highways alone can not meet the anticipated future demand with reasonable levels of service because even today

motorways are losing their efficiency in terms of carrying capacity owing to the high proportion of private cars, and so total transport efficiency is gradually decreasing.

Preference to high level railway services, such as Saemaul-ho (Class 1 train) is particularly noticeable and the demand for air transport is rapidly increasing nowadays. Such a trend is expected for the time being as the national income is continuously increasing, so it is necessary to improve the level of service quality, more especially, the speed, safety and comfort of the railway. The improvement of service quality of the railway could contribute to attracting passengers of other transport modes on to the railway. A high quality rail service is necessary to meet the anticipated large future demand, to efficiently utilise limited national land, to develop a harmonised national transport network and to meet the people's desire for better transport service.

Thus construction of a high speed rail has been proposed for a long time to meet the increasing travel demand as well as providing high quality of transport service. High speed rail (HSR) is expected to enhance the mobility of people in response to the change in living patterns and the growth of national income, and to improve the quality of transport services, KOTI (1997). Korea is, therefore, proceeding with the high speed railway projects for the major transport corridors such as the Seoul-Pusan corridor, the Honam corridor and the East-West corridor. Among these, the Seoul-Pusan HSR is under construction, while the others are under discussion.

With regard to the transport development of the Seoul-Pusan corridor, several alternatives were considered such as line realignment, longer trains, electrification of existing rail and new high speed rail construction. However, line alignment, longer trains and electrification alternatives as temporary measures to increase the capacity of the line have some constraints in implementation and the effectiveness of implementation appears insufficient to cope with the increasing demand of the axis. Therefore, in the long term perspective, new line addition would be the desirable solution to meet the increasing travel demand and better quality of transport service.

For the development of the HSR line of the Seoul-Pusan corridor, the feasibility of HSR construction was established by the feasibility study which was carried out in 1984 by the Ministry of Transport, and the route and stations (Seoul, Cheonan, Taejon, Daegu, Kyongju and Pusan) was decided in 1990. However, solely regarding the Kyongju alternative, much criticism and public reluctance in the area in terms of the conservation of cultural assets and historical sites forced the decision to be reconsidered in 1996. According to the reconsideration, new sets of alternatives of routes and stations of the Kyongju area were selected in the feasibility study by the Korea Transport Institute (KOTI), then the final alternative was decided last year.

2.4.2 HSR (High Speed Rail)

2.4.2.1 HSR Scheme

The distance of the existing Seoul-Pusan line is 445 km. A new HSR line is planned so that HSR could run on the new trunk line and existing branch line together. Its length is 426.2 km with 6 stations including Seoul and Pusan, it will carry only passengers. The existing line will carry passengers and freight as usual. The construction started at 1992 and it should be finished in 2001.

The specification of HSR is summarised as shown in Table 2.10 (also refer to Figure 2.1)

Table 2.10 Details of HSR Scheme

Travel type	Stops	Track length (km)	Travel time (min)	Operating speed (km/h)	Max. operating speed	Max. Design speed	Min. curvature (m).	Max. gradient (o/oo)
every stop	Seoul-Cheonan	96.1	34.0	197	300	350	7000	15
	Cheonan-Taejon	62.9	19.0					
	Taejon-Daegu	122.4	33.0					
	Daegu-Kyongju	63.6	18.0					
	Kyongju-Pusan	81.2	26.0					
	Total	426.2	130.0					

source: KOTI, 1996

2.4.2.2 HSR Process

■ ***Project Chronology of Events***

- Mar 1983-Nov. 1984: Long-term transport investment requirements in the Seoul-Pusan corridor and feasibility of a HSR reviewed
- July 1989-Feb. 1992: Technical studies and basic design of the Seoul-Pusan HSR carried out
- Jun. 1990: The route of the Seoul-Pusan HSR was confirmed and announced
- Jun. 1996: The route of a part (Kyongju) of HSR was reconsidered and feasibility reviewed
- March 1997: The route of a part (Kyongju) of HSR was announced

■ ***Schedule of Project Implementation***

- Jun. 1992-Dec. 1997: Construction of Chonan-Taejon test track section
- Jun. 1997: Delivery of two of the 46 train sets to be delivered
- Jan. 1998-Dec. 2001: Implementation of the first and second run
- Jan. 2000: Initial commercial operation (Seoul-Taejon)
- Jan. 2002: Full-scale commercial operation
- The schedule from 1997 has been postponed due to national debates of huge investment costs, concerns over its necessity and financial deficiency.

2.4.3 Kyongju Line

2.4.3.1 Background

Before the selection of final alternatives, quite a few routes (12) and stops (480) alternatives were considered. Through the preliminary evaluation, 7 alternatives for detailed analysis were selected, and a full scale economic analysis was carried out by

KOTI, and then the basic alignment, Seoul-Chonan-Taejon-Taegu-Kyongju-Pusan, was selected and announced as the best alternative in terms of the harmonised national transport network by the Ministry of Transport in 1990 as shown in Figure 2.1.

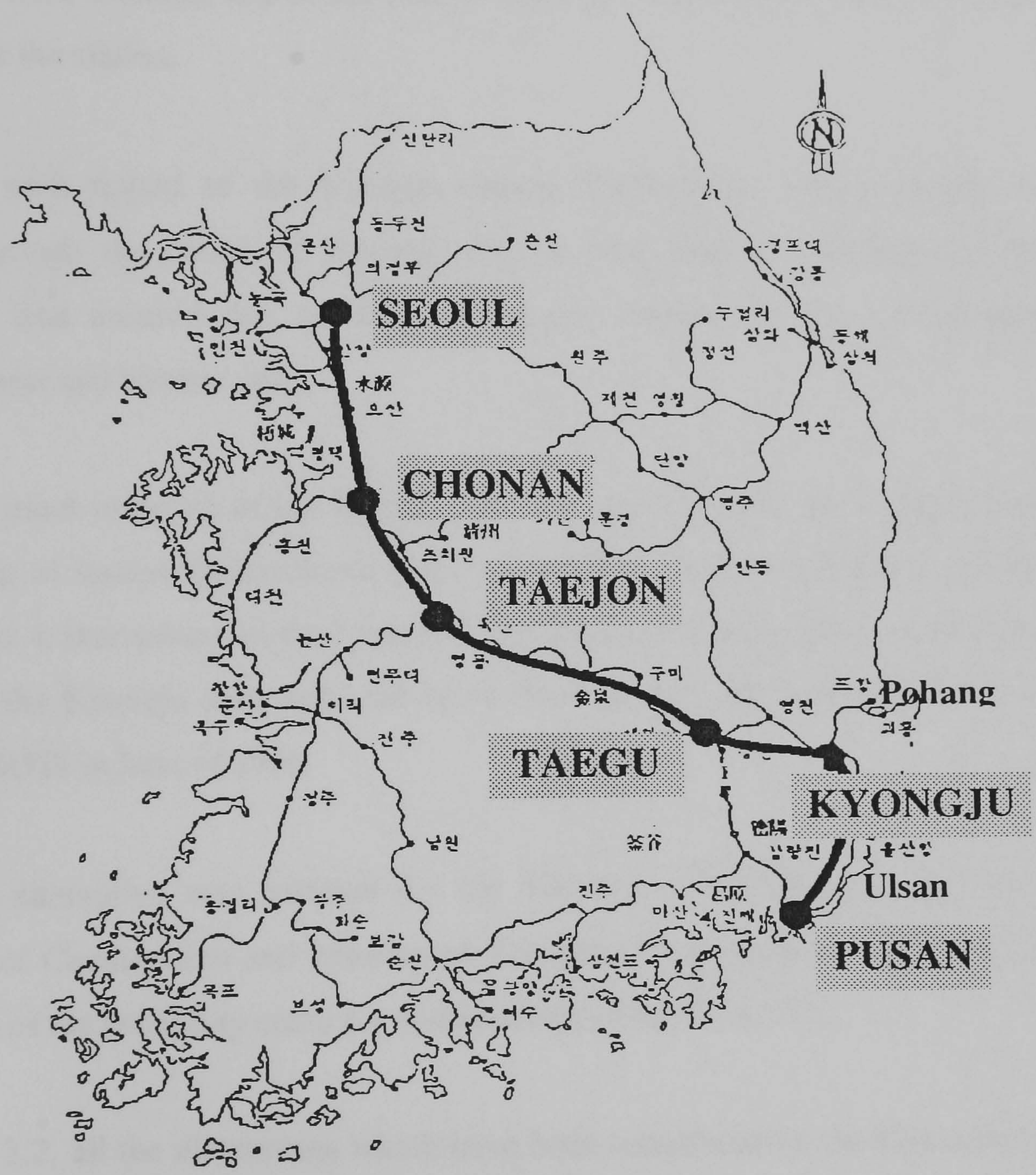


Figure 2.1 High Speed Rail Route Plan and its Circumstances

According to the selection of the basic alignment, the research on the location of stations followed, and the alternatives for the evaluation were six for Seoul, three for Chonan, four for Taejon, five for Taegu, and three for Kyongju.

By the preliminary evaluation with weighted score and detailed evaluation with cost effectiveness analysis, evaluation was carried out and final alternatives of the location of stations were selected, and in the case of Kyongju, Bukneokdul was chosen as the location for the station.

However, with regard to the Kyongju station, Bukneokdul, which has the route passing through the centre of Kyongju city, a great deal of criticism and public reluctance was aroused due to expected adverse impacts on the conservation of cultural assets and historic sites.

Following much criticism of the Kyongju line, the alternative to the Kyongju line and the location of station finally chosen were cancelled leaving many debates, and instead new sets of 4 alternatives to the route (68 km) with individually different locations of station in the Kyongju area were set up to find the best alternative via a feasibility study by KOTI in June of 1996.

The final alternative was selected by the Ministry of Construction & Transport (Ministry of Construction and Ministry of Transport were merged in 1992) based on the results of the feasibility study for 4 alternatives of KOTI in 1997.

In Figure 2.2, all the alternatives which have been considered by the Government are shown. Bukneokdul is the alternative considered at first and alt 1 to alt 4 are the new sets of alternatives considered in the feasibility study done by KOTI in 1996.

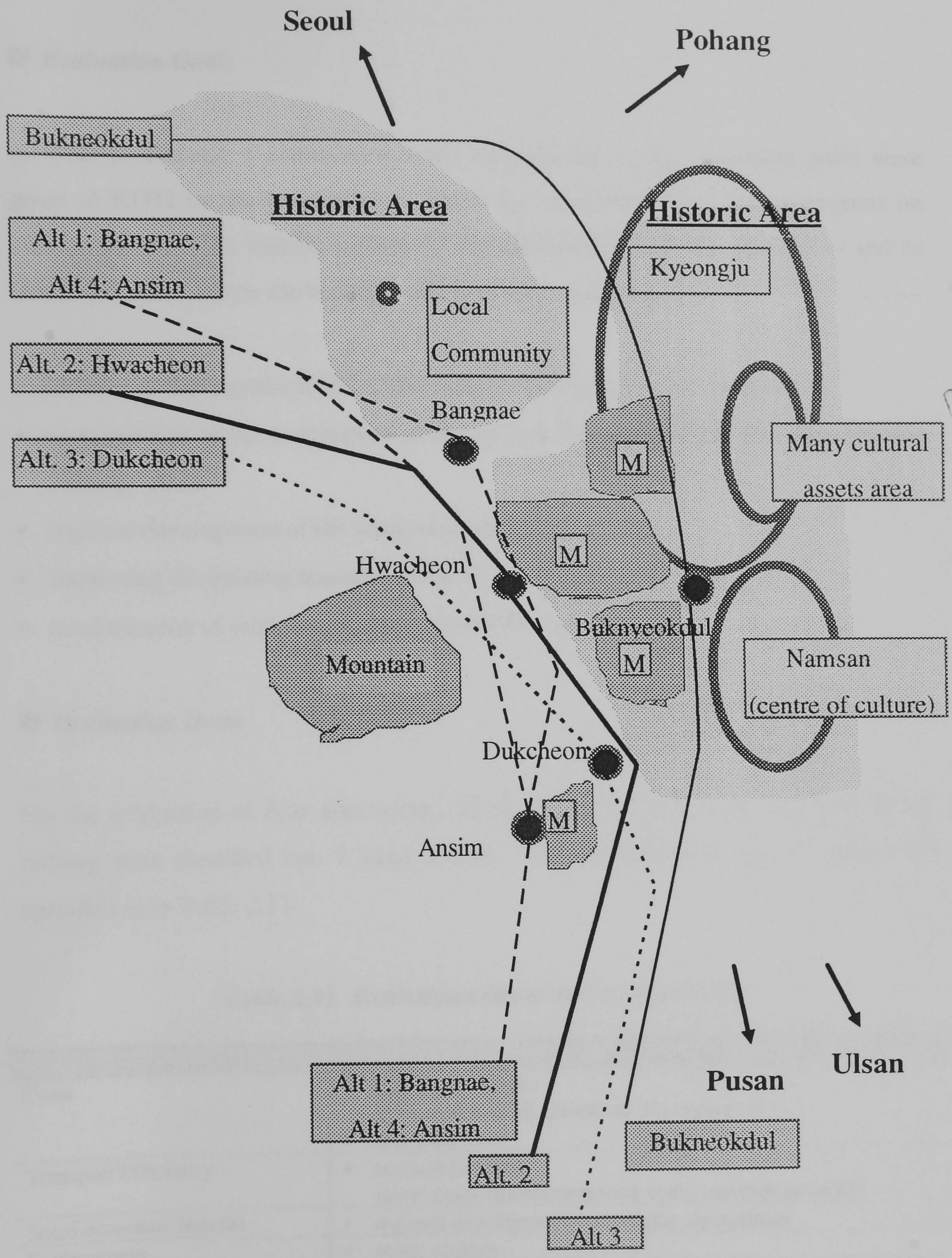


Figure 2.2 Kyongju HSR Line Alternatives by the Government

2.4.3.2 Evaluation of Kyongju Line Alternatives by KOTI

■ ***Evaluation Goals***

In order to evaluate 4 alternatives to the Kyongju line, some evaluation goals were given to KOTI by the Government. Those are to minimise the adverse impacts on cultural assets, to be feasible technically and economically for the alternatives and to locate the station inside the Kyongju administrative boundary.

In addition to these goals, KOTI added more evaluation goals as follows:

- maximisation of the accessibility of the proposed area including adjacent cities like Pohang, Ulsan
- regional development of the south-east area
- Improving the existing transport network
- maximisation of joint development around the station

■ ***Evaluation Items***

For the evaluation of four alternatives, all the factors related to the selection of the railway were classified into 5 large criteria. Detailed attributes of each items were specified as in Table 2.11.

Table 2.11 Evaluation Items and its Attributes

Items classification	Attributes
Costs	• construction costs: HSR, access road, relocation of existing rail • operating costs
Transport Efficiency	• accessibility costs: travel costs, urban congestion costs, transport networks
Socio-economic benefits	• regional development, households replacement
Environment	• noise, ecology
Cultural conservation	• min. visual intrusion • min. adverse impacts on cultural assets and historic sites

■ *Evaluation Method*

Using the rate (13%) which is normally used in public investment as a social discount rate, the benefits and costs were calculated for each alternative and discounted to 1995 from the opening year 2005 to 2025 for quantifiable items. For the quantifiable items with different units, not monetary unit, such as the number of households to be replaced or the number of cultural sites to be affected, they were normalised and compared with each other. For the selection of the best alternative, the subjective judgement of KOTI researchers for all items was used for synthesis instead of weighting the items, and the best alternative was recommended according to the evaluation results.

2.5 Conclusion

After reviewing the transport trends and evaluation methodology used in Korea, it can be said that it needs improvement in resource allocation and evaluation methodology despite of huge increase of transport sector investment. These are caused by several reasons as follows and these also indicate a direction for improvement.

- a lack of balance for investment between transport modes
- a lack of a conceptual or theoretical evaluation framework which enables to include and evaluate all factors to be considered within
- rigid application of evaluation method despite changed nature of public needs
- increase in controversy surrounding transport investment due to political influence or the pressures of public opinion due to the evaluation process by a single decision maker and their subjective judgements which other decision makers are not involved in.

Many findings, which indicates the need for improvement, of current transport trends, evaluation processes and methodologies are deemed necessary for:

- more balanced investment between modes under a comprehensive transport investment policy toward balanced transport development and sustainable development
- a comprehensive transport plan and investment priority among modes and projects
- the development of well-established, useful and understandable evaluation methods that enable the inclusion of all factors within a framework

Chapter Three

Transport Appraisal Methods

3.1 Introduction

The appraisal of transport investment projects forms part of a broader investment planning framework whose aim is to provide the information necessary to decide which of the various options best meets the political, economic and social objectives.

There are various types of transport investment evaluation methods such as cost-benefit analysis, financial analysis, cost-effectiveness analysis and multiple criteria analysis, which vary in the way they measure the various gains and losses associated with a certain project as well as in the objectives of undertaking a certain investment evaluation exercise.

In this chapter, some currently available evaluation techniques are discussed and some of the advantages and disadvantages are reviewed for understanding the necessity of more developed evaluation techniques.

3.2 Transport Appraisal Methods

3.2.1 Cost-Benefit Analysis (CBA)

CBA originated as a technique for guiding resource allocation in a number of different fields, and after being used in the appraisal of water resource projects in the US in the

1930s, it gradually spread to transport, health, education and other areas and has been widely applied since 1960s.

Cost-benefit analysis was developed as a technique for examining the achievement of a single objective, namely economic efficiency. CBA is, therefore, based on undertaking the monetarisation of cost and benefit to judge whether the project is profitable or not from an economic point of view. This objective may be broadly defined as the maximisation of net project or system contribution to economic efficiency.

Conventional cost-benefit analysis requires the translation of both the costs and the benefits of a project into monetary terms. Nash (1997) notes that "these monetary values represent the willingness of the beneficiaries of the project to pay for their benefits, and the compensation required by the losers to put up with their losses. If the willingness to pay of the beneficiaries exceeds the compensation required by the losers, then the project has the potential to make everyone better off. As such the project is said to bring about an increase in economic efficiency".

CBA analysis is processed on the following four sequential steps.

1. Identify the items of the project's costs and benefits
2. Measure those costs and benefits in monetary terms
3. Costs and benefits are then calculated throughout project life using time discounting, at a rate of discount such as the social discount rate
4. Once costs and benefits are expressed in present values and then summed up, a decision has to be taken whether to recommend the project for implementation or not, as well as to compare the various alternative projects using several techniques such as the net present value (NPV), the payback period (PBP), internal rate of return (IRR), benefit cost ratio (B/C Ratio).

Net present value (NPV) measures the difference between its discounted costs and benefits. The NPV technique is most widely used in comparing different projects.

$$\text{NPV} = \sum_{i}^{n} (B_i - C_i) / (1+r)^i$$

where, B = benefits, C = costs, i = years (1,..n), r = rate of discount

To measure, a particular interest rate must be chosen for discounting which indicates the periodic drop in values of anticipated benefits and costs as they become reduced further into the future. The NPV should be positive for the project to be acceptable on the economic criterion decision making. However, the rank by NPV often gives wrong answers because of budget constraints. Table 3.1 shows four projects and their cost and benefit flows.

Table 3.1 An Example of NPV and B/C Ratio

Project	Cost	Benefit	NPV	B/C Ratio
X	100	200	100	2.0
Y	50	110	60	2.2
Z	50	120	70	2.4
Z'	55	120	65	2.18

source : Pearce and Nash, 1981

If a capital constraint of 100 units exits then an NPV ranking would be X, Z, Y and X project would be taken (net benefits 100) as a wrong answer because choosing the two apparently lower ranked projects maximises the overall NPV (60 + 70 = 130) that can be achieved for a given capital constraint. As a complementary method, benefit-cost ratios is suggested as a better way to rank projects.

The benefit-cost ratio (B/C Ratio) means the ratio of total discounted benefits to total discounted costs using the following formula:

$$\text{BCR} = \sum_{i}^{n} B_i / (1+r)^i \; / \sum_{i}^{n} C_i / (1+r)^i$$

where, B = benefits, C = costs, i = years (1,..n), r = rate of discount

If this ratio is greater than 1, e.g. the benefits were greater than the costs at the total discounted level, the proposed project is acceptable. In the above example, the

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ranking by B/C Ratio gives a better decision than that by NPV alone. Therefore this technique is useful to use with NPV. However, this rule does not always work. Suppose project Z were replaced by Z'. Of the three projects X, Y, Z', only one would now be possible within the budget constraint, and project X with the highest benefits would be chosen even though it has the lowest benefit-cost ratio. This requires the use of programming techniques to find the correct ranking.

The payback period (PBP) measures the number of years needed for the net discounted benefits to equal to the cost of investment.

$$\sum_{i}^{n} \frac{B_i - C_i}{(1+r)^i} = 0 \qquad \text{where, PBP} = n$$

A short pay-back period is useful where the future is uncertain or where funds are not available on a long-term basis. So these considerations are much more important for private business than for governments. In these techniques, the IRR approach may overstate the desirability of a short-life project, so projects giving very high returns in the early years will be the only one that meets this requirement. Therefore, this technique is not appropriate for comparing investments having a different time stream of benefits and for judging public investment such as transport projects whose benefits take a long time to materialise.

The internal rate of return (IRR) is the rate of discount which discounted costs and benefits are equal. It is calculated by setting the discounted value of the net benefit stream equal to the initial capital outlay and solving the resulting equation for the value of the discount rate.

$$\sum_{i}^{n} \frac{B_i - C_i}{(1+r)^i} = 0 \qquad \text{where, IRR} = r$$

If the calculated IRR is greater than the desired discount rate and the opportunity cost of capital, the proposed project can be undertaken. It is said that IRR is probably more meaningful than a cost-benefit ratio or a statement of the net worth of a project to

compare the profitability of projects, so when investment opportunities are in general, it is generally very appropriate. However, Adler (1971) pointed out that it might sometimes be misleading in comparing projects with different lives or different time streams of benefits. Another disadvantage of the IRR is that it is quite possible to obtain more than one solution rate which may equalise costs and benefits where there are periodic negative net benefits during the life of the project. However, this is rare in the case of transport projects since the costs are predominantly incurred in the early stages and the benefits arise later, in which case the solution would be unique.

In all the techniques, money becomes the numeraire which is used to capture all significant consequences of different projects and CBA then provides a straightforward mechanism for comparing alternatives. Therefore, Hochkiss (1977) states that "CBA goes well beyond the methods conventionally used for evaluating investment proposals in the private sector and attempts to take account of externalities in addition to those items considered by the private decision-maker". CBA is more suitable for ranking or comparing courses of action designed to attain the same ends rather than for testing the absolute desirability of a project.

However, this method as a project evaluation tool is criticised on many sides. Economic cost-benefit analysis cannot provide guidance in the allocation of investments between various sectors, for example transport, education or housing. Given two diverse projects, for example a school vs. a road, each costing the same amount, and a budget only sufficient to build one of them, cost-benefit analysis can give no guidance in the choice because there exists no common scale for comparing the benefits of a new school and a new road, Hill (1973).

Nash (1993) criticised CBA in that "foremost amongst the perceived faults are the failure to conduct appraisal at a strategic level, so that a full range of options is not properly considered, and a failure to look beyond the direct effects to quantify and value a full range of relevant effects". As there may be strong interdependencies both between investment projects and between investment and other policies and they will

effect with each other, it becomes necessary to consider individual projects by themselves, given an assumed strategy and assumptions as to what other projects will be implemented and groups of projects, given an overall strategy and strategies as a whole. For example, a road transport investment project is dependent on the other investments or policies going ahead such as traffic restraint, pricing changes, land use charges and so on. Therefore, there is a need to look not just an individual projects but also at alternative packages of projects in the light of feasible alternative strategies.

However, for this, it needs huge data requirement in the measurement of costs and benefits items and many assumptions on the policy or strategy related to the project. Furthermore, if there is only one criterion or sector, the decision has already been implicitly made and it is sufficient to make it explicit by the related acts of measurement and search. However, in essence, no single criterion decision problem can exist because all decisions, public and private, individual and collective, are characterised by multiple, conflicting criteria. In these respects, CBA has a difficulty in measurement of whole impacts and in making a decision including multiple criteria and stakeholders because CBA was developed to examine the achievement of a single objective, namely economic efficiency, and so it tends to omit outputs whose effects can not be quantified.

Moreover as CBA aggregates gains and losses and presents them in one figure, it obscures the nature of the various gains and losses to the decision-makers in the respect of distributional impact on various sectors. Thirdly, it doesn't consider the distributional incidence of benefits and costs between social groups or regions.

As a result, the concept of *social cost-benefit analysis* was developed to face the criticism by assigning weights to the beneficiaries at different income levels as one of technique improvements. But in some projects it may be impossible to make a reasonable estimate of the distribution of benefits or to identify the beneficiaries. Therefore, if social cost-benefit analysis is to be applied, it should be used with due

regard to the data limitation and simplification involved and it should be applied consistently to all projects.

Other alternative approaches to cost-benefit analysis have been developed such as *the Planning Balance Sheet* - later extended and renamed to form *Community Impact Evaluation* to eliminate the drawbacks of the cost-benefit analysis. It is firmly founded in the CBA tradition. This method aims at a description of the effects of plan alternatives for the various sectors. This formulation is not only concerned with the single goal of economic efficiency but considers all benefits and costs with respect to all community goals in one enumeration.

In the analysis, each item is measured in monetary units or physical terms as far as possible or otherwise noted as an intangible. If alternative plans are being compared, the analysis aims at the difference in costs and benefits that will arise under each alternative. It is possible by this approach to produce systematically, in descriptive and tabular form, a complete set of social accounts which show all the significant costs and benefits which would result from the implementation of the plan, or from alternative plans and their incidence.

So the technique involves setting down, in tabular form, all of the costs and benefits associated with alternative plans and the accounts are subdivided to show the effect of different schemes on the groups affected and this offers guidance to distributional implications. In the Table 3.2 illustrating the balance sheet, the various sectors that are affected by the plans are considered both as producers (X, Y, Z) and consumers (X^1, Y^1, Z^1). The costs and benefits that would accrue to the various sectors are indicated.

The costs and benefits that would accrue to each sector are measured, aggregated and compared for each plan under consideration. The costs and benefits can be expressed in a wide variety of measures, all in different units - monetary terms, quantitative but nonmonetary terms, verbal descriptions. So the ultimate choice is judgemental. By providing this framework within which all the relevant consequences of a planning

proposal can be considered, the analyst is laying the basis for a more rational decision. The measurement of costs and benefits, though desirable, is not strictly necessary, but a well-defined objective and a precise description of the costs and benefits on the relations of them enables the decision maker to add or compare them, Hill (1973).

Table 3.2 The Balance Sheet of Development

Producers					
	Plan A		Plan B		Difference
	Benefits	Costs	Benefits	Costs	
X Y Z					
Difference					

Consumers					
	Plan A		Plan B		Difference
	Benefits	Costs	Benefits	Costs	
X Y Z					
Difference					

The significant advance which use of *the planning balance sheet* can make possible is the identification of the size of gains and losses and of the groups to whom they accrue as a range of impact groups. Hochkiss (1977) recognises that it is then possible to obtain contributions from gainers or provide adequate compensation to losers, so that the decision maker can meet Little's requirement "that the income redistribution not be "bad" by PBS. In addition to this, Nash (1997) stressed that as costs and benefits of the planning balance sheet were described in physical as well as monetary terms, the analysis might be comprehensive.

Burton (1993) also stressed two advantages of the use of *the planning balance sheet*; "firstly, it shifts the emphasis of analysis away from the total measurement of net benefit to the distribution of the costs and benefits among affected groups, and secondly, it circumvents many of the problems associated with expressing all costs and benefits in monetary terms".

However, he also stated some inherent limitations of *the planning balance sheet* approach, despite its attractions, "In particular, it depends on crude ranking criteria and scaling methods. The selection of instrumental objectives is itself highly subjective and can result in conflict between interested parties. There is also the danger that the subjectivity of these objectives and trade-offs is forgotten in the mass of data incorporated in the accounts".

While *the planning balance sheet* has been seen as an extension of CBA, it may also be viewed as a primitive form of multiple criteria decision making techniques in that they are more concerned with various interest groups and weighting the different effects of an investment to reflect social priorities.

Nash (1997) concluded that the CBA and the alternative approaches to appraisal "at its best, CBA offers a technique which provides a rigorous analysis of who gains and who loses from a project and by how much, and still has a very important role in the evaluation field. Nevertheless, CBA has some inherent disadvantages; what CBA can never do by itself is to determine the relative weights to be attached to the costs and benefits of different groups and the items measured in monetary and non monetary terms". Therefore he emphasised that a thorough attempt should be made to identify all relevant effects of projects and trace them back to appropriate incidence groups.

For this purpose, CBA has to be improved and combined with other evaluation approaches, such as a combination of cost-benefit analysis and multiple criteria decision making systems, that enable the decision maker to consider various factors beyond economic efficiency and to include various interest groups. This is caused by

the fact that the other methods were developed as complementary rather than competing with CBA.

3.2.2 Financial Analysis

This measures the flows of receipts and expenditures to one agency (investor) throughout the period of useful life of the project. The flows of receipts and expenditures are measured in terms of market prices and will include not only the real costs of factors, goods and services but also the taxes, loans and subsidies affecting them. Then the principle of discounting is applied to those cash flows to indicate the contribution of the project in achieving the profitability of the transport enterprise providing the service.

Financial analysis predicts impacts in terms of the financial resource required for the project and the flows of income (receipts) and capital (expenditures) to the investor. This method compares the costs (financial costs) that will be incurred by the investor with the benefits (financial returns) he would obtain. The financial analysis gives detailed information on the financial implications of a scheme, but the financial appraisal only considers all benefits which accrue to the investor. While CBA considers those benefits irrespective of to whom they accrue. So financial appraisal shows the funding gap the public sector must fill.

Financial analysis, therefore, does not lead to maximisation of national welfare except in the rare case where the market price does not diverge from the social or shadow price which reflects the social welfare. The financial analysis is used to assess how close to commercial viability a project might be and the CBA to assess the overall social benefits through a consideration of all relevant effects, especially external ones.

3.2.3 Cost-Effectiveness Analysis

In some situations, there are only one or two measures of impacts that are important in the evaluation of alternatives. If there is a single predominant goal for the project such as reducing delay or increasing capacity, total projects costs are assigned to a single associated cost effective index such as cost per passenger minute saved or cost per added vehicle hour of capacity - the degree of attainment for each objective. When more than one impact measure is important, total costs are allocated among different goals according to their importance weights.

The main purpose of this method is to deal with non quantifiable or subjectively measurable impacts when we evaluate project alternatives that have just a few important outcomes that cannot be valued in monetary units and so give the decision maker reasonable and understandable information for decision making. The technique uses two sets of measures, costs and indicators of objective attainments, which would be the basis of the choice of the best alternative.

One of the forms for measuring and comparing is the matrices method that can represent each alternative by their effectiveness, e.g. the alternatives appear in rows and effectiveness or costs appear in columns. In the table, costs are defined as the total monetary outlay needed to accomplish the alternative, and effectiveness is defined as the degree of attainment for each objective. Goal attainments may be described mathematically, verbally or pictorially and the decision maker will be able to construct a composite picture of the consequence of each alternative.

Table 3.3 General Inputs-Outputs Table for Cost-Effectiveness Analysis

	Goal	Alt 1	Alt 2	----	Alt n
Effectiveness	-----				
	Air pollution				
	Accessibility				

Cost	-----				
	Construction cost				
	Maintenance cost				

Hence, *cost-effectiveness analysis* has the appeal that it is simpler than cost-benefit analysis when only a single effectiveness measure is used because benefits do not need to be valued in monetary units. For this reason, CBA can be replaced with *cost effectiveness* whereby the hard and aggregate data on costs can be compared to some indices of outcome in non-monetary units. *Cost-effectiveness ratios* are calculated for several important measures, and these ratios are used as the main information source for the decision making instead of the simple or unitary measures from which the ratios are derived. Hence, it is probably preferable to use only the unitary measures when several measures have to be considered.

However, it has several disadvantages; firstly, when there is more than one important goal, project costs must be allocated among the different results, but as there is no commonly accepted way to arrive at the correct allocation, the results are usually difficult to interpret and may produce conflicting results. Moreover, it is not possible to select or rank the project alternatives with multiple outcomes, unless one project alternative is superior for all outcomes.

Secondly, cost effective criteria do not show whether or not a project is economically attractive unless some threshold of desirability are set for all criteria, but doing that would enable direct computation of the benefits and a much simpler cost-benefit display of results, Reinke et al (1983).

3.2.4 Multicriteria Evaluation Method

The Multiple Criteria Decision Making (MCDM) field can be said to have begun at the beginning of 70's in the international conference held at the University of South Carolina though many works, researches, or studies explored the multiplicity of decision criteria such as Simon on satisficing and the work of Charnes and Cooper on goal programming before that, Zionts (1994). Basic groundwork for MCDM was laid down in the articles and books of Pareto, von Neumann, and many others, and MCDM

was in connection with operational research and management science. Operational sciences (operations research, management science, decision science, system analysis) have devoted most of their history to problems characterised by a single, aggregate criterion of choice, Zeleny (1984). They dealt with problems of measurement and search in connection with simple problems.

In very few problems of interest we find a single important criterion of choice. If there is only a single criterion, it is sufficient to make it explicit by the related acts of measurement and search. In fact, there is no decision making involved in situations characterised by a single criterion of choice. For example, if you are asked to select the largest apple from a basket, it is entirely sufficient to measure objects with respect to the criterion and then search for the maximal alternative. However, we often worry whether the largest apple is the juiciest, the sweetest and the freshest. Under these multicriterion conditions measurement and search are no longer sufficient for deciding. With multiple criteria the choice is never implicit in the measurement and cannot be explicated by unidimensional search.

In real life, all problems have multiple objectives, attributes, goals and criteria, and a number of elements have been identified as important. All decisions, public and private, individual and collective, are characterised by multiple, apparently conflicting, criteria. The problem is complicated by the imperfect knowledge that inevitably exists when decisions need to be made. A great deal of work, in terms of formulating and solving multiple criteria problems, has been carried out over the past three decades to provide help and guidance to the decision maker in discovering his or her most desired solution to the problem. MCDM has been used in goal programming, compromise programming, multiobjective programming typically, but also for economics, business and management, Zeleny (1984).

So nowadays there is a wide variety of multiple criteria decision methods. These methods are not only used in the context of conventional project and plan evaluation,

but also as an operational framework for conflicting analysis. The following reasons may be mentioned for the increasing popularity of these methods, Munda et al (1993):

- the difficulty of including intangible and/or incommensurable effects in conventional evaluation methods
- the conflictual nature of modern planning problems
- the desire in modern decision making to be confronted with a spectrum of open feasible solutions

Multicriteria evaluation methods serve to investigate a number of alternative choices in the light of multiple criteria and conflicting priorities and these alternatives choice can be alternative plans or strategies, H Voogd (1983). MCDM methods are management decision aids used in evaluating competing alternatives defined by multiple criteria.

MCDM methods have the following common characteristics: 1) a fixed set of alternatives to be prioritised, selected or ranked, 2) multiple criteria (goals or attributes), 3) different units of measurement, 4) decision matrix, where one dimension expresses the various alternatives and the other dimension the criteria by which the alternative must be evaluated.

The increasing awareness of negative effects of economic growth and transport investment have led to a need for appropriate analytical tools for analysing conflicts between policy objectives. Nowadays a wider range of transport policy objectives are emerging due not only to increasing awareness of the public as well as the politician but also the increasing complexity of the problem. Transport investment planning is a typical example which has multiple objectives because there are many objectives and trade-offs between objectives such as expanding capacity and environment and furthermore many intangible and incommensurable factors.

In addition to this, there are so many interests groups affected by transport projects that it requires appropriate evaluation tools to include people's preference and weight them in the process to derive the best solution which most parts of the groups can be

satisfied with. Therefore we need evaluation techniques which enable information on planning goals and objectives to be converted into evaluation criteria and to be brought into a framework that incorporates the opinions of interest groups.

So many multiple criteria methods, which aim to provide such a set of tools with simultaneous consideration of many evaluation criteria and multiple interests groups, to overcome these problems have been studied for the following reasons:

- to include intangible effects which are incommensurate and so often omitted in conventional cost-benefit analysis methodology
- to overcome the conflicting nature of modern planning problems between several separate groups affected, instead of a single decision maker
- to give decision makers more institutional and procedural decision making
- to end up not with dimensionless single indices for a preferred alternative and forced solution dictated by a researcher but with a spectrum of feasible solutions from which a choice can be made in modern public decision analysis

Generally an evaluation process of multiple criteria evaluation method will have the following structure. It starts with a definition of what has to be evaluated. Next, various alternatives must be defined. Thirdly the evaluation criteria and interest groups have to be defined and criterion priority have to be defined by the weights. These criteria can be used as a guideline for the analysis of the impacts of the alternatives.

Together with this analysis, sensitivity analysis for some particular criterion may then be used to investigate how project ranking and selection would change; this type of sensitivity analysis may be valuable for investigating effects of change in some criteria and weights. After all these processes, more than one project is viable and so it needs the selection of the most preferable project via preference scaling or weighting methods. The process of project selection may be formalised and made explicit if weights or preference among the various criteria are defined.

Nijkamp et al (1990) have the view that "the major feature of multiple criteria analysis is that it addresses evaluation and choice problems marked by various conflicting interests. The aim of multiple criteria analysis is to provide in a systematic framework information on the nature of these conflicts so as to make the trade-offs in a complex choice situation more transparent to a decision maker or policy agency", and this defines the multiple criteria decision making method clearly.

Multiple Criteria Decision Making methods serve to enhance the quality of planning and decision-making by providing both a sound methodological platform for decision analysis and an operational framework for actual decision-making that incorporates the opinions of various interest groups. A wide variety of theoretical and empirical contributions can be found in the field of regional, urban and transport economics. Many multiple criteria evaluation methods have been employed, both theoretically and empirically.

3.3 The Classification of Multiple Criteria Evaluation Methods

Nijkamp (1990), when discussing the classification, stated "In practical situations, an evaluation problem is often reformulated in order to let it comply with the features of the evaluation methods at hand. Such a topological approach might lead to a meaningful classification of evaluation methods for physical planning. Each entry indicates where in principle a certain class of evaluation methods may be useful for evaluating transportation problems".

Multiple Criteria Decision Making (MCDM) methods are closely related to other topics, for example, Multi Objective Decision Making (MODM), Multi Attribute Decision Making (MADM). MODM is generally used to define the set of alternatives given a series of objectives which act as constraints and/or goals, and then to find the best one. This method is sometimes viewed as a natural extension of mathematical

programming, where several objective functions are considered simultaneously. MODM is not associated with the problem where the alternatives are predetermined.

The thrust of these models is to design the 'best' alternative by considering the various interactions within the design constraints which best satisfy the decision maker by way of attaining some acceptable levels of a set of some quantifiable objectives. MODM problems involve designing the best alternative given a set of conflicting objectives. For example, automobile manufacturers who wish to design a car that maximises riding comfort along with fuel economy and minimises production cost. The alternatives are created by the design process, and there can be as many as it produces. Thus MODM is associated with design problems. Considering these, MODM was not considered to be appropriate to the evaluation of the projects which had predetermined alternatives.

In contrast to MODM, MADM (Multiple Attribute Decision Making) is used to make preference design (e.g., evaluation, prioritisation, selection) over the available alternatives and select the best one, given that each alternative is characterised by scores for sets of attributes. The MADM methods are oriented toward ranking and selection of fully predetermined alternatives lying within a finite set of possibilities, while MODM for design. MADM have the notion that decisions entailing multiple objectives are aided by specifying quantified outcomes and preference-based weighting schemes. The quantitative ratings generated by these methods are seen as tools for decision makers to compare simultaneously more alternatives and attributes than they would have been capable of otherwise, given the complexity of the information.

Generally, MADM methods proceed according to five basic steps: (1) identify relevant participants in the decision process, (2) identify the dimensions, criteria or goals that will characterise the alternatives, (3) generate preference-based weighting schemes, (4) develop measures by which each of the alternative projects is assessed along each of the relevant dimensions, (5) rank or rate alternatives based on measured outcomes and group's preference, and perform analyses, Levine (1996).

Therefore, the distinguishing feature of the MADM is that there is usually a limited number of predetermined alternatives. The alternatives are associated with a level of the achievement of the attributes based on which the final decision is to be made. The final selection of the alternative is made with the help of comparisons of all attributes for the alternatives. The comparisons may involve explicit or implicit trade-offs.

The possible method to be chosen for ranking and selecting the best alternative among a given finite set of alternatives should be one among many MADM methods. There are many MADM methods according to the type and salient features of the information received from the decision maker, and application process. Among all the methods, a few popular methods are currently widely used, which are Goals-Achievement Method (GAM), Multi-Attribute Utility Theory (MAUT), Simple Additive Weighting Method (SAW), Outranking Methods (Concordance Analysis), and Analytic Hierarchy Process (AHP).

Brief descriptions of each method such as advantages and disadvantages of each usage, capability and limitations are reviewed in the following section, and the most suitable method chosen for the application as a case study among these several methods is to be discussed in the next chapter.

3.3.1 Goals-Achievement Method

This method was developed by Morris Hill (1967) to surmount the weak points of cost-benefit analysis in accommodating intangible factors, in measuring the social welfare of impact groups by proposed projects, in considering secondary consequences of proposed projects. This method has often been used for evaluating public projects. This method links each criterion to a quantitative achievement level or target value.

The evaluation of the alternatives requires the determination for each alternative of whether or not the benefits outweigh the costs. In this, benefits represent progress toward the desired goals whilst costs represent retrogression from desired goals.

Evaluation essentially involves taking the achievement score for each criterion, and aggregating these to give a total achievement score for each alternative plan. In this method, it is proposed that a methodology in which a separate cost-benefit analysis would be constructed for each goal, each goal weighted, and then the degree of achievement of weighted goals are compared between each alternative.

This method offers an explicit treatment of various goals and applies a set of predetermined weights to them so that each option can be assessed in terms of goals achieved. The final goals achievement account employs the weighted index of goal achievement to determine the preferred course of action.

The first step in goals achievement analysis is the determination of goals. Hill (1973) defines goals as "an end to which a planned course of action is directed" such as increased accessibility, minimised air pollution, and minimised traffic congestion. Hill suggests a number of approaches to goal selection; elected officials and community groups, public opinion sampling, and examination of previous allocations of public investment. Once goals are selected, the impacts of transport alternatives on the goals are examined. Important issues are identified (goals) and the future impacts of each alternative are estimated. Hill's solution to this problem of comparability is to aggregate similar impacts within each goal category using a weighting summation procedure and then compare the results for different alternatives

The set of goals is known, and the relative value to be attached to each goal is established. The goals are defined and the consequences of each alternative are determined for each goal. The relative weights to be attached to each group is also established. The key to decision making by the *goals achievement analysis* is the weighting of goal, attributes and groups. It is possible to arrive at a unique conclusion by applying relative weights and these are derived by asking decision makers to weigh them up.

In this analysis, costs and benefits are always defined in terms of goal achievement. Thus costs represent retrogression from desired goals while benefits represent progress toward the desired goals. Where the goal can be and is defined in terms of quantitative units, the costs and benefits are defined in terms of the same units. Where no quantitative units are applicable, costs and benefits indicate progress and retrogression toward (or from) the qualitative states that the objective describes. Thus, if a benefit of x units accrues, it can be nullified by a cost of x units, provided both costs and benefits apply to the same objective. This interpretation of costs and benefits differs from the traditional conception of costs and benefits, Hill (1973).

The conceptual product of the analysis is given in Table 3.4. In the Table, α, β, γ are the descriptions of the goals. Each goal has a weight of 2, 3, 5,.. as has been previously determined. Various groups of people, a, b, c, d, e,.. are identified as affected by the course of action. These groups may be combined in any meaningful manner in order to indicate the differential incidence of costs and benefits. A relative weight is determined for each group, either for each goal individually or all goals together. The letter A, B, C...are the costs and benefits that may be defined in monetary or non monetary units or in terms of qualitative states. To express qualitative aspects as numerical values for the comparison, some scaling techniques such as nominal, ordinal, interval and ratio scale can be introduced and used

Table 3.4 Conceptual Product of Analysis

Goal Description		α		β		γ	
Relative Value		2		3		5	
Incidence		Costs	Ben.	Costs	Ben.	Costs	Ben.
Groups Affected	Relative Weights						
Group a	1	A	D	E	---	N	
Group b	3	H	J	---	R		
Group c	1	L	J	---	S	---	M
Group d	2	---	---	T	---	---	
Group e	1	B	K	---	U	P	
		Σ	Σ				

Costs and benefits are recorded for each goal according to the parties that are affected. A dash (--) in a cell implies that no costs or benefits related to that goal would accrue to that party. Σ indicates the summation of the costs and benefits is meaningful or useful. The total costs and benefits with respect to that goal can then be compared. This will be the case when all the costs and benefits are expressed in quantitative units (goal α), but it is obviously not the case with the intangible costs and benefits (goal β, γ). It is most unlikely that all the costs and benefits of all the goals can be expressed in the same units.

The following is the comparison of goals-achievement for alternative course of actions, then the decision making. There are some techniques to evaluate the degree of goals achievement of each alternative such as *the goals achievement account*, *the weighted index*. In *the goals achievement account* techniques, entire account of each goal is presented to the decision maker without synthesis. The decision maker, then, selects the best alternative by considering trade-offs and relative priority by their own subjective judgement. This approach would leave the planner's analysis less open to criticism than the subsequent approaches but places a greater responsibility on the decision maker.

On the contrary, in *the weighted index* technique, the combined weight of the objectives and their incidence is assigned to the measures of achievement of the objectives. The weighted indices of goals-achievement are then summed and the preferred alternatives can be selected that gets the largest index. However, this approach requires several arbitrary assumptions concerning the relationship of the measures of achievement of the individual objectives and is subject to the criticism with respect to aggregation of benefits and costs referring to different objectives, and with respect to the use of indices, that the index cannot be understood in terms of a single unit of measurement and is difficult to interpret. But as the index is determined in a similar manner for all alternative plans under consideration, it does enable a comparison to be made, Hill (1973)

The Goals-Achievement methods can be quite attractive for overall evaluation problem incorporating qualitative information which need to be treated with very simple and straightforward methods in approach procedure for governmental premiums, and also this method appears to be easier to use be cause of relatively little computational burden compared with the other methods. Moreover this can be easily be constructed by the analysts and understood by the decision maker.

However, this method is very complex to determine various classes of weights, for individual goals and each group. Moreover as the various goals of each group are in conflict, it is not easy to derive the weights with group consensus that are mutually concurrent among the members of the party. As many specified criteria (or goals) are considered, the problem becomes more sophisticated and difficult to handle because this method is better for one or two major overall goal achievement assessment and it is difficult to include a comprehensive consideration of sectors affected by transport plans.

The application of the goals-achievement matrix requires the weighting of objectives and their incidence. Hill (1967) himself recognises that "the goals-achievement matrix is obviously of limited usefulness if weights cannot be objectively determined. The further development of methods for the determination of weights is thus of first priority for the successful application of the goals-achievement matrix".

For the determination of weights, it requires considerable research. There is no single approach to this problem that is universally applicable. However, there can be a few approaches such as empirical review or sensitivity analysis. First of all, the planner's intuitive knowledge based on his experience and expertise is very important in the development of the initial hypotheses concerning goals and weights. Another indirect approach is the analysis of the pattern of previous allocations of the goal priorities implicit in previous decisions on the similar scheme. For the case which the relative valuation of goals has not been determined empirically, the effect of changes in weights

on the relative desirability of alternative plans may be usefully explored as the shape of sensitivity analysis priorities.

3.3.2 Multi-Attribute Utility Theory (MAUT)

This approach attempts to characterise planning options in terms of their objective and subjective attributes or characteristics and assigns numerical subjective utilities. This was developed for reducing conflict by aggregating human judgements regarding the utility or value attached to alternative policy outcomes with multiple attributes. This approach addresses issues pertaining to the relevance of policy attributes to the choice at hand, the measurement of values ascribed to those attributes by actors and stakeholders, the aggregation of values used to establish priorities from among a set of attributes, and choice of a policy that contains the prioritised attributes, Saaty & Kearns (1985).

The core of this approach is, therefore, the definition of the individual utility function of a decision-maker. A multi-attribute utility function is a mathematical statement that indicates the utility of all combinations of values for the various attributes or objectives that are under consideration.

According to Vargas & Dougherty (1982), there are five basic steps usually followed when applying utility theory to the evaluation of alternatives characterised by multiple attributes. The first two steps consist of the identification of relevant characteristics and their quantification through the assignment of quantifiable variables to each of the attributes. The third step is the selection and construction of utility functions for each of the individual attributes and for each of the alternatives as a function of the attributes. The fourth step is the synthesis of the individual utility functions into a single additive/multiplicative utility function, and the fifth step is the evaluation of the alternatives using the function obtained in the fourth step.

This approach consists in first representing the preference of the decision maker, for each criterion (attribute) i, by a function U_i such that a is better than b for i if $U_i\,(a) > U_i\,(b)$. In a second step, these functions U_i are aggregated in a unique function U so that the initial multiple criteria problem is replaced by a unicriterion problem. In fact, this approach is based on the following postulate: There exists a function U representing the global preference of the decision maker and the scientist will help him to discover this function. This postulate allows problems to be tackled in an operational way, but the question is to know if it is compatible with the nature of the multiple criteria problem, Vincke (1986).

An essential component part of the MAUT is the assessment of unidimensional utility functions over single attributes, which provides a basis for reducing problem of assessing a multiattribute utility function into one of assessing consistently scaled unidimensional utility functions. The MAUT method is based on the idea that the utility for a specific alternative is a function of the utilities of the attributes levels associated with that alternative.

Of fundamental importance in identifying simple representations of individual preference is the verification and exploitation of certain independence properties which may exist among the decision maker's preference for various amounts of different attributes, Keeney (1973). Several types of independence conditions have arisen in multiattribute utility theory, e.g. mutual utility independence, additive independence, French (1986)

Subject to various sets of conditions involving independence properties such additive independence and utility independence, the functional form of the corresponding utility function is restricted to additive/multiplicative function. If we example two independence condition, firstly, additive independence refers to all the members of a set of attributes X_i, i = 1, 2, ..., n being value independent of each other. The main theorems which are implied by additive independence are generally stated in the following form:

$$u(x_1, x_2, \ldots, x_n) = \sum_{i=1}^{n} k_i u_i(x_i),$$

where u and u_i are utility functions scaled from zero to one and $\sum_{i=1}^{n} k_i = 1$.

Whereas additive independence concerned preference for alternatives with more than one attribute varying in amount simultaneously, utility independence concerns alternatives with only one attribute. For example, if preferences between attributes with varying levels of X and a common, fixed level of Y are independent of that fixed level of Y, X is said to be utility independent of Y, French (1986). Mutual utility independence generally leads to a additive or multiplicative form of the utility function as following:

$$u(x_1, x_2, \ldots, x_n) = \sum_{i=1}^{n} k_i u_i(x_i),$$

or multiplicative,

$$\mathrm{I} + ku(x_1, x_2, \ldots, x_n) = \prod_{i=1}^{n} [1 + kk_i u_i(x_i)]$$

where u and u_i are utility functions scaled zero to one and k and k_i are scaling constants, Keeney (1993).

All concerns a decision maker's preference for consequences described in terms of multiple attributes. These functions usually involve weighted sum and products of utility functions over subgroups of the complete set of attributes. Thus, given a specific problem, if independence conditions are verified, the assessment of the utility function can be simplified.

The strength of this method is that this approach is quite useful for guiding decisions and for involving decision makers in the evaluation process heavily. However, the assessment of an appropriate multi-attribute utility function is so complex and intricate that the aim of much theoretical work in this approach is the investigation of

possibilities for simplifying multi-attribute utility assessment problems. The other main criticisms of this approach are:

- the construction of the multi-attribute utility function requires a heavy questioning process, and so multi-attribute utility functions are very difficult to construct in a practical situation.
- all the prescriptive implications of the model utility are strongly founded upon the hypothesis that, even if the decision maker has not been forced during the interview process, he is rational in the sense that he is supposed to obey a set of intuitively convincing axioms of behaviour.
- MAUT assumes that the respondent possesses perfect information when expressing their preference and has rational behaviour.

Cohon (1978) addressed that this complexity has motivated the other techniques in that the approaches present attempts to capture decision maker's preference by working with value judgements that are applicable to relevant ranges of alternatives without the comprehensiveness or generality of the utility function.

3.3.3 Simple Additive Weighting (SAW) Method

Yoon & Hwang (1995) recognise that the SAW method is probably the best known and widely used MADM method by easy use and simplicity. A score in the SAW method is obtained by adding contributions from each attribute. Since two items with different measurement units cannot be added, a common numerical scaling system such as normalisation is required to permit addition among attribute values.

To each of the attributes, the decision maker assigns importance weights which become the coefficients of the variables. He can then obtain a total score for each alternative simply by multiplying the scale rating for each attribute value by the importance weight assigned to the attribute and then summing these products over all attributes. After the total scores are computed for each alternative, the alternative with the highest score is the one prescribed to the decision maker

Formally the value of an alternative in the SAW method can be expressed as

$$V(A_i) = V_i = \sum_{j=1}^{n} w_j v_j(x_{ij}), \qquad i = 1, \ldots, m$$

where, $V(A_i)$: the value function of alternative A_i,

w_j and v_j : weight and value functions of attribute X_j.

The normalisation process allows direct addition among attributes. The value of alternative A_i can be written as

$$V_i = \sum_{j=1}^{n} w_j r_{ij}, \qquad i = 1, \ldots, m$$

where r_{ij} is the comparable scale of X_{ij} which can be obtained by a normalisation process.

Yoon & Hwang (1995) give an example to show how to apply this SAW method in evaluation and selection of projects with military fighter selection decisions. Three competing models of jet fighters are available for purchase to reinforce an airforce. They proceed to generate selection criteria by way of a goal hierarchy in Figure 3.1.

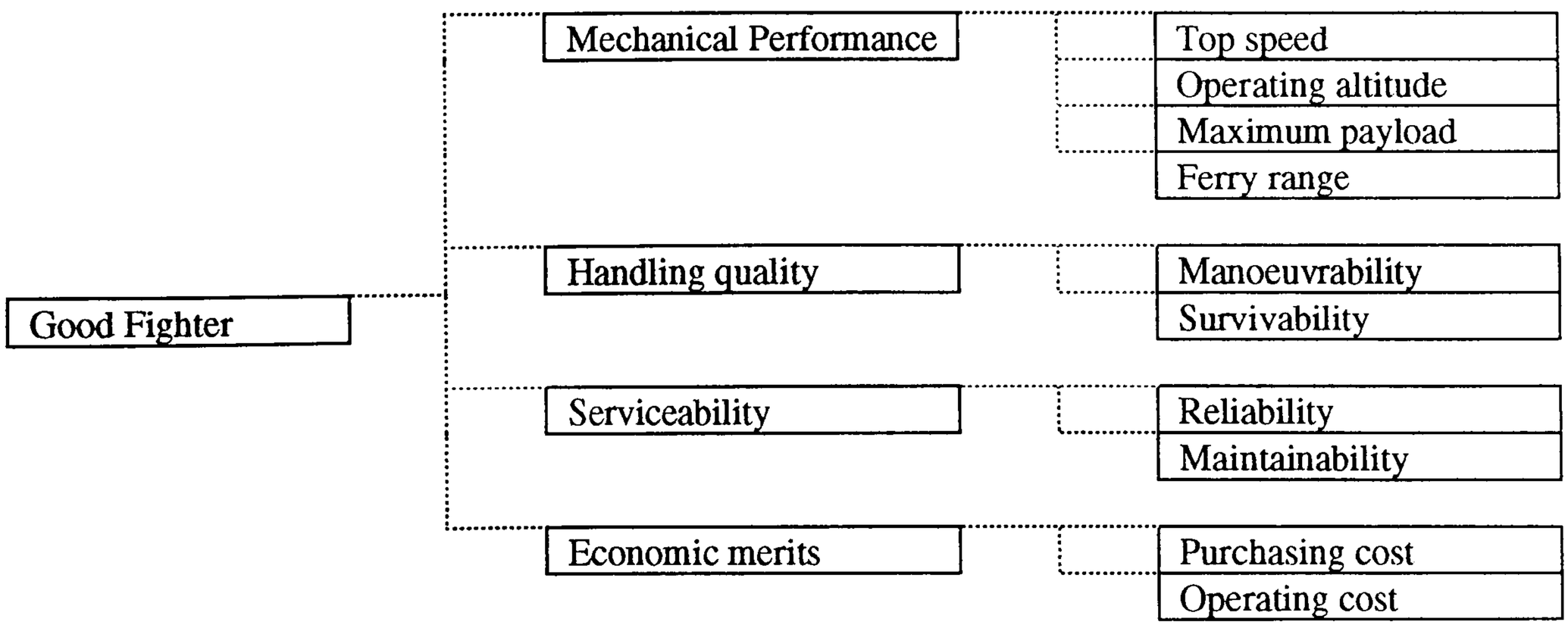


Figure 3.1 A Hierarchy for Fighter Evaluation

Four mutually exclusive objectives are generated, and ten attributes emerge from these four criteria. First, a comparable rating is obtained by using linear normalisation (a

simple procedure that divides the ratings of a certain attribute by its maximum value) which is most often used. To get a set of attribute weights, the decision maker first considers four major criteria, then judges each attribute within each criterion step by step along the levels. The final weights for attributes (from 'top speed' to 'operating cost') are obtained by multiplying weight together through the levels. The weights and normalised data are shown in the Table 3.5.

Table 3.5 Data for Evaluation of Fighter Selection

			Alternatives				normalised		
		weights	A_1	A_2	A_3		A_{11}	A_{22}	A_{33}
Mechanical Performance	top speed (mach)	0.20	2.0	2.0	2.5		0.80	0.80	1.00
	operating altitude (100 ft)	0.04	60	50	60		1.00	0.83	1.00
	Maximum payload (1000 pounds)	0.04	23	20	18		1.00	0.87	0.78
	Ferry range (NM)	0.12	1900	2000	3500	➡	....		...
Handling quality	Manoeuvrability (*)	0.09	7	8	9				
	Survivability (*)	0.21	8	9	7				
Serviceability	Reliability (*)	0.12	8	7	9				
	Maintainability (*)	0.08	9	7	8		...		...
Economic merits	Purchasing cost ($M/ea.)	0.06	4.5	5.0	6.5		1.00	0.90	0.69
	Operating cost ($1000/yr.)	0.04	90	70	100		0.78	1.00	0.70

* units are from a 10 point scale, from 1 (worst) to 10 (best).

The value of alternative A_1 is derived as:

$$V_1 = \sum_{j=1}^{10} w_j r_{ij}$$

$$= 0.2(.8) + 0.04(1.0) + ... + 0.04(.78) = 0.8396,$$

and the value of the other alternatives can be derived as same.

With the value, the preference order is set for decision making.

3.3.4 Outranking Method

Outranking Method which was developed based on outranking relations and widely used in Europe makes use of the binary relations of preference in the form of pairwise comparisons of the objects. The procedure is to measure the dominance of one option over another with a view to identifying the option which outranked others. The terms 'outranking' or 'concordance methods' are now generally used in many of the techniques which have based on this concept.

The methods known by the names of ELECTRE(Elimination and Choice Translating Reality), PROMETHEE (Preference Ranking Organisation Method for Enrichment Evaluations) are typical examples of such a process, and the most well known outranking method is the ELECTRE and since it was developed by Roy in 1968, it has been revised to ELECTRE 4. This method is used to describe these outranking method approaches.

The roots of concordance analysis are to be found in France and was developed by Roy (Masaam, 1988) and has been used in numerous applications in Europe. This method is a multicriteria evaluation technique which uses pairwise comparisons to give an overall ranking of projects using the metric interval characteristics of the various scores in the evaluation matrix. This is used for selecting one alternative from a set of alternatives with respect to relevant criteria. Each criterion is assigned a weight which corresponds to its relative importance.

This method begins with a matrix of alternate plans, a set of criteria and a set of weights for the criteria. Two different indices are calculated from the project effects matrix, *concordance* and *discordance index*, in order to obtain outranking relationships and this index can be viewed as measurements of satisfaction and dissatisfaction, 1) *Concordance Index* which measures the extent to which a particular project is better than the competing projects, 2) *Discordance Index* which measures the opposite, the extent to which a particular project is worse than the competing projects.

The concordance and discordance index for a pair of plans *i* and *j* is defined in the following way:

- C_{ij} = (Sum of the weights for those criteria when plan *i* is rated equal to or better than plan *j*) / (Sum of all the weights for the full set of criteria)
- *Dij* = (Largest negative difference (i.e. *j* is rated higher than *i*)) / (The difference between the maximum obtainable rating and the minimum obtainable rating)

Dominance indices are developed from the concordance and discordance scores, and they are used to establish the relative preference of each alternative with respect to the given weighting schemes. The process for this analysis with the example of a budget reduction decision case for athletic department from Yoon & Hwang (1995) is summarised as follows.

1. Normalise all attributes to enable their value applicable: The decision matrix and its comparable ratings by vector normalisation which tend to put greater emphasis on the larger values are given below. Regarding normalised value X_1, it was based on the inverse of raw score of attribute X_1 because it is of cost, negative benefit:

- vector normalisation: raw score / $\sqrt{\sum (raw score)^2}$

programs	Attributes				normalised value		
	X_1	X_2	X_3		X_1	X_2	X_3
A_1 : drop skiing	30	174140	average: 3		0.3466	0.9126	0.4243
A_2 : drop baseball	29	74683	low: 4		0.3587	0.3914	0.5657
A_3 : drop golf	12	22496	very low: 5		0.8667	0.1179	0.7071

X_1: number of people directly affected
X_2 : department cost savings
X_3 : subjective judgement of the impacts
weights : X_1 - 0.2, X_2 - 0.7, X_3 - 0.1

2. Derive the weighted normalisation: The weights (0.2, 0.7, 0.1) are multiplied with each column of the normalised rating matrix. The weighted normalised ratings v_{ij} (*i*: alternative, *j*: criteria) are computed as

	X_1	X_2	X_3
A_1	0.0693	0.6388	0.0424
A_2	0.0717	0.2740	0.0566
A_3	0.1733	0.0825	0.0707

3. Identify Concordance and Discordance sets for each pair of projects: Compare alternatives 1 and 2. Then alternative 1 performs better than (or equal to) alternative 2. This set is called the concordance set related to alternative 1 and 2; it will be denoted as $C_{12.}$ Similarly, the discordance set for the pair of alternatives (1,2) is the set of criteria for which alternative 1 performs worse (or equal to) than alternative 2. The union of C_{pq}, and D_{pq} is always the whole set of criteria.

pair of alternatives (p, q)	concordance set C_{pq}	discordance set D_{pq}
(1, 2)*	2	1, 3
(1, 3)	2	1, 3
(2, 1)	1, 3	2
(2, 3)	2	1, 3
(3, 1)	1, 3	2
(3, 2)	1, 3	2

* : alt.1 performs better than alt.2 in terms of criteria 2, and worse in terms of criteria 1 and 3

4. Compute concordance and discordance index: The concordance index is introduced to indicate the weight of the concordance set. It is defined as the sum of the weights of the criteria (0.2, 0.7, 0.1) according to which alternative p is more attractive than q, while the discordance index is introduced indicating the maximum difference of scores for alternative p and q, on those criteria for which alternative q is preferred to p. The weights of each objective are arbitrarily given and normalised.

$$c_{pq} = \sum_{j \in c_{ii}} \gamma_j \,, \quad \text{where } \gamma_j \text{ is the weight given to the } j\text{th objective}$$

$$d_{pq} = \left(\sum_{j^o} \left| v_{pj^o} - v_{qj^o} \right|\right) / \left(\sum_{j} \left| v_{pj} - v_{qj} \right|\right),$$

where j^o represents attributes that are contained in the discordance set D(p. q)

For example, in the table

$C_{12} = (3)$, so $C_{12} = 0.7/(0.2+0.7+0.1) = 0.7$

$$D_{12} = (1, 3), \text{ so } D_{12} = \left(\sum \left| v_{11} - v_{21} \right|\right) / \left(\sum_{j}^{3} \left| v_{1j} - v_{2j} \right|\right)$$

$$+ \left(\sum \left| v_{13} - v_{23} \right|\right) / \left(\sum_{j} \left| v_{1j} - v_{2j} \right|\right)$$

$$= 0.0063+0.0372 = 0.0435$$

pair of alternatives (p, q)	concordance index C_{pq}	discordance index D_{pq}
(1, 2)	**0.7**	**0.0435**
(1, 3)	0.7	0.1921
(2, 1)	0.3	0.9565
(2, 3)	0.7	0.3766
(3, 1)	0.3	0.8079
(3, 2)	0.3	0.6234

5. The next step is to eliminate less favourable alternatives by setting threshold values, $\overline{c},\overline{d}$. Threshold values are elicited from the decision maker to reduce the number of alternatives on the basis of $\overline{c},\overline{d}$, and, the average of C_{pq}, and D_{pq}. By defining a critical value, one may state that alternative *i* outranks *j* if $C(p.\ q) > \bar{c}$ and $D(p,\ q) < \bar{}$ with respect to each criterion. In the example, $\bar{}$ is 0.5 ((0.7+0.7+...+0.3)/6) and $\bar{}$ is 0.5 ((0.0435+0.1921+..+0.6234)/6). From the table above, three outranking relationship are obtained: (alt 1, alt 2), (alt 1, alt 3) and (alt 2, alt 3), and it means alt 1 (dropping the ski program) is the best alternative for budget reduction with least criticism.

To summarise the underlying theoretical structure of the method, it can be shown in Figure 3.2.

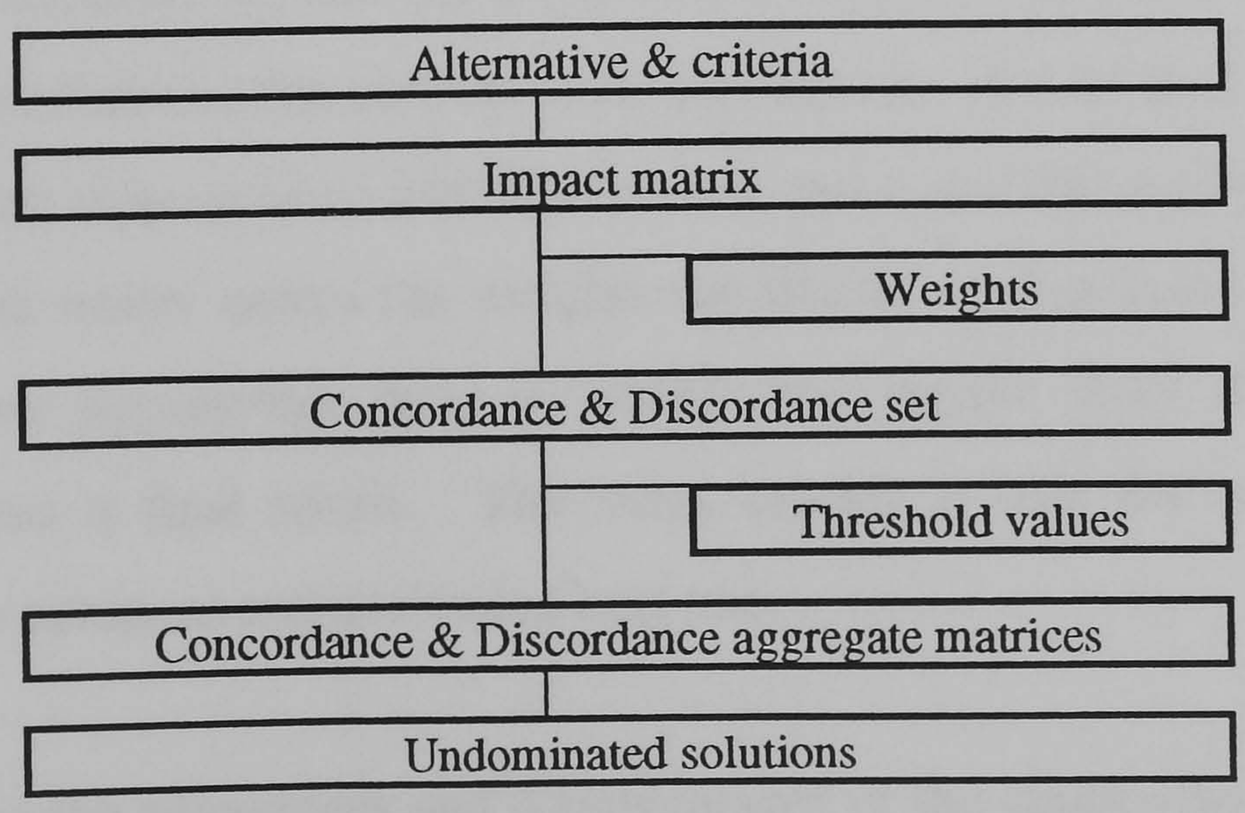


Figure 3.2 Structural Diagram of Outranking Method

According to this figure, the inputs or the initial information required by this method are the alternatives (transport plans) and criteria (performance measures). These are the essential inputs for the analysis. After the impacts are predicted on the basis of the chosen criteria and the alternatives, weights should be assigned to all criteria. These weights represent the relative preferences of the decision maker for each criterion. The weights can provide a basis for deriving pairwise comparisons of competing alternatives. All that remains is to choose the best (undominated) alternatives by threshold values.

Obviously, the exploitation of an outranking relation in order to obtain the best decision or in order to rank them is much more difficult because of inherent technical complexity than in the Multi-Attribute Utility Theory and Goals-Achievement Method. In addition, there is no doubt that there is a lack of basic theory for this approach. This may make this method difficult for the decision maker to comprehend because final selection of best alternative is based on the both numbers of concordance index and discordance index and there is no appropriate way to compromise these two indices.

This method, however, is satisfactory with respect to this criterion if there is only a single or a few decision makers and a few criteria to be considered, while if there are multiple decision makers, this method is not appropriate. It is caused by the fact that it is calculated from concordance and discordance index according to the weights given by each decision maker unless the weights are unified among many decision makers, and there is no appropriate way to enable the results from all weights to be incorporated into a final result. The more criteria it has, the more difficult and complex it is to compare and derive the best one.

If we summarise the advantages and disadvantages of the concordance method, firstly, this method has a few advantages amongst which it is said that it can handle non-quantifiable criteria, and it is responsive to the preference structure of decision makers.

Yet, this method requires a large set of a priori parameters from the decision maker, and also needs weights and thresholds for every criteria. However, the weights and thresholds are given subjectively because there is no appropriate way to derive these weights and the threshold values even though there have been a few methods to arrange threshold values by the averaging method, a graphical display of the concordance and discordance measures and the sliding threshold values, Voogd (1983) and their impact on the ultimate result may be significant.

In addition, it is often very difficult to interpret certain parameters used in this process. These can be the disadvantages of the method in decision making which requires a more objective judgement. Nonetheless, this outranking method is attractive in terms of its interaction requirement between analyst and decision maker and it is easy to conduct the sensitivity test as this is designed to provide information to a single or a few decision makers.

3.3.5 Analytical Hierarchy Process (AHP) Analysis

The Analytical Hierarchy Process, developed by Thomas L. Saaty (1980), is essentially the formalisation of our intuitive understanding of a complex problem using a hierarchical structure. So this is sometimes called the hierarchical SAW method because the hierarchical levels in AHP are connected by algebraic addition. The crux of the AHP is to enable a decision maker to structure a MADM problem visually in the form of an attribute hierarchy, Yoon & Hwang (1995). AHP has been used as a means of aiding multiobjective choice, Zahedi (1986). This approach has been used to convert subjective judgements of relative importance into a linear set of weights, which can then be used to rank alternatives both in analyses involving one decision maker, as well as group settings.

According to Saaty (1995), the AHP is based on four principles:

1. *Decomposition*. A complex problem is decomposed into a hierarchy with levels consisting of a few manageable elements

2. *Prioritisation.* The impacts of the elements of the hierarchy are assessed through paired comparisons done separately in reference to each of the elements of the level immediately above
3. *Synthesis.* The priorities are pulled together through the Principle of Hierarchic Composition to provide the overall assessment of the available alternatives
4. *Sensitivity Analysis*. The stability of the outcome to change in the importance of the criteria is determined by testing the best choice against a what-if type of change in the priorities of the criteria

The AHP carries out pairwise comparisons of the elements involved in a decision in an appropriate manner to derive their scale of priorities. Only homogeneous elements are compared and to do this, clustering (constructing Hierarchy) is needed to group and compare such elements. A hierarchy should be structured to descend gradually from the most general factors (focus or overall goals) in a level to the more concrete and specified levels (competing alternatives) below. From the comparisons, priorities for the elements are derived in the form of the principal eigenvector of a pairwise comparison matrix. So this method also called the eigenvalue approach.

This comparison is made by using a scale of verbal judgement to make it possible to represent people's differences in feelings when they make comparisons. It also should represent all distinct shades of feeling that people have as well as possible.

There is no satisfactory statistical evidence showing how many points or which scale is best to express and divide people's preference. Many efforts have concentrated on comparing scales, but a hierarchy of no more than seven factors is recommended because of psychological theories concerning the limitation of the mind to consider more than some number of factors at one time. Detailed reasons for using a scale of nine in the research is described in section 5.3.2.

Using a verbal scale (an example of using verbal measurement is shown in section 5.3.2), the pairwise comparison procedure is carried out for each hierarchical branch.

Then in order to obtain an accurate relative score (priority) for each pairwise comparison table, the square matrix is constructed by entering the reciprocal of ratings at the corresponding symmetric locations for each criterion, in which the alternatives are compared with respect to that criterion. The criteria themselves are then compared in a similar way, resulting in a separate pairwise criteria matrix.

Table 3.6 Scale of Verbal Measurement

Numerical Value (Saaty's descriptor)	Definition
1	Equally important or preferred
3	Slightly more important or preferred
5	Strongly more important or preferred
7	Very strongly more important or preferred
9	Extremely more important or preferred
2, 4, 6, 8	intermediate values to reflect compromise

Next, the relative scale (priority) of importance can be obtained by normalising any column, and for each column, the implied relative importance weights can be obtained by dividing each column element by the column total. A number of means exists to obtain the overall weights. Saaty proposes the eigenvector of this matrix. In the method, the information in each matrix is aggregated using an eigenvalue procedure. This involves the calculation of scores and weights, which are then used in a weighted summation procedure to determine an aggregated appraisal score for each alternative plan. Details about this method is described in chapter 5.

	X	Y	Z	W_i
X	1	a	b	
Y	1/a	1	c	
Z	1/b	1/c	1	

X,Y,Z : each objective of each level or each group
a, b, c : relative importance between each objective by verbal scale
W_i : relative importance of group í

Figure 3.3 A Pairwise Comparison Matrix

AHP also provides a measure of consistency, which can be used to validate whether the differences in the ratios obtained were greater than expected at random. Saaty has proposed a cut-off limit of 10 percent of the mean inconsistency for random samples. If the consistency index for a pairwise matrix is above this limit, the pairwise comparisons should be redone with the intent of being more consistent. Details about this is also described in chapter 5.

The practical nature of the AHP method has led to its application in highly diverse areas including education, politics, and sociology. The AHP process has several major uses. It allows the decision maker to: 1) design a form that represents a complex problem, 2) measure priorities and choose among alternatives, 3) measure consistency and design feedback planning, 4) analyse conflict resolution.

Therefore, the AHP analysis is suitable for solving complicated decision problems particularly in rating decision alternatives for evaluation, selection or prediction. For the evaluation of the projects involving ranking decision alternatives for evaluation and selection and including tangible and intangible criteria with multiple decision makers, a method like AHP is considered to be appropriate for the step wise approach by construction of a hierarchy of multiple objectives, criteria and alternatives of this research. However, the AHP is not free from criticisms due to a few problems such as a large amount of data requirements, difficulty in structuring a hierarchy. Details about the AHP method is described in chapter 5.

3.4 Conclusion

In this chapter, most evaluation methods used for transport project evaluation were reviewed. Each has different characteristics (advantages and disadvantages), usage and requires different input data. It means many methodologies can be applied in various ways according to the situation, that is to say, transport mode and circumstances surrounding transport investment.

In Korea, cost-benefit analysis and financial analysis have been widely used because economic efficiency has been considered as the most important factor for evaluation. However, transport planning has been characterised by complexity and the country's socio-economic status has been changing rapidly due to economic development. Accordingly people's concerns shifted from the economic issues to other aspects such as environmental and social circumstances. So many conflicts have occurred in investment planning which potentially have a great impacts on a society with regard to socio-economic and environmental effects.

Therefore the recent work has focused on improving public participation and involving many diverse interests such as environmental and social welfare from various interest groups in the evaluation and decision process. As a result, many evaluation methods which are able to reflect and measure people's diverse interests and various factors in transport investment have been considered. In this respect, the utilisation of MCDM techniques have been recommended for this to complement traditional evaluation methods and to overcome drawbacks and conflicts resulting from current transport evaluation methodology and process, and then incorporate evaluation criteria and various opinions of interest groups into a framework.

This chapter showed the various methods in terms of their applicability and merits and demerits in use. Based on the information from this chapter, a suitable method shall be selected for the application of transport investment alternatives in Korea in next chapter.

Chapter Four

Comparison and Selection of A Method for Application

4.1 Introduction

In making decisions, we frequently encounter situations which involve a number of conflicting criteria and many alternatives. In most cases, however, we must make a decision, while the complexity leaves a great deal of uncertainty in our minds. Moreover, the difficulty of evaluating the complexity with suitable analytical techniques means that we are probably achieving lower quality outcomes than is desired.

Wedley (1990) notes that the complexity comes from two main sources; the first is our relative inability to conceptualise and structure the numerous components of the problem into a framework which facilitates understanding and analysis, and the second is the nature of the components - some are quantitative whereas others are subjective or non-quantitative".

The selection of an appropriate method for the application is, therefore, very important to make the decision easy and understandable for decision makers and public. In order to select the best one, all methods possible are to be compared with each other and selected by their capability to evaluate the transport project. In the previous chapter, we reviewed quite a few evaluation methods currently widely used.

This chapter firstly shows the comparison of evaluation methods based on the characteristics which were reviewed in the previous chapter and secondly the selection of method for this research through the comparison. In the first part, conventional

cost-benefit analysis is compared with multicriteria analysis, and then multicriteria evaluation methods, amongst them, several principal MCDM methods, are compared within each other. As a tool for comparison, a subjective judgement is used. In the second part, the most appropriate evaluation method among many methods is selected for the proposed methodology in this research with the reasons for the selection.

4.2 Comparison of Appraisal Methods

4.2.1 CBA vs. MCDM

For most people in most circumstances with a decision to make, they decide at a particular moment based on prior experience, intuition, advice from others, etc. However, some people have a very hard time making even the most mundane decisions and, in major decisions, we all have trouble in convincing others. Thus, for most decisions, we either approach the problem from an intuitive point of view or break the decision down into components in order to better understand the problem or communicate with someone else why a particular course of action was chosen, Golden et al (1989).

The simplest and most efficient decision making methodology among several recent methodologies is the intuitive approach in which one can decide the preferred alternative depending on intuition without analysis. But, for most decisions, one needs a more scientific and logical approach to decision making.

The second most popular method of decision making is the method of listing *pros and cons*, which is also analytical and does decompose the problem into subcomponents. Most decision makers have used this method at some point: take a piece of paper, list the positive aspects of an alternative on one side, the negative on the other, and choose the alternative with the most "*pros*." The most representative example is *the cost -*

benefit analysis, which has a long history, and was mostly used on a large scale since the 1930s.

Basically the method calls for an assessment of total costs and benefits of each of several alternatives in monetary units. It has been criticised for its restrictive assessments on quantifiable impacts, failure to analyse distributional incidences of benefits and costs, and inapplicability to systematic problems which include multiple factors and various interest groups within a framework even though it provides the conceptual foundation for most evaluation methods.

This method as a project evaluation tool is criticised from many sides. As we mentioned in the previous chapter, Nash (1993) stated that CBA had difficulty in conducting appraisal at a strategic level, so that a full range of options is not properly considered, and also failed to look beyond the direct effects to quantify and value a full range of relevant effects.

In addition, CBA can never alone determine the relative weights to be attached to the costs and benefits of different groups and to the items measured in monetary and non monetary terms. Moreover, it also doesn't consider the distributional incidence of benefits and costs between social groups or regions, so that it obscures to the decision-makers the nature of the various gains and losses.

Some elaborate techniques of cost-benefit analysis to overcome the weakness of conventional cost benefit analysis have been developed such as the *Social Cost Benefit Analysis* and *Planning Balance Sheet,* and the components of the techniques were modified depending on whether it is applied to public or private sector problems.

Planning balance sheet was developed as an alternative approach, which aims at a description of the effects of plan alternatives for the various social sectors. These effects are expressed in monetary terms or own unit of an item. Despite those efforts, the methods provide no explicit technique for eliciting and synthesising the weights of

each attribute and for systematising the preference of multiple decision makers between the various sectors and aspects. Nevertheless, as this analysis is concerned with various interest groups and weighting the different effects, but it is regarded as an extension of CBA, it may be viewed as a intermediate approach situated on the boundary of the monetary evaluation methods and multicriteria methods.

Nash (1993) stressed that a thorough attempt should be made to identify all relevant effects of projects and trace them back to appropriate incidence groups. For this purpose, cost-benefit analysis has to be improved and combined with other evaluation approaches, such as combination of cost-benefit analysis and multiple criteria decision taking systems, that enable the decision maker to consider more than economic efficiency.

As a result, Multiple Criteria Decision Making (MCDM) methods which serve to investigate a number of choice possibilities in the light of multiple criteria and conflicting priorities as a complementary tool of CBA have been required. MCDM methods are applicable to a wide variety of problems, capable of including multiple criteria and of comparing alternative plans or strategies so that decision makers are presented with useful and understandable information for appropriate decisions.

4.2.2 MCDM vs. MCDM

As there are many multicriteria methods and each of them has its own characteristics, usage, assumptions, it is very difficult to compare each other directly. So some are to be subjectively judged and selected by reviewing the main characteristics of each method such as practical usage, information and data requirement.

The methods to be considered in the scope of the research should be one of many MADM methods for ranking and selecting the best alternative among a given finite set of alternatives, and the MADM methods considered in this research are the several principal MCDM approaches, among them Multi-Attribute Utility Theory (MAUT),

Goals-Achievement Method (GAM), Outranking Methods (Concordance Analysis), and AHP analysis because of their popularity and capability.

In order to select the best suitable method for the research among these several methods, the advantages and disadvantages of each method in terms of each usage, capability and limitations are to be compared with each other.

Firstly, regarding MAUT, this approach is very useful for guiding decisions by means of a few advantages that make evaluations more likely to be used in decisions in similar ways as other several multicriteria evaluation methods. These advantages are various decision maker's involvement in evaluation process, the consideration of intangible impacts, useful and understandable results for decision makers.

Despite a few advantages and its popularity, MAUT is very complex and requires a heavy questioning process to develop the Multi-Attribute utility function. So this makes its adaptation for evaluation of transport projects with multiple criteria and decision makers difficult.

Moreover basically MAUT requires the decision maker to answer questions on an interval scale dealing with probabilities and then derives the utility function. In some contexts, the probabilistic questions are very natural, but in others they are very unnatural. It means that it is very difficult to get valid answers from respondents not used to probabilistic questions.

The main criticisms of this approach can be summarised as the following as in previous chapter:

- complexity and intricacy of the assessment of appropriate multiattribute utility function
- a heavy questioning process of the construction of multiattribute utility function
- difficulty in constructing Multi-Attribute utility functions in a practical situation.
- hypothetical prescriptive implications of the model utility

- difficulty in dealing with several levels of complexity

Contrary to Multi-Attribute Utility Theory, Goals-Achievement Method is quite appropriate for overall evaluation problem incorporating qualitative information which need to be treated with very simple and straightforward methods in the approach procedure for governmental policy measurement. This method, therefore, appears to be easier to use because of relatively little computational burden compared with the other methods. Moreover this can be easily constructed by the analysts and understood by the decision maker.

However, this method has several limitations in application. Firstly, as the various goals of each group are in conflict, it is not easy to derive weights because the weights apply to all groups equally. And secondly, as many specified criteria (or goals) are considered, the problem is becoming more sophisticated and difficult to handle because this method is better for one or two major overall goals achievement assessment. Thirdly, it is difficult to include a comprehensive consideration of sectors to be affected by transport plans even though the application of the goals-achievement matrix requires the weighting of objectives and their incidence.

The key to plan evaluation by means of goals-achievement analysis is the identification and weighting of objectives for alternatives, groups or sectors. The determination of objectives and their relative valuation is no easy task and requires considerable research because each group has his own preference for each goal, but this method requires a unique single weight for each goal. In this respect, the goals-achievement matrix has a disadvantage in getting weights by consensus because there is no single approach to this problem that is universally applicable even though there can be a few approaches such as empirical review or sensitivity analysis for the problem.

So the goals-achievement matrix has a disadvantage in getting weights by consensus because each group has his own preference for each goal, but it requires a single weight for each goal even though, for the determination of weights, there can be a few

approaches such as empirical review or sensitivity analysis (see section 3.3.1). In addition, this method has some disadvantages in the evaluation of the projects with several criteria, multiple decision makers because it has been devised for the evaluation of plans for development in a single functional sector, Hill (1973). Therefore, it is difficult to be used for the evaluation of complex projects including a comprehensive consideration of sectors to be affected by transport plans.

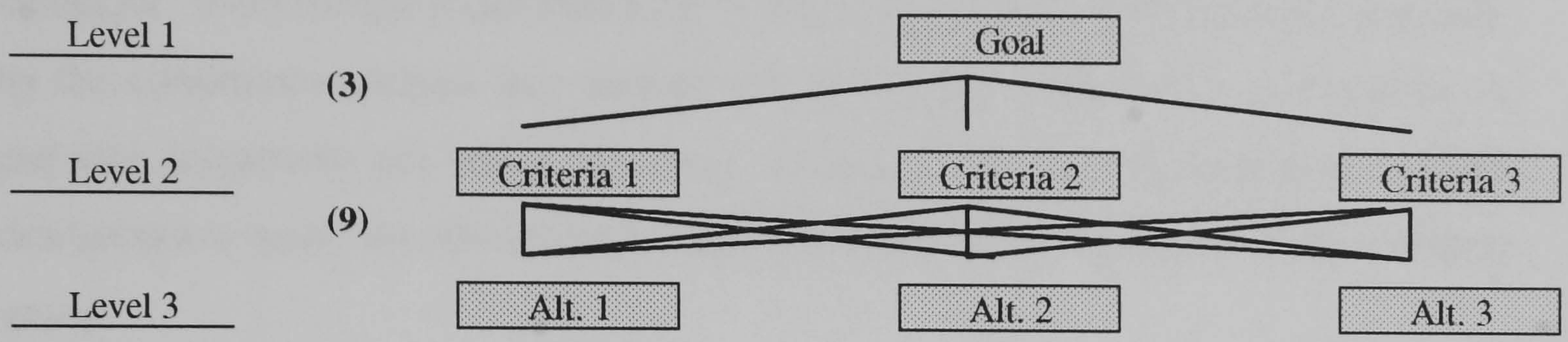
The outranking methods have the advantages in terms of its interaction requirement between analyst and decision maker. Nevertheless the exploitation of an outranking relation in order to obtain the best decision or in order to rank them is much more difficult because of technical complexity inherent than in the Multi-Attribute Utility Theory and Goals-Achievement Method.

This may make this method difficult for the decision maker or layman to comprehend because final selection of the best alternative is based on the both numbers of concordance index and discordance index and there is no appropriate way to compromise these two indices. Moreover, if there are multiple decision makers, this method is not appropriate because the alternative selection procedures and implementation are heavily influenced by many different decision making groups in real world situations.

AHP is also criticised for a large amount of data requirements. As the number of levels and the number of criteria increases, the number of paired comparisons required rises quite dramatically. For example, if there is a hierarchy of 3 levels with overall goal, 3 criteria and 3 alternatives, it requires 12 numbers of pairwise comparisons to derive the weights (pairwise comparisons of importance of each criteria for overall goal - $3(3-1)/2 = 3$, comparison of alternatives for each criteria - $3(3-1)/2 \times 3$ criteria = 9).

However, if the level increases to 4 (each criteria has three sub-criteria respectively), the number of pairwise comparisons increase to 39 (importance of each criteria for

overall 3, importance of sub-criteria for each criteria 3(3-1)/2 × 3 criteria = 9, comparison of alternatives for each sub-criteria - 3(3-1)/2 × 3 × 3 = 27).



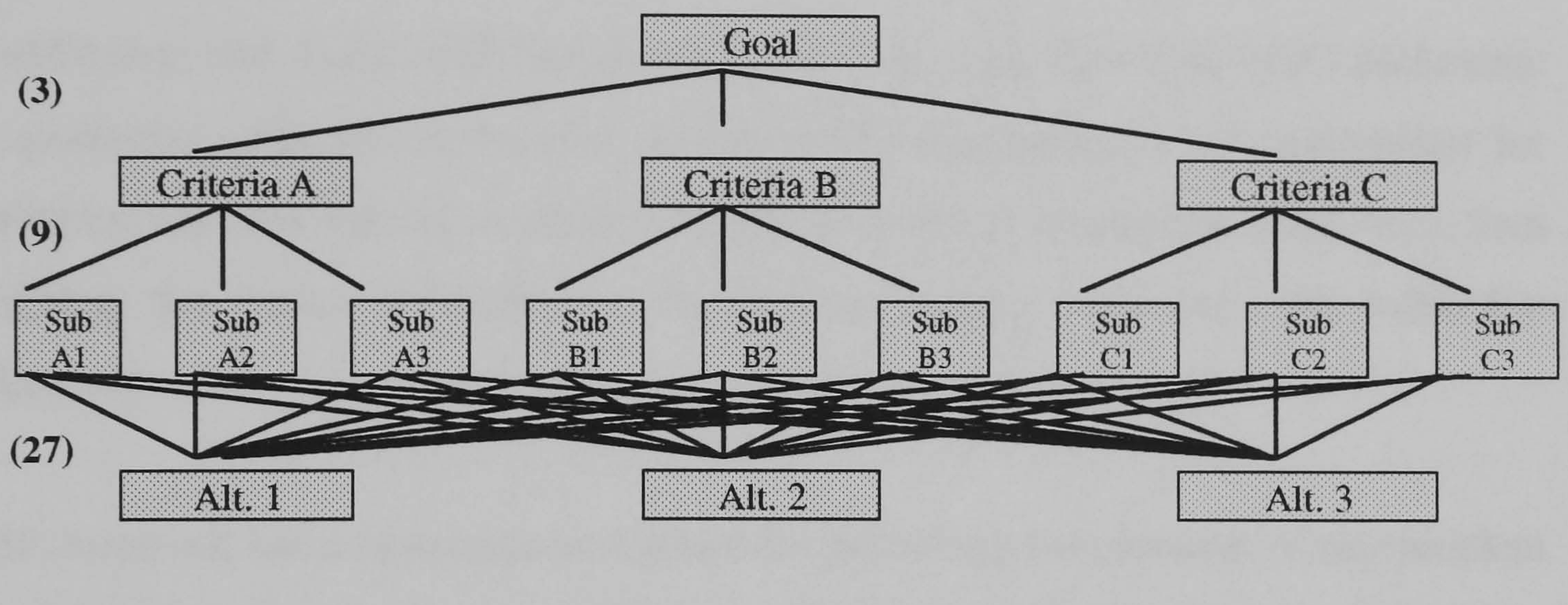


Figure 4.1 Hierarchy Samples for 3, 4 Levels and its Number of Comparisons

Another drawback of the AHP is that it is very difficult to reach agreement about the overall hierarchical structure of the decision problem, so one can have different hierarchies from a group of individuals on the same decision problem. For example, consider a group that is trying to decide on the best course of action to construct a new road in a local city. The local community members might argue that environmental issues such as noise and ecology are the key decision factors and favours placing near the top of the hierarchy. Another member might take a broader view and talk about the transport, economic, social and environmental factors, then those issues of community group appears as those of the sub-criteria of the environmental factors.

Debate and discussion among the participants can be used to generate a hierarchy that adequately presents a problem, but reaching agreement may prove to be quite difficult., Moreover, there is no appropriate way to check the validity of a structure of a hierarchy. Even though it can feed back to the starting point of structuring a hierarchy by the consistency analysis (see section 5.4, 6.3.4), it is limited to a few number of pairwise judgements not whole structure. Therefore, we have to depend on enough discussions to make the differences narrow in judgement among stakeholders or expert group.

In addition to this, as the AHP was developed for the evaluation of people's preference for qualitative evaluation items as a decision aid for management, it is appropriate for qualitative decision making to decompose the complex problems into small ones, then weighting the factors according to the decision group's preference and subjective judgement.

AHP, however, has a systematic procedure for presenting the elements of any problem hierarchically. It organises the basic rationality by breaking down the problem into smaller constituted parts and then guides decision making through a series of pairwise comparison judgements to express the relative strength of intensity of the elements in the hierarchy. Moreover, it is a group decision making methodology, in which judgements of individuals can be all fused into a single judgement through compromises or through the geometric mean criterion. Hence a method like AHP is considered to be appropriate for the step wise approach by construction of a hierarchy of multiple objectives, criteria and alternatives including tangible and intangible criteria with multiple decision makers involved.

By applying the AHP to structure complex problems, we achieve three extensions of traditional methods. First is that we can quantify intangible, non-economic factors which have so far not been effectively integrated in traditional decision making, second is that this approach can make explicit and informed tradeoffs among multiple selection criteria, including multiple performance objectives and output activities. Third one is

that criteria of all the projects could be categorised under many labels such as social, economic, political according to the overall goal or strategy, and that the interdependence of these categories could be accounted for in the assessment of alternatives. As the objectives and their attributes can be changed or set up in structuring a hierarchy according to its goal or strategy of investment, the AHP can compare a lot of alternatives and their attributes in a pairwise fashion in terms of the strength of their respective contribution to the fulfilment of goal or strategy.

Therefore, this approach can be applied to strategic planning, the process of knowing how to attain desired future, using the knowledge to steer the logical future toward a more desired one, and then repeating the operation, by incorporating the informed judgements and intuition of experienced decision makers, by allowing for discussion of conflicting judgements among multiple decision makers and stakeholders, and by accounting for interaction among the elements of a planning problem, proceeding logically from objectives through criteria to alternative solutions or mixes of solutions.

For comparison, it can also be possible to compare with some criteria established in advance for comparison. Kirti (1992) has carried out this comparison by subjective judgement through the establishment of some criteria and this shows the differences between methods.

According to her research, she compared and evaluated several multicriteria methods (group decision making methods) with quite a few criteria. She set up quite a few criteria for the evaluation of many methods. Among them, several criteria such as *effectiveness of group decision making, prioritising group members, consideration of other actors and stakeholders, applicability to intangibles, validity of the outcome* were considered more important than other criteria in comparing many group decision making methods for the research.

Summarising the results from the comparison by Kirti (1992), they are:

- *Effectiveness of group decision making*: AHP provides collaborative tools to enhance communication effectiveness, inconsistency measures that provide feedback to the group members to ensure validity of the outcome, the means to obtain group judgements, while Outranking and MAUT provide nothing more than simple structures to assist a facilitator.
- *Prioritising group members*: Outranking and MAUT treat individual members of the group equally, and relative weights can only be assigned rather arbitrarily. With the AHP, the hierarchy levels may include areas of responsibilities or expertise that can be used to prioritise the individuals.
- *Consideration of other actors and stakeholders*: MAUT with its limited structural representations makes it difficult to address the possible diversity of actors, while AHP can facilitate a group to explicitly include other actor's concerns as parts of the problem structure and quantify them.
- *Applicability to intangibles*: Outranking and MAUT must use absolute measurement, but AHP's fundamental measurement ensures its applicability to intangibles naturally, that gives discretion to the user whether using relative, ideal, or absolute measurement.
- *Validity of the outcome*: The reliance on ratio scales of the AHP derived from pairwise comparisons which enable one to model a problem by ordering its elements and levels in a structured way to legitimise the meaningfulness of the comparisons, while Outranking and MAUT use cardinal measurement with a relatively simplified model representation.

Kirti (1992) also thought a method must be applicable, valid, and reflect the truth as follows: "One, therefore, would be concerned with such issues as: (1) is the method applicable to conflict resolution, (2) does it apply to intangibles in the same way it does to tangibles, (3) does it have mathematical validity and generality, and is it supported with axioms and theorems, (4) is the outcome valid, ensuring, for example, reliability in prediction".

Applicability to conflict resolution means the method must provide a way for each conflicting party to evaluate the costs and the benefits of giving up some of what it has, in return for getting what it wants from the other party. *Applicability to intangibles* involves inclusion, and measurement of, the multi dimensionality of the factors involved. *Mathematical validity and generality* calls for formal mathematical representation of the logic and reasoning behind a theory and the economy of additional assumptions required for its generalisation. *Validity of the outcome* involves the accuracy of the outcome in predicting situations.

From the results of subjective evaluation with its criteria, the AHP method is relatively well evaluated over most criteria compared with other group decision making methods, firstly in prioritising group members, secondly in consideration of other actors and stakeholders as the appropriate method that facilitates a group to explicitly include other actor's concerns, thirdly in scientific and mathematical generality, fourth in good applicability to intangibles and conflict resolution, and fifth in fine validity of the outcome.

Whilst outranking method and MAUT have several weaknesses in that they treat individual members of the group equally, their limited structural presentation not to address the possible diversity of actors, and they use cardinal measurement with a relatively simplified model representation.

She concluded that AHP makes group decision making intrinsically efficient for at least three reasons: (1) it provides a framework and tools for group collaboration that systematise the group process, (2) it enables the group to break its task into distinct sub-tasks, with each managed almost independently with respect to the manpower allocated and to the group techniques used, and (3) it provides feedback measures to facilitate judgement improvement while allowing a certain degree of inconsistency in the judgements.

4.3 Selection of A Method for Application

4.3.1 Background of The Project

The project to be considered as a case study in this research is to develop the railway network passing by a historic city with many cultural assets. Therefore it has long been debated in Korea about the development of a railway there and which alternative is the best network if it is to be developed. Those debates resulted from the conflicts between transport efficiency maximisation and cultural conservation among various stakeholders affected by the project.

The project has a set of finite alternatives, already defined, which is a part with a station of the whole high speed railway line from Seoul to Pusan. The issue is to choose the best alternative among a given set of alternatives which is able to compromise two conflicting goals and also to satisfy various stakeholders affected by the project.

All the alternatives are similar to each other because the part of line is located on such a small local area that the difference between each route and the location of station is slight. It means a similar travel demand and capacity supply to the local area. So it does not need specific commercial feasibility or financial analysis as in normal railway evaluation as it was considered in the feasibility study of the development of HSR in Korea.

Hence the various multiobjective decision making methods are not considered to be appropriate. It requires the evaluation methods for selecting the best transport scheme alternative which is able to include and analyse the various factors including intangible ones and multiple decision makers affected by the project.

Unfortunately, there is no specific rule because different MADM methods are used for different situations. The methods for this research has to be a multicriteria evaluation

methods that is capable of handling multiple criteria problems and to have the ability to organise and analyse systematically the multiple criteria including tangible and intangible criteria such as economic, environmental and transport impacts and the preference of multiple decision makers as well. In higher level policy situations, wherein respondents are asked to compare alternatives that entail multiattribute impacts, responses become considerably more complex.

4.3.2 Selection of A Method for Application

For these reasons, an approach that would require information regarding preference on and tradeoffs between transport system attributes without requiring the respondent to consider and compare complex bundles of attributes simultaneously may be suited to the task of comparison between alternative transport policies.

The best method chosen for this research is, therefore, one among many MADM methods for the ranking and selection of the best alternative among a given finite set of alternatives, and among them the AHP analysis is considered to be very appropriate because of the characteristics of systematic and hierarchical procedure for solving the complex transport problem including multiple decision makers and multiple attributes as discussed in 4.2.2.

According to Carlson (1995), the AHP has some strengths as a decision system. An obvious strength is that it permitted us to collect all the relevant elements of the problem into one model and then to interactively work out their interdependencies and their perceived consequences. Another strength of the AHP comes from its reliance on pairwise comparisons, which force AHP users to articulate the relative importance of criteria and then to decide the relative contributions of their alternatives to the criteria.

A third strength is the hierarchy used in the AHP; it was very useful in structuring the problem. A fourth strength is the inconsistency measure; users need to know when they have made inconsistent judgements, especially if they are working as a group.

People want to be logically consistent in making decisions, especially regarding politically sensitive issues, for example, transport facility location, that have been the target of heated public debate.

Despite a few weaknesses as mentioned in the previous section, the AHP method is a valid descriptive theory of decision making among several multicriteria methods and can easily be developed to become a still better descriptive theory of decision making. It has some advantages in view of rating decision alternatives for evaluation, selection and handling both quantitative and qualitative parameters systematically and efficiently in the complex alternative by allocating weights for them.

Of course, other decision making tools exist which can be useful in their proper contexts. We should be very careful to understand where they would fit and where they would not in each of these methods. While being more formal than simple pros-cons choices and not dealing directly with probability/risk as in MAUT, the AHP does provide an efficient and effective tool for decision making in a wide range of problems.

Comparison would be very easy if all items could be quantified in numerical values. However, many items can not be monetarised and current situation in decision making including transport field requires the evaluation on various impacts or interests, which needs more systematic evaluation framework to handle whole impacts from various interest groups. In this research, the AHP which has the systematic and hierarchical procedure for solving the complex problem with qualitative and quantitative factors is to be used as a main scheme of methodology. Alongside the AHP, the basic concept of cost-benefit analysis is to be used with the AHP for complementing it to quantify all evaluation items for the tangible factors which can be quantified in units.

4.4 Conclusion

This chapter has provided us with an opportunity to compare many methods and to select most appropriate method for the evaluation of transport investment project. The AHP method is found to be most appropriate in that it is able to deal with intangibles and with many stakeholders and multiple attributes by mathematical generality and validity.

This method helps to select from various alternatives that contain complex attributes such as tangible or intangible ones. Because of its simplicity, practicality and validity, it has been applied in diverse and numerous areas such as economics and planning, management, conflict resolution, project selection, budget allocation, politics, sociology etc.

The Analytic Hierarchy Process (AHP) is one such process which is able to both structure problems and combine quantifiable and intangible attributes that has found rich applications in decision theory, conflict resolution for solving the problem like above. Vargas (1990) emphasised the advantage of AHP "The AHP provides a general theory of measurement for expressing both tangible and intangible factors. It is based on the principle that, to make decisions, experience and knowledge of people is at least as valuable as the data they use".

According to the comparison, the AHP is used as a main methodology for the application of the transport investment project with many attributes and stakeholders to elicit and synthesise the weights of each attribute and the preference of multiple decision makers in this project. These are for checking the applicability to the transport project appraisal in Korea as a one of multiple criteria decision making methods.

Chapter Five

Analytic Hierarchy Process

5.1 Introduction

In the previous chapter, it has been concluded via comparison of several evaluation methods that the combination of CBA and AHP was most appropriate for the evaluation of transport projects with many stakeholders and multiple attributes. This chapter will explain the proposed methodology, Analytic Hierarchy Process, in detail for the appropriate application to be discussed in next chapters.

5.2 Overview of The AHP

5.2.1 Background of The AHP

The lack of a coherent procedure to make decisions is especially troublesome when our intuition alone can't help us to determine which of several objectives or alternatives is the most desirable, and neither is logic of any help. Individual knowledge and experience are inadequate in making decisions, and so participation and debate are needed both among individuals and between the groups affected.

But making decision only with participation and debate is limited to very simple and small problems, and in the cases with many groups and criteria affected it is of much greater difficulty. Therefore we need a logical and systematic way to build consensus and compromise to determine which objectives or alternatives outweighs another.

A decision making approach for solving the problems should be simple in construction, adaptable to both groups and individuals, natural to our intuition and general thinking, easy to understand and communicate, and logical in theory. The approach, therefore, needs various kinds of knowledge, information, and technical data for the problems for concerning decision making, the people or actors involved, their objectives and policies, and the influences affecting outcomes. All of this information should also be resolved in a decision making process and be progressed step by step for making decisions, such as a framework from structuring a problem through derivation of judgements to synthesising these results.

The analytic hierarchy approach to systems design and problem solving provides a solution to the requirement mentioned above, and it draws upon the innate capacity of humans. The AHP is based on the innate human ability to think logically and creatively, i.e. to identify events and establish relations among them, and then to make sound judgements, and so it facilitates decision making by organising perceptions, feeling, judgements, and memories into a framework that exhibits the forces that influences a decision.

In this respect, Saaty & Kearns (1985) note that "people have three communicative attributes. The first is their ability to impart and observe things, the second is their ability to discriminate by establishing relations and their intensity among what is observed and the third is to synthesise their relations into a total understanding". These abilities are evolved into *the principle of identity* and *decomposition*, *the principle of discrimination* and *comparative judgement (prioritisation),* and *the principle of synthesis* in the AHP

Since it was invented by T. L. Saaty, the analytic hierarchy technique has evolved into a very flexible tool for decision making and this method is applied in diverse and numerous areas such as shown on the following page over the years. However, as it served as a qualitative analysis tool for decision making, it has not often been used in

the transport field. A number of typical application examples of AHP are listed below, Zahedi (1986) as well as a few applications in transport field:

- economics and planning: *Application of The Analytic Hierarchy Process to Long-Range Planning Process,* Emshoff and Saaty 1982, European Journal of Operational Research
- energy (policies and allocations of resource): *A Desired Energy Mix for The United States in The Year 2000: An Analytic Hierarchy Approach,* Gholamnezhad and Saaty, 1982, International Journal of Policy Analysis and Information Systems
- conflict resolution: *The Forward and Backward Processes of Conflict Analysis,* Alexander and Saaty, 1977, Behavioural Science
- project selection: *Prioritisation of Research Projects,* Johnson and Hihn, 1980
- marketing, budget allocation: *Marketing Applications of The Analytic Hierarchy Process,* Wind and Saaty, 1980, Management Science. *A Network Optimisation Model for Budget Allocation in A Multi-Campus University,* Sinuany-Stern, 1984, Journal of the Operational Research Society
- politics, sociology: *A Theory of Analytical Hierarchies Applied to Political Candidacy,* Saaty and Bennett, 1977, Behavioural Science. *Projecting Average Family Size in Rural India by The Analytic Hierarchy Process,* Saaty and Wong, 1983, Journal of Mathematical Sociology
- environment: *High Level Nuclear Waste Management: Analysis of Options,* Saaty and Gholamnezhad, 1982, Environment and Planning B
- Transport: *The Analytic Hierarchy Process: Scenarios Priorities and Cost-Benefits for The Sudan Transport Plan*, Saaty, 1981, Operational Research. *Analytic Hierarchy Process in The Benefit Cost Framework: A Post-evaluation of The Trans-Sumatra Highway Project*, Aziz, I.J., 1990, European Journal of Operational Research, 48/1

5.2.2 Principles and Axioms of The AHP Theory

Vargas (1990) defined the AHP as a theory of measurement which was able to both structure problems and combine quantifiable and intangible attributes that has found

rich applications in decision theory, and in conflict resolution for solving problems. It is based on the principle that, to make decisions, experience and knowledge of people is at least as valuable as the data they use.

Saaty (1994) and Vargas (1990) notes that a useful feature of the AHP is its applicability to the measurement of intangible criteria along with tangible ones through ratio scales. In addition, by breaking a problem down into its constituent parts and relating them in a logical fashion from the large parts, descending in gradual steps, to the smaller and smaller parts, one is able to connect through simple paired comparison judgements the small to large and so to understand the problems for making decisions more easily by *the principle of identity* and *decomposition*, *the principle of discrimination* and *comparative judgement* mentioned in the above section.

A major assumption of the AHP is that all knowledge is subjective and that the methods we employ in predicting knowledge and in controlling our processes are also subjective. AHP can incorporate judgements based on intuition (and experience), quantitative facts and analysis. Trade-offs among alternatives can be handled using AHP without the requirements that all dimensions of the decision problem use a uniform scale.

For instance, cost-benefit analysis, intuitive judgement, multicriteria, panel consensus, can be integrated into an AHP model. Because of its flexibility, AHP has been applied in a variety of decisions and planning projects, especially in qualitative decision making. Some of the advantages and disadvantages of the Analytic Hierarchy Process were reviewed in the previous chapter. If we summarise the advantages using AHP method once again, it can be expressed based on Geoffrey (1992) as in Figure 5.1.

The AHP is a tool that is found in a wide range of problem areas and the axioms of the theory are as follows, Saaty (1994, 1995).

- Axiom 1: (reciprocal comparison). Whenever we make paired comparisons we need to consider both members of the pair to judge the relative value. The

comparison matrices that we consider are formed by making paired reciprocal comparisons. Decision makers make comparisons and state the strength of his

Unity:

The AHP provides a single, easily understood, flexible model for a wide range of unstructured problems

Process Repetition:

The AHP enables people to refine their definition of a problem and to improve their judgement and understanding through repetition

Complexity:

The AHP integrates systematic approaches in solving complex problem

Judgement and Consensus:

The AHP does not insist on consensus but synthesises a representative outcome from diverse judgements

Decomposition:

The AHP can decompose large problems into small ones which we can understand easily.

AHP

Tradeoffs:

The AHP takes into consideration the relative priorities of factors in a system and enables people to select the best alternative based on their goals

Hierarchic Structuring:

The AHP reflects the natural tendency of the mind to sort elements of a system into different levels and to group like elements in each level

Synthesis:

The AHP leads to an overall estimate of the desirability of each alternative

Measurement:

The AHP provides a scale for measuring intangibles and a method for establishing priorities

Consistency:

The AHP tracks the logical consistency of judgements used in determining priorities

Figure 5.1 Advantages of The Analytic Hierarchy Process

preferences. The intensity of these preferences must satisfy the reciprocal condition, i.e., $a_{ij} = 1/a_{ji}$ for all i, j (A If element A is x times more preferred than element B, then B is 1/x times more preferred than A). The violation of Axiom 1 indicates that the question used to elicit the judgements or paired comparisons is not clearly or correctly stated.

- Axiom 2: (homogeneity). Homogeneity is essential for comparing similar things, as the mind tends to make large errors in comparing widely disparate elements. When the disparity is great, the elements are placed in separate clusters of comparable size giving rise to the idea of levels and their accommodation. Therefore the preferences are presented by means of a bounded scale for the comparison of elements within the same level. It means that the decision maker never judges one to be infinitely better than another, i.e., $a_{ij} \neq \infty$ for all $i, j \in A$ If Axiom 2 is not satisfied, then the elements being compared are not homogeneous and one may need to form clusters.

- Axiom 3: (dependence). Decomposition implies containment of the small elements by the large clusters or levels. In turn, this means that the smaller elements depend on the outer parent elements to which they belong, which themselves fall in a large cluster of the hierarchy. The process of relating elements in one level of the hierarchy according to the elements of the next higher level expresses the outer dependence of the lower elements on the higher elements. This way comparisons can be made between them and the steps are repeated upward in the hierarchy through each pair of adjacent levels to the top element, the goal. The elements in a level may depend on one another with respect to as property in another level. If Axiom 3 is not satisfied, the principle of hierarchic composition would no longer apply because of outer and inner dependence among levels or components which need not form a hierarchy.

- Axiom 4: (expectations). For the purpose of making a decision, the hierarchic structure is assumed to be complete. All criteria and alternatives which impact on

the given decision problem are represented in the hierarchy. If Axiom 4 is not satisfied, then the decision maker is not using all the criteria and/or all the alternatives available or necessary to meet his reasonable expectations and hence the decision is incomplete.

5.3 Application Procedure of The AHP

The application of the AHP method is based on the three main principles, *the principle of decomposition*, *the principle of prioritisation (measurement of preference)* and *the principle of synthesis*. According to these principles, decision applications of the AHP are carried out in two phases: *Hierarchy Design and Evaluation phase*.

The design of hierarchy requires a thorough experience and knowledge of the decision problem. There is, however, no unique hierarchy that describes problems, so one can have different hierarchies from a group or individuals on the same decision problem. Therefore, it requires that a group of people work together to reach consensus through discussion and negotiation on the hierarchy design.

The evaluation phase consists of two steps, prioritisation (measurement of preference) and synthesis, and is based on the concept of paired comparisons. The elements in a level of the hierarchy are compared in relative terms as to their importance or contribution to a given criterion in the level immediately above the elements being compared.

In the comparison, judgements are expressed as a ratio, a relative scale of measurement of the priorities or weights of the elements. The relative weights or intensities of the items being compared are represented in matrix form which is used to derive a priority vector which in turn gives an estimate of the preference structure. The final or global weights of the elements at the bottom level of the hierarchy are obtained by adding all the contributions of the elements in the level with respect to all

the elements in the level above. This is known as *the principle of hierarchic composition.*

Using AHP in solving a decision problem involves four steps.

- Step 1 (*Decomposition: hierarchy design*)) : A complex problem is decomposed into a hierarchy with each level consisting of a few manageable elements by breaking down the decision problem into a hierarchy of interrelated decision elements via group discussion and consensus.
- Step 2 (*Prioritisation: measurement of preference*) : The impacts of the elements of the hierarchy are assessed and prioritised through paired comparisons done separately in reference to each of the elements of the level immediately above. Relative weights of decision elements are derived at each level.
- Step 3 (*Synthesis: aggregation of relative weights*) : The priorities are pulled together through the principle of hierarchic composition to provide the overall assessment (global priority) of the alternative.
- Step 4 (*Sensitivity analysis*) : The stability of the outcome to changes in the importance of the criteria is determined by testing the best choice against "what-if" type of change in the priorities of the criteria.

At step 1, which is perhaps the most creative and crucial part of the AHP to get desirable outcomes, the decision analyst should break down the complex decision problem into a hierarchy of homogeneous decision elements and this also should be structured to descend gradually from the most general goal in a level to the more concrete and controllable factors in the level below.

In setting up the decision hierarchy, the number of levels depends upon the complexity of the problem and on the degree of detail the analyst requires to solve the problem. Since each level entails pairwise comparisons of its elements, Saaty (1995) suggests that the number of elements at each level be limited to a maximum of nine based on G.A.Miller's theory (Miler, 1956) to be described later.

In step 2, all the elements at each level are compared for each pair of elements of one level that contribute to achieving the objective of the next higher level. Verbal statements are provided to assign values to paired comparisons of elements. $\frac{n(n-1)}{2}$ number of pairs in each level are compared, where n means total number of elements being compared in each level. Individual judgements are, then, combined to get the group judgement.

After getting the group (combined) judgement on each pair of each matrix, the relative priority (weights) is derived on each matrix with the group judgement data combined. This priority is derived for all the matrices and this can be accomplished by using several principal methods such as *eigenvector, geometric row mean or logarithmic least square method.*

Step 3 aggregates relative weights of various levels obtained after completing comparisons for every element at each hierarchy level at step 2. This step is to produce a vector of composite weights which serve rating of the decision alternatives in achieving the most general objective of the problem. The global priorities are used in making final decisions.

Finally in step 4, the stability and robustness of a decision made is checked by what-if type of change (sensitivity analysis) in the weights against stakeholders and elements.

The specific steps involved in the development and analysis of an analytical hierarchy are summarised by Vargas & Dougherty (1982), and this process was slightly modified in more detailed way as follows.

1. Define the problem and specify the overall goal (solution) desired.
2. Structure the hierarchy from the overall goal through relevant intermediate levels to the alternative level which is able to solve the problem.
3. Compare all the elements for each pair of elements of one level that contribute to

achieving a criterion of the next higher level.

4. Obtain all *n (n-1)/2* judgements at each level

5. Produce a group judgement as an input data for derivation of relative priority, and then produce a pairwise comparison matrix of each element or criterion.

6. Derive the relative priorities at every matrix with consistency analysis.

7. Steps 4,5, and 6 are repeated for all levels and clusters in the hierarchy.

8. Hierarchical composition is now used to derive the overall priorities and the sum is taken over all weighted priorities corresponding to each element to obtain the composite priority of the element in a level.

9. Consistency is then evaluated for the entire hierarchy by simply multiplying each consistency index by the priority of the corresponding criterion and adding all such products. Unless the ratio should be acceptable under the threshold value, the quality of the judgmental data, hierarchy should be reviewed and improved.

5.3.1 Design of A Hierarchy (Decomposition)

In the AHP, a problem is structured as a hierarchy. A useful way to proceed is to come down from the goal as far as one can by decomposing it into the most general and most easily controlled factors. Decomposing a complex decision problem into smaller and less complex entities enables a decision maker or an analyst to identify the factors that are important to the decision problem and it also helps to reveal how the factors relate to one another.

Constructing or designing a hierarchy requires a thorough understanding and experience of the decision problem. However, as there is no unique hierarchy that describes the problem, one can have different hierarchies from a group of individuals on the same decision problem. Therefore, enough discussions through brainstorming and negotiations to narrow differences in judgement is highly required when there are a number of people or groups that have a stake in the problem,.

Saaty (1994) suggests the following process for an elaborate design of a hierarchy: (1) Identify the overall goal. What are you trying to accomplish? (2) Identify the subgoals of the overall goal. (3) Identify criteria that must be satisfied to fulfil the subgoals of the overall goal (4) Identify subcriteria under each criterion. (5) Identify the actors who will be affected by your definition of the problem. (6) Identify the actors'(or stakeholders') goals and policies through giving them an opportunity to participate in constructing the hierarchy. (7) Identify options or outcomes.

What to include in a hierarchy requires a certain amount of expertise and experience. Nevertheless, there is sufficient commonality between structures to allow generalised guidelines to be satisfied. Wedley (1990) summarised the process for hierarchy structuring as follows:

- Include only relevant and sufficient detail. Sufficient detail means that all relevant aspects and perspectives are included in the problem, but not so many that the problem becomes too large or unwieldy.
- Work downwards from perspective level, through criteria levels, to alternative.
- Have nine items or fewer below each level. Based upon the psychologist G. A. Miller's finding* that humans have difficulty when considering more than nine items (exactly seven plus or minus two) at one time, it is recommended that nine items or fewer items should be below any level in the hierarchy. If more than nine items are relevant, then they should be decomposed into an additional level whereby there are two or more homogeneous sub-groups, Golden et al (1989).

  * Saaty (Fundamentals of Decision making and Priority Theory, 1994) explained it in more detail. "This explanation has to do with the brain limit on the identification of simultaneous events. The perception or simultaneity span is the ratio of the buffer delay time to the attention integration time. The more intense the stimulus the greater the perception or simultaneity span. The reason is that with increased intensity the time of span integration reduced. The most common duration time estimate for the short term memory (buffer-delay) is 750 milliseconds and that for item-integration time is 100 milliseconds. Therefore, the ratio is about seven".

- Cluster like elements of the same order of magnitude. On any level, the items should be homogeneous (similar nature) and within the order of magnitude.

5.3.2 Determining The Priorities (Prioritisation)

The next step is the evaluation of the hierarchy made via discussion and negotiation. The respondents translate their information about elements or alternatives into paired comparisons by answering questions. For this, verbal statements are provided as a measurement of preference and the judgements are expressed as ratios from a numerical scale. This procedure is repeated for the elements in a level with respect to the all elements in the level above. The relative weight of the elements being compared are represented in matrix form which is used to estimate the underlying unidimensional scale on which the elements in a level are measured.

If we take an example of analytic hierarchy analysis, overall implementation procedure will be very easy to understand, and an example was taken from the AHP analysis of Vargas (1990). This case is to choose the best house to buy among three candidate houses. The first step is the structuring of a hierarchy. For this, it has been assumed that the family already identified eight criteria they considered very important and three alternatives with different specifications against criteria were defined.

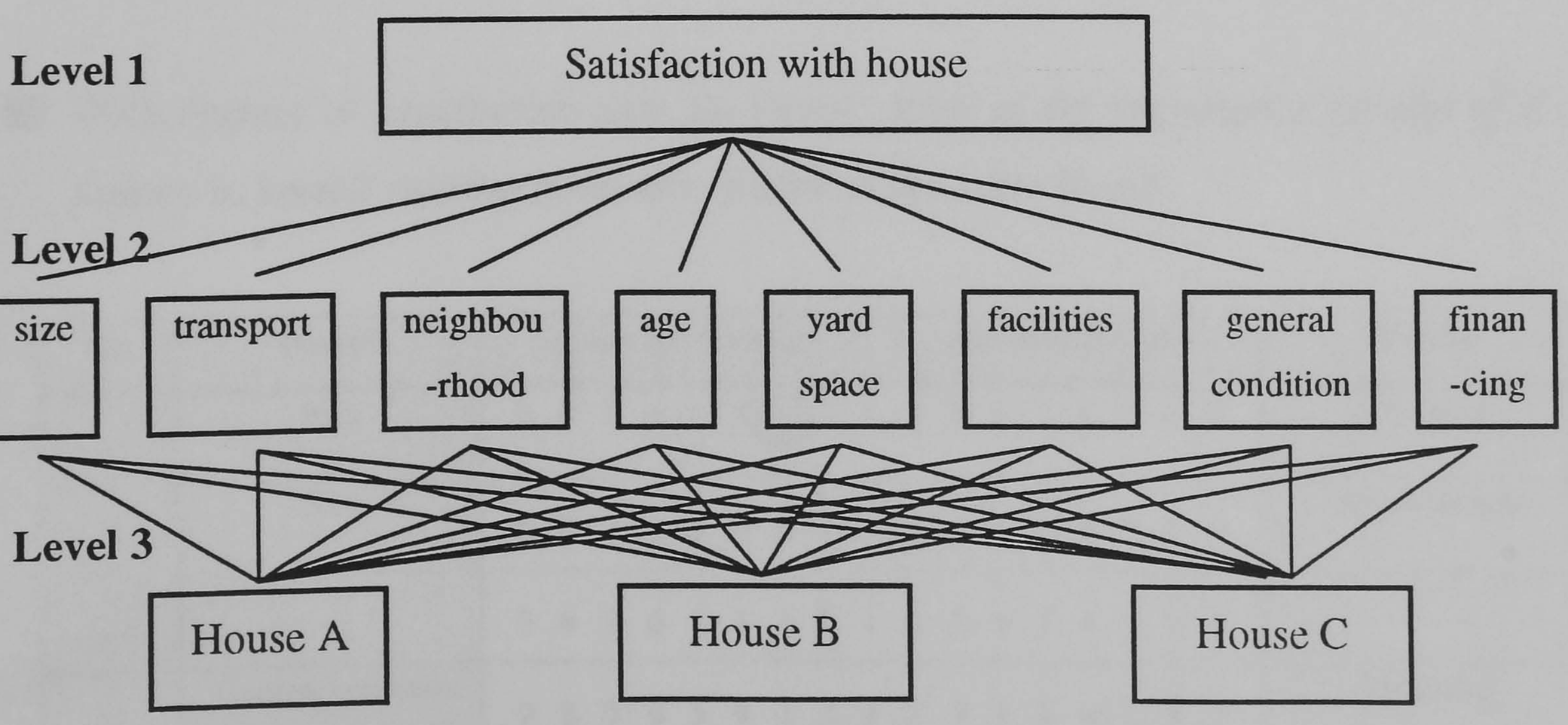


Figure 5.2 A Hierarchy for House Choice Example

In the first level, is the overall goal of "Satisfaction with house". In the second level are the eight criteria which contribute to the goal, and the third level are the three candidates.

- ***Pairwise comparison***

After constructing the hierarchy, the AHP proceeds by implementing a measurement methodology to establish priorities among the elements within each level of the hierarchy. This is accomplished by asking the participants to evaluate each set of elements in a pairwise fashion with respect to each of the elements at the next higher level. Using the 1-9 ratio verbal measurement of scale, the participants assess the dominance of each element over the others with respect to each element of the next higher level of the hierarchy.

In this example, the questionnaire to get the preference for the level 2 (factors' preference) may be "With respect to satisfaction with the house , what is the importance of *one of 8 factors in level 2* relative to *another factor* in same level?", and the questionnaire for level 3 "With respect to a factor ("**Size**" for example), what is the desirability of House A relative to House B or House C?",

* Example 1 : pairwise comparison between factors with respect to overall goal

■ *With respect to satisfaction with the house, what is the importance of one of 8 factors in level 2 relative to another factor in the same level?*

No.	Factor	←more important								more important→									Factor
1	Size	9	8	7	6	5	4	(3)	2	1	2	3	4	5	6	7	8	9	Transport
2	Size	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Neighbourhood
---		9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
28	General condition	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Financing

In the case of level 2 which consists of 8 factors, the respondents should answer 8(8-1)/2 = 28 pairwise comparison. For example, if the relative preference of factor **Size** over factor Transport among all the factors in buying a house is **3** (it means **Size** is ***slightly more important*** than Transport with respect to satisfaction with the house, refer to Table 5.1), the ratio is marked in the left side of the scale as Figure 5.2.

* Example 2 : pairwise comparison of alternative with respect to each factor

■ *With respect to a factor ("Size" for example), what is the desirability of House A relative to House B or House C?*

- Size

	Alternative	**← better**										**better →**									**Alternative**
1	Alt A	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9			Alt B
2	Alt A	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9			Alt C
3	Alt B	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9			Alt C

- Transport

	Alternative	**← better**										**better →**									**Alternative**
1	Alt A	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9			Alt B
2	Alt A	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9			Alt C
3	Alt B	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9			Alt C

- Financing

	Alternative	**← better**										**better →**									**Alternative**
1	Alt A	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9			Alt B
2	Alt A	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9			Alt C
3	Alt B	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9			Alt C

Figure 5.3 Example of Survey Questionnaire

In the example of buying a new house nine sets of pairwise comparisons would be required, one for the comparison of the factors at the second level of the hierarchy with respect to overall goal as in example 1 and eight for alternative comparisons with

respect to each factor at the third level as in example 2. Respectively 28 pairwise comparisons are given to the respondents for the factor comparison, and 3(3-1)/2 = 3 pairwise comparison with respect to each one of 8 factors respectively for the alternative comparison.

- ***Verbal scale of measurement***

The scale of verbal measurement for comparison should make it possible to represent people's differences in preference or feelings when they make comparisons. It should represent as much as possible all distinct shades of feeling that people have. However, as reviewed in the previous psychological case, our perception ability of simultaneous events is limited, and there is no statistical theory that would assist us in deciding which judgmental scale and how many unit corresponds to reality and represents distinction.

From our experience, our ability to discriminate is limited and when there is considerable discrepancy between the alternatives or attributes being compared, our guesses tend to be arbitrary and usually far from the actual to be inconsistent in comparison. Saaty (1996), therefore, suggests that our scale should have a finite range. In fact, the bounds should be rather close in a region which reflects our capability at making ratio comparisons. Since unity is our standard of measurement, the upper bound should not be too far from unity, but sufficiently far to represent our range of discrimination

In this research, 1-9 scale is used as a verbal measurement scale for comparison. There are several reasons for using 1-9 scale as follows:

1. The qualitative distinctions are meaningful in practice and have an element of precision when the items being compared are of the same order of magnitude or close together with regard to the property used to make the comparison, Saaty (1996).

2. Our ability to make qualitative distinction is well used to be at and represented by five intensities: equal, moderate, strong, very strong and extreme. However when many items are considered, this scale is not sufficient to express all items more precisely the disparity. For this, we can add the intermediate scale when greater precision is needed as compromises between adjacent intensities. Then, it would be nine scales. With the same concept, a practical method is often used to evaluate items into the classification of three regions: rejection, indifference, acceptance. For finer classification, each of these is subdivided into another three scale of low, medium, and high-in all indicating nine shades of meaningful distinctions.
3. The psychological limit of 7 ± 2 items in a simultaneous comparison suggests that if we take 7 ± 2 (in this example, 8 elements are to be compared each other), and if they are all slightly different from each other, we would need the maximum 9 points to distinguish all these differences.

Scale of verbal measurement for the research, therefore, follows the nine classification and their definition as follows

Table 5.1 Scale of Verbal Measurement for AHP, Saaty (1985)

Intensity of Importance	Definition	Explanation
1	Equally important or preferred	Two activities contribute equally to the objective
3	Slightly more important or preferred	Experience and judgement slightly favour one activity over another
5	Strongly more important or preferred	Experience and judgement strongly favour one activity over another
7	Very strongly more important or preferred	An activity is strongly favoured and its dominance demonstrated in practice
9	Extremely more important or preferred	The evidence favouring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values to reflect compromise	When compromise is needed
Reciprocals of above non zero numbers	If activity *i* has one of the above non zero numbers assigned to it when compared with activity j, then j has the reciprocal value with compared with *i*	

- ***Making group consensus as input data for estimating the relative priority***

Once the group has agreed on the hierarchy and individual judgements have been derived, it must then generate representative entries for the pairwise comparison matrices at each level as group judgements. This can be generated by consensus vote, but this attempt requires that the group reach a consensus agreement on each entry in a matrix. Of course a considerable amount of discussion might be required to produce this number, so this may not be possible because it is very tedious and time-consuming, and there are many elements, criteria and multiple decision makers to be considered in a project. Therefore it needs a mathematical method to elicit and combine the individual judgements as group consensus data.

If the number of individual judgements in each matrix are small and disagreements are small, one may consider taking the average of the group's judgements using the *arithmetic mean*. However cases like this are very rare and moreover this method does not preserve the reciprocal property in the combined pairwise comparison matrix. Therefore it needs a more appropriate method and *the geometric mean method* is one of these. This method is a very appropriate averaging method for combining judgements in the AHP because it preserves the reciprocal property in the combined pairwise comparison matrix.

The process for applying this geometric mean method are is follows.

- Individual judgements of n people for a pair (A, B: a_{12})

  $(a_{12})_1,\ (a_{12})_2,\ (a_{12})_3,\ ....,\ (a_{12})_N$

  $\rightarrow$ combined judgements of n people

  $$(a_{12})_c = [(a_{12})_1 \times (a_{12})_2 \times (a_{12})_3 \times,....,\times (a_{12})_N]^{1/N}$$

After getting the combined judgements from individual judgements on each pairwise comparison, this data is input as group consensus data in the pairwise comparison matrix in Table 5.2 and then the relative priority is to be derived on each matrix with this data. The individual judgements are made in a group setting, involving the

relevant decision makers, and serve as a basis for a discussion on the reasons for maintaining specific judgements. Vargas (1982) pointed out that such discussion often results in agreement and in those cases in which consensus cannot be reached, a sensitivity analysis can be conducted to assess the extent to which divergent judgements would lead to significantly different results.

Table 5.2 Pairwise Comparison Matrix for Level 2

Overall satisfaction with house	size	trans.	--	--	--	--	gen. con.	financing	relative priority
size	1	$(a_{12})_c$	--				--	$(a_{1n})_c$	w_s
trans.	$1/(a_{12})_c$	1							w_t
--	--		1						
--				1					
--					1				
--						1	--		
gen. con.	--						1	$(a_{(n-1)n})_c$	w_g
financing	$1/(a_{1n})_c$					--	$1/(a_{(n-1)n})_c$	1	w_f

Table 5.3 Pairwise Comparison Matrix for Level 3 (example :Size)

- Size

Size	House A	House B	House C	Relative Priority
House A	1	$(a_{12})_c$	$(a_{13})_c$	w_A
House B	$1/(a_{12})_c$	1	$(a_{23})_c$	w_B
House C	$1/(a_{13})_c$	$1/(a_{23})_c$	1	w_C

- ***Derivation of weights: Eigenvector Method*** **(EM)**

The solution technique of the AHP takes as input, the pairwise comparisons and produces the relative priorities, w_1, w_2,..., w_n last column in Figure 5.2, 3, of elements at each level as output.

If the judgements were perfectly consistent, then the entries of the matrix would contain no errors and could be expressed as

$$a_{ij} = w_i / w_j \quad (for\ i, j = 1, 2, ..., n)$$

In this case, simply normalise any column j of matrix to produce the final relative weights :

$$w_i = a_{ij} / (\sum_{k=1}^{n} a_{ij}) \quad for\ all\ i = 1, 2, \ldots, n$$

However, errors in judgements are typically made and, therefore, we need the method for estimating the weights when errors in judgements exist. *Eigenvector method* proposed by Saaty (1996) answers this problem to estimate the weights when its judgement is not consistent. This method solves for the principal eigenvector in $A \bullet w = \lambda_{max} \bullet w$ where, λ_{max} is the principal eigenvalue of the matrix A. This method uses the principal eigenvector of the matrix A as an estimate for the vector of priorities.

$$A = \begin{bmatrix} w_1/w_1 & w_1/w_2 & \ldots. & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \ldots. & w_2/w_n \\ \ldots. & \ldots. & \ldots. & \ldots. \\ w_n/w_1 & w_n/w_2 & \ldots. & w_n/w_n \end{bmatrix}$$

If the judgements are perfectly consistent (e_{ij}: *a perturbation factor which in general should be near 1* = 1), we have an ideal case

$$a_{ij} = (w_i / w_j) \bullet e_{ij} = w_i / w_j \quad \text{or} \quad a_{ij}\, w_j = w_i \qquad i, j = 1, 2, \ldots, n$$

Now we observe that from the equation above we obtain

$$a_{ij}\, w_j / w_i = 1 \qquad i, j = 1, 2, \ldots, n$$

and consequently

$$\sum_{j=1}^{n} a_{ij}\, w_j \frac{1}{w_i} = n \quad or \quad \sum_{j=1}^{n} a_{ij}\, w_j = n w_i \qquad i = 1, 2, \ldots, n$$

which is equivalent to

$$A \bullet w = n \bullet w$$

In matrix theory, this formula expresses the fact that w is an eigenvector of A with eigenvalue n. When written out fully this equation looks as follows:

$$A \bullet w = \begin{bmatrix} w_1 / w_1 & w_1 / w_2 & .... & w_1 / w_n \\ w_2 / w_1 & w_2 / w_2 & .... & w_2 / w_n \\ .... & .... & .... & .... \\ w_n / w_1 & w_n / w_2 & .... & w_n / w_n \end{bmatrix} \bullet \begin{bmatrix} w_1 \\ w_2 \\ .... \\ w_n \end{bmatrix} = n \bullet \begin{bmatrix} w_1 \\ w_2 \\ .... \\ w_n \end{bmatrix}$$

In general cases, the a_{ij} are not based on exact measurements, but on subjective judgements. Thus, the a_{ij} will deviate from the exact ideal priority ratios w_i / w_j, and therefore, $A \bullet w = n \bullet w$ equation will no longer hold.

Two facts of matrix theory comes to our rescue, Saaty, (1996):

The first one is this. If $\lambda_1, ... , \lambda_n$ are the numbers satisfying the equation

$$A \bullet x = \lambda \bullet x$$

i.e., are the eigenvalues of A, and if $a_{ii} = 1$ for all i, then

$$\sum_{i=1}^{n} \lambda_i = n$$

Therefore, if the equation $A \bullet w = n \bullet w$ holds, then all eigenvalues are zero, except one, which is n. Clearly, then, in the consistent case, n is the largest eigenvalue of A.

The second helpful fact is that if one changes the entries a_{ij} of a positive reciprocal matrix A by small amounts, then the eigenvalues change by small amounts. Combining these results we find that if the diagonal of a matrix A consists of ones ($a_{ii} = 1$), and if A is consistent, then small variations of the a_{ij} keep the largest eigenvalue λ_{max} close to n, and the remaining eigenvalues close to zero.

Therefore, our problem is to find the vector w, as good estimates, which satisfies

$$A \bullet w = \lambda_{max} \bullet w$$

The eigenvector w can be calculated by solving the eigenvector equation. If the evaluator could know the relative weights of n elements, the matrix of the pairwise comparisons would be trivially obtained from each one of n rows of matrix A.

AHP posits that the evaluator does not know w and, therefore, is not able to produce the pairwise relative weights of matrix A accurately. Thus, the observed matrix A contains inconsistencies. The estimation of w (denoted $\hat{w}$) could be obtained from $\hat{A} \bullet \hat{w} = \lambda_{max} \bullet \hat{w}$, where λ_{max} is the largest eigenvalue of $\hat{A}$ and $\hat{w}$ is its eigenvector. $\hat{w}$ constitutes the estimation of w. λ_{max} may be considered the estimation of n, which is always real and not smaller than n.

λ_{max} is derived as follows:

$$\lambda_{max} = \left(\sum_{j=1}^{n} a_{ij} w_j \right) / w_i$$

Observe that since small changes in a_{ij} imply a small changes in λ_{max}, the deviation of the latter from n is a measure of consistency. It enables us to evaluate the closeness of our derived scale from an underlying ratio scale with we wish to estimate. The closer the value of computed λ_{max} is to n, the more consistent are the observed values of $\hat{A}$.

This property has led to the construction of as our indicator of "closeness to consistency", i.e. for how far our estimates are from fulfilling $a_{ij}\ w_j = w_i$, this is called the *Consistency Index* (C.I.)

C.I. = $(\lambda_{max} - n) / (n-1)$,

The original development of the eigenvalue method was based on "symmetric" input matrices. That is, the upper triangle elements of matrix $\hat{A}$ are observed, and the lower triangle elements are constructed from the consistency requirement $a_{ji} = 1/a_{ij}$.

Using the symmetry of $\hat{A}$, Saaty (1996) proves that for a primitive matrix $\hat{A}$, we have

$$\lim_{k \to \infty} (\hat{A}^K e / \left\| \hat{A}^K \right\|) = C \cdot \hat{W}$$

where C is a constant, $\hat{W}$ is the normalised eigenvector corresponding to eigenvalue $\lambda_{max,}$, e is a unit column vector, and $\left\| \hat{A}^K \right\| \equiv (A^K e)^T e$ is the norm of matrix A^K.

To compute $\hat{W}$, therefore, K is increased iteratively until a convergence criterion for the $(m+1)_{st}$ iteration is satisfied:

$$\hat{W}_{m+1} - \hat{W}_{m} < \varepsilon$$

The eigenvector solution is, therefore, given by

$w = \lim_{k \to \infty} (A^k e / e^T A^k e)$, where e is the unit column vector

This is accomplished by raising the matrix A to increasing powers K and then normalising the resulting system. It is instructed to stop when the difference in the priority vector between two consecutive calculations is of a desired degree of accuracy at a certain decimal position.

As we reviewed in the eigenvector method, it has the interpretation of being a simple averaging process by which the final weights w are taken to be the average of all possible ways of comparing the alternative. Thus the eigenvector is appropriate for computing the weights, especially in inconsistent cases. In this research, the eigenvalue method is to be used as a tool for derivation of priorities, and the following is an example of calculation of eigenvector method to the case to buy the best house. The first major task at this step in the AHP involves the estimation of the weights of a set of objects (criteria or alternatives) from a matrix A of pairwise comparisons which is positive and reciprocal in the Table 5.3.

If we use the eigenvector method, consider an example of the Table 5.3 (suppose $a_{12} = 6$, $a_{13} = 8$ and $a_{24} = 4$), we get the matrix a as follows:

$$A^1 = A = \begin{bmatrix} 1 & 6 & 8 \\ 1/6 & 1 & 4 \\ 1/8 & 1/4 & 1 \end{bmatrix}$$

Applying the first iteration of the algorithm stated above yields:

$$w^1 = A^1 e / e^T A^1 e = (0.696325,\ 0.239845,\ 0.06383)$$

And raising A to the second power $A^2 = A \times A$

$$A^2 = A = \begin{bmatrix} 3 & 14 & 40 \\ 0.833333 & 3 & 9.33333 \\ 0.291667 & 1.25 & 3 \end{bmatrix}$$

which in turn creates the second estimate of the weights:

$w^2 = A^2e / e^T A^2e = (0.762967, 0.176241, 0.060792)$

This process is iterated when the error in the priority vector between two consecutive iterations is of a desired degree of accuracy at a certain decimal position, this process has converged in eleven iterations until two consecutive weights derived is same at a fifth decimal point.

w^{final} = House A, House B, House C = (0.753554, 0.181135, 0.065311)

Once we have computed the weights, the consistency measure can be computed as follows:

$$\lambda_{max} = \left(\sum_{j=1}^{3} a_{1j} w_j \right) / w_1 = 3.136,$$

$C.I = (\lambda_{max} - n) / (n-1) = (3.136-3)/(3-1) = 0.068$

For the remaining 7 matrices of elements to compare each alternative with respect to each element and one matrix to compare each element with respect to the overall goal, the eigen priority vector (relative weights), λ_{max} (eigenvalue) and consistency ratio can be derived by the same procedure. The results are as follows:

Table 5.4 Derivation of Eigenvector

	EIGEN PRIORITY VECTOR							
	Size	Transport	Neighbourhood	Age	Yard space	Facilities	General Condition	Financing
House A	0.754	0.233	0.754	0.333	0.674	0.747	0.200	0.072
House B	0.181	0.055	0.065	0.333	0.101	0.060	0.400	0.650
House C	0.065	0.713	0.181	0.333	0.226	0.193	0.400	0.278

element	eigen priority vector
Size	0.173
Transport	0.054
Neighbourhood	0.188
Age	0.018
Yard space	0.031
Facilities	0.036
General Condition	0.167
Financing	0.333

5.3.3 Composition of Priorities (Synthesis)

As the next step, in order to compute the overall priorities of the alternative with respect to the overall goal, we must propagate the weights of the elements in a level to all the elements in the level below it. This is done by means of *the principles of hierarchic composition.*

After getting the relative weights for every element at each hierarchy level, one then synthesises the priorities from the individual levels into a global measure of priority. The global priority can be derived by employing *the principle of hierarchic composition.* This process states that the weights are created by summing the priority of each element according to a given criteria by the weight of that criteria as follows:

If there is a complete hierarchy with n levels and overall goal G, and if V_K is the priority matrix (which consists of priority vectors, E) of k^{th} level where k = 1,2,...,n.

$$V_K = \begin{bmatrix} E_1^{K1} & E_1^{K2} & \cdots & E_1^{Kp} \\ E_2^{K1} & E_2^{K2} & \cdots & E_2^{Kp} \\ \cdots & \cdots & \cdots & \\ E_q^{K1} & E_q^{K2} & \cdots & E_q^{Kp} \end{bmatrix}$$

where, K: level number, 1, 2, ..., n
p: number of elements of (K-1)
q: number of elements of K^{th} level

If we consider the example to choose the best house,

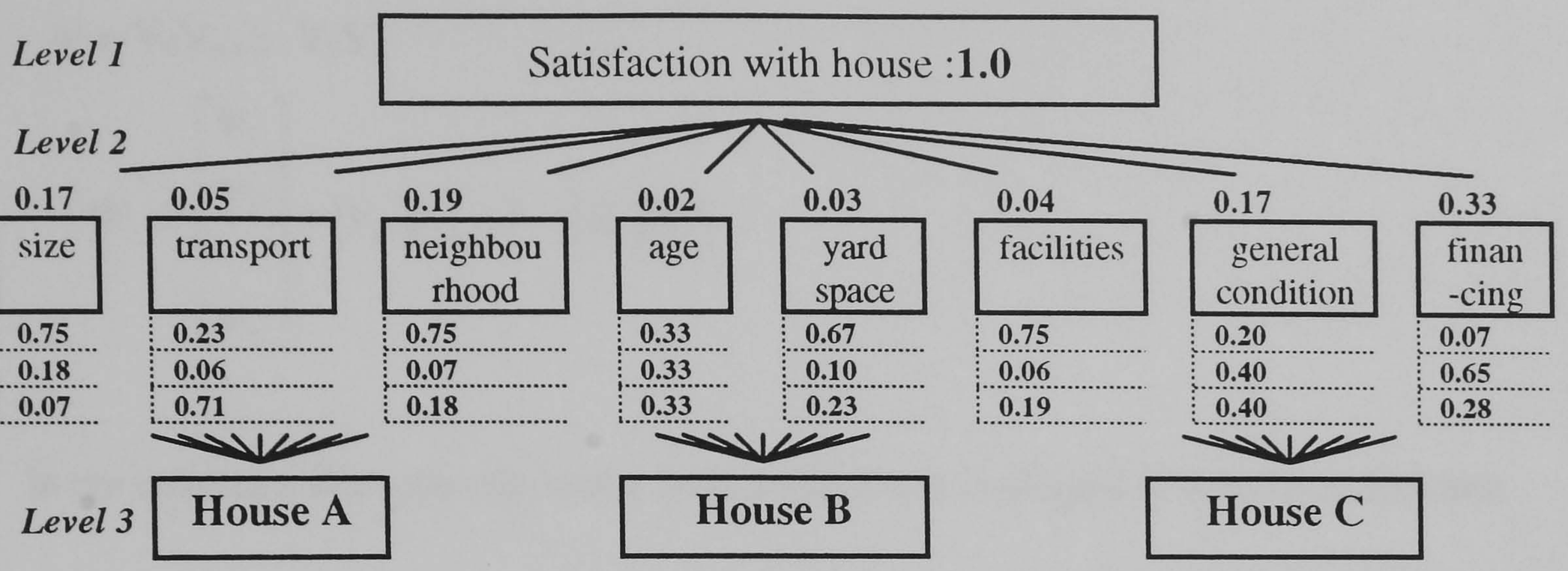


Figure 5.4 Composition of Priorities of The Example

In this example, the number of levels, k, is 3, the number of elements in level 3, q, is 8, and the number of elements of level (k-1) =2, p, 3.

$$V_3 = \begin{bmatrix} E_1^{31} & E_1^{32} & \ldots . E_1^{38} \\ E_2^{31} & E_2^{32} & \ldots . E_2^{38} \\ E_3^{31} & E_3^{32} & \ldots . E_3^{38} \end{bmatrix} = \begin{matrix} \text{size} \\ \\ \\ \end{matrix} \begin{matrix} \text{transport} \\ \\ \\ \end{matrix} \begin{matrix} \text{financing} \\ \\ \\ \end{matrix} \begin{bmatrix} 0.754 & 0.233 & \ldots . 0.072 \\ 0.181 & 0.055 & \ldots . 0.650 \\ 0.065 & 0.713 & \ldots . 0.278 \end{bmatrix}$$

As the same procedure, we can get V_2 as follows (k = 2, p = 3, q = 1):

$$V_2 = \begin{bmatrix} E_1^{21} \\ E_2^{21} \\ \ldots \\ E_8^{21} \end{bmatrix} = \begin{bmatrix} 0.173 \\ 0.054 \\ \ldots \\ 0.333 \end{bmatrix},$$

The priority weight of level 1 is 1 as a single element, so

$$V_1 = 1$$

The overall priority vector of alternatives with respect to overall goal is given by

$$w = V_n V_{n-1} \ldots V_2 V_1$$

$$W = \begin{bmatrix} w_1 \\ w_2 \\ \cdots \\ w_a \end{bmatrix} = [V_K][V_{K-1}] \cdots [V_2][V_1]$$

In the example, final priority vector with respect to overall goal is derived as follows:

$$W = \begin{bmatrix} w_1 \\ w_2 \\ w_3 \end{bmatrix} = \begin{bmatrix} 0.754 & 0.233 & 0.754 & 0.333 & 0.674 & 0.747 & 0.200 & 0.072 \\ 0.181 & 0.055 & 0.065 & 0.333 & 0.101 & 0.060 & 0.400 & 0.650 \\ 0.065 & 0.713 & 0.181 & 0.333 & 0.226 & 0.193 & 0.400 & 0.278 \end{bmatrix} \begin{bmatrix} 0.173 \\ 0.054 \\ 0.188 \\ 0.018 \\ 0.031 \\ 0.036 \\ 0.167 \\ 0.333 \end{bmatrix} \times 1$$

$$= \begin{bmatrix} 0.396 \\ 0.341 \\ 0.263 \end{bmatrix}$$

This result can be summarised as follows. House A turned out to be the best alternative which can satisfy the buyer, while House C is preferred least among alternatives.

Table 5.5 Local and Global Priorities

element	local priority								composite priority
	1 (0.173)	2 (0.054)	3 (0.188)	4 (0.018)	5 (0.031)	6 (0.036)	7 (0.167)	8 (0.333)	
House A	0.754	0.233	0.754	0.333	0.674	0.747	0.200	0.072	0.396
House B	0.181	0.055	0.065	0.333	0.101	0.060	0.400	0.650	0.341
House C	0.065	0.713	0.181	0.333	0.226	0.193	0.400	0.278	0.263

The resulting priorities of each level represent the intensity of the respondents' judgements as to the relative importance of the elements represented in the hierarchy considering the importance of and trade-off among criteria, and the global priorities represent the preference among alternatives (or policies) and so they are used in making final decisions.

5.4 Consistency Analysis

The last stage of the process of principal eigenvector extraction is a determination of the consistency of the pairwise judgements as well as that of the hierarchy. In a perfectly consistent matrix, the maximum eigenvalue λ_{max} is equal to n as we discussed in previous section. For a positive reciprocal matrix, λ_{max} is always greater than or equal to n and its departure from n is a measure of the consistency of the matrix.

If we take the deviation from n^2 (what the values would be with perfect consistency) and then divide by n^2, we obtain an index of relative departure from consistency:

$$(n\,\lambda_{max} - n^2)/n^2 = (\lambda_{max} - n)/n$$

which is not too different from the usual

$$(\lambda_{max} - n)/(n-1)$$

So the *Consistency Index* (C.I.) is defined as:

$$C.I. = (\lambda_{max} - n)/(n - 1)$$

How bad the consistency of the matrix is can be determined by comparing *Consistency Index* (C.I.) with *the Random Index* (R.I.). For each size of matrix n, random matrices were generated and their mean C.I values were computed over a large number of reciprocal matrices of the same order whose entries are random. R.I was derived from a sample of size 1000 of randomly generated reciprocal matrices using the scale

1/9,1/8,...,1,2,...,9 and calculate the average of their eigenvalues . This average is used to form the Random Consistency Index.

The ratio of C.I. to the average random consistency index (R.I.) for the same order matrix is called the *Consistency Ratio* (C.R). C.R is a measure of how a given matrix compares to a purely random matrix in terms of their C.I's. We also define the *Consistency Ratio* (C.R.) as the ratio of C.I. and R.I as :

C.R. = C.I./R.I.

C.R. provides a measure of the probability that the matrix was filled in purely randomly. The number 0.1, for example, says that, loosely speaking, there is a 10% chance that the decision maker answered the questions in a purely random manner. With more consistent judgements, the less likely it is that the matrix was filled in at random and thus C.R. decreases. If C.R is significantly small (carefully specified to be about 10% or less), we accept the estimate of *w*. Otherwise, one needs to obtain more data on the elements being compared in the particular matrix, and typically such data collection is followed by another round of judgements to improve consistency. According to Saaty (1995), for a 3-by-3 matrix this ratio should be about 5%, for a 4-by-4 matrix about 8%, and for larger matrices, about 10%.

Table 5.6 Random Consistency Index (R.I.)

Matrix Order	1	2	3	4	5	6	7	8	9	10	11	12
R.I.	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48

5.5 Conclusion

AHP can structure the relevant components of a problem into a framework which people understand. Complexity is reduced to a functional hierarchical representation

of the important decision elements. Secondly, AHP can analyse both the quantitative and intangible aspects of those elements through ratio scales which tie the framework together to make this method a flexible tool of decision making.

Analytic decision making is of value, but it must be simple and accessible to the lay user, and must have scientific justification of the highest order. Saaty (1994) describes the benefits of the descriptive analytical approach as follows and this description also represents most characteristics of the AHP method very well:

First is the morphological way of thoroughly modelling the decision, including people to make explicit their tacit knowledge. This leads people to organise and harmonise their different feelings and understanding. Secondly, particularly in the framework of hierarchies and feedback systems, the process permits decision makers to use judgements and observations to surmise relations and strength of relations in the flow of interacting forces moving from the general to the particular and to make predictions of the most likely outcomes.

Thirdly, people are able to incorporate and trade off values and influences with greater accuracy of understanding than they can using language alone. Fourth, people are able to include judgements that result from intuition and emotions as well as those that result from logic. Finally, a formal approach allows people to make gradual and more thorough revisions and to combine the conclusions of different people studying the same problem in different places.

Chapter Six

Model Development for Application

6.1 Introduction

The evaluation of a railway network development project is a problem of choice which has multiple criteria and various interest groups. This project has conflicting objectives and many intangible factors so that it needs a systematic procedure which is able to deal with complex problems and conflict solution. As we have discussed in the previous chapter, for the application, a model for the evaluation of the rail network development project is to be developed based on the analytic hierarchy analysis method with the basic concepts of cost-benefit analysis.

To apply the AHP to this project, the research should have two main streams, those are a questionnaire survey to decide the weights of the stakeholder's role and to judge the preference of the objectives and various criteria, and a project survey to collect related data and to quantify into units.

With regards to the questionnaire survey, the objectives set up for implementing overall goals of the project are to be confirmed by the expert survey as well as the importance of each stakeholder's role. On the other hand, the degree of importance of the objectives and elements, and the preference of intangible factors are examined via a questionnaire survey for each interest group.

From the project survey, all the related data with the project which can be quantified into units is collected, then these values should be normalised into the units between 0 to 1 for comparison with each other. The normalised value from the project survey is

used as the relative priority like the weights derived from matrix calculation of intangible factors. Therefore, these tangible factors don't need to derive the priority among elements because normalised value itself expresses the priority (or weight) of each alternative with respect to the specific evaluation items. The derivation of relative priority is based on the concepts of cost-benefit analysis.

By combining the results of the questionnaire survey and the project survey, we can determine the relative weights of each factor and alternative at various levels of the hierarchy. With regard to the relative weights derived, consistency is checked, and if the results are not consistent, the whole process is repeated to get a consistent result. After getting consistent results, sensitivity analysis is to be done to check the change of stakeholder's role and the objective's preference.

All the results from the AHP application are to be compared with that of the existing applied evaluation method, then the difference between two methods is analysed focusing on the ranking and the evaluation process. In addition, the applicability and suitability of the AHP method itself will be investigated using a few subjective criteria.

In this chapter, the whole evaluation process is reviewed by the analytic hierarchy approach method. The model development procedure for the application will, therefore, be set up based on the analytic hierarchy approach method, and the procedure of analysis for the evaluation and comparison with current evaluation method will also be described.

6.2 Model Development

6.2.1 Model Development Procedure

In order to develop the model, first of all, all the problems have to be described and the solution (for the overall goal) desired is to be specified. Then, we have to select the alternatives, and then to identify the actors (stakeholders). The second step is the identification of the main considerations (objectives) of each stakeholder, main factors for accomplishing actor's policies (objectives) is to be identified. Then, a hierarchy which includes all relevant factors in solving the problem will be structured. According to the hierarchy structured, pairwise comparison is made via a questionnaire survey at each level, and the weights are derived.

The process for model development and application is summarised as follows:

1. *To select the alternatives:* The alternative courses of action for this research are adopted from those Government considered in a real-life project in Korea. This project was to develop the HSR railway network passing a historic city of Kyongju in the south-east of Korea and choose the best railway route among four route alternatives for providing capacity, improving accessibility of the area, and minimising the adverse impacts on the environment, including cultural assets. It has been done according to the view of a single decision maker with traditional economic analysis, and their subjective judgements. For the comparison with current evaluation method of this project, the alternative scheme was mainly based on this project, but through the pilot survey, the original 4 alternatives were changed into 3 alternatives, and various interest groups took part in the evaluation process from the first step, which was different from the project.

2. *To determine the decision makers:* During the past decades, in Korea, the role of Government in the economic sector has been very important and so Government has played a leading role as the single decision maker. But, as mentioned in chapter two, the socio-economic status of Korea has changed and people's demand diversified. As a result of the change, many considerations for a variety of interest groups as the multiple decision makers affected by transport investment are required in the evaluation process. The transport project carried out by the Government has

been evaluated mainly according to the their own view. In this research, in order to review the whole evaluation process which includes the various interests of multiple stakeholders, three main decision makers, supplier, user and community members, are involved and surveyed by questionnaire.

3. *To identify the objectives and criteria of each objective:* The identification and development of appropriate objectives is the essential starting point of future transport plans. Explicit, clearly defined objectives facilitate the identification of problems, the development and design of appropriate solutions. For the selection of appropriate objectives, all objectives available are firstly considered for this research through the reviewing of past transport investment trends and future demands. Then among all objectives considered the appropriate objectives are selected by the questionnaire survey (the expert survey) for transport planners and academic researchers who are involved in transport planning and research.

4. *To construct the hierarchy:* Overall focus, objectives, attributes, and alternatives are structured as a hierarchy to decompose a complex problem and then to solve it. In the hierarchy, there is an overall goal at top level, the objectives at the next level followed by attributes, and finally alternatives.

5. *To get the individual preference and derive group judgement data:* The assignment of weights to the set of project objectives is a critical part of any evaluation as it establishes the relative importance of each objective and the effectiveness of multiple criteria analysis depends on the ability to address preference on each objective. The pairwise comparison matrix is, therefore, constructed for comparisons of the elements involved in a decision to derive their scales of priorities. To make the pairwise comparison judgements, the fundamental verbal scale of the AHP is used. To get the group judgement data as input data, all individual judgement data is combined into one, and the geometric mean which can preserves the reciprocal property is used for this purpose.

6. *To derive relative weights among criteria:* To derive relative priorities among criteria, the eigenvector method proposed by Saaty for the estimation of the weights is used. However, the eigenvector method is applied only for intangible factors. For the derivation of relative weights of several tangible factors, the normalised values are used as relative priorities.

7. *To synthesise the priorities for overall assessment of the alternatives:* The next stage is the synthesis of the weights of elements for various levels. The global priority of the individual alternative can be obtained by multiplying the relative priorities by weights of the given criterion and choosing the alternative with the highest total.

8. *To perform the sensitivity analysis:* One might be interested in verifying the effect, if there is any, of changing the importance of interest groups and their objectives. In order to do this and see how robust the decision is, a sensitivity analysis is carried out by changing some importance (weights) of stakeholder's role and their preference for objectives. The sensitivity analysis is a crucial step in any modelling effort and should not be ignored in a careful application of the AHP because this test enhances better understanding of the decision situation and this can make decision makers have a flexible decision for the uncertainty of the future.

9. *To analyse the method and compare with traditional evaluation technique:* In order to assess the method itself and compare with current evaluation methods applied to the project, the implementation procedure and results are compared with the result from the existing evaluation method in terms of the ranking of alternatives, and then the adaptability and suitability of the AHP method itself are assessed for the analysis of the advantages and disadvantages of using the MCDM method. The criteria for the assessment of the analytic hierarchy approach will be the various criteria such as data and information requirement, applicability to transport projects and linkage to the decision-making process.

10. *To make suggestions for transport investment planning:* Conclusion and some suggestions about the adaptability and suitability of MCDM method for evaluating the transport investment projects in Korea is carried out through the analysis of application and comparison

The process for model development and application is shown in Figure 6.1.

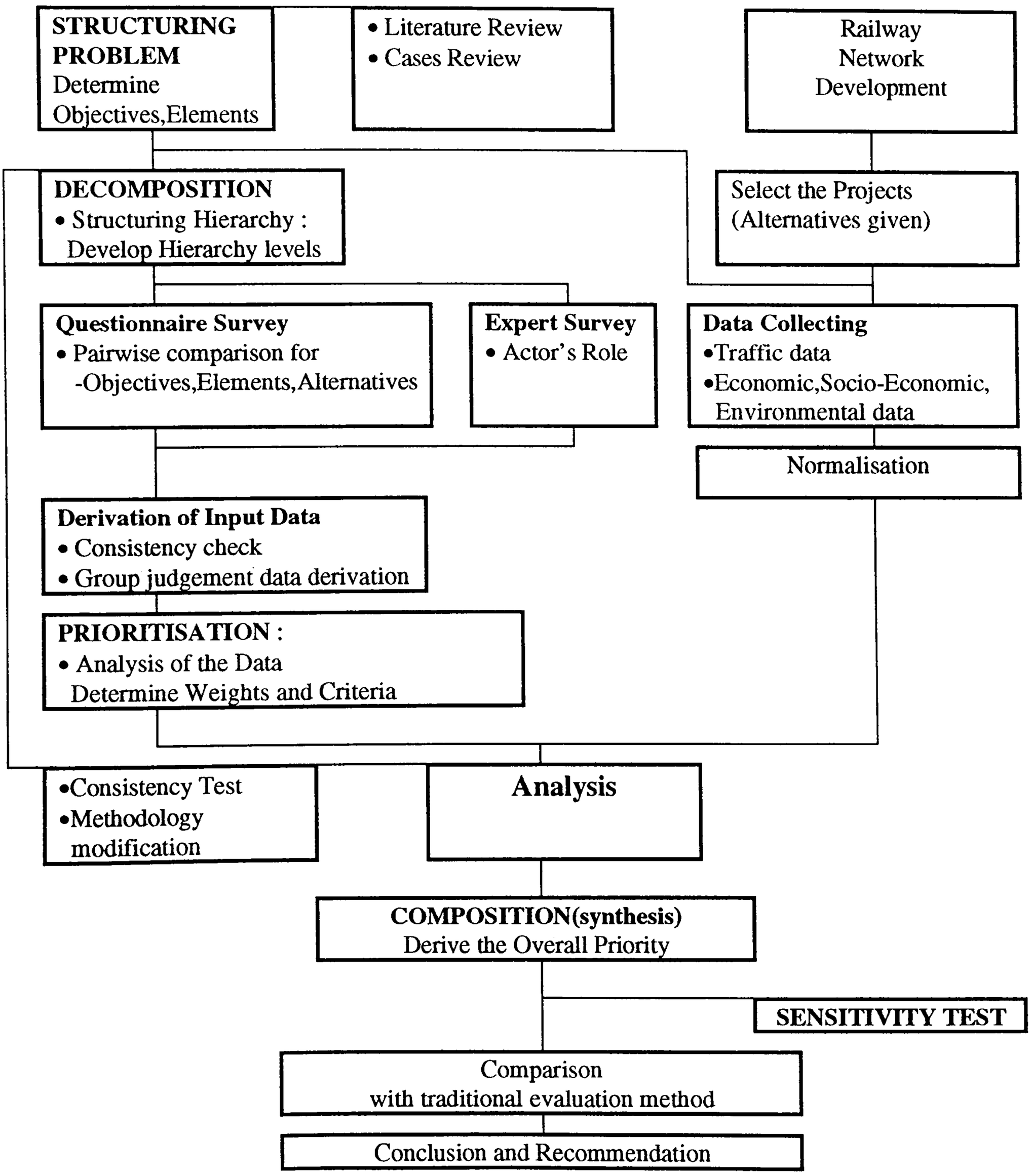


Figure 6.1 Model Development and Application Procedure

6.2.2 Selection of Alternatives

In this research, the alternatives were based on the alternatives which were considered in the feasibility study carried out the KOTI (The Korea Transport Institute) so as to compare the results from the application of the AHP with that of KOTI project. The KOTI project is to develop the railway network passing through/by a historic city of Kyongju in the south of Korea and choose the best railway route among 4 alternatives for increasing regional development and improving accessibility, but protecting invaluable cultural assets. As the research is based on the KOTI project, most schemes and data come from the project.

But according to the results of the pilot survey which was carried out in the University of Leeds in October 1997, the alternatives finally selected for this research were changed from the original 4 alternatives of KOTI to 3 alternatives (2 alternatives given from KOTI and another alternative from former alternative). It was due to the fact that all the alternatives of KOTI were very hard to differentiate each other and find the trade-offs between the attributes which they had (it is caused by the fact that these alternatives were made under many constraints such as limited range of area for route development and the location of station).

Therefore, in order to maximise the trade-offs between evaluation criteria (it is also for getting easy answers and clear comparison between criteria), especially *"accessibility and development"* and *"cultural assets conservation and minimisation of adverse impacts on ecology and environment"* and to meet the goal for the study, the alternatives for the research were selected to be as differentiable and comparable as possible.

6.2.2.1 Background

Presently passenger demand for the Seoul-Pusan line is increasing steadily. As this trend continued with the economic growth over a decade, the capacity of existing lines

have been reached since the beginning of 1990. Therefore HSR railway development to increase capacity, enhance mobility of people and to improve the quality of transport service was considered as a desirable solution which can result in more positive impacts on the national development than the existing line improvement or the construction of another express way. In particular, this was greatly concentrated in the Seoul-Pusan corridor because the corridor is the major arterial route in Korea as the major transport axis.

For the development of HSR line of the Seoul-Pusan corridor, the feasibility of HSR construction was established by the feasibility study which was carried out in 1984 by the Ministry of Transport, and the route and 4 intermediate stations were decided upon in 1990. However, regarding the Kyongju station and the route passing through Kyongju area chosen, much criticism and public reluctance arose in the area in terms of the conservation of cultural assets and historic sites which caused the decisions to be reconsidered in 1996.

The rest of the whole network except Kyongju line was selected without very much controversy in the view of better accessibility and regional development. Choosing the best railway network for the Kyongju area has, however, been long debated across the whole country because the city has so many cultural assets as the oldest historic city in Korea and it is very difficult to meet the both of goals, "transport development for increased accessibility, and regional development" along with "cultural asset conservation".

The Kyongju line is a part (68 km) of main railway (high speed rail: 426.2 km) from Seoul to Pusan, and passes through a historic city with a great number of historic cultural assets. The main purpose of actual high speed rail project is to increase capacity for relieving the severe traffic congestion on the Seoul-Pusan traffic axis (70% share of total regional traffic demand), and this case is to provide better accessibility to the south-eastern part of Korea including Kyongju and then to improve regional

development of those areas through connecting these huge investment projects to its area as a part of a main investment project.

This case, therefore, needs systematic analysis considering intangible criteria such as environmental factors, especially cultural assets, and also multiple decision makers involved in the projects, supplier, user, community. Therefore, it is worthy to study this case and apply the multicriteria evaluation approach.

According to the reconsideration in 1996-1997, new sets of 4 alternatives of route and station of Kyongju area were selected by the feasibility study by KOTI, and then the final decision was taken in 1997 by the government. The case considered for the research is based on the project carried out by KOTI to choose the best railway network passing by the oldest historic city, Kyongju.

However, as these alternatives considered by KOTI are not appropriate for this research purpose, the alternatives were modified from the original 4 alternatives of KOTI according to the pilot survey which is to see how the AHP approach works in this case and how suitable the alternatives given by KOTI are for the research. In the pilot survey, firstly, the suitability of the alternatives for the research has been examined, and then the methodology, and survey questionnaire have been checked. From the pilot survey, the alternatives for the research were chosen and the procedure and methodology for application were specified and modified. The pilot survey is discussed in the chapter seven.

6.2.2.2 Alternatives for Application

A brief description of the alternatives set up for the application are as follows. Most of this data for each alternative was provided by KOTI research and the rest of data which is unavailable is simply assumed by the researcher.

◆ Alternative 1 : Hyeongsan (Buknyeokdul) Route

This alternative route passes through Kyongju city and the site of the station is located very close to Kyongju city, so its expansion of the site for further development is limited, but sufficient for the station development. This site has the advantages of easy access and very easy connections to local roads, motorway junction, and to the current railway network. It means that the existing transport network can be used for a new railway network with minimal cost.

The route consists of 68.4 km (48% through tunnels and 26% over bridges). This route is situated very close to residential areas as well as cultural sites, so it may affect more cultural assets (28 sites) than the other alternatives. Moreover, as this route is close to Namsan, a national park with many cultural and environmental assets, it is visually intruded upon by this railway.

◆ Alternative 2 : Hwacheon Route

The route of alternative 2 passes by Kyongju city, but the site of the station is located relatively close to Kyongju city. The scope for further development on site is extendible due to the wide, plain area nearby. This site has relatively good access and easy connections to local roads, motorway junction, and to the current rail network.

The route consists of 58.9 km with tunnel (56%) and bridge (16%). This route is situated close to residential areas, but it may affect fewer cultural assets (17 sites) than the other alternatives. However, this route is relatively close to Namsan.

◆ Alternative 3 : Duckcheon Route

The site of the station is located farthest from Kyongju city, but the scope for further development of the station site is limited due to the mountains around the station. This site, therefore, does not have easy access. But the access to local roads and the current railway is easy, while the connection to existing motorway needs a junction or access road because it is a long way from the junction.

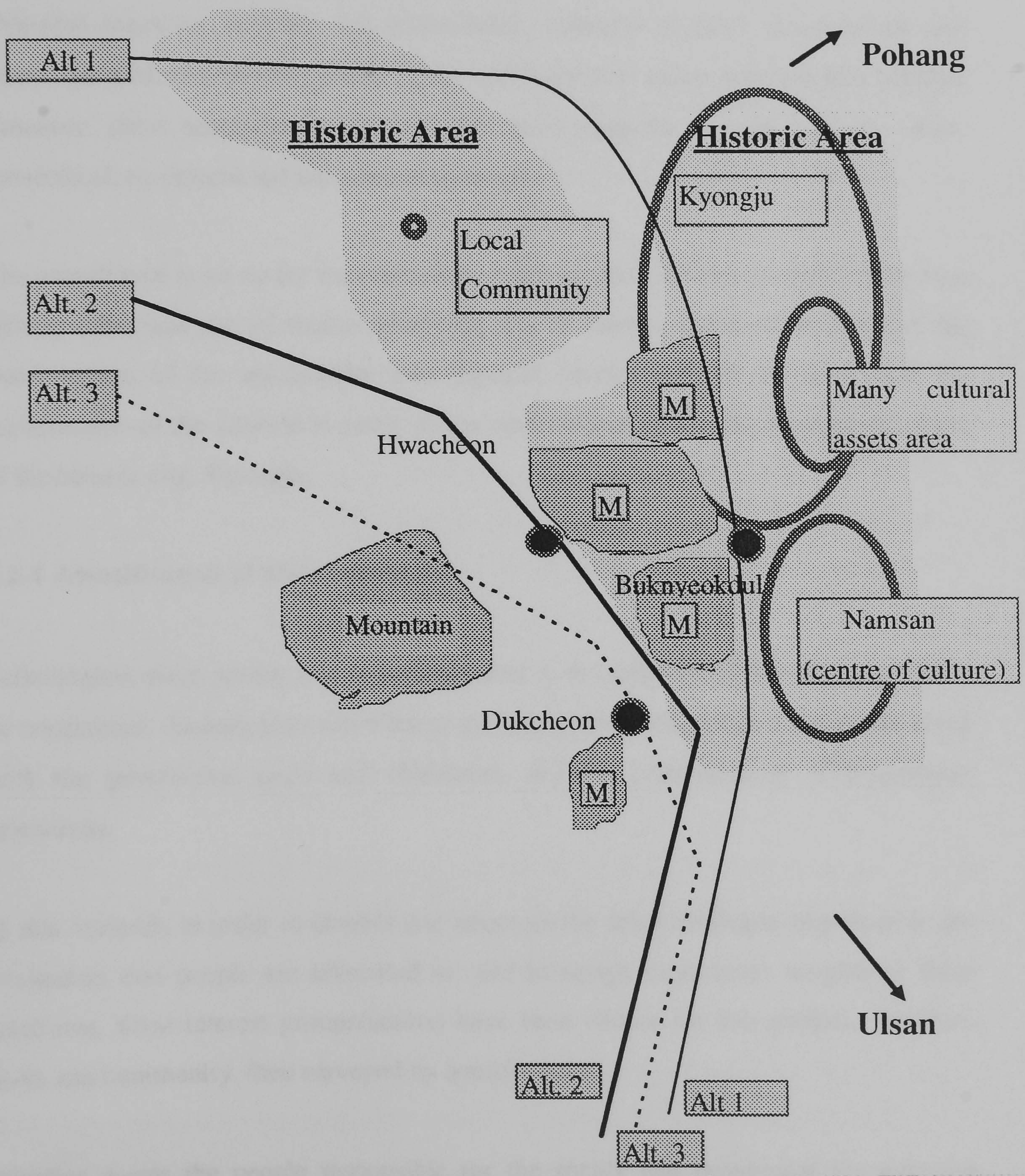
The route consists of 58.3 km with tunnel (67%) and bridge (15%). This route is the farthest from the residential area, therefore, this route alternative has less impact on house. However, it is not far from the cultural assets and Namsan.

Table 6.1 Brief Descriptions of Each Alternative

	Alternative 1 Hyeongsan	Alternative 2 Hwacheon	Alternative 3 Duckcheon
ROUTE			
Distance from city	very close	close	far
Site and its Circumstance	- enough extendibility	-between the mountains -limited, but enough extendibility	-limited site area -limited area for extension
Connection to local road	- easy connected	-easy connected	-easy connected
motorway	-easy connected to motorway	-easy connected to motorway and access road	-need new I.C and access road
rail	-easy connection	-easy connection	-easy connection
Extendibility & Feasibility for Development	-limited due to visual intrusion on Namsan, but extendible	-extendible due to wide area nearby	-limited due to mountains nearby & visual intrusion on Namsan and
STATION			
Length	-68.4 km	-58.9 km	-58.3 km
Tunnel	-48%	-56%	-67%
Bridge	-26%	-16%	-15%
Distance from city	-very close	-close	-very far
from cultural area	-close to residential area -close to Namsan	-not far from historic area -close to Namsan	-far from residential area -very close to Namsan
Number of cultural assets nearby	-28 sites	-17 sites	-25 sites

A brief map of the alternatives is as follows.

Figure 6.2 Route Alternatives and its Circumstance



6.2.3 Definition of Overall Goal

Transport investment influences not only individual life styles but also has direct impacts on the society as a whole. Improvement of the transport system results in significant changes of mobility, economic behaviour and interaction and also improves quality of life, accessibility and regional development. As a result, it can lead to improved transport facilities and accessibility, balanced regional development and assists the achievement of regional equity and improved interaction between regions. However, these transport investments also have negative impacts such as socio-economical, environmental and ecological impact.

The overall goal is set up for the evaluation of this project, which is to develop the best railway route and site of station which are able to reach a compromise between the maximisation of the accessibility and regional development of the area, and the minimisation of the adverse impacts on the environment, especially the cultural assets of the historic city, Kyongju.

6.2.4 Identification of Stakeholders

Stakeholders mean people who have an interest in the project and whose views should be considered. Stakeholders are often at the policy level of decision making concerned with the programme goals and objectives, and the consequences of programme operations.

In this research, in order to identify and structure the value attributes important to the evaluation that people are interested in, and to assign importance weights to these attributes, three interest groups(actors) have been chosen for this project, suppliers, users and community, then surveyed by questionnaire.

Supplier means the people responsible for the supply and investment for transport facilities. So, mainly government officials fulfil this role, and they have many

objectives relatively different from the other actors under the basis of maximising social welfare via transport supply. It means that they have greater consideration of the transport facilities supply for transport efficiency such as to increase capacity, to relieve congestion, to improve safety, the financial allocation for economic efficiency and the national land development than the other actors who have their own interests.

Users are the people affected with regard to individual mobility by the project through which includes the change of travel time, cost, safety and convenience using those facilities. There can be various kinds of users, for example, the users who live or go on purpose frequently to the site using HSR mode and Kyongju station, and other users who pass by the area.

The last and most significant group is the people, community members, who live in the areas that are affected directly by the project. They are interested in their living circumstances and environment individually or on a community level, and those matters become more important social issues currently. This group can be also classified into two groups, one is the people on the proposed route or very nearby route affected directly by the impacts of the project such as housing displacement, noise, pollution, the other group is the people off the route with indirect impacts such as land use and value, quality of life, transport and economic change.

6.2.5 Definition of Objectives and Attributes

The identification and development of appropriate objectives is the essential starting point of transport plans. Explicit, clearly defined objectives facilitate the identification of problems, the development and design of appropriate solutions.

The first step for identifying them is to question stakeholders about what value from their perspective the programme may affect. Secondly in the view of each stakeholder, lists of objectives and attributes are considered from the topic which people are interested in, then those with ambiguous similarity are eliminated out of all attributes to

avoid double counting. After doing this, whole attributes are amalgamated across stakeholders. All of the appropriate objectives selected are screened by the expert survey of transport experts. In this research, all lists of objectives and attributes were firstly collected reviewing the past trend of transport planning and future demand on behalf of stakeholders.

The performance of a railway system can be expressed by the measures of criteria for certain alternative routes. A set of objectives aimed at in these projects can be established and their criteria could serve as explanatory variables. These objectives available and each criterion can be listed in Table 6.2 by reviewing all the objectives possible from the actors.

In the case of this railway network development project as a part of whole line, the objectives to be considered are different from those of other transport development. Because of its characteristics (all the alternatives are just a part of the HSR line and have only one station, so travel demand to that area would be very similar), some objectives such as maximising capacity or travel demand are not appropriate to compare in the evaluation process and some are overlapped with others.

All objectives and the attributes possible considered for choosing the best railway route in the historic city, Kyongju and their details are listed and defined as follows and it is chosen via the expert survey.

In order to select the appropriate objectives of each decision maker among all objectives considered, the questionnaire survey (expert survey) is carried out for transport experts who are involved in transport planning and accomplishment. The cumulative percentage of the highest ranking can be used for the selection of objectives. The objectives for the research were selected as in Figure 6.3 and the selection procedure is described in section 6.3.1.

Table 6.2 The Objectives

Objective		Measurement
Max. Capacity (Mobility Increase)		• increased transport capacity to south-eastern area,
Min. Travel Time		• rail passenger travel time to next cities on HSR line + access time to destination
Max. Accessibility		• accessibility to the area
Improved Transport Network Connection		• depends on connection ability to local road, regional railway and expressway
Improved Comfort & Convenience		• comfort measured by physical layout such as the roughness of rail route, constitution of route • for convenience, it depends on route condition such as tunnel, bridge, gradient, railroad crossing of each alternative, and the location of station
Min. Project Cost (Construction & Oper. cost)		• construction cost of railway, collector road to rail, relocation of existing railway for connection, and its operating cost
Max. Return on Investment		• depends on travel demand and fare
Min. Congestion Cost		• generalised cost in Kyongju city on all roads caused by all of travellers for urban journeys according to the location of station
Min. Energy Consumption		• depends on fuel consumption by travel distance, time
Max. Socio-Economic Benefits	Developed Regional Eco.	• different with site location & condition of station
	Min. Severance Effects	• the severance effects of neighbourhood relationship and urban social, economical relationship.
	Min. House Replacement	• measured by total numbers of replaced house against alternative routes within predetermined distance
Min. Adverse Environmental Effects	Noise (sound pollution)	• measured by total number of the exposed house against alternative routes within a predetermined distance
	Air Pollution	• less polluted electric power
	Vibration	• similar effect to sound pollution
	Ecological Impacts	• depends on railway route passing through the mountains, rivers
	Min. Visual Intrusion	• assessed by the view from Namsan
	Min. adverse impacts on Cultural Assets	• depends on number of cultural sites affected by the project within predetermined distance

6.2.6 Design of A Hierarchy

The third step of application is to structure the hierarchy from the overall goal through the intermediate level to the lowest level with the chosen elements. As can be seen in Figure 6.2, the hierarchy for this case study consists of five levels.

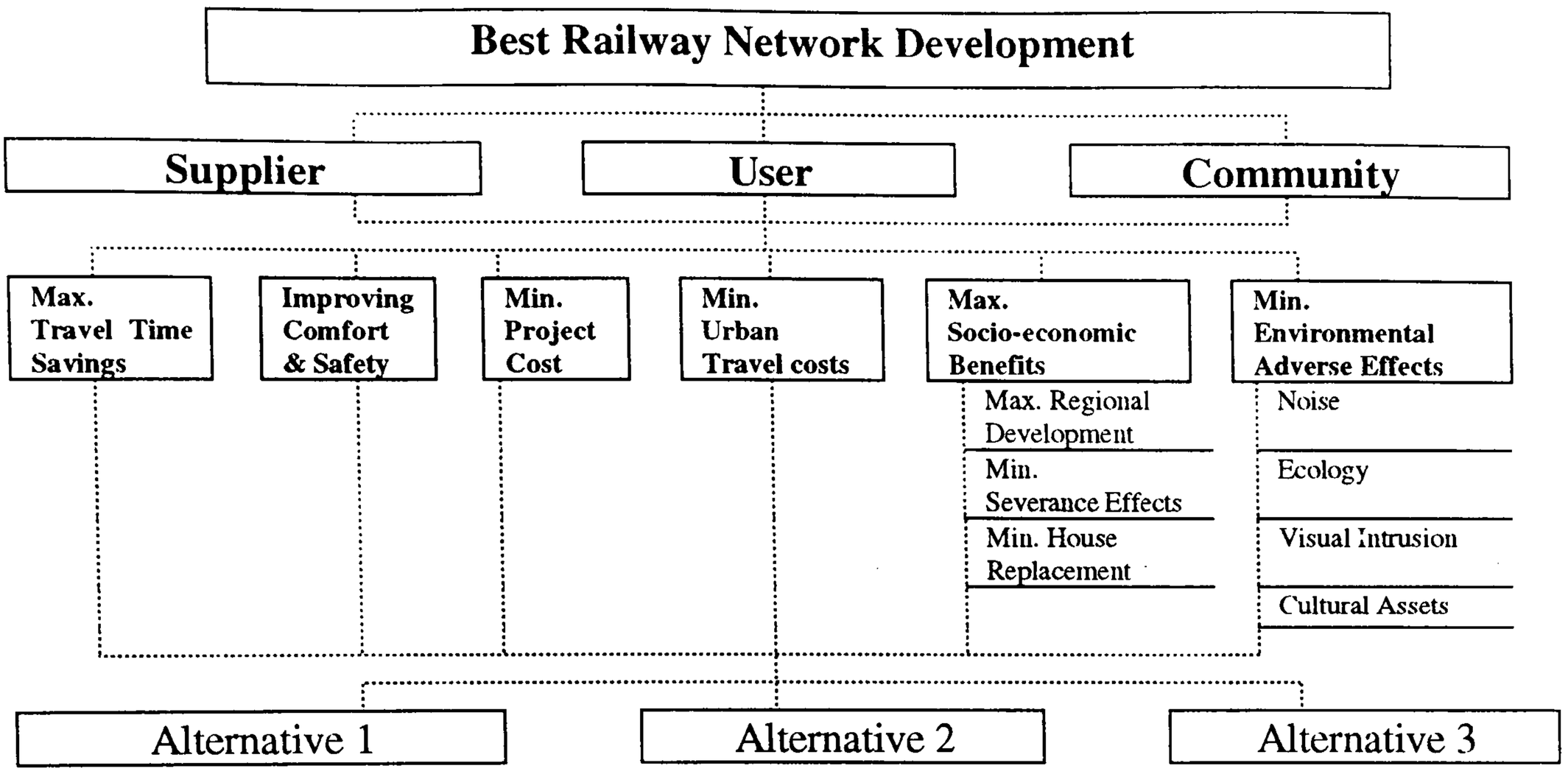


Figure 6.3 Structuring A Hierarchy

In the first level is the overall goal "Best Railway Network Development", in the second level are the actors involved in this project as decision makers, in the third level are the objectives (they were selected by the expert survey, which is described in section 7.4.1.2) which contribute to the goal, in the fourth level are the elements which have impacts on each objective, and in the final level are alternatives which are to be evaluated in terms of the elements in the next upper level.

6.3 Questionnaire Survey and Derivation of Weights

The next step is the elicitation of pairwise comparison judgements. Through conducting questionnaires and personal interview, the relative importance of the elements with respect to the higher level can be elicited.

6.3.1 Expert Survey

In this survey, we investigate two goals, one is to find the importance of stakeholder's role, and the other is to check the preference of objectives. For the derivation of relative priority of stakeholder's role, the pairwise comparison for each pair is to be carried out. The second goal of this survey is to select the objectives for the application of railway investment project.

In order to select the appropriate numbers of objectives and criteria of transport investment evaluation, it is necessary to obtain the experience and knowledge of the experts who are involved in the transport planning and accomplishment directly or indirectly. This is why they are in the line of planning and implementation of transport investment and know the main factors as well as the constraints influencing transport infrastructure investment rather than the people affected.

Before the survey, all possible sets of evaluation factors (see Table 6.2) in transport investment are extracted by using a literature review and also by reviewing the past transport investment trend and future transport policy. With this setting, the survey is carried out among transport experts to select the objectives and criteria of the research.

With the result of this survey, the next step is to prove the validity for determining the number of objectives. In order to do this, the cumulative percentages of highest ranking to avoid too many selection of objectives can be used as basic measurements for this.

The questionnaire for the expert survey consists of three parts.

Part 1: general background: professional identity and the length of experience

Part 2: subjective rating about the degree of importance for the role of each decision maker in transport investment

Part 3: subjective rating of objectives affecting transport investment

6.3.2 Questionnaire Survey and Derivation of Weights

Assessment of priority weights reflecting the importance of the various impacts considered in most multiple criteria evaluation methods is a crucial step in evaluation research. It is mainly at this point that a difference between multiple criteria evaluation and cost-benefit analysis emerges. In traditional cost-benefit analysis, an effort is made to evaluate the importance of impacts of alternatives by means of a market approach, i.e., prices, whilst in multiple criteria methods the weights reflect the subjective insights of decision makers.

The way of measuring priorities varies and among these methods, the easy way for the analyst to deal with it is to ask the decision-maker to distribute a constant number of points among the objectives distinguished in such a way that the number of points allocated to an objective reflects its relative importance. For this research which has a hierarchy with several decision makers and many objectives, it needs the ranking and the difference in importance between the objectives.

Therefore, a pairwise comparison approach in ranking method is more appropriate even though it needs extensive data collection and iteration. For this, the scale of relative importance is used to determine the degree of importance between the objectives based on the decision maker's information, experience and personal judgement through the questionnaire survey.

Questionnaire surveying for preference of the objective is carried out for all stakeholders on selected goals and objectives, and the main contents of this survey are to describe the relative degree of importance between elements. Therefore, the contents will be more greatly specified rather than in the expert survey as follows:

. Part 1: general background

. Part 2: subjective judgement of the relative degree of importance between objectives

. Part 3: subjective judgement of the relative degree of importance between attributes

. Part 4: subjective judgement of the relative degree of importance between alternatives

6.3.2.1 Collecting Data (input data)

The respondents translate the available information into paired comparisons by answering the questions. This can be accomplished by asking the participants to evaluate each set of elements in a pairwise fashion with respect to each of the elements at the next higher level. Using the ratio scale, the participants assess the dominance of each element over the others with respect to each element of the immediately higher level of the hierarchy.

With the results, the pairwise comparison matrix is constructed for comparisons of the elements involved in a decision to derive their scales of priorities. If numerical judgements (tangible) are used, the assessment is how many times one is judged superior to the other as normalised values predicted based on the concepts of cost-benefit analysis via the project survey, while when the pairwise comparison process is concerned with intangibles, verbal judgements (the fundamental scale of the AHP of nine absolute values) are used.

The way of pairwise comparison is to attach weights to each of the objectives which reflects their importance to each decision-maker based on their information, experience and personal judgement through questionnaire survey.

6.3.2.2 Deriving Group Judgement Data

As the next step, to get the group judgement data as input data, all individual judgement data is combined into one, and for this the geometric mean which preserves the reciprocal property is used. The process for applying the geometric mean method is described in section 5.3.2.

After getting the combined judgements on each pair of each matrix, the relative priority is derived on each matrix. This procedure is repeated for the elements in a level with

respect to all elements in the level above. This can be accomplished by using the principal eigenvector of the matrix of paired comparisons.

6.3.3 Derivation of Weights

In the hierarchy, the priorities of the alternatives in the fifth level are determined by the objectives in the third level whose priorities are determined in terms of the goals. The priorities of the goals are determined by the decision makers in the second level. The priorities of the decision makers are determined especially by the expert survey considering the overall goal. To derive the scales of priorities, *an eigenvector approach* proposed by Saaty for the estimation of the weights from a matrix of pairwise comparison is used.

6.3.4 Consistency Check

After estimating the weights, the decision makers are provided with a measure of the inconsistency of the given pairwise comparisons. This *Consistency Ratio* C.R. provides a measure of the probability that the matrix was filled in purely at random. That is, the C.R. is a comparison of the current matrix and a purely random answering of questions. The number 0.1 which means there is a 10% chance that the decision maker answered the questions in a purely random manner is the accepted upper limit for the C.R..

With more consistent judgements, the less likely it is that the matrix was filled in at random and thus, C.R. decreases. If C.R. > 0.1, it is recommended that the decision maker revise some judgements since they are highly inconsistent, Golden et al (1989), so we follow the rule in this research, which means that if the final results is not consistent (C.R> 0.1) we go back to the first stage to check the structure of the hierarchy and the questionnaire, and then implement another survey to get their preferences.

6.3.5 Project Survey

The case considered for this research is a part of HSR implementation projects in Korea, and the master plan for constructing the HSR railway network of Kyongju area has already been carried out by The Korea Transport Institute (KOTI), a governmental organisation. KOTI carried out detailed planning for developing HSR railway system and as a part of that, in order to select the best railway route network passing the historic city of Kyongju, they evaluated 4 route alternatives by cost-benefit analysis with their subjective judgements including non quantifiable effects.

As this research is based on the KOTI project, many data comes from the project. In this research, there are eleven factors to be assessed in the model, from travel time to the cultural assets. The alternative could be compared with the value of every factor in numerical terms, so most of the factors should be expressed, as much as possible, in numerical terms.

However, there are some difficulties to express these in numerical terms for subjective or complicated factors such as comfort, severance effects, etc. So these factors are compared in terms of quality or verbal judgements, while the other factors (five factors) are derived in numerical values.

The value of most tangible factors for the research are collected from the research of the KOTI project. Then the factors are normalised on the scale from 0 to 1 for the process. For the normalisation, a formula below is used, and if the value means negative impacts on the project, the inverse of the value is normalised :

normalised score = raw score / the sum of all raw score

$$W_i^j = V_i^j \,/ \sum_k V_k^j$$

$$and \sum_k W_k^j = 1.0$$

where W_i^j : normalised value of factor j for alternative i, V_i^j : raw value of factor j for alternative i , k : number of alternative $(i \in k)$, j: indicates the number of factors (1 ... n)

6.3.5.1 Urban Travel Cost of Kyongju city

This objective can be expressed by measuring the vehicle operating cost and the value of travelling time of all travellers using the road network in Kyongju city area after the construction of the HSR railway. The cost will be different according to the location of station in each alternative. The vehicle operating cost consists of two parts, fixed cost and variable cost, and the value of time is distinguished into two, work trip and non work trip.

Costs were estimated for the possible year of opening 2005 to 2025, and the annual increase rate was derived to calculate the years between and estimated for the rest of years. Costs streams were all discounted at a uniform rate of discount of 13%, the rate used by the Korean Government for national investment procedures based on 1995 figures. The price units are 100 million Korean won.

Table 6.3 Urban Travel Cost of Kyongju area

	2005	2015	2025	total 2005-2025	inverse	normalised priority
alt. 1	21892.4	88651.2	290102	2335358	4.28E-07	**0.3323**
alt. 2	21797.8	87596.4	287346.3	2311836	4.33E-07	**0.3357**
alt. 3	21980.3	88673.1	290470.7	2337859	4.28E-07	**0.3320**

Source : KOTI, 1996, The feasibility study for selection of the best HSR railway route passing by Kyongju city

Final output calculated by KOTI is shown in Table 6.3. According to the Table, all alternatives showed similar results. To derive the relative priority, derived cost of each alternative is inversed and then normalised because this figure means a negative preference.

6.3.5.2 Project Cost

Project cost is the total amount required for the proposed alternative. It consists of two categories, construction and operating cost. Construction cost is again divided into three costs, the construction cost of HSR railway and access road, the replacement cost of existing railway to connect new station, and the operating cost of HSR. According to the final output of Table 6.4, construction cost of alternative 2 compares less favourably with those of others, but it requires a greater cost for the connecting roads. Alternative 1 has the advantages of easy connection to existing railway because it is routed relatively adjacent to existing railway. The operating costs were estimated from 2005 to 2025, then discounted and totalled up to 1995. Alternative 1 requires high operating costs to maintain it.

Table 6.4 Project Cost

	cons.cost	access road	re-route	construction (A)	operating (B)	total (A + B)	normalised priority
alt. 1	18107.5	280.5	3797.5	22185.5	11771.3	33956.8	**0.3098**
alt. 2	15915.1	418	4516.4	20849.5	9527.946	30377.45	**0.3463**
alt. 3	16451.7	233.2	4546.6	21231.5	9358.609	30590.11	**0.3439**

Source : KOTI, 1996, The feasibility study for selection of best HSR railway route passing by Kyongju city

6.3.5.3 Travel Cost of Rail Passengers

This objective can be expressed by measuring the travel time and the value of travelling time of existing rail passengers of the south-east railway from their destinations to Kyongju new station. It can represent the degree of time savings and accessibility to each alternative station because it is affected by the location of station.

As the existing railway (Donghae nambu Line) runs to Seoul, Daegu, Ulsan and Pohang. The travel time was derived from the base point of each destination to the

station of each alternative. In order to calculate cost, the number of rail passengers from 2005 to 2025 was estimated, and then the cost was derived by the value of time. Costs were discounted and added up as above.

Final output calculated by KOTI is shown in Table 6.5. According to the Table, alternative 2 compares more favourably than the others, while alternative 3 is least favoured. It may be caused by the fact that the station of alternative 3 is relatively far from most destinations.

Table 6.5 Travel Cost

	2005	2015	2025	total 2005-2025	inverse	normalised priority
alt. 1	144.5	171.8	215.6	3686.455	0.000271	**0.3180**
alt. 2	114	135.6	170.1	2909.013	0.000344	**0.4030**
alt. 3	164.7	195.8	245.8	4201.941	0.000238	**0.2790**

Source : KOTI, 1996, The feasibility study for selection of best HSR railway route passing by Kyongju city

6.3.5.4 House Replacement

House replacement is one of the most serious social impacts for community residents. It can be measured by the total number of house to be removed and replaced by the proposed project implementation. So in consideration of human and community life patterns, we can determine the total number of the house that have to be removed and replaced to another place as the measure of this objective. The total number of house to be replaced were counted by KOTI, and house within 50 m from the route were considered to be replaced.

Table 6.6 House Replacement

	number	inverse	relative priority
alt. 1	423	0.002364	**0.2678**
alt. 2	315	0.003175	**0.3597**
alt. 3	304	0.003289	**0.3726**

Source : KOTI, 1996, The feasibility study for selection of the best HSR railway route passing by Kyongju city

6.3.5.5 Noise

Noise is one of the major disadvantages caused by transport investment. It affects the quality of life of community residents just as house replacement does. There are many ways to compare the impacts of noise among alternatives such as NNI (Noise Number Index), compensation cost for welfare loss of the area and its neighbours and house numbers exposed at noise. But in this research, the total number of house exposed to noise within 250m from the proposed route is used the same as KOTI used for its measurement.

Table 6.7 Number of House exposed to Noise

	number	inverse	relative priority
alt. 1	2271*	0.000440	**0.2745**
alt. 2	1817	0.000550	**0.3431**
alt. 3	1632	0.000613	**0.3824**

source : KOTI, 1996, The feasibility study
* : estimated figure

Summarising the results from the project survey, alternative 2 was favoured in minimising travel costs of railway users because of its reasonable location of station, and alternative 3 in minimising house replacement and noise as this route and station was far from the residential area. Alternative 1 was least favoured in many ways because it was so close to the residential area and city.

Table 6.8 Summary of Relative Priorities for Tangible Objectives

	Alt. 1	Alt. 2	Alt. 3
min. urban travel cost	33.23%	33.57%	33.20%
min. project cost	30.98%	34.63%	34.39%
min. travel cost of rail passenger	31.80%	40.30%	27.90%
min. house replacement	26.78%	35.97%	37.26%
min. noise	27.45%	34.31%	38.24%

However, these figures do not decide the final priority of alternatives because they are just a part of much input data for the evaluation of the Kyongju line. This data is used to combine the intangible factors in the analysis with tangible factors, and then the global priority of alternatives are derived.

6.4 Composition of Priorities

After estimating a set of weights for each alternative, the next stage is the synthesis of the weights of elements for various levels with the normalised factor values of every alternative. The principle of *hierarchic composition* provides a way of computing the overall priority of the alternative. The overall priority of the individual alternative can be obtained by multiplying each weight of the level with that of the sublevels which belongs to certain elements of the level as the linear, additive function.

This process simply states that the weights are created by totalling the priority of each element according to given criteria by the weight of the criteria, and this process for matrix composition is shown in section 5.3.3.

6.5 Sensitivity Analysis

The sensitivity analysis is a crucial step in any modelling effort and should not be ignored in a careful application of the AHP because this test enhances better understanding of the decision situation. One might be interested in verifying the effect, if there is any, of changing the importance of stakeholder's role and their preference for the objectives. The result from that sensitivity analysis could provide more accurate or flexible decisions for the decision maker and for checking the relative importance varied along with uncertainties of the future.

In this research, in order to see how the decision changes in accordance to the weight and preference, a sensitivity analysis is carried out by changing the importance of each decision-maker's role and his preference for several objectives, then the results of the analysis is compared with the base case. These results are described pictorially, and then assessed mainly with the impacts (rank order changes) on alternative priorities via the researcher's subjective judgement.

In addition to this, as a quantitative method for measuring discrepancy to decide which actor's role has a greater impact on the alternative decision or which objective has a greater impact on each stakeholder's decision, Kullback-Leibler discrimination measurement is used. This measurement is to measure the discrepancy between two priority vectors by incremental changes of each stakeholder's role and the preference of several objectives from 0% to 100% respectively.

The Kullback-Leibler discrimination measurement which uses a information index for measuring discrepancy between two discrete probability distribution (or priority vector) $P = (P_1, P_2, ..., P_n)$ and $q = (q_1, q_2, ..., q_n)$, that is, the relative entropy (also referred to as cross entropy) given by:

$$I(p: q) = \sum_{i=1}^{n} p_i \ln(\frac{p_i}{q_i})$$

was used. $I(p: q)$ is always non negative and is equal to zero if and only $p = q$, Sanchez & Soyer, (1994).

KL measures also can be used to assess whether a priority vector changes significantly as a result of the pairwise comparison provided by the decision maker. This can be achieved by measuring the KL distance between the two priority vectors during the pairwise comparison process. If p_k denotes the priority vector after the k^{th} judgement and p_{k-1} is the priority vector after the $(k-1)^{st}$ judgement, then we can obtain the KL measure

$$I(p_k: p_{k-1}) = \sum_{i=1}^{n} p_{ik} \ln(\frac{p_{ik}}{p_{i,k-1}})$$

and we can determine whether to stop after the k^{th} judgement based on its magnitude.

But in this research, instead of this measurement to stop the judgement, the researcher's programme to stop the calculation when the digit is to 4 decimal points converges into the same figure was used because most priority vectors converges into one figure easily as the calculation goes on. KL measurement was only used as the base for the judgement to see which objective has strong impacts (large KL figure means large discrepancy) on the decision of each group in the research..

6.6 Comparison of The Results

All the results from the AHP application are to be compared with that of the existing applied evaluation method, the cost-benefit analysis with a subjective judgement for a few intangible factors. The difference between the two methods and their results is analysed focused on the ranking and the evaluation process.

In addition, the applicability and suitability of the AHP method itself will be assessed by the following several criteria. For this, advantages and disadvantages found throughout the application of this project are investigated in as much detail as possible from the data collecting (survey questionnaire) through structuring a hierarchy to derivation of weight in terms of a few qualitative criteria. These criteria for the assessment of the methodology are as follows:

- computational burden: data requirement, computational efficiency, inclusion of qualitative information, combination of tangible and intangible data
- evaluation procedure: easy and understandable process, dealing with a complex problem,
- degree of interaction with the decision maker: understandability of methods, encouragement of public participation, flexibility for the decision maker
- applicability: applicability to transport project, linkage to decision making process

Chapter Seven

Model Implementation & Analysis

7.1 Introduction

The objective of this research is to find the best railway route with a station passing through/by Kyongju area as a part of the whole HSR line. As this project has a variety of criteria to be considered and various interests from multiple groups affected by project as mentioned before, the method for this research has to be a multiple criteria evaluation method which can incorporate quantitative and qualitative judgements from various interest groups.

This research is based on the project carried out by KOTI. However, as these alternatives are not appropriate for the research purpose (it is described in following section), the alternatives were modified from the original 4 alternatives to the distinguishable and comparable ones according to the pilot survey which checks the suitability of the alternatives for the research, the methodology, and survey questionnaire for the analytic hierarchy approach.

The whole evaluation process was done by the analytic hierarchy process method following the evaluation procedure which was set up and described in the previous chapter. Two judgements, a quantitative judgement for the quantifiable items and a subjective judgement for the preference of intangible criteria, were incorporated in this analytic hierarchy approach. For tangible criteria, the costs derived by KOTI were used based on CBA concepts, while the respondent's subjective judgements via the questionnaire survey which is to judge the weights of the stakeholder's role and the

preference of the objectives and various criteria, were used to derive the priorities of intangible criteria.

With regards to the questionnaire survey, the importance of each stakeholder's role was derived by the expert survey and the objectives were also confirmed in this survey, while the preferences for intangible factors were examined by the questionnaire survey for each interest group. The results of the questionnaire survey and the project survey were combined to derive the relative weights of each factor and alternative at various levels of the hierarchy, and then decide the overall priority (the best alternative). All the data was calculated and analysed through software which was developed for this research based on Saaty's method

7.2 Pilot Survey

The pilot survey was undertaken in June in 1997. It was undertaken to guide the main survey questionnaire in the right way, and for checking the suitability of the alternatives for the research. 19 respondents (students in University of Leeds) were given a brief explanation about the survey scheme and alternatives attached to the front of the questionnaire, they were then asked to mark their relative preference of each pair of comparison question on each element via their subjective judgement as well as their comments and recommendation on the survey scheme.

The questionnaire consists of two types of survey forms, one is the expert survey, and the other is the questionnaire survey. For the expert survey, 7 students in the Institute for Transport Studies were selected and given questionnaire. 12 other students in the University of Leeds answered the question to find out their relative preference of objectives and alternatives regarding the transport investment projects via the questionnaire survey.

In order to check the validity of the questionnaire, the consistency of all responses were checked individually before the derivation of group judgement data. This is caused by the fact that the consistency could imply whether the questionnaire works in getting proper answer without confusion or bias and whether the hierarchy is well structured or not for pairwise comparison.

Each survey includes two and four parts respectively. The survey questionnaire is attached in Appendix 1.

The expert survey to find the degree of importance of the stakeholder's role consists of two parts:

part 1: general background

part 2: degree of importance of stakeholder's role

and the questionnaire survey has four parts:

part 1: general background

part 2: relative importance of each objective with respect to the overall goal

part 2: relative importance of each element with respect to the objective

part 2: relative importance of each element with respect to each alternative

A pilot survey was carried out in following manner, and the results were summarised as follows:

■ Conduct of Questionnaire

1. A total of 19 respondents were randomly selected among the Korean students in the University of Leeds, among them 7 students majoring in transport were asked to answer the questionnaire for the expert survey, while 12 students not in transport fields were asked to respond to the questionnaire survey. When giving the questionnaire to them, the survey scheme and the case study were explained very briefly by the researcher (these were also attached to the front of the questionnaire)

and they were asked to mark their preference of each pair of comparison questions on every element via their subjective judgement.

2. The questionnaires were of two types, one was for the importance of the stakeholder's roles (expert survey), the other for the preference of each elements (questionnaire survey). The alternatives which were given to respondents were the same as those of KOTI project.

3. 7 and 12 replies were collected for the expert survey and questionnaire survey respectively with some comments and recommendations about the survey scheme which researchers elicited. The data was analysed via typical AHP process, and calculated by spread sheet to check every step of the process.

■ Results from Pilot Survey

1. Summarising the results of the expert survey, which derives the expert's subjective judgement on *"Which actor's opinion should be considered more important and reflected in the decision of the best alternative ...?"*, 6 of 7 respondents made consistent pairwise comparisons. They replied that the opinion of user and community group should be considered more important in the evaluation process than the supplier group. Among these two groups, user and community, community members should be considered slightly more important (41%) than users (34%). Most of the respondents replied that the supplier's group role should be reduced from its current role in the decision.

2. Following the comparison of the relative importance of the objectives in the questionnaire survey, half (6) of all responses (12) turned out to be inconsistent, which may be caused by a slightly ambiguous definition of a few objectives and unclear relationship between each other. It implies that it needs a clearer definition of objectives and independent relationships to avoid double counting for the comparison of degree of importance with each other.

3. Summarising the results only with consistent cases (6 cases among 12), *minimising adverse environmental impacts* (28.4%) and *maximising socio-economic benefits* (24.6%) were considered more important and *improved transport network* (13.9%) and *reduced travel time* (10.1%) were chosen as the second important factors to achieve the overall goals "best railway network development in Kyongju".

4. In the comparison between 4 environmental factors, *noise, visual intrusion, ecological effects* and *cultural assets,* most of the responses (10 of 12) were consistent because those items were familiar to recognise and the definition and information given to the respondents was relatively clear. According to the result from this comparison, 4 elements were categorised into two, *ecological effects* (36%) and *cultural assets* (37%), *noise* (14%) and *visual intrusion* (13%). The former pair was highly considered more important than the latter pair. *Ecological effects* and *cultural assets* turned out to be the most important factors in minimising adverse impacts on environment with respect to the railway network development in Kyongju.

5. According to the synthesis process of the weights of elements for various levels from expert and questionnaire survey, the global priority of 4 alternatives was derived respectively. Among 4 alternative, alternative 2 showed the highest priority with the relative priority of 32.1%, while the relative priorities of the rest of alternatives were very similar to each other with 22%, 23%, 23%. This similarity might be caused by the facts that, firstly, it was very hard to distinguish three alternatives (alternative 1, 3, 4), secondly, it was difficult to compare each objective and attribute which had no clear relationship of trade-offs or conflicts, and then to find the compromise.

The pilot survey was implemented based on the analytic hierarchy process. Through this pilot survey, the researcher got many important findings for the application of the AHP in advance of the main survey as follows, and these became useful guides for the elicitation and modification of the main survey questionnaire.

1. The results from the pilot survey proved difficult in distinguishing 4 alternatives (see Figure 2.2, alternative 1 to 4) from each other in comparison of the alternatives or elements of each alternative. This was caused by the fact that there was no huge and clear difference between alternatives. Moreover, as information about each alternative was ambiguous in many ways, many respondents felt it hard to differentiate each alternative and compare a few items with respect to the alternative. So it requires alteration of alternatives into alternatives with much more comparable objectives and attributes each other.

2. In order to make it clear for the comparison and maximise the trade-offs between evaluation criteria, especially, "accessibility and development" and "cultural assets conservation and minimisation of adverse impacts on environment", and to check the validity of this analytic hierarchy approach, it required more clear distinction of alternatives and objectives. Moreover this also meant alternatives for the research to be modified and objectives reconsidered without double counting. Regarding the alternative modification, 4 alternatives were changed into 3 for solving the conflicts and trade-offs. Two alternatives from the KOTI project were taken and another alternative was added. The three alternatives finally selected were as follows:

- Alternative 1 (Hyeongsan route) - the closest to the residential area and cultural assets with regard to transport accessibility and positive development
- Alternative 2 (Hwacheon route) - located between alternative 3 (conservation) and new alternative 1 (good accessibility)
- Alternative 3 (Duckcheon route) - farthest from the residential area and cultural assets for cultural conservation

3. From the pairwise comparison of the objectives in the pilot survey, as there were several objectives which overlapped or duplicated, for example, *reduced travel time* and *improved transport network* had the same attribute of access improvement, many respondents were confused and asked for clarification of the differences of each objective. It required considerable consideration when selecting and dividing the elements. According to the result, it is necessary to reconsider the objectives

for the main survey and then they were screened and finally selected by the transport experts (see section 7.3.1.2).

4. It was also felt to be very difficult for respondents to keep the whole perception throughout the survey for pairwise comparison between each other. As there were *n(n-1)/2* judgements of each pairwise comparison for every items (for example in case of the pairwise comparison of 7 objectives, it needs 7(7-1)/2=21 pairwise comparison), it was very hard in replying unless they had the whole perception from the first pair to the last pair in a level. It requires the researcher to give the respondents iterative information which enable the respondents to keep the whole perception throughout the questionnaire unless the number of elements to be compared is small below 4 or 5.

5. With regard to the analysis, it was not easy to use a spread sheet as well as AHP software due to being time consuming or having many iterative input processing works. For a sequence of analysis and attempts in various ways to get various conclusions, the development of a new programme was necessary. It was designed for the research by the researcher based on the AHP method.

The final version of the two surveys, expert survey and questionnaire survey, for the main survey were updated based on the findings from this pilot survey, and implemented in the main survey. The survey questionnaire for the main survey is also presented in the Appendix 2.

7.3 Conduct of The Questionnaire

The main survey questionnaire evolved from the pilot survey, then it was carried out from September to October, 1997, in Korea. In order to get the data for the judgement from the questionnaire, the respondents were randomly selected among

transport experts for the expert survey and among the general public for the questionnaire survey respectively.

The respondents for the expert survey, which judge the stakeholder's role and select the appropriate objectives for the alternative evaluation, were selected from fields of those that were related with the transport sector. The respondents for the questionnaire survey, which compares and evaluates the relative priority, were selected among transport facility suppliers, transport users of the Seoul-Pusan transport axis and community members in the proposed area, Kyongju. The background of the respondents is described in next section.

The survey was carried out as follows: Firstly, the expert survey was carried out on transport expert by mail to derive each stakeholder's role and to decide the objectives for the research. Secondly, with the objectives finally confirmed by the expert survey, the questionnaire was designed for the questionnaire survey. The questionnaires for supplier and community members were sent out and collected by mail, while users were interviewed by some surveyors at bus terminals and rail stations and on board trains and inter regional buses. To aid their decisions, a description of the survey scheme and the information were attached to the front of the questionnaire as a reference. The questionnaire forms used are attached in Appendix 2.

The respondents were asked to translate the information into paired comparisons by answering the questions after getting information from the attachments or surveyors. This was accomplished by asking the participants to evaluate each set of elements in a pairwise fashion with respect to each of the elements at the next higher level. Using the ratio scale, the participants assessed the dominance of each element over the others with respect to each element of the immediately higher level of the hierarchy..

A total of 137 and 478 replies for the expert survey and the questionnaire survey were collected respectively from transport experts and the general public. The background of the respondents is as follows:

7.3.1 Expert Survey

- Background

- researchers who work for the transport research institutes such as:
  KRIHS: Korea Research Institute for Human Settlements
  KOTI : The Korea Transport Institute
- members of transport academic associations including university faculties, transport engineers, researchers and students
- transport experts of transport engineering & consultant companies

A total of 137 responses for the expert survey were collected. Among them, 57 experts having working experience in the transport field greater than or equal to 7 years, and the other 70 having less than 7 years working experience. The classification of working experience was based on the number of years which were thought necessary to get used to their field since starting job. This classification is to see some changes of their priorities according to their experience.

Table 7.1 Expert Survey Respondents

Career	≥ 7 yrs	< 7 yrs	unmarked*	Total No. of respondents
No. of respondents	57	70	10	137
%	41.6%	51.1%	7.3%	100 %

* the respondents who did not answer the career question

7.3.2 Questionnaire Survey

- Background

•supplier	Ministry of Construction and Transport Korean High Speed Rail Authority
• user	passengers on board trains, buses of the Seoul-Pusan transport axis passengers in terminals (rail, bus) of Seoul, Kyongju
• community	Kyongju city community members

A total of 478 responses were collected or interviewed for the questionnaire survey, 124 as suppliers, 174 as users and 180 as community members. In order to check some change in priorities according to their circumstances, each group was divided into two sub-groups respectively, supplier by career (≥7 years or <7 years), user by frequency of using transport mode (more than once a month or less frequently), and community by living area (the area passing the proposed route or not).

Table 7.2 Questionnaire Survey Respondents

group	sub-group	No. of respondents	%
Supplier	≥ 7 yrs	56	45.2
	< 7 yrs	60	48.4
	unmarked	8	
	total	124	100
User	once per month	75	43.1
	less frequent	92	52.9
	unmarked	7	
	total	174	100
Community	affected area	62	34.4
	non-affected area	118	65.6
	total	180	100

7.4 Derivation of Weights

As the next step, to derive the group judgement data as input data for the analytic hierarchy approach, all individual judgement data was combined into group judgement data by the geometric mean method which could preserve the reciprocal property as mentioned in chapter five.

The quantifiable items such as *Max. travel time savings, Min. project costs, Min. Urban travel cost, Min. house replacement, Min. noise impacts* were calculated as numerical units such as costs or house numbers, and then assessed how many times one alternative (or criteria) was judged superior to the other. These normalised values represent the relative priorities (weights) of alternatives with respect to factors.

Regarding the qualitative items which needed a subjective judgement (or preference) of respondents in this research, *Improving comfort & convenience, Max. regional development, Min. severance effects, Min. ecological adverse impacts, Min. visual intrusion, Min. adverse impacts on cultural assets*, verbal judgements were used on each item. These judgements were also derived in the expert survey to find out the importance of each stakeholder's role. The individual judgement data was merged into a group judgement data to derive the weight of alternatives.

In the process, the missing answers were excluded when calculating the geometric mean. With the figures from the calculation of the geometric mean of intangible items, each pairwise comparison matrix was constructed for all intangible items, then the relative priority was derived on each matrix. These calculations for deriving the relative priorities were accomplished by using the principal eigenvector of the matrix of paired comparisons. This process is shown in Figure 7.1 below.

- questionnaire & response sample of respondents 1 to n of item *i*

item *i*	a pairwise comparison between alternatives with respect to one (*i*) of the criteria	
respondent 1		
A	9 8 7 6 5 4 3 ❷ 1 2 3 4 5 6 7 8 9	B
A	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	C
B	9 8 7 6 5 4 ❸ 2 1 2 3 4 5 6 7 8 9	C
respondent 2		
A	9 8 7 6 5 4 ❸ 2 1 2 3 4 5 6 7 8 9	B
A	9 8 7 6 5 4 3 2 1 2 3 4 ❺ 6 7 8 9	C
B	9 8 7 6 5 4 3 2 1 2 3 4 5 6 ❼ 8 9	C
.....	.....	
.....	.....	
respondent n		
A	9 8 7 6 5 4 3 2 ❶ 2 3 4 5 6 7 8 9	B
A	9 8 7 6 ❺ 4 3 2 1 2 3 4 5 6 7 8 9	C
B	9 8 7 6 5 4 3 ❷ 1 2 3 4 5 6 7 8 9	C

▼

- calculation of geometric mean

respondents	questionnaire		
	A-B	A-C	B-C
1	2	missing	3
2	3	1/5	1/7
.	.	.	.
.	.	.	.
n	1	5	2
geometric mean	$(2\times3\times..\times1)^{1/n}$	$(1/5\times...\times5)^{1/(n-1)}$	$(3\times1/7\times...\times2)^{1/n}$

▼

- structuring comparison matrix and derivation of weights for item *i*

item *i*	A	B	C	Priorities
A	1	$(2\times3\times...\times1)^{1/n}$	$(1/5\times...\times5)^{1/(n-1)}$	
B	$1 / [(2\times3\times...\times1)^{1/n}]$	1	$(3\times1/7\times...\times2)^{1/n}$	
C	$1 / [(1/5\times...\times5)^{1/(n-1)}]$	$1 / [(3\times1/7\times...\times2)^{1/n}]$	1	

Figure 7.1 Example of Group Judgement Data Calculation and Comparison Matrix Structuring

According to this procedure, the weights of each matrix were derived. The survey result is shown in the following sections, which indicates the relative importance of each decision maker's role by the expert survey, and the relative priorities of objectives, elements, and alternatives with respect to each factor by the questionnaire survey.

7.4.1 Expert Survey

7.4.1.1 The Comparison of Stakeholder's Role

Summarising the result of the expert survey which derives the expert's subjective judgement about **"*Which actor's opinion should be considered more important and reflected in deciding the best railway route with respect to the railway network development in the historic city, Kyongju*?"**, it turned out that the opinion of *user group* should be considered more important (51.5%) than any other stakeholder groups and the second most important group was *community members* (34.2%) in deciding the best alternative for this transport project.

We can find in this figure that non-governmental portions (around 86%), user and community groups, were considered important among stakeholders. This implies that the role of *supplier*, especially that of the governmental official, is getting smaller from the dominant position in the decision of most transport projects in the past, and their role should be reduced. Instead, those of the other stakeholder's opinions should be considered more than ever.

This can be explained by the facts that the main controversy of many transport investments resulted from the current environmental and socio-economic impacts on users or community members, not the economic terms in government (see section 1.1). This means that we need greater consideration of the various interests of various interest groups.

Table 7.3 The Comparison Matrix of Stakeholder's Role

	Supplier	User	Community	Priorities
Supplier	1	0.2856	0.4111	**0.1437**
User	3.5019	1	1.5426	**0.5148**
Community	2.4326	0.6483	1	**0.3415**
λ_{max} = 3.0005		C.I. = 0.0003		C.R = 0.0005

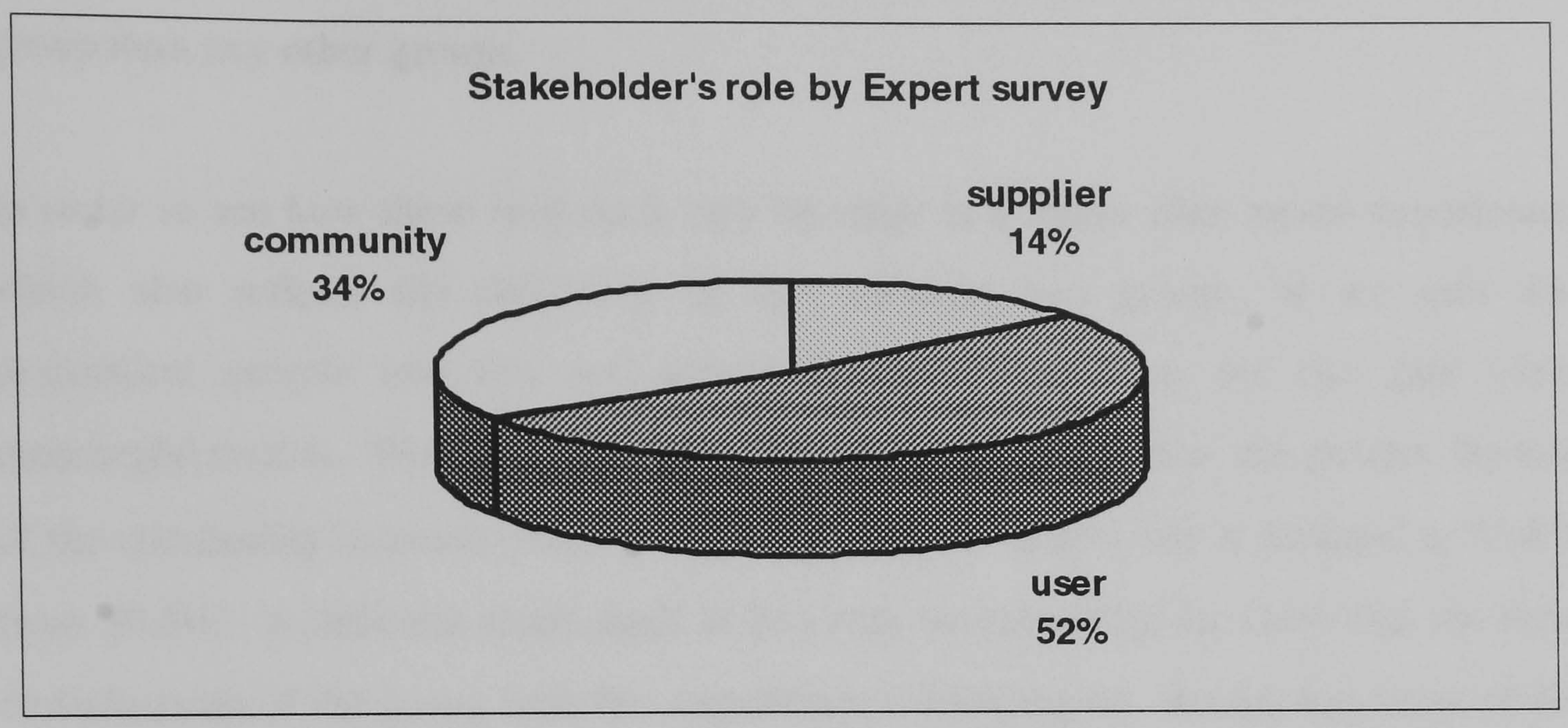


Figure 7.2 Stakeholder's Role by Expert Survey

During the past decade, in Korea, the role of the government in the socio-economic development has been very important and had a major role in decision as a single decision maker. It encouraged economic activities and increased social welfare by investing its money in the infrastructure, which were considered as the first priority. Yet the socio-economic status has changed and people's demand and interests were diversified. Many interest group's diversified demands made society democratic and reduced the political power of government. It means we need a comprehensive evaluation process for transport investment which all of interests groups are able to take part in. Therefore, it is said that the role of Government has been relatively reduced relatively even though they have the power to take a final decision.

On the other hand, the role of community members is continually increasing. So, the role of community members has the trade off relationship with that of Government due to the changed circumstances and this group should be considered more important in transport investment. The importance of the user group has been widely considered most significant in transport supply. This is owing to the fact that most of the objectives for transport investment such as travel time, cost, congestion, safety,

comfort which we consider very important factors are still more related with the user group than any other groups.

In order to see how these responses vary by stage in a career (this means experience) which also reflects the difference of age between two groups, if we split this respondent sample into two sub groups by their experience, we can gain other meaningful results. We can find that the less experience they have, the greater the role of the community increase (33.2% → 34.5%), and the user's role is reduced to 53.8% from 50.8%. A different result such as this may be caused by the facts that the main consideration of the group with less experience is focusing on the improvement of the socio-economic status and quality of life in terms of the society they belong to, however, the difference is not large.

Regarding the difference of the weights between the two sub groups of transport experts, there is no appropriate way to apply a statistical test to prove whether they are significantly different or not. It is caused by the facts that individual raw data was combined into a group judgement data, then all group judgement data was used as the input data for derivation of the weight by matrix manipulation (see section 7.3 about the calculation procedure). It means that original raw data is totally different from these figures (weights) derived through matrix manipulation and calculation.

Therefore, these two sets of weights are all data without population which is to be compared by statistical analysis, so whatever difference there may between the two groups when we try to measure the difference between the two weights, it is too small to be reliably detected in such a small sample. In this research, therefore, only the discrepancy of the priority between the two sub-groups of each stakeholder could be examined, KL discrimination measures (see 6.5) can be used for the measuring of the discrepancy between the two sub-groups of each stakeholder.

When regarding the importance of each stakeholder's role in this AHP process, it is nor necessary to divide them into subgroups as they are not greatly different. The

relative priorities for the whole groups are 14.37% for supplier, 51.48% for user and 34.15% for community members and these are used for the AHP process onward.

Table 7.4 The Relative Priority of Stakeholder's Role: ≥ 7 yrs

	Supplier	User	Community	R.P
Supplier	1	0.2472	0.3848	**0.1303**
User	4.0458	1	1.6514	**0.5377**
Community	2.5987	0.6055	1	**0.3320**
λ_{max} = 3.0004		C.I = 0.002		C.R = 0.0003

Table 7.5 The Relative Priority of Stakeholder's Role: < 7 yrs

	Supplier	User	Community	R.P
Supplier	1	0.2986	0.4126	**0.1470**
User	3.3485	1	1.5154	**0.5076**
Community	2.4238	0.6599	1	**0.3454**
λ_{max} = 3.0009		C.I = 0.0005		C.R = 0.0008

Table 7.6 The Relative Priority of Stakeholder's Role: Summary

	≥ 7 yrs	case: all	< 7 yrs
Supplier	13.03%	**14.37%**	14.70%
User	53.77%	**51.48%**	50.76%
Community	33.20%	**34.15%**	34.54%

7.4.1.2 The Preference for Objectives

In order to screen the predetermined objectives and confirm the final appropriate objectives among all objectives for this research, the survey was carried out on transport experts who were involved in transport planning and accomplishment. The question for this was ***"How much each objective in the table below should be considered important as the main factor as compared with other objectives for implementing the overall goal, the best railway network development in the historic city of Kyongju*?**, and the five point semantic scale, from *much less important* to *much more important*, was used to judge individual preference. The questionnaire form is attached in Appendix 2.

For the analysis, descriptive statistics about their subjective preference which could derive general statistical results such as mean and standard deviation were used. The ranking by mean was used as one of measurements for the selection of objectives. On the questionnaire, the respondents were asked to mark their preference of each objective via their subjective judgement in the box divided by the five semantic scales given. Each scale was attached 1 for *much less important* to 5 for *much more important* for the calculation. The statistic results from the survey are given in Table 7.8.

According to the Table, most of the environmental factors, *Minimising cultural adverse effects (rank 1), Min. adverse ecological impacts (2), Min. visual intrusion (5) and Min. noise pollution (8)* were ranked higher than the other factors, and just a few transport factors closely related with the quality of transport service, *Improving comfort & convenience, Max. accessibility* were also ranked high, while the factors most considered important in the past, *Min. urban travel cost, Max. revenue, Min. energy consumption* were ranked relatively low. These showed that the preference or the importance of the objectives in transport investments was changing

Table 7.7 Statistics of Expert Survey for Preference of Objectives

	Mean	S. Deviation		Rank
Max. Traffic Capacity	3.330882	1.142156	Min. Cultural Effects	1
Min. Travel Cost	3.919708	0.891614	Min. Ecological Effects	2
Max. Accessibility	3.555556	0.911507	Improved Transport Network	3
Improved Transport Network	3.962963	0.849999	Min. Travel Cost	4
Improved Comfort & Conv.	3.79562	0.87564	Min. Visual Intrusion	5
Min. Project Cost	3.051095	1.066338	Improved Comfort & Conv.	6
Max. Return on investment	2.881481	1.022521	Min. Noise	7
Min. Urban Travel Cost	3.044444	0.854022	Min. Vibration	8
Min. Energy Consumption	3	0.931476	Min. Pollution	9
Developed Regional Economy	3.343284	0.88517	Max. Accessibility	10
Min. Severance Effects	3.286765	0.957683	Developed Regional Economy	11
Min. House Replacement	3.014815	1.029311	Max. Traffic Capacity	12
Min. Noise	3.773723	0.831306	Min. Severance Effects	13
Min. Population	3.642336	0.905354	Min. Project Cost	14
Min. Vibration	3.715328	0.865591	Min. Urban Travel Cost	15
Min. Ecological Effects	4.088889	0.805454	Min. House Replacement	16
Min. Visual Intrusion	3.919708	0.84938	Min. Energy Consumption	17
Min. Cultural Effects	4.240876	0.836005	Max. Return on investment	18

To select the appropriate objectives for the research, firstly, the objectives were screened by rank, then the objectives with a lower rank were given lower priorities of choice. Secondly, similar objectives with the risk of double counting were consolidated into a single objective, thirdly the objectives which one was not able to differentiate in value, in other words, the objectives which have the same effects on each alternative were excluded.

Nevertheless, in the selection process, as many objectives as possible were attempted to be included in the analysis. The objectives finally selected (in **bold** and *italic*), their definition, reasons for excluding and measurement method are described in Table 7.8.

Table 7.8 The Objectives and The Reasons & Measurement

Objective		Measurement
Max. Capacity (Mobility Increase)		-increased transport capacity to south-eastern area, -but the route is a part of whole line with one station, so approximately same in terms of nation-wide travel demand
Min. Travel Cost		-generalised cost of rail passenger
Max. Accessibility		-accessibility to the area -assessed and considered by *Min. Travel and urban travel Cost* attribute
Improved Transport Network Connection		-depends on connection ability to local road, regional railway and expressway -considered in *Min. Travel Cost* attribute as access time
Improving Comfort & Convenience		-measured by physical layout such as the roughness of rail route, constitution of route -subjective judgement
Min. Project Cost *(Construction & Oper. cost)*		-construction cost of railway, collector road to rail, relocation of existing railway for connection, and its operating cost
Max. Return on Investment		-depends on travel demand and fare -travel demand to south-eastern area assumed same among alternatives, so not considered
Min. Urban Travel Cost		-total generalised cost of Kyongju city on all roads caused by all of travellers for urban journeys according to the location of station
Min. Energy Consumption		-depends on fuel consumption by travel distance, travel time -train energy consumption not distinguishable, and urban journey considered in *Min.Urban Travel Cost*
	Max. Regional Development	-approximately same each alternative, but slightly different from site location & condition of station -considered by site development of station -subjective judgement
Max.	***Min.***	-the severance effects of neighbourhood relationship and

Socio-Economic Benefits	***Severance Effects***	urban social, economic relationship. -measured by geographical situation of each alternative -subjective judgement
	Min. House Replacement	-measured by total numbers of replaced house for alternative routes within predetermined distance
	Min. Noise pollution	-measured by total number of the exposed house for alternative routes within predetermined distance
	Air Pollution	-less polluted electric power, not considered here
Min. Adverse Environmental Impacts	Vibration	-not different from alternatives
	Min. adverse Impacts on Ecology	-depends on railway route passing through the mountain, river -subjective judgement
	Min. Visual Intrusion	-assessed by the view from Namsan -subjective judgement
	Min. adverse impacts on Cultural Assets	-depends on number of cultural sites affected by the project within predetermined distance and conservation of sites -subjective judgement

7.4.2 Questionnaire Survey

7.4.2.1 Overview of Survey Questionnaire

A questionnaire survey for relative preference of objectives, elements and alternatives was carried out for all stakeholders, and the main contents of this survey are to describe the relative degree of importance between criteria.

The respondents were asked to mark their preference of objectives, elements of the information given and their own subjective judgement. For the comparison of objectives, the definitions for objectives were given according to the results from expert survey, and a brief explanation of each alternative also given as an attachment in survey questionnaire. The detailed explanation was given especially for 6 tangible criteria *Improving comfort & convenience, Improving regional development, Min. severance effects, Min. ecological adverse impacts, Min. visual intrusion and Min adverse impacts on cultural assets* because the respondent's judgements were mainly subject to this information.

7.4.2.2 Derivation of Weights

■ **Objectives**

To derive the relative priority of the objectives which had been set up by the expert survey, the question, ***"Which objective in this transport project should be considered more important as the objective in choosing railway network in Kyongju?"***, was asked to the respondents, supplier, user and community members. There were six objectives considered in this research, *Max. travel time savings, Improving comfort & convenience* and *Min. urban travel costs* in terms of transport efficiency, *Min. project costs* in terms of economic efficiency, *Max. socio-economic benefits* in socio-economic efficiency, *Min. adverse environmental impacts* in terms of environmental efficiency.

Regardless of the difference between the two sub-groups of each stakeholder, we need to measure the discrepancy between each stakeholder to see which stakeholder's sub-group shows a large discrepancy between their sub-groups. It is useful when we divide and select the stakeholder groups to ascertain their various opinion in the evaluation of transport investment projects in the future. To measure the discrepancy, the Kullback-Leibler (KL) discrimination measure was used.

- **Supplier group**

The paired comparison matrix was structured by the geometric mean calculation of individual responses, and then the relative priority was calculated by the eigenvector method for the importance of objectives. The paired comparison matrix of Table 7.9 is for the preference of objectives for supplier group.

Summarising the results of pairwise comparison of objectives by supplier group, of six objectives, *Minimising adverse environmental effects (28.6%)* and *Improving comfort & convenience (23.9%)* were considered more important than the others, and *Maximising socio-economic benefits (16.9%)* was regarded as the second most

important objective in transport investment in high speed rail in Kyongju. It could be said that the results were so consistent (the consistency ratio, 0.0029, was much lower than the threshold value 0.1) as to explain the supplier's preference significantly.

Regarding the importance of *Improving comfort & convenience* objective, it may be caused by the facts that HSR is so considered as a future transport mode with a high speed and safety reliability, which can compete with airlines, that it is easily thought to be an expensive mode to use, which means that high fares and travel time saving are taken for granted, yet enough consideration is not given to comfort.

Therefore, the degree of importance of comfort and convenience which they believe to be achieved as a major objective of HSR project may be emphasised in their responses. Moreover people's preference of transport modes is beginning to show preferences for convenient ways to travel on a transport service such as comfort, good access and information service on travel times and costs. This is caused by the fact that most of the roads are so congested and the capacity of all transport modes is so limited that they tend to trade-offs the travel time and costs with comfort when the travel time is similar even though it costs more than ordinary modes (excellent express inter regional bus costs 60-70% more than the normal service).

We can see this situation via an example of increasing demands of a high standard service in railways and express buses. Despite the same travel time from origin to destination, travellers increasingly use a higher class of modes (for example, excellent express buses with more comfortable seats, mobile phone and toilet).

The importance of a transport service in such as *Improving comfort & convenience* was more greatly emphasised in the case of the supplier (23.9%) who was responsible for transport facilities supply to maximise transport efficiency such as reduced travel time and improved transport service compared with the other groups (user 21.9%, community 17.9%).

In the comparison of sub-groups, we can also find that the less working experience they have, the more concerns they have on comfort and socio-economic benefits, but the less they are concerned with travel time savings and project cost than the people with more experience in Table 7.10. This shows some changes in their interests in decision making.

Table 7.9 The Comparison Matrix for Objectives: Supplier

	MTTS	ICC	MPC	MUTC	MSEB	MAEE	R.P
MTTS	1.0000	0.4309	0.9026	0.9019	0.5464	0.3868	**0.0983**
ICC	2.3205	1.0000	2.5803	2.4342	1.4249	0.7337	**0.2390**
MPC	1.1079	0.3876	1.0000	1.0449	0.6707	0.4189	**0.1075**
MUTC	1.1087	0.4108	0.9570	1.0000	0.5263	0.3666	**0.1003**
MSEB	1.8302	0.7018	1.4909	1.9001	1.0000	0.5153	**0.1686**
MAEE	2.5854	1.3630	2.3872	2.7275	1.9408	1.0000	**0.2863**
λmax.= 6.0195			C.I = 0.0039			C.R = 0.0031	

•MTTS: Max. Travel Time Saving
•ICC : Improving Comfort & Convenience
•MPC : Min. Project Cost
•MUTC: Min. Urban Travel Cost
•MSEB: Max. Socio-Economic Benefit
•MAEE: Min. Adverse Environmental Effects

Table 7.10 Comparison of Objectives by Supplier's Career

Object	≥ 7 yrs	< 7 yrs	difference
MTTS	10.38%	9.50%	**- 0.88**
ICC	22.37%	25.29%	**+ 2.92**
MPC	12.37%	9.46%	**- 2.91**
MUTC	10.68%	9.82%	**- 0.86**
MSEB	15.59%	18.05%	**+ 2.46**
MAEE	28.60%	27.88%	**- 0.72**
KL measures	**0.008343**		

- **User group**

In the case of the user group, they showed similar preferences of the environment (31.4%) and comfort factor (21.9%) to the supplier group, yet travel time (10.4%)

was more important than in the case of the supplier (9.8%) and community group (9.4%). Generally it is thought that users may consider the travel time and cost the most important factors in the view of transport efficiency. However, as we can see in the results, they gave much consideration to the environment and socio-economic status as well as transport efficiency. These results indicate some changes in circumstances as mentioned previously.

Table 7.11 The Comparison Matrix for Objectives: User

	MTS	ICC	MPC	MCC	MSEB	MAEE	R.P
MTS	1.0000	0.5112	1.5420	0.8842	0.4868	0.3443	**0.1037**
ICC	1.9563	1.0000	3.2642	2.2644	1.3057	0.5442	**0.2193**
MPC	0.6485	0.3064	1.0000	0.6998	0.4559	0.3285	**0.0782**
MCC	1.1310	0.4416	1.4290	1.0000	0.6447	0.3661	**0.1098**
MSEB	2.0542	0.7659	2.1933	1.5512	1.0000	0.5109	**0.1751**
MAEE	2.9047	1.8377	3.0443	2.7317	1.9574	1.0000	**0.3141**
λmax.= 6.0442			C.I = 0.0088			C.R = 0.0071	

In comparing the two sub groups of the user group, we can firstly find that the user group who use transport modes (rail or inter-region bus) more frequently (at least once a month) showed an emphasis towards *travel time savings* (12.5%) than less frequent users (8.9%). Less frequent users showed a considerable preference for *improving comfort* compared with the frequent users, which illustrates the general tendency for better transport with greater comfort as we mentioned above. In addition, they showed a greater interests in minimising the adverse impacts on environmental factors as the general public.

Table 7.12 Comparison of Objectives by Frequency: User

Object	≥ once per month	less once per month	difference
MTTS	12.53%	8.94%	**- 3.59**
ICC	23.79%	20.82%	**-2.97**
MPC	7.95%	7.32%	**- 0.63**
MUTC	10.68%	10.92%	**+ 0.24**
MSEB	17.57%	17.52%	**-0.05**
MAEE	27.49%	34.48%	**+ 6.99**
KL measures	**0.016435**		

- **Community group**

Table 7.13 shows the pairwise comparison matrix of objectives for the preference of community members. For some decades, those factors were ignored. Nobody seriously considered the community members, and their interests in the evaluation process has not been considered enough due to too much concentration on economic development. However, socio-economic status has changed and so its interests also diversified to various factors, and moreover the political power to take a decision was reduced and instead many stakeholders were involved in the decision process.

Accordingly community members' involvement was considered more important than the other groups because it became very difficult to implement transport investment in their area without their agreement and their power which get stronger as democracy develops.

In this survey, they showed their preference for the quality of life where they live. Their preference of objectives was focused on socio-economic and environmental factors as these factors were directly related to their quality of life.

According to the results from the survey, most of the results showed some great change in these respects. In terms of community members directly affected by the transport investment to their quality of life, they emphasised environmental and socio-economic circumstances (together 51.6%) more than the other factors (supplier: 45.5%, user: 48.9%).

In the comparison between the two sub-groups classified by the area where they live, they showed very similar preferences. But the small difference indicates that the closer to the proposed transport facilities they live, the more they are concerned with congestion of the area and environment, along with socio-economic factors.

Table 7.13 The Comparison Matrix for Objectives: Community

	MTTS	ICC	MPC	MUTC	MSEB	MAEE	R.P
MTTS	1.0000	0.5821	1.1776	0.6734	0.3871	0.3358	**0.0944**
ICC	1.7179	1.0000	2.3893	1.6132	0.8264	0.5088	**0.1789**
MPC	0.8492	0.4185	1.0000	0.7542	0.4397	0.3366	**0.0881**
MUTC	1.4851	0.6199	1.3260	1.0000	0.6195	0.3990	**0.1232**
MSEB	2.5832	1.2101	2.2741	1.6143	1.0000	0.6040	**0.2079**
MAEE	2.9781	1.9654	2.9705	2.5060	1.6555	1.0000	**0.3076**
λmax.= 6.0285			C.I = 0.0057			C.R = 0.0046	

Table 7.14 Comparison of Objectives by Area

Object	affected	non	difference
MTTS	9.53%	9.37%	**- 0.16**
ICC	16.24%	18.77%	**+ 2.53**
MPC	9.99%	8.22%	**- 1.77**
MUTC	12.88%	12.01%	**- 0.87**
MSEB	21.21%	20.55%	**- 0.66**
MAEE	30.16%	31.08%	**+ 0.92**
KL measures	**0.004233**		

- **Comparison between groups**

If we summarise the results from the comparison of objectives from all stakeholders, first of all, we can find that all groups considered *Minimising adverse environmental impacts* the most important objective of transport investment evaluation in Kyongju, and secondly *Improving comfort* (supplier, user) or *Maximising socio-economic benefits* (community) as the next most important factor. The importance of the factors considered important in the past, such as travel time, project cost, and congestion cost were relatively less considered than those factors. These results show the changed circumstances in decision making circumstances.

As we can see in Table 7.15, Figure 7.3, suppliers and users have similar preference for objectives of transport efficiency such as the improvement of the quality of the transport services, *Minimising travel time savings* and *Improving comfort and convenience*. They especially emphasised the importance of the quality of the

transport service, *Improving comfort & convenience*, and it could be said that the main concern about transport efficiency has moved to the factors of the improvement of the transport service from those of travel time and cost in the past.

User groups considered travel time savings and congestion in the proposed area more important than any other groups, while supplier group considered project costs as a more important factor than other groups because these factors are related to their main interests.

In terms of community members, they showed greater priorities on *Maximising socio-economic benefits and Minimising adverse environmental effects* than the other groups. They also showed a concern over *Minimisation of urban travel cost* which implies traffic congestion in the area.

This may be caused by the fact that it is very closely related to their living circumstances. It means that the transport supplier can meet with great reluctance if they do not consider the community's interests and quality of life as we can see in the cases of developed countries when they do invest in transport in local area.

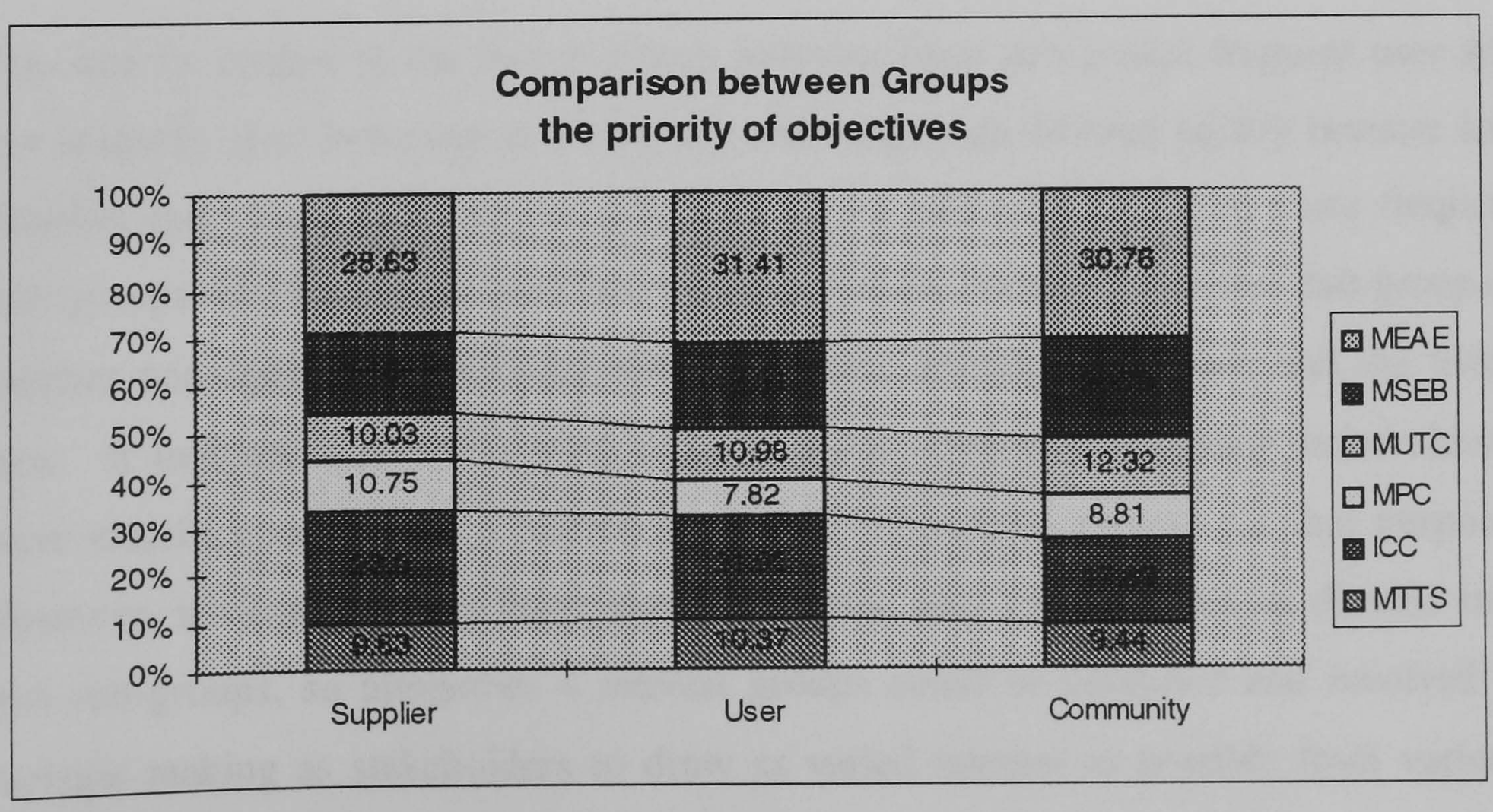


Figure 7.3 Comparison of The Priority of Objectives between Groups

Table 7.15 Comparison of The Priority of Objectives between Groups

	supplier	user	community
MTTS	0.0983	0.1037	0.0944
ICC	0.2390	0.2193	0.1789
MPC	0.1075	0.0782	0.0881
MUTC	0.1003	0.1098	0.1232
MSEB	0.1686	0.1751	0.2079
MAEE	0.2863	0.3141	0.3076

With regard to the difference between each stakeholder's sub-group, the discrepancy between each sub-group was checked by the KL measurement. It will be useful as a guide in the classification of decision makers to draw various interests from multiple stakeholders. According to the results, user groups showed the largest figure (means that the discrepancy between two sub-groups is larger than that of the other sub-groups) between their two sub-groups, while community members showed smallest figure.

Table 7.16 Kullback-Leibler Statistics

	Supplier	User	Community
KL measures	0.008343	0.016435	0.004233

This may be caused by the fact that their interests (user sub-group: frequent user and less frequent user) in transport investment and usage was differed greatly because less frequent users have more similar attributes to the general public than more frequent user groups who have their specified interests. On the contrary, the other sub-group of supplier and community had very similar interests despite their career and the living area. It indicates that if we want to get various opinions from many stakeholders, these classifications of three interest groups are reasonable enough for that purpose. However, if we need many more varied opinions, user groups could be divided into two sub-groups, so altogether 4 interest groups could be classified and involved in decision making as stakeholders to draw as varied interest as possible from various stakeholders.

■ Socio-economic factors

Socio-economic factors consist of three elements, *Improving regional development, Min. severance effects* and *Min. house replacement.* In the comparison between socio-economic factors from the question: ***"Which element among several factors should be considered more important as the main evaluation factor in maximising socio-economic benefits on the area with respect to the railway network development in Kyongju?"***, *Improving regional development* dominated as the most important factor for all stakeholders even though regional development was defined as the site development of the station and surrounding area in this survey.

The supplier groups were most concerned with the regional development which they have regarded as main goals for economic development and regional equity in transport investment for a long time. All the groups showed similar results, while in the case of the community, they considered *Improving regional development* as a slightly more important factor in maximising socio-economic benefits than the other groups.

Table 7.17 Comparison of the Priority of Socio-economic Factors

- comparison matrix - supplier

	MRD	MSE	MHR	R.P
MRD	1.0000	2.2988	2.5516	**0.5423**
MSE	0.4350	1.0000	1.7802	**0.2761**
MHR	0.3919	0.5617	1.0000	**0.1816**
λmax.= 3.0248	C.I = 0.0124			C.R = 0.0214

- comparison matrix - user

	MRD	MSE	MHR	R.P
MRD	1.0000	2.0476	2.0188	**0.5019**
MSE	0.4884	1.0000	1.5059	**0.2823**
MHR	0.4953	0.6640	1.0000	**0.2159**
λmax.= 3.0200	C.I = 0.0100			C.R = 0.0173

- comparison matrix - community

	MRD	MSE	MHR	R.P
MRD	1.0000	2.6293	2.4196	**0.5549**
MSE	0.3803	1.0000	1.6498	**0.2564**
MHR	0.4133	0.6061	1.0000	**0.1888**
λmax.= 3.0380	C.I = 0.0190			C.R = 0.0328

- composite priorities of socio-economic factors - summary

	supplier	user	community
MSD	**0.5423**	**0.5019**	**0.5549**
MSE	**0.2761**	**0.2823**	**0.2564**
MHR	**0.1816**	**0.2159**	**0.1888**

- MRD: Maximisation of Regional Development
- MSE : Minimisation of Severance Effects
- MHR : Minimisation of House Replacement

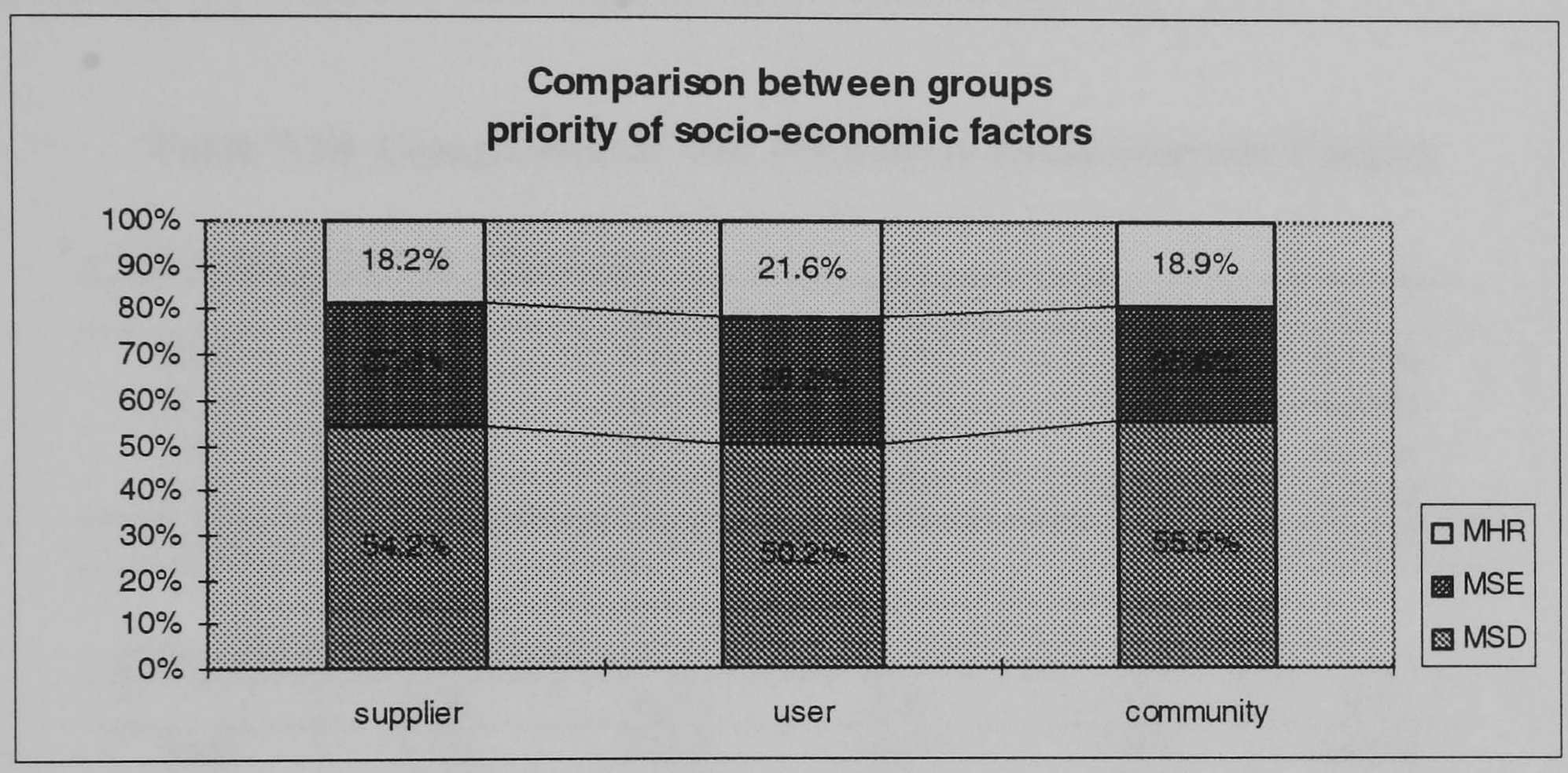


Figure 7.4 Comparison of The Priority of Socio-economic Factors

■ Environmental factors

In the comparison between environmental elements via the question: ***"Which element among several factors should be considered more important as the main evaluation factor in minimising adverse environmental impacts on the area with respect to the railway network development in Kyongju?",*** the importance of each element, noise, visual intrusion, cultural assets and ecological effects, were compared with each other.

According to Table 7.18, all 4 factors were categorised into two, *cultural assets and ecological effects, noise* and *visual intrusion.* The former pair was considered more

important than the latter pair. All of these showed similar results for all stakeholders, while in case of the community, it showed some interesting results as they considered the ecology factor (*Minimising adverse impacts on ecology*) as the more important factor than cultural factor (*Min. adverse impacts on cultural assets*) among environmental factors, and this may result from that it is being more closely related to the environmental quality of life of the area they live than cultural factors. This result gives us quite an interesting result as this feasibility project of Government was mainly generated with a view towards cultural asset conservation.

Table 7.18 Comparison of The Priority of Environmental Factors

- comparison matrix - supplier

	NOI	ECO	VIS	CUL	R.P
NOI	1.0000	0.3960	0.5680	0.3415	**0.1196**
ECO	2.5253	1.0000	2.2228	0.8879	**0.3403**
VIS	1.7605	0.4499	1.0000	0.5386	**0.1840**
CUL	2.9284	1.1263	1.8568	1.0000	**0.3562**
λmax.= 4.0184		C.I = 0.0061			C.R = 0.0068

- comparison matrix - user

	NOI	ECO	VIS	CUL	R.P
NOI	1.0000	0.3535	0.4674	0.2604	**0.0998**
ECO	2.8288	1.0000	2.3121	0.9450	**0.3447**
VIS	2.1394	0.4325	1.0000	0.4215	**0.1730**
CUL	3.8403	1.0582	2.3725	1.0000	**0.3825**
λmax.= 4.0283		C.I = 0.0094			C.R = 0.0105

- comparison matrix - community

	NOI	ECO	VIS	CUL	R.P
NOI	1.0000	0.4307	0.6323	0.3477	**0.1284**
ECO	2.3216	1.0000	1.9975	1.0755	**0.3459**
VIS	1.5815	0.5006	1.0000	0.6276	**0.1939**
CUL	2.8762	0.9298	1.5934	1.0000	**0.3318**
λmax.= 4.0136		C.I = 0.0045			C.R = 0.0051

- Composite priorities of environmental factors - summary

	supplier	user	community
NOI: Min. Noise Impact	**0.1196**	**0.0998**	**0.1284**
ECO: Min. Adverse Impacts on Ecology	**0.3403**	**0.3447**	**0.3459**
VIS: Min. Visual Intrusion	**0.1840**	**0.1730**	**0.1939**
CUL: Min. Adverse Impacts on Cultural Assets	**0.3562**	**0.3825**	**0.3318**

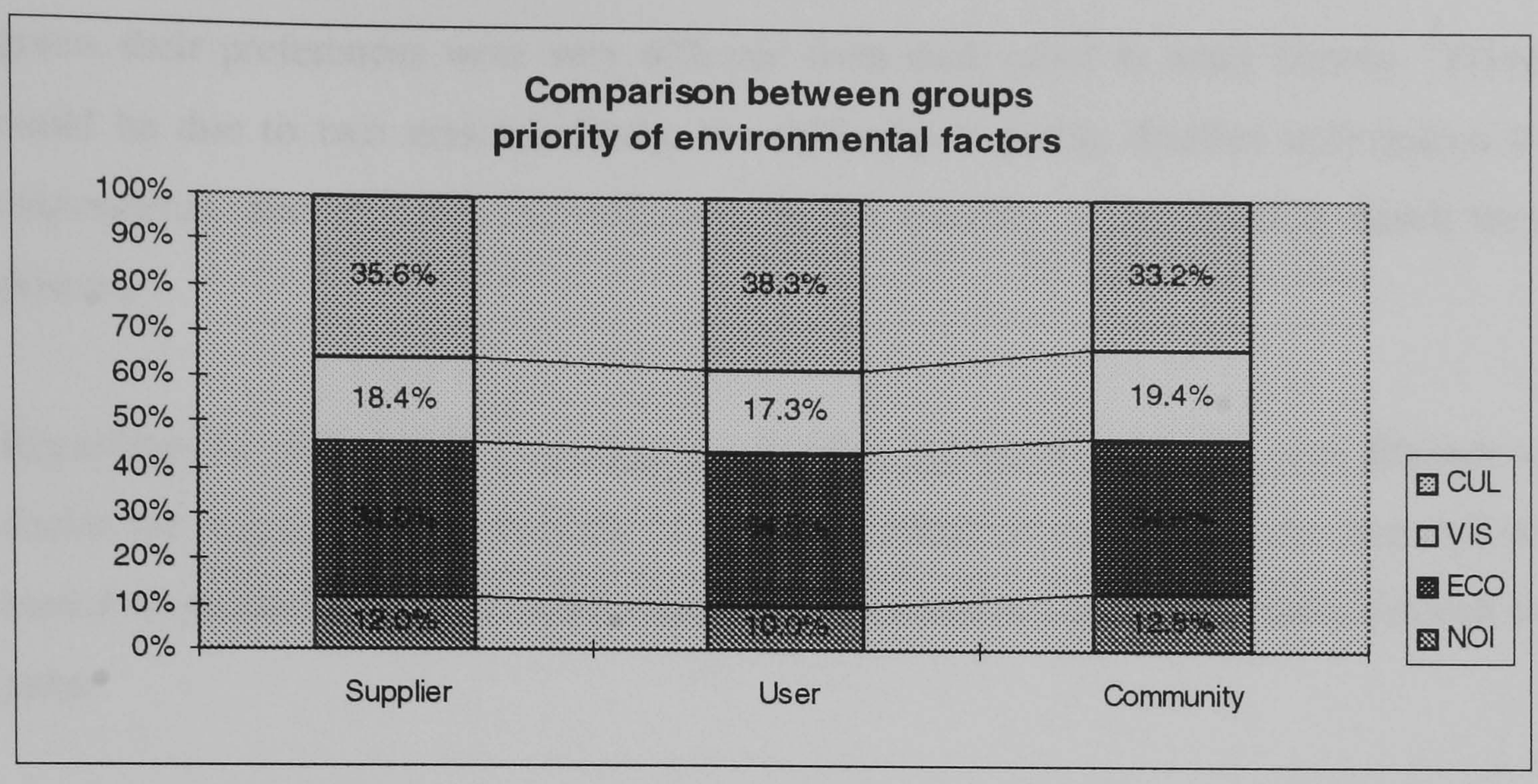


Figure 7.5 Comparison of The Priority of Environmental Factors

■ Comparison of alternatives with respect to intangible factors

Alternatives were compared with each other with respect to all factors. Among them, 5 tangible factors were compared by the normalised values which represent the relative priority of alternatives. For the six intangible factors such as *Improving import & convenience* (ICC), *Maximisation of regional development* (MRD), *Maximisation of socio-economic benefits* (MSE), *Minimisation adverse impacts on ecology* (ECO), *Minimisation of visual intrusion* (VIS), *Minimisation of adverse impacts on cultural assets* (CUL) pairwise comparisons were made via the questionnaire survey.

For comparison via their subjective judgement, a brief description about each factor was necessary and was given to respondents with the questionnaire, and with the information given respondents were asked to mark their relative preference via their subjective judgement.

Table 7.19 shows each stakeholder's preference for each alternative with respect to each factor. Despite the fact a brief description of the alternatives and factors was

given, their preferences were very different from each other in many factors. These could be due to two reasons, firstly, the difficulty in giving detailed information to respondents, and secondly the difference in the quantity of information which they possess.

Regarding the difficulty in providing the detailed information, it was very difficult to decide the degree of detail because too much information could make the respondents biased or decline to answer, while inefficient information could make them difficult to judge.

As far as the information is concerned, each group possesses different information on alternative and factors (suppliers and community groups have more information than user groups because they are more closely related to transport supply investment or their own living circumstances), which means the group who has less information depends on only the information given, while the other groups who have more information than those given could use their knowledge including the information given for subjective judgement.

In this survey, supplier and community group shared preferences in quite a few factors such as regional development, ecology and visual intrusion, while user groups and community groups showed very different preferences for most factors, and the supplier and user groups also showed different preferences except on cultural assets.

Regardless of the limitation of information, in summarising the results, alternative 2 is more favoured than other alternatives with respect to many factors such as *Min. severance effects, Min. adverse impacts on ecology, Min. visual intrusion*, while alternative 1 is favoured in *Improving comfort & convenience* and *Max. regional development* because this alternative is so close to the city that this merit may affect the response, and alternative 3 is favoured on the side of *Min. adverse impacts on cultural assets* because this alternative is located farthest from the residential and cultural area.

On the other hand, alternative 1 turned out to be the worst in terms of *Min. adverse impacts on cultural assets* because of its very close location to cultural sites. The supplier's preference of *Improving comfort and convenience* showed the reason for the debate between the suppliers who want to improve accessibility and the local public who is interested in cultural conservation (this alternative proposed by the supplier had been rejected by the public on grounds of cultural conservation).

Table 7.19 Comparison of Alternatives with respect to Factors

- supplier

Improving Comfort & Convenience

	Alt 1	Alt 2	Alt 3	R.P
Alt 1	1.0000	1.1487	1.6836	**0.3988**
Alt 2	0.8706	1.0000	2.0907	**0.3908**
Alt 3	0.5940	0.4783	1.0000	**0.2104**

C.R.= 0.0121

Max. Regional Development

	Alt 1	Alt 2	Alt 3	R.P
Alt 1	1.0000	0.9611	1.4009	**0.3612**
Alt 2	1.0405	1.0000	1.6412	**0.3910**
Alt 3	0.7138	0.6093	1.0000	**0.2478**

C.R.= 0.0013

Min. Severance Effects

	Alt 1	Alt 2	Alt 3	R.P
Alt 1	1.0000	0.6012	0.6754	**0.2416**
Alt 2	1.6633	1.0000	0.9533	**0.3805**
Alt 3	1.4806	1.0490	1.0000	**0.3779**

C.R.= 0.0026

Min. Adverse Ecological Impacts

	Alt 1	Alt 2	Alt 3	R.P
Alt 1	1.0000	0.8430	1.1583	**0.3281**
Alt 2	1.1862	1.0000	1.3573	**0.3876**
Alt 3	0.8634	0.7367	1.0000	**0.2844**

C.R.= 0.0000

Min. Visual Intrusion

	Alt 1	Alt 2	Alt 3	R.P
Alt 1	1.0000	0.5904	0.8093	**0.2552**
Alt 2	1.6936	1.0000	1.2639	**0.4208**
Alt 3	1.2357	0.7912	1.0000	**0.3240**

C.R.= 0.0006

Min. Adverse Impacts on Cultural Assets

	Alt 1	Alt 2	Alt 3	R.P
Alt 1	1.0000	0.3374	0.3130	**0.1389**
Alt 2	2.9640	1.0000	0.7163	**0.3776**
Alt 3	3.1951	1.3961	1.0000	**0.4836**

C.R.= 0.0064

- user

Improving Comfort & Convenience

	Alt 1	Alt 2	Alt 3	R.P
Alt 1	1.0000	0.8177	0.8928	**0.2971**
Alt 2	1.2229	1.0000	1.4924	**0.4032**
Alt 3	1.1200	0.6701	1.0000	**0.2998**

C.R.= 0.0094

Max. Regional Development

	Alt 1	Alt 2	Alt 3	R.P
Alt 1	1.0000	1.1262	1.1695	**0.3632**
Alt 2	0.8879	1.0000	1.3636	**0.3532**
Alt 3	0.8550	0.7333	1.0000	**0.2836**

C.R.= 0.0071

Min. Severance Effects

	Alt 1	Alt 2	Alt 3	R.P
Alt 1	1.0000	0.9239	0.8539	**0.3075**
Alt 2	1.0823	1.0000	0.9966	**0.3413**
Alt 3	1.1711	1.0034	1.0000	**0.3512**

C.R.= 0.0005

Min. Adverse Ecological Impacts

	Alt 1	Alt 2	Alt 3	R.P
Alt 1	1.0000	0.7351	0.8049	**0.2777**
Alt 2	1.3604	1.0000	0.9119	**0.3555**
Alt 3	1.2424	1.0967	1.0000	**0.3668**

C.R.= 0.0032

Min. Visual Intrusion

	Alt 1	Alt 2	Alt 3	R.P
Alt 1	1.0000	0.7094	0.6924	**0.2595**
Alt 2	1.4096	1.0000	0.9758	**0.3657**
Alt 3	1.4442	1.0248	1.0000	**0.3748**

C.R.= 0.0000

Min. Adverse Impacts on Cultural Assets

	Alt 1	Alt 2	Alt 3	R.P
Alt 1	1.0000	0.4940	0.4793	**0.1949**
Alt 2	2.0245	1.0000	0.7534	**0.3627**
Alt 3	2.0862	1.3273	1.0000	**0.4424**

C.R.= 0.0061

- community

Improving Comfort & Convenience

	Alt 1	Alt 2	Alt 3	R.P
Alt 1	1.0000	0.7092	1.0548	**0.2861**
Alt 2	1.4100	1.0000	2.6807	**0.4910**
Alt 3	0.9481	0.3730	1.0000	**0.2229**

C.R.= 0.0334

Max. Regional Development

	Alt 1	Alt 2	Alt 3	R.P
Alt 1	1.0000	1.0591	1.5325	**0.3779**
Alt 2	0.9442	1.0000	2.1072	**0.4045**
Alt 3	0.6525	0.4746	1.0000	**0.2176**

C.R.= 0.0136

Min. Severance Effects

	Alt 1	Alt 2	Alt 3	R.P
Alt 1	1.0000	0.5749	1.1842	**0.2725**
Alt 2	1.7394	1.0000	2.6656	**0.5164**
Alt 3	0.8445	0.3752	1.0000	**0.2111**

C.R.= 0.0064

Min. Adverse Ecological Impacts

	Alt 1	Alt 2	Alt 3	R.P
Alt 1	1.0000	0.5053	1.0169	**0.2525**
Alt 2	1.9788	1.0000	2.0021	**0.4988**
Alt 3	0.9834	0.4995	1.0000	**0.2487**

C.R.= 0.0000

Min. Visual Intrusion

	Alt 1	Alt 2	Alt 3	R.P
Alt 1	1.0000	0.4928	0.8054	**0.2294**
Alt 2	2.0293	1.0000	2.1698	**0.5115**
Alt 3	1.2416	0.4609	1.0000	**0.2591**

C.R.= 0.0077

Min. Adverse Impacts on Cultural Assets

	Alt 1	Alt 2	Alt 3	R.P
Alt 1	1.0000	0.4381	0.4564	**0.1807**
Alt 2	2.2828	1.0000	1.5978	**0.4758**
Alt 3	2.1911	0.6259	1.0000	**0.3434**

C.R.= 0.0175

7.4.3 Project Survey

The value of tangible factors was collected from the research of KOTI for comparison with the output of this research as follows, and these factors were normalised for synthesis with intangible criteria as stated in chapter 6. It can be summarised as follows, and the details are in the chapter 6.

Table 7.20 Summary of Relative Priorities for Tangible Objectives

	alt. 1	alt. 2	alt. 3
min. urban travel cost	33.23%	33.57%	33.20%
min. project cost	30.98%	34.63%	34.39%
min. travel cost of rail passenger	31.80%	40.30%	27.90%
min. house replacement	26.78%	35.97%	37.26%
min. noise	27.45%	34.31%	38.24%

7.5 Synthesis

We now have the priorities of each alternative under various criteria and subcriteria as well as the relative importance of these criteria. The next step is to add up each (local) priority by weighting them with the priority of the given criterion. This addition creates a composite measure (global priority) of the importance for each alternative with respect to the overall goal.

7.5.1 Local Priorities

Local priorities mean the global priorities of each stakeholder. Therefore, these priorities are also added up from bottom to top, based on the weights of each attribute on each level according to each stakeholder's preference of objectives and elements as above.

For example, in the case of the supplier, firstly composite priorities of socio-economic and environmental factors (see Table 7.21, 7.22) with sub-level were derived respectively by weighting them with the priorities of each criterion because only these two objectives have sub-levels. Secondly the composite priority (Table 7.23) at the next higher level was derived through adding up the priorities of each objective by weighting them with the priorities of those objectives from the supplier's preference. For user and community, we can derive the overall priority by same process. Final global priority was derived to add up by weighting them with the priorities of each stakeholder derived from expert survey.

In local priorities, we could firstly find each stakeholder's preference for each criterion and alternative. It gives us quite interesting results because we can get each stakeholder's preference directly so we can compare not only the preference between groups but also global priority with the local priorities. In the following section, three composite priorities of alternatives with respect to the overall goals for each stakeholder are described.

7.5.1.1 Supplier

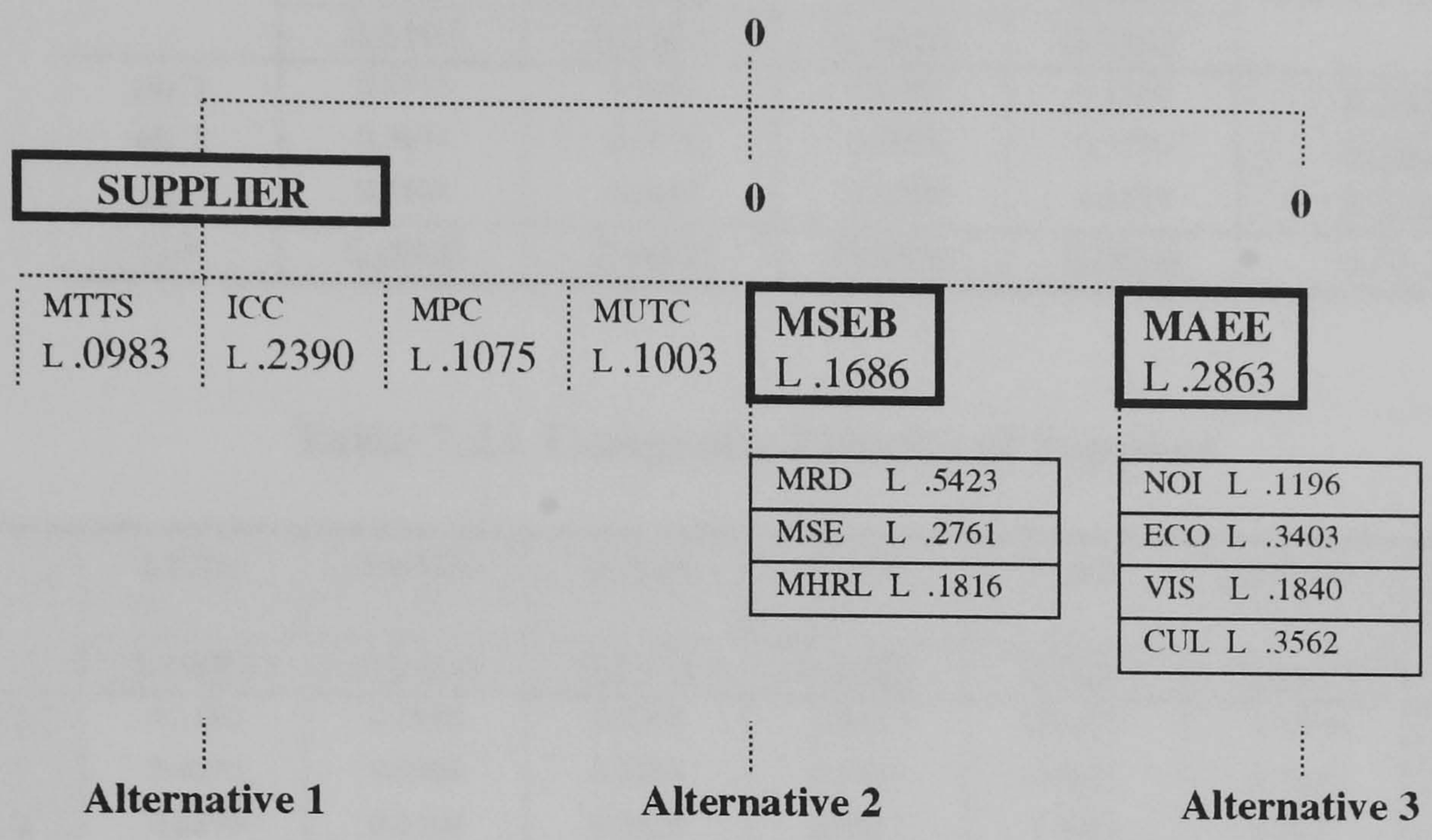


Figure 7.6 Composition of Priorities : Supplier Group

In the case of the supplier group, we could gain the overall priority that alternative 2 showed the highest priority with the score of 37.9%. Alternative 1 comes next and alternative 3 the lowest priority among all alternatives even though the difference between alternative 1 and 3 is very small. In local priorities of socio-economic factors, the supplier group preferred alternative 2, alternative 3 was least favoured, while alternative 1 was favoured in terms of accessibility related to regional development. In the case of environmental factors, alternative 1 was least favoured despite less adverse impact on ecology because of a very low preference in the rest of environmental elements and especially negative impacts on cultural assets.

Table 7.21 Composite Priority under Socio-economic Benefits: Supplier

	regional development	severance	house replacement	relative priority
	0.5423	0.2761	0.1816	
ALT 1	0.3612	0.2416	0.2692	**0.3115**
ALT 2	0.3910	0.3805	0.3589	**0.3823**
ALT 3	0.2478	0.3779	0.3719	**0.3063**
C.R	0.0013	0.0026	0.0	0.0014

Table 7.22 Composite Priority under Environmental Factors: Supplier

	noise	ecology	vision	culture	relative priority
	0.1196	0.3403	0.1840	0.3562	
alt 1	0.2745	0.3281	0.2552	0.1389	**0.2409**
alt 2	0.3431	0.3876	0.4208	0.3776	**0.3848**
alt 3	0.3824	0.2844	0.3240	0.4836	**0.3743**
C.R	0.0000	0.0000	0.0006	0.0064	0.0024

Table 7.23 Composite Priority of Supplier

	t.time	comfort	p.cost	r.time	socio	environ.	relative priority
	0.0983	0.2390	0.1075	0.1003	0.1686	0.2863	
alt 1	0.3180	0.3988	0.3098	0.3323	0.3115	0.2409	**0.3147**
alt 2	0.4030	0.3908	0.3463	0.3357	0.3823	0.3848	**0.3785**
alt 3	0.2790	0.2104	0.3439	0.3311	0.3063	0.3743	**0.3067**
C.R	0.0000	0.0121	0.0000	0.0000	0.0014	0.0024	0.0038

7.5.1.2 User

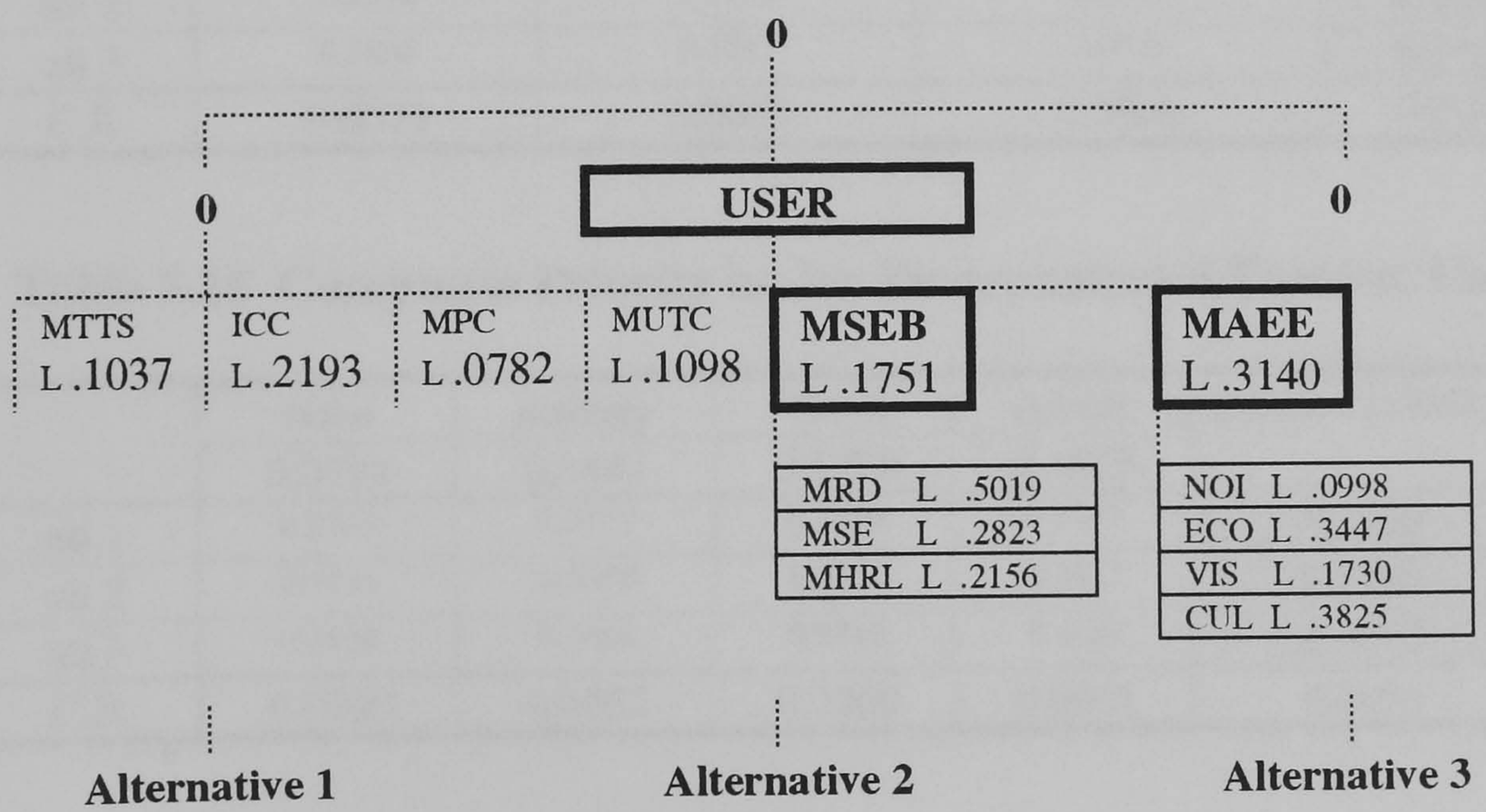


Figure 7.7 Composition of Priorities : User Group

In the user group, alternative 2 showed the highest priority because alternative 2 was more favoured in many factors than others as the same with the supplier group's preference despite the fact that alternative 3 was most favoured in the environmental

factor. Alternative 3 comes next and alternative 1 shows the lowest priority, which is different from supplier group, and this was caused by the facts that higher importance weights (31.4%) were given to environmental objectives by the user group than the supplier group (28.6%) so as enough to rank the alternative 3 much higher than alternative 1.

Regarding local priorities, alternative 2 was most favoured in socio-economic factors, while it was less favoured in environmental factors than alternative 3 because most of the environmental factors were related to the distance from the area. It means that there seem fewer adverse impacts of noise pollution, visual intrusion and cultural assets when a relatively long way from the residential area and cultural sites.

Table 7.24 Composite Priority under Socio-economic Benefits: User

	regional development	severance	house replacement	relative priority
	0.5019	0.2823	0.2159	
alt 1	0.3632	0.3075	0.2692	**0.3272**
alt 2	0.3532	0.3413	0.3589	**0.3511**
alt 3	0.2836	0.3512	0.3719	**0.3217**
C.R	0.0071	0.0005	0.0000	0.0037

Table 7.25 Composite Priority under Environmental Factors: User

	noise	ecology	vision	culture	relative priority
	0.0998	0.3447	0.1730	0.3825	
alt 1	0.2745	0.2777	0.2595	0.1949	**0.2426**
alt 2	0.3431	0.3555	0.3657	0.3627	**0.3588**
alt 3	0.3824	0.3668	0.3748	0.4424	**0.3987**
C.R	0.0000	0.0032	0.0000	0.0061	0.0035

Table 7.26 Composite Priority of User

	t.time	comfort	p.cost	r.time	socio	environ.	relative priority
	0.1037	0.2193	0.0782	0.1098	0.1751	0.3141	
alt 1	0.3180	0.2971	0.3098	0.3323	0.3272	0.2426	**0.2923**
alt 2	0.4030	0.4032	0.3463	0.3357	0.3511	0.3588	**0.3682**
alt 3	0.2790	0.2998	0.3439	0.3311	0.3217	0.3987	**0.3394**
C.R	0.0000	0.0094	0.0000	0.0000	0.0037	0.0035	0.0038

7.5.1.3 Community

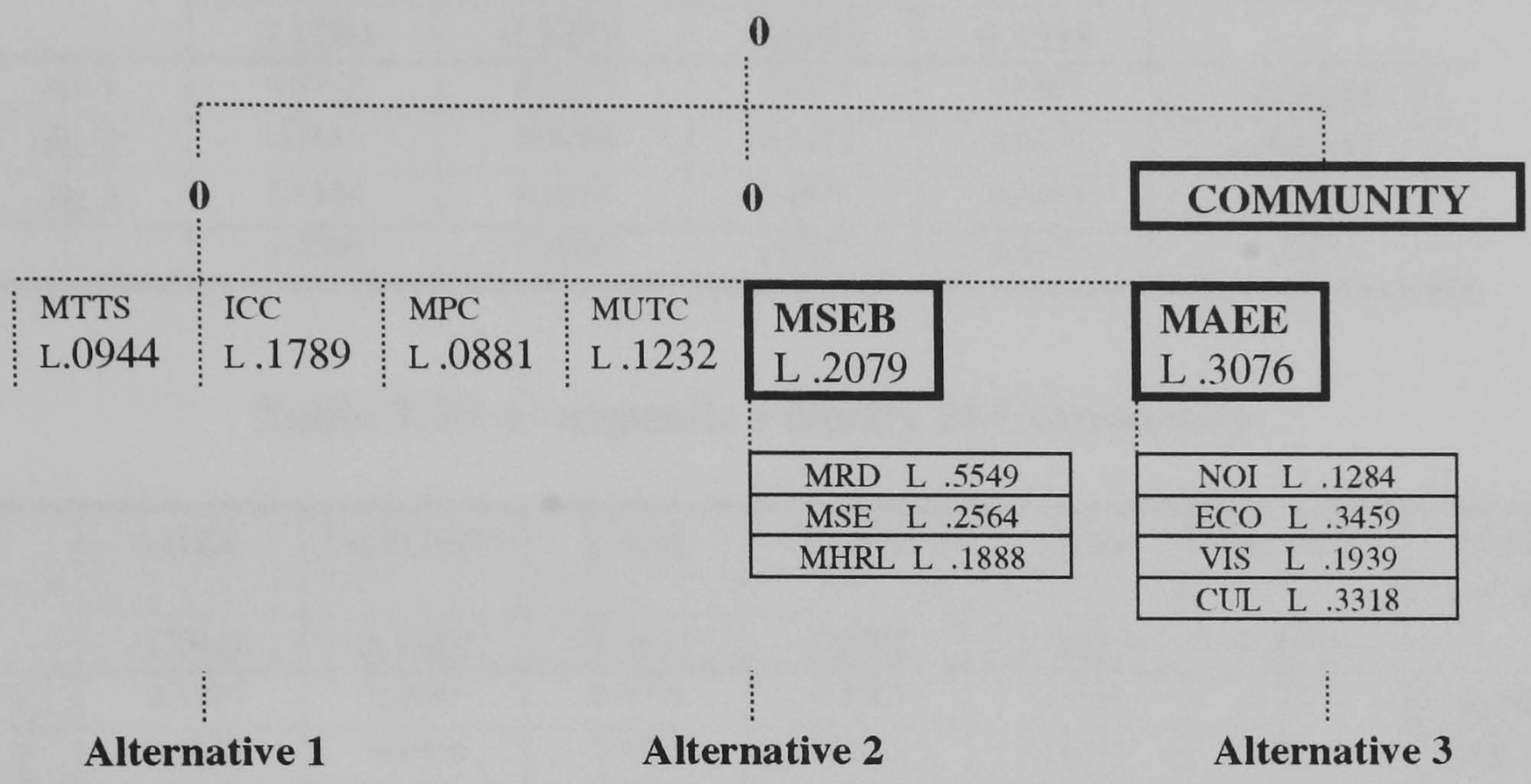


Figure 7.8 Composition of Priorities : Community Group

In the community group, alternative 2 shows a higher priority than in the other stakeholder's case, and this was caused by the highest priorities on comfort, socio-economic and environmental objectives which all stakeholders considered a most important objective in transport investment on the proposed area. Community group considered these objectives very important. Alternative 1 comes next and alternative 3 the lowest priority with a small difference from that of the priority of the user, but in the same order as that of the supplier. In the comparison of the two factors, their preference was different. That is, alternative 1 was preferred in terms of socio-economic factors, especially regional development to alternative 3 by good accessibility to the city, while alternative 1 was least favoured because of the trade-offs with the violation of the environment by its factor, proximity to the city.

Table 7.27 Composite Priority under Socio-economic Benefits: Community

	regional development	severance	house replacement	relative priority
	0.5549	0.2564	0.1888	
alt 1	0.3779	0.2725	0.2692	**0.3304**
alt 2	0.4045	0.5164	0.3589	**0.4246**
alt 3	0.2176	0.2111	0.3719	**0.2451**
	0.0136	0.0064	0.0000	0.0092

Table 7.28 Composite Priority under Environmental Factors: Community

	noise	ecology	vision	culture	relative priority
	0.1284	0.3459	0.1939	0.3318	
alt 1	0.2745	0.2525	0.2294	0.1807	**0.2270**
alt 2	0.3431	0.4988	0.5115	0.4758	**0.4737**
alt 3	0.3824	0.2487	0.2591	0.3434	**0.2993**
	0.0000	0.0000	0.0077	0.0175	0.0073

Table 7.29 Composite Priority of Community

	t.time	comfort	p.cost	r.time	socio	environ.	relative priority
	0.0944	0.1789	0.0881	0.1232	0.2079	0.3076	
alt 1	0.3180	0.2861	0.3098	0.3323	0.3304	0.2270	**0.2879**
alt 2	0.4030	0.4910	0.3463	0.3357	0.4246	0.4737	**0.4317**
alt 3	0.2790	0.2229	0.3439	0.3311	0.2451	0.2993	**0.2803**
C.R	0.0000	0.0334	0.0000	0.0000	0.0092	0.0073	0.0101

7.5.2 Global Priority

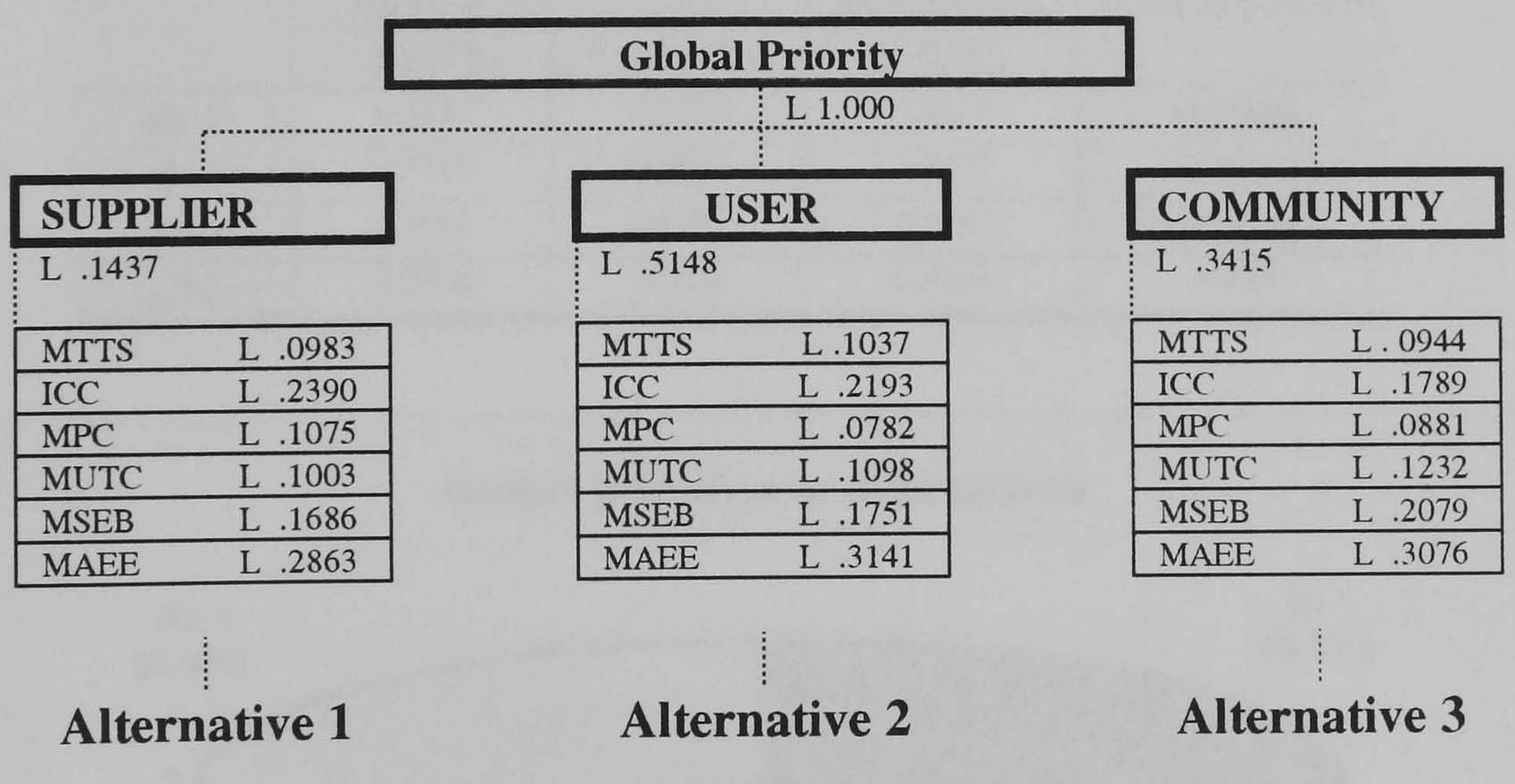


Figure 7.9 Composition of Priorities for All

Finally Table 7.30 contains the results of adding all the local priorities of each group by the weights of each stakeholder derived from the expert survey to yield the overall priorities. According to the following Table and Figure, alternative 2 showed the

highest priority with the relative priority of 39%, this is mainly caused by the dominance on many sides such as comfort, socio-economic and environmental factors as the compromise solution between the transport efficiency and the negative environmental impacts, especially cultural assets conservation.

Alternative 3 comes next and alternative 1 shows the lowest priority even though the relative priorities of those two alternatives are very similar (29%, 31%). As the user's role was much greater than the supplier and community group's role and the user group preferred alternative 3 to alternative 1, alternative 3 turned out to be a slightly better alternative even though the difference between alternative 1 and 3 in both groups was minimal. If we assume that the community role in transport investment will increase as time goes on, the preference order could be changed. The role change is described in the sensitivity analysis of the next chapter.

Table 7.30 Global Priority of Alternatives

	supplier	user	community	relative priority
	0.1437	0.5148	0.3415	
alt 1	0.3147	0.2923	0.2879	**0.2940**
alt 2	0.3785	0.3682	0.4317	**0.3914**
alt 3	0.3067	0.3394	0.2803	**0.3145**
C.R	0.0038	0.0038	0.0101	0.0060

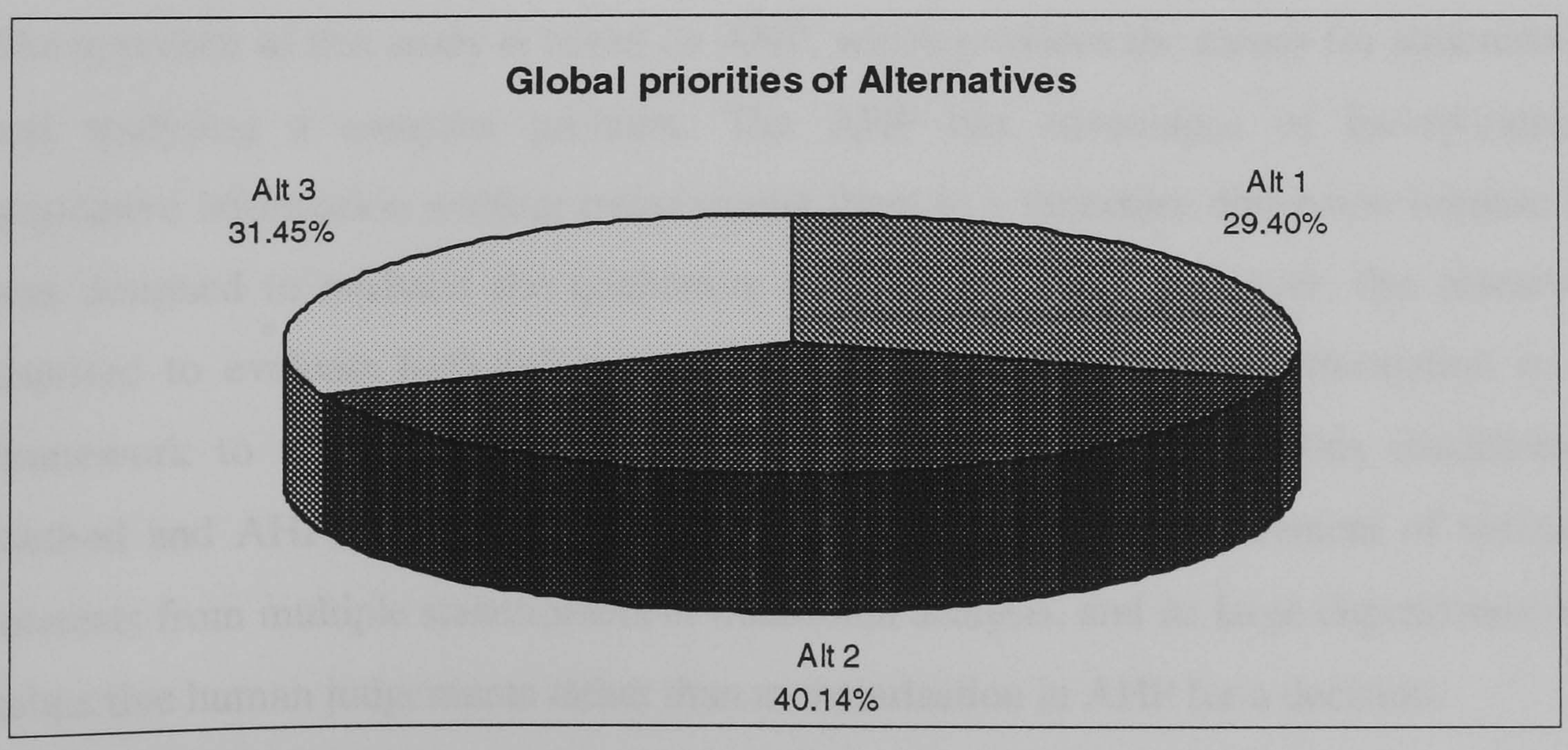


Figure 7.10 Global Priority of Alternatives

Each group showed different preference against alternatives. The supplier group preferred alternative 1 which had been rejected by the strong objection of some cultural experts in the local area to alternative 3, which is caused by the fact that alternative 1 is better than alternative 3 in accessibility and time savings which they still consider very important. This implies the differences between single decision making (supplier) and multiple decision making (all stakeholders involved).

Community members also preferred alternative 1 to 3 the same as the supplier group. These results of the two groups' preference may be more relevant to their information about this project and its circumstances than the user group as we discussed in section 7.3.2.2. Moreover as alternative 1 had been rejected by a few cultural experts in the community, this result on the preference for alternatives gives us a meaningful result. It showed that they did not quite agree with the opinion of a few cultural experts who objected to the Government's decision (alternative 1) as the first alternative of Kyongju line and had it cancelled. This indicates that a more appropriate way to draw the people's preference and to combine them is needed.

7.6 Conclusion

The approach of this study is based on AHP, which provides the means for structuring and analysing a complex problem. The AHP has advantages of incorporating qualitative information without transforming them to a monetary dimension because it was designed to evaluate the qualitative decision problem. However, this research required to evaluate both information, qualitative and quantitative information in a framework to overcome the following constraints from both methods (traditional method and AHP), a lack of distributional incidence and of involvement of various interests from multiple stakeholders in traditional analysis, and its large dependence on subjective human judgements rather than monetarisation in AHP for a decision.

Therefore, it has been tried to pick out advantages from each method, then to combine each advantage of CBA and the AHP in the evaluation process within a framework. The main point is to blend quantitative information with qualitative information, i.e. to use monetarisation and human experience and judgements, to elicit public opinion and organise them in the process. It is different from other normal AHP process. That is why this is called as the analytic hierarchy approach.

The model has four levels of hierarchical structure with three interest groups and six objectives and eleven factors. Alternatives were based on a real project by the Government, but they were modified according to the pilot survey. A total of 137 from the expert survey were used as data to derive the stakeholder's role, and 478 cases were used as a data for analysing the preference of each element.

The results of derived weights of all elements in the model indicate some interesting facts:

1. According to the expert survey to see the importance of each stakeholder's role, it turned out that the opinion of *user group* should be considered more important (51.5%) than any other stakeholder groups and the second most important group was *community members* (34.2%) in the case of this transport project. We can find the role of *supplier*, especially governmental official, is getting smaller from the dominant position in decision of most transport projects in the past, and their role should be reduced. Instead, those of the other stakeholders should be considered more than ever. It means the requirements of the public participation in the evaluation and decision process.

2. For transport investment in Kyongju, the objectives which are related with environmental and socio-economic concerns and the quality of transport services were ranked high among transport experts. The objectives finally selected from the expert survey are as follows:
   - Min. Travel Cost
   - Improving Comfort & Convenience

- Min. Project Cost
- Min. Urban Travel Cost
- Max. Socio-Economic Benefits (Max. Regional Development, Min. Severance Effects, Min. House Replacement)
- Min Adverse Environmental Impacts: (Min. Noise pollution Min. adverse Impacts on Ecology Min. Visual Intrusion Min. adverse impacts on Cultural Assets)

3. In the case of comparison between the two sub-groups of transport experts classified by the length of career, it is shown that the less experience they have, the more the portion of the community's role increases. This may be caused by the fact that that main consideration of the second group with less experience is focusing on the improvement of the socio-economic status and quality of life in terms of the society they belong to even if it is not significantly different.

4. Regarding the importance of objectives from the questionnaire survey, the most important objective turned out to be *Minimising adverse environmental effects*, and *Maximising socio-economic benefits* and *Improving comfort & convenience* were also considered as a very important factor for all stakeholders. These results imply important consideration of the environment and some change in socio-economic status. Regarding transport efficiency which was considered most important in the past, the result shows the increased preference for the quality of the transport service such as *Improving comfort* from the travel time & cost.

- The importance of transport service such as *Improving comfort & convenience* is emphasised more in the case of supplier group who is responsible for transport facilities supply to reduce travel time and improve service than the other groups with environmental and socio-economical factors.
- In the user group, it shows some change in preference of objectives. They consider the environmental factors as very important factors in this transport investment, and are also greatly concerned over the improvement of transport service such as comfort as well as travel time and cost as in the past. This implies a change in circumstances.

- In terms of community members directly affected by the transport investment in their quality of life, they emphasised environment and socio-economic circumstances (52%) more than the other factors (supplier: 46%, user: 49%). This figure gives us great meanings because no one seriously considered the community members and their interests for some decades in the evaluation process due to over consideration of economic development.
- For measuring the quantity of the discrepancy between sub-groups, KL measurement was used to assess the discrepancy between two priorities. According to the results of measurement of discrepancy of each sub-group with respect to the objectives, user sub-groups showed the larger differences than the other sub-groups. This implies that when we need a more detailed classification to gain more various opinions, user group can be divided into more sub-groups from the current classification of three stakeholders, supplier, user and community because these two sub-groups showed much more different views than other sub-groups.

5. Elements to be most significantly considered among many environmental factors turned out to be *Minimising adverse impacts on cultural assets* and *ecological circumstances* for all stakeholders, whilst community members regarded *Min. ecological factors* more important than environmental factors. This may result from the fact that it is very closely related to the quality of life of the area where they live in.

6. As the best alternative which is able to compromise the transport efficiency and conservation of environment including historic cultural assets, alternative 2 showed the highest priority with the relative priority of 39% with the dominance on many sides such as comfort, socio-economic and environmental factors. Alternative 3 came next and alternative 1 showed the lowest priority even though the relative priority of rest of alternatives are very similar (29%, 31%).

- The degree of global priories are not greatly different from the results (local priorities) of each group. Each group showed some different preference for

alternatives. The supplier group preferred alternative 1 which had been rejected due to the strong objection of a few cultural experts in the area to alternative 3. In community, they also preferred alternative 1 to 3 as did the supplier group, which did not go with the opinion of a few cultural experts in the area. All of these imply that we needs more appropriate way to draw various interests of multiple stakeholders, then to combine their various interests for a decision.

Chapter Eight

Sensitivity Analysis & Comparison

8.1 Introduction

The sensitivity analysis is a crucial step in the application with the analytic hierarchy approach because the priority or preference of the criteria was derived based on the current situation. This was that it could be changed according to the respondents and circumstances around transport investments due to uncertainty of the future.

Therefore, it is necessary in gaining more accurate and flexible judgements by the decision maker and this could enhance better understanding of the decision situation. In order to do this and see how robust the decision is, a sensitivity analysis is carried out by changing some importance (weights) of stakeholder's role and their preference for objectives.

On the other hand, one of the objectives of this research is to compare the current evaluation method and the analytic hierarchy approach method, and then to assess the applicability and suitability of the MCDM, especially the analytic hierarchy approach method, for transport investment project appraisal in Korea. In order to do this, the implementation procedure and results are compared with the result from the existing evaluation method mainly in terms of the ranking of alternatives. However, as the alternatives were different from each other for both applications from both conventional methods and this method, a direct comparison of ranking was not easy, so the comparison was focused on the comparison of the methods which have been used for the evaluation themselves.

The adaptability and suitability of the AHP method are assessed by a few qualitative criteria. These assessment criteria will be the various criteria such as data and information requirement, inclusion of qualitative information, degree of interaction with the decision-maker, understandability of methods, degree of public participation, interaction requirements, applicability to transport projects and linkage to the decision-making process.

8.2 Sensitivity Analysis

Sensitivity analysis is used to investigate how robust the decision is because the preference could change according to economic development and socio-economic status. In the future, these priorities for alternatives and criteria would be different from current preferences under different conditions due to the change of circumstances.

However, unfortunately as we can not predict people's preferences in the future, we have to assume them so as to evaluate a transport investment which can affect the future and prepare for the uncertainty. In this respect, it is very important to see how its priority is changed by different weights on the stakeholder's role and preferences on their objectives for guiding the decision maker into a flexible way for the evaluation and selection of transport investments in the future. In addition to this, it is also very useful for setting the objectives in transport planning to see which objective has an impact on the choice of an alternative.

It is necessary to help more accurate and flexible judgements of the decision maker and for checking relative importance varied due to uncertainty of the future. It is also very useful to see how the alternative priority changes according to change of preference or weights. Through the sensitivity analysis over stakeholder's role and the degree of importance of the objectives of each stakeholder, the degree of impacts on the decision as to the best alternative is identified.

Sensitivity analysis in this research was carried out using incremental changes of the importance of interest groups and the preferences for their objectives. These incremental changes were implemented based on the weight derived from the expert and questionnaire survey.

8.2.1 *Sensitivity Analysis on Stakeholder's Role*

The weights of the stakeholders involved in the project have changed since 1980 due to the changed circumstances of the economic situation and various demands on investment in Korea from the single decision maker of Governmental side to users and community members. This trend will continue along with the continuous change of circumstances around society and transport investment. Therefore, to investigate which stakeholder has a potential impact on the decisions on transport investment and how much they have is very useful for the transport plan.

This analysis was done by incremental increase of each stakeholder's role from 0 to 1, "0" means the role of the decision maker was excluded from the decision, while "1" means its role is exclusive, i.e. single decision making. The relative weights of three stakeholders' role which should be changed by incremental change were calculated based on the overall weights derived from expert survey, supplier 0.144, user 0.515, community 0.342. This means that as the priority of one of the stakeholder is changed from 0 to 1 the other two stakeholders' role increases or decreases at the same increasing or decreasing rate of change based on the proportion of the overall weight.

In this research, we calculate the results global priorities of alternatives according to the change of the weights of stakeholder's role from 0 to 1. A sensitivity analysis like this is to check the sensitive relationship of each stakeholder's role with global priority, i.e. impacts of stakeholder on overall decision (global priorities of alternatives), by the change of relative priorities of stakeholder's role.

But as this sensitivity shows the change of the global priorities of alternatives numerically or pictorially, we need a quantitative measurement for deciding how sensitive each stakeholder is to the decision to compare stakeholder groups with each other. This (measurement of quantity of the change) could be measured by KL measurement because it shows the degree of discrepancy of two priority vectors as in the case of sub-groups of each stakeholder, and this could explain the sensitive relationship with relative priority of alternatives by incremental change.

8.2.1.1 Sensitivity on Supplier's Role

In terms of the supplier group, first of all it shows the smallest change compared with the other groups' case. From the base weight of supplier's role, 14.4% (relative priorities of alternatives at the base weight: alt 1: 29.4%, alt 2: 39.1%, alt 3: 31.5%) derived from the expert survey, as the supplier's role is close towards 1 (it means that only the supplier's opinion is considered as a single decision maker), alternative 2 keeps the highest ranking even though the priority becomes slightly smaller (39.9% → 37.9%), and the other two alternatives' priorities converged into similar priority (alternative 1: 29.1% → 31.5%, alternative 3: 31.6% → 30.7%).

All of these results do not show that there are significant relationship with the preference order of alternatives. However, it shows that if only the opinion of supplier is considered in decision making, alternative 1 which had been objected to by the other groups could be the second best alternative.

In measuring the quantity of the discrepancy between the two priority vectors from 0 to 1 by KL measurement, it also showed the least change (0.001374) among stakeholders. This indicates that supplier's participation in the evaluation and decision making process is less sensitive to the global priorities (preference order) than the other groups.

Table 8.1 Sensitivity Analysis on Supplier's Role

	0	rank		actual weights	rank		1	rank	difference (0 → 1)
Alt 1	29.06	3		29.40	3		31.47	2	**+2.41**
Alt 2	39.35	1	➡	39.14	1	➡	37.85	1	**-1.50**
Alt 3	31.58	2		31.45	2		30.67	3	**-0.91**
Kullback-Leibler measures				**0.001374**					

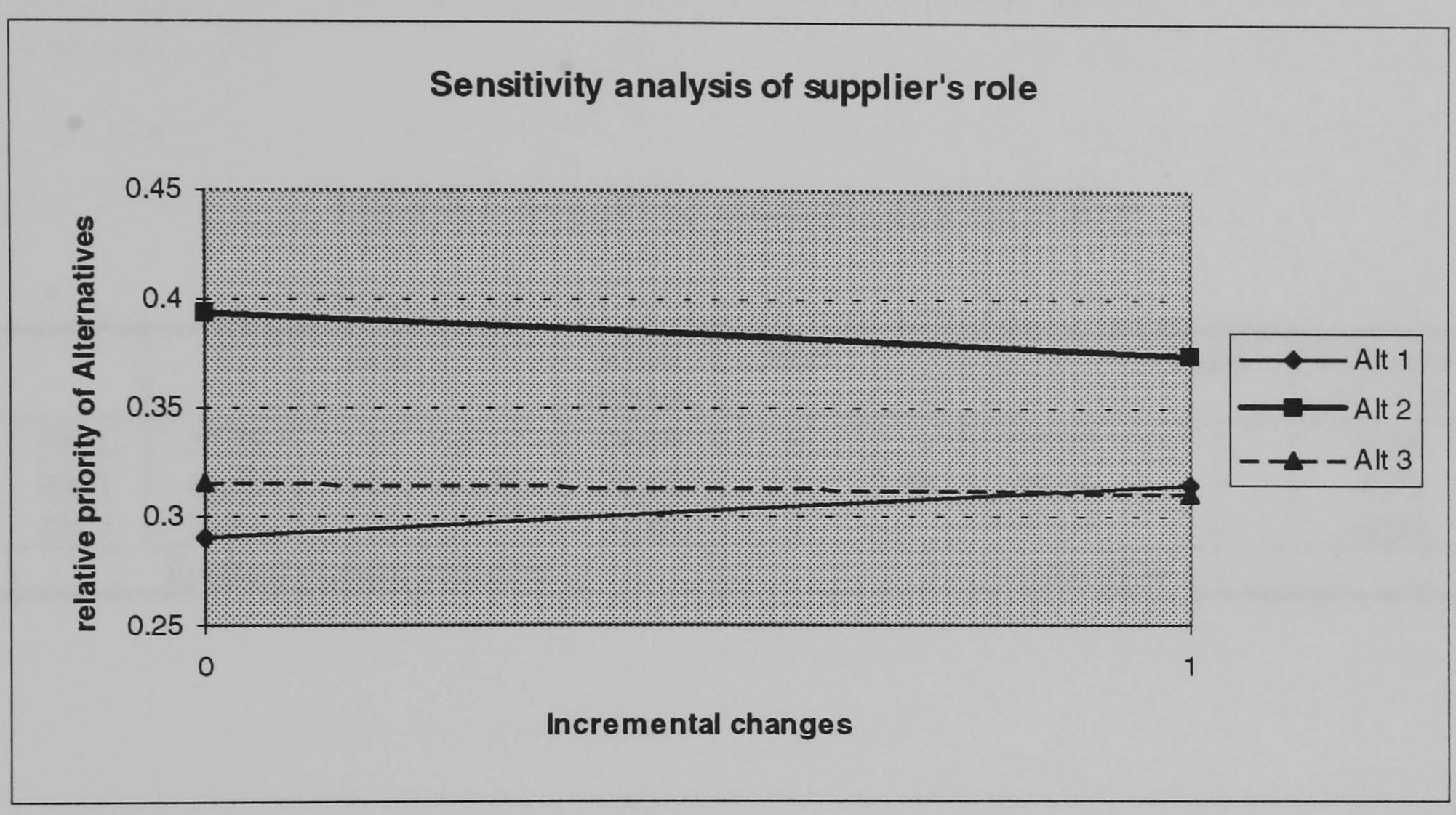


Figure 8.1 Sensitivity Analysis on Supplier's Role

8.2.1.2 Sensitivity on User's Role

With regard to the user group, the test results showed a slightly different pattern from the case of the supplier. The highest alternative 2 remains in the same position from 0 to 1 even though the priority is reduced to 37% from 42%, while the other two alternatives swap preference orders and the difference between the two alternatives gets larger from the priorities of non consideration of the user's opinion (alt 1: 29.6% → 29.2%, alt 3: 28.8% → 33.9%) as the importance of user's role increases towards 1. The trend is similar to the supplier's case, but the difference of two priorities of alternatives is larger.

In measuring the quantity of discrepancy between the two priorities, the user group showed larger discrepancy than suppliers case, but smaller than community member's role. This implies that their opinion is more sensitive to the preference order of alternatives than the supplier groups, so the user's group's involvement in the evaluation and decision process and their views may change the ranking of the projects. It makes it ever more crucial for them to take part in the decision process and to obtain their views for the right decision which many people can understand.

Table 8.2 Sensitivity Analysis on User's Role

	0	rank		actual weights	rank		1	rank	difference (0 → 1)
Alt 1	29.58	2		29.40	3		29.23	3	**-0.35**
Alt 2	41.59	1	➨	39.14	1	➨	36.82	1	**-4.77**
Alt 3	28.81	3		31.45	2		33.94	2	**+5.13**
Kullback-Leibler measures							**0.006974**		

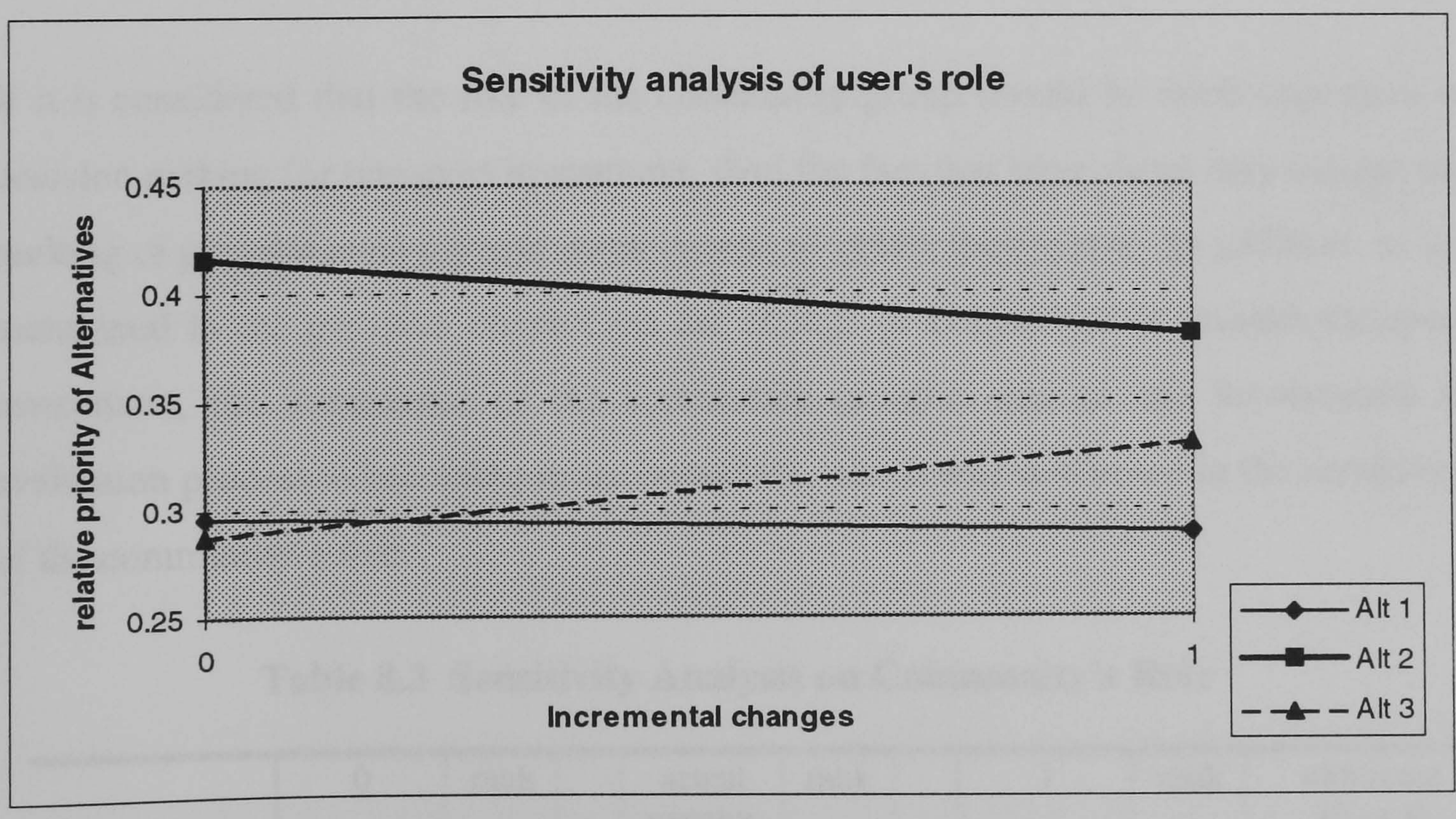


Figure 8.2 Sensitivity Analysis on User's Role

8.2.1.3 Sensitivity on Community's Role

In the case of the community group, alternative 2 also remains the highest as its weighting increases to 1, and the other two alternatives change preference order contrary to the case of the user group (This pattern is similar to the case of supplier, but as the importance of community's role increases towards 1, the difference between two alternative 1 and 3 is slightly larger than the supplier case). So if we consider the community alone, the preference order might change, and this shows a more sensitive relationship with the weight given to the group of community members in selecting the best alternative rather than the supplier's case.

In measuring the quantity of discrepancy, the community group showed the largest discrepancy between the priorities of alternatives. This indicates that community member's role has the most sensitive relationship with the global priorities of alternatives than other groups. If we remember that the results of the user group's weight derived from the expert survey was the largest at 52% (community 34%), these results give us different, but quite meaningful implications.

If it is considered that the role of the community group should be more important in decision making for transport investment, then the fact that their views may change the ranking of projects makes it ever more crucial to obtain their views. In addition, as we mentioned in the previous chapter on the change of circumstances around transport investment, the importance of the community group's opinion and involvement in evaluation process is becoming more important, which was confirmed in the sensitivity of the community's role.

Table 8.3 Sensitivity Analysis on Community's Role

	0	rank		actual weights	rank		1	rank	difference (0 → 1)
Alt 1	29.72	3		29.40	3		28.79	2	**-0.93**
Alt 2	37.04	1	➡	39.14	1	➡	43.17	1	**+6.13**
Alt 3	33.23	2		31.45	2		28.03	3	**-5.20**
Kullback-Leibler measures				**0.009273**					

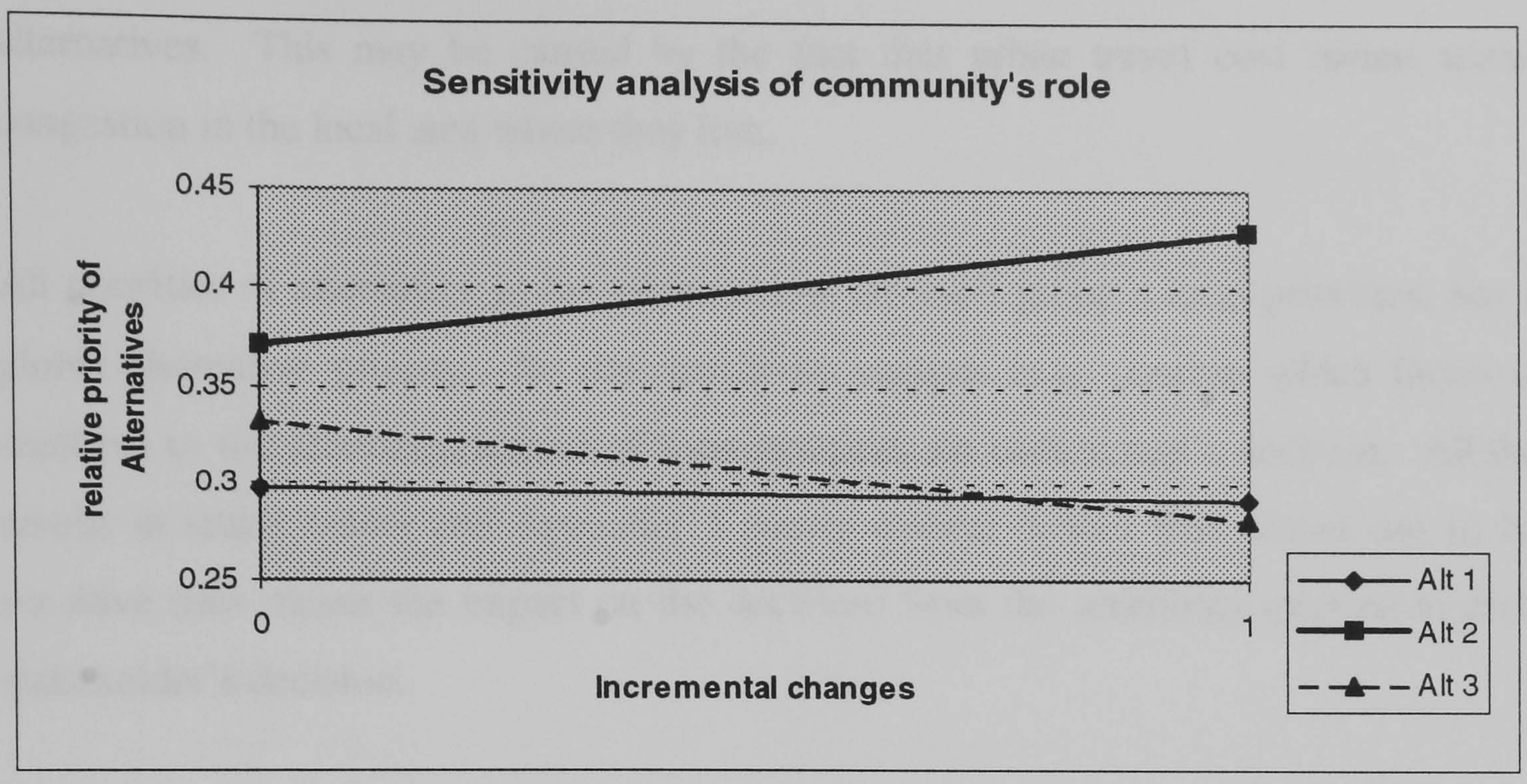


Figure 8.3 Sensitivity Analysis on Community's Role

8.2.2 Sensitivity Analysis on The Importance of Objectives

Most of test results about factors in the third level in the hierarchical structure showed that the sensitivity of alternatives was somewhat different between the stakeholders. For suppliers, quality of transport service, i.e. comfort (ICC), and environmental factors (MAEE) are considered more important for the decision (i.e. they have a sensitive relationship with alternative priority, so we can say that these factors have some important effects on decision making in case of suppliers).

While in the user group, in addition to the quality of service (ICC) and environmental factors (MAEE), travel cost and time (MTTS) turned out to be sensitive. It is caused by the fact that it is strongly related to the value of time and costs.

In terms of the community group, socio-economic (MSEB) and environmental factors (MAEE) were very sensitive and considered most important to their priority. In addition, urban travel cost (MUTC) was also sensitive to the relative priorities of

alternatives. This may be caused by the fact that urban travel cost means travel congestion in the local area where they live.

All priorities of alternative in the tables below are each group's local priorities, not a global alternative priority. So this sensitivity analysis is to confirm which factor is sensitive to the relative priorities of local priorities on each group's decision. All the results in tables below and Appendix 3 shows several factors that turned out to be sensitive (this means the impact on the decision) from the sensitivity analysis in each stakeholder's decision.

- **Supplier**

Table 8.4 Sensitivity Analysis of Supplier's Preference for Objectives

MTTS	0		1
Alt 1	0.3143		0.3180
Alt 2	0.3759	➡	0.4030
Alt 3	0.3097		0.2790
ICC			
Alt 1	0.2883		0.3988
Alt 2	0.3747	➡	0.3908
Alt 3	0.3369		0.2104
MPC			
Alt 1	0.3153		0.3098
Alt 2	0.3824	➡	0.3463
Alt 3	0.3022		0.3439
MUTC			
Alt 1	0.3127		0.3323
Alt 2	0.3833	➡	0.3357
Alt 3	0.3040		0.3311
MSEB			
Alt 1	0.3153		0.3115
Alt 2	0.3778	➡	0.3823
Alt 3	0.3068		0.3063
MAEE			
Alt 1	0.3443		0.2409
Alt 2	0.3760	➡	0.3848
Alt 3	0.2796		0.3743

•MTS : Min. Travel Cost
•ICC : Improving Comfort & Convenience
•MPC : Min. Project Cost
•MCC: Min. Congestion Cost
•MSEB: Max. Socio-Economic Benefit
•MAEE: Min. Adverse Environmental Effects

- **User**

Table 8.5 Sensitivity Analysis of User's Preference for Objectives

		0		1
MTTS	Alt 1	0.2894		0.3181
	Alt 2	0.3643	➨	0.4031
	Alt 3	0.3465		0.2791
ICC	Alt 1	0.2910		0.2972
	Alt 2	0.3585	➨	0.4033
	Alt 3	0.3506		0.3000
MPC	Alt 1	0.2909		0.3099
	Alt 2	0.3702	➨	0.3464
	Alt 3	0.3391		0.3440
MUTC	Alt 1	0.2874		0.3324
	Alt 2	0.3723	➨	0.3358
	Alt 3	0.3405		0.3312
MSEB	Alt 1	0.2849		0.3273
	Alt 2	0.3720	➨	0.3512
	Alt 3	0.3432		0.3218
MAEE	Alt 1	0.3151		0.2427
	Alt 2	0.3727	➨	0.3589
	Alt 3	0.3123		0.3988

- **Community**

Table 8.6 Sensitivity Analysis of Community's Preference for Objectives

		0		1
MTTS	Alt 1	0.2848		0.3180
	Alt 2	0.4347	➨	0.4030
	Alt 3	0.2805		0.2790
ICC	Alt 1	0.2883		0.2861
	Alt 2	0.4188	➨	0.4910
	Alt 3	0.2928		0.2229
MPC	Alt 1	0.2858		0.3098
	Alt 2	0.4400	➨	0.3463
	Alt 3	0.2742		0.3439
MUTC	Alt 1	0.2817		0.3323
	Alt 2	0.4452	➨	0.3357
	Alt 3	0.2732		0.3311
MSEB	Alt 1	0.2768		0.3304
	Alt 2	0.4336	➨	0.4246
	Alt 3	0.2896		0.2451
MAEE	Alt 1	0.3150		0.2270
	Alt 2	0.4131	➨	0.4738
	Alt 3	0.2719		0.2993

8.3 Comparison

8.3.1 Comparison of The Results of Both Techniques

Regarding the comparison with the results of the KOTI project, there is no direct way to compare them because the alternatives are different (KOTI has 4 alternatives, while this research has 3 alternatives. 2 of which are the same) as we can see in Table 8.7.

Table 8.7 Alternative Modification

			This research
1990	former alternative: Hyongsan	➡	Alternative 1
KOTI (1996)	Alternative 1: Bangnae		
	Alternative 2: Ansim		
	Alternative 3: Duckcheon	➡	Alternative 3
	Alternative 4: Hwacheon	➡	Alternative 2

In the KOTI project, they implemented their project based on cost-benefit analysis. Therefore, they quantified all tangible criteria which could be monetarised into costs, and for the other criteria which could not be monetarised, they used numbers or verbal expression for comparison. With the results of these, they took a final decision via their subjective assessment, but they did not allocate individual weight to each evaluation item.

Regarding the results from the evaluation of KOTI project, it can be analysed in two ways, one is the results of the economic evaluation of tangible criteria, and the other is that of comprehensive judgement considering all factors in the project. Economic evaluation items which were considered in the KOTI project were typical construction, operating costs and generalised costs. Table 8.2 shows the total costs of each alternative and ranking (preference order) in terms of economic evaluation and comprehensive judgement.

The results of the KOTI project showed that the alternative 4 was most favoured in terms of economics, and it was also recommended as the best alternative from comprehensive judgement considering all the relevant factors of the project, but the overall ranking was not given and only the best one was recommended.

Table 8.8 The Results of KOTI Project Evaluation

	Economic Evaluation	Ranking	Comprehensive judgement
Alternative 1: Bangnae	2350574.8	2	
Alternative 2: Ansim	2372991.7	4	n.a
Alternative 3: Duckcheon	2372651.2	3	
Alternative 4: Hwacheon	2345119.5	1	1

Table 8.9 The Results of The Application of Analytic Hierarchy Approach

	Evaluation for Economic items *	Ranking	Global priority
Alternative 1: Hyongsan	2372901.3	3	0.2940
Alternative 2: Hwacheon	2345119.5	1	0.3914
Alternative 3: Duckcheon	2372651.2	2	0.3145

* : Total sum of costs of the main tangible criteria, construction and operating costs, urban travel costs, passenger travel costs, unit 100 million won.

	Supplier	Rank	User	Rank	Community	Rank
Alternative 1: Hyongsan	0.3147	2	0.2923	3	0.2879	2
Alternative 2: Hwacheon	0.3785	1	0.3682	1	0.4317	1
Alternative 3: Duckcheon	0.3067	3	0.3394	2	0.2803	3

The best alternative from KOTI research was the same with the result of this research even though the direct comparison of alternatives is not meaningful because both alternatives are different from each other, and the overall ranking of the KOTI project is not given except the best alternative.

Nevertheless, if we attempt to compare the results of the analytic hierarchy approach with that of KOTI, these differences could be told in terms of prioritising the alternatives and the selection process of the best alternative as follows. Therefore, it

implies a difference between current evaluation method applied and multiple criteria decision making, especially the analytic hierarchy process, themselves.

The result of the KOTI project did not provide the preference order of alternatives except in the best alternative recommended. It implies that the degree of difference between alternatives is not known in the project, so it has the risk that the best alternative could be strongly advocated than other alternatives even though of the case that its difference is not large. In the analytic hierarchy approach, the ranking (preference order) is given with the degree of preference so that we could distinguish the relationship between alternatives prioritised. However, in the analytic hierarchy approach, it was more difficult and confused to compare very similar alternatives just by subjective preference in a few qualitative attributes rather than attempts to measure in costs and benefits fashion. It indicates that the detailed information and data for judgement should be given for the analytic hierarchy approach.

The other is for judgement incorporation. The analytic hierarchy approach method provided greater scope of aggregating the data in accordance with the objectives of the stakeholders than current evaluation methods, and allocated due weights to the objectives and elements. Moreover, all stakeholders were involved in the evaluation process. In the KOTI project, they considered all the quantifiable criteria based on the cost-benefit analysis and the other non-quantifiable attributes were considered without attempting to combine them together to express them in a single index of project desirability. Opinions from various interest groups were solely considered as a reference for decision making and not within a evaluation framework.

In the analytic hierarchy approach, human judgements such as expert opinion, experiences of governmental officials and people's general preferences were incorporated in a evaluation framework of the decision making process and the weights were allocated even though their preferences and weights could be changed according to social, economic and political situation and it requires to take a survey for every evaluation. This can be a significant difference between the two methods.

8.3.2 Assessment of The Analytic Hierarchy Approach

For the evaluation of transport investment projects, many techniques are available. Among these, the cost-benefit analysis was widely used for the evaluation of transport investment projects in Korea. The case study for the application of the analytic hierarchy approach was based on the KOTI project, which was also evaluated based on the cost-benefit concepts with some consideration of socio-economic and environmental effects.

Through the application of the analytic hierarchy approach method, it provided much wider scope than the conventional evaluation method, and it also provided a consistent framework in which all possible transport responses to transport policy and objectives may be judged with the distribution of weights on all stakeholders. However, it also showed some disadvantages such as the requirement of a large amount of data, a preparation (survey) for the preference change of attributes on every time.

For the assessment of the applicability of this approach, a number of criteria were established based on the evaluation criteria to conduct the evaluation of three multicriteria methods by J. Won (1990). These are as follows:

- Computational burden: data requirements, possibility of sensitivity analysis, inclusion of qualitative information
- Degree of interaction with the decision maker: understandibility of methods, degree of public participation
- Applicability to various field: applicability to transport projects, incorporation of uncertainty, linkage to planning and decision making process

- Data and information requirement

The amount of data requirement varies depending on the various effects, such as information requirement, alternatives, attributes and iteration. The amount of data for the analytic hierarchy process depends on the number of levels including stakeholders,

objectives, attribute and alternatives, while CBA depends on the number of cost and benefit items. It means the greater the number of levels, criteria and interest groups (items of CBA) are involved, the larger amount of data it requires.

As the AHP was developed to make a decision through pairwise comparison of mainly non-monetary items, i.e. qualitative attributes by human judgements, it requires only subjective judgements as the shape of pairwise comparison from respondents or brainstorming, while CBA requires the calculation of the costs and benefits of each item into numerical units. Therefore, in normal AHP analysis, it doesn't require too much data and too sophisticated data even though the evaluation process needs quite a few iterative mathematical calculations.

However, in this research, tangible and intangible factors were dealt with differently from the normal AHP analysis. In order to get the relative weight of tangible factors, they were firstly calculated based on the numerical units such as CBA, then compared with each other. The relative priorities were derived by the normalisation process. While those of the intangible factors were derived only by subjective judgement with the verbal measurement as in normal AHP process.

These two priorities from CBA and AHP were combined to get overall priority by the synthesis process of the analytic hierarchy process. Therefore, in this research, it required a large input of data compared with CBA, but it was necessary to make the programme for the whole sequence of evaluation.

- Inclusion of qualitative information

As we discussed above, the AHP was developed to evaluate the qualitative decision items. The AHP functions best in terms of incorporating qualitative information without transforming it into a monetary dimension, and it is the great advantage of the AHP to accommodate and preserve qualitative information in a meaningful way.

CBA has difficulty in monetarising all relevant cost and benefit items and in conducting appraisal at a strategic level so that a full range of impacts is not properly considered within a framework, which was a typical situation in most of the transport project evaluation in Korea. In this research, qualitative and quantitative objectives and elements were combined, which is a major advantage of the analytic hierarchy approach to weigh each evaluation item and derive the overall priority.

In the KOTI project, qualitative impacts such as regional development, visual intrusion were subjectively assessed by investigation of the area, but those items were limited due to the difficulty in obtaining suitable data on more than a restricted set of criteria and a lack of evaluation framework to organise multiple factors. In this research, all relevant qualitative factors were included because they could be judged within an evaluation framework.

- Understandibility of methods

The relatively complex evaluation process of the AHP may make it difficult for the decision maker or stakeholders to understand compared with conventional evaluation methods such as CBA which is easily understood for decision maker and public. It is a drawback of the AHP, but most of the multiple criteria methods have same characteristics as this analytic hierarchy approach.

However, the analytic hierarchy approach can easily be both structured by the analyst and understood by the decision maker compared with other multiple criteria decision making methods. In this analytic hierarchy approach, the complex problem was decomposed into small problems, which was confirmed by the pilot survey (see 7.2), then the pairwise comparison was undertaken to mark their relative preference on evaluation items.

- Degree of public participation

A major drawback of the conventional cost-benefit analysis is a lack of a way to determine the relative weights to be attached to the costs and benefits of different groups. Some elaborate techniques such as social cost-benefit analysis and planning balance sheet analysis were developed to overcome these weaknesses, but it provides no explicit technique for eliciting the preference of multiple interest groups.

The analytic hierarchy approach shows a systematic framework to elicit public opinion and combine in the process. From the first step, various interest groups, supplier, user, community groups, were involved to mark their preference in the process, then the overall priority was derived based on these subjective preferences. This application showed how to involve multiple decision maker's interests and to incorporate their preferences into the evaluation framework.

In most transport investment appraisal in Korea, Government still plays a leading role in decision making without enough consideration of various interest groups, so it caused many debates and made its implementation very difficult. The main reason for this is due to a lack of evaluation framework which enables various opinions to include in a process. In the KOTI project, public participation was limited to public hearing, not in a evaluation process. However, this application showed how to include and incorporate various opinions from various interest groups in the evaluation process. This will be useful to avoid costly indecision and incomplete evaluation rather than the traditional evaluation method by the way of direct public participation.

- Applicability to transport projects

The evolution of the transport planning process has been characterised by complexity. As a result, the ever increasing range of possible solutions for each problem considered has widened and the number of participants in the planning process has increased. In the traditional transport evaluation method focused on economic efficiency, a whole range of impacts which need to be taken into account in project evaluation have not been considered, and public participation was very limited. As a result, many transport

investment projects have been faced with strong objection for reasons such as regional socio-economic disadvantages or environmental adverse impacts so that the projects had to be reconsidered or cancelled.

Therefore, in order to form the transport investment plans, it should encompass explicit considerations of various factors, tangible and intangible, economic and otherwise, and various interests groups should be involved. Accordingly, evaluation methods such as Multiple Criteria Decision Making (MCDM) methods have been proposed for evaluating these investments to reflect and measure diverse interests of environmental, socio-economic concerns involved in the project in a framework.

In this research, the analytic hierarchy approach was used to evaluate and select the best one among the complicated transport project alternatives with multiple criteria and multiple decision makers. Through the application, it showed quite meaningful results different from the Government project using traditional evaluation method, which was the public participation and incorporation of their opinions into an evaluation framework. This would be quite useful for the transport appraisal, especially in Korea which has a difficulty in implementation of the project due to a lack of concerns on environmental, social attributes and public's opinions which are main reasons of debates around the transport investments.

The application of the analytic hierarchy approach for the transport investment in Korea could make it possible to improve these costly indecision by several reasons. Firstly, it could include various group's changed concerns (its preference and weights) on attributes from only the economic issues. Secondly, it made public (transport experts and general public) participation possible directly in the evaluation process (see section 7.4). This could give the final decision maker more efficient tools which enable to get consensus and makes the implementation more easily than current investment appraisal and implementation process .

Despite the great advantages of multiple criteria evaluation method, especially AHP method, it also showed some disadvantages through the application as follows

- It required a large amount of input data. The more factors and levels that are considered, the more pairwise comparisons it needs. As it needs n(n-1)/2 pairwise judgements at each level, it could make the respondents answer rather roughly.
- For comparison of each objective and alternative, it required the information with as much detail as possible. But there are limitations in giving the information in terms of time taken to answer and the fact that giving too much information could cause bias.
- Moreover, in answering the questions, the respondents should have a full perception of the factors to be compared in a pairwise way. But it is not easy to maintain the whole relationship between all attributes at the same level to be compared throughout the comparison.
- The analytic hierarchy approach method requires structuring a hierarchy. In order to do this, first of all attributes should be decomposed and arranged at each level and the attributes at the same level should be homogeneous. As the weights of each attribute in each level could be changed in accordance with the number of factors and homogeneity. Unfortunately as there is no appropriate way to check homogeneity, it should depend on the researcher's or expert's subjective judgements.
- In structuring a hierarchy, if there is something to be changed, it would take a long time to feed back because it means another structuring of a hierarchy and another survey.

8.4 Conclusion

From the sensitivity analysis and comparison with current evaluation methods, and the assessment of the analytic hierarchy approach method, we have reached the following conclusions.

1. From the sensitivity analysis of each stakeholder's role, the alternative priorities showed the strong sensitive relationship with community members. Their involvement in the evaluation and decision process and their views may change the ranking of projects, so it makes it ever more crucial to obtain their views. It was also confirmed in the measurement of discrepancy between the two priority vectors by KL measurement to see a sensitive relationship (or impacts on the decision) according to the degree of involvement of the stakeholder in the decision process.

2. In the sensitivity analysis, however, the preference for alternative 2 was dominant regardless of the change of the stakeholder's role. It is caused by the fact that alternative 2 was most favoured in many attributes (see table 7.19~20) as an alternative which enabled to compromise two conflicting objectives, transport efficiency (alternative 1) and environmental conservation (alternative 3).

3. Despite the dominance of the alternative 2, the sensitivity analysis provided the decision maker with the guidance, firstly, of which group (user and community group) has an important impact on the decision making and these results might be useful to set stakeholder group to be involved in transport investment planning and appraisal. For a decade, Government had a leading role in decision as a single decision maker, but it has made many conflicts occur in many investment planning by the changed nature and circumstances and it requires public participation in the decision process. Secondly, it showed the guidance that the change of weight on stakeholder's role and their preference for criteria could change the preference order of alternative (especially alternative 2 and 3), which enables the planner or decision maker to set the stakeholder group and objectives in future transport planning in the respect of public participation and multiple criteria, and to give flexible ways of judgement in decision.

4. In the sensitivity test to see the impacts of the objective on the alternative priority of each stakeholder, most of the results about factors in the third level in the hierarchical structure showed quite meaningful results. In the supplier, comfort

and environmental factors have some sensitive relationship with alternative priority. While in the user group, comfort, travel cost and time turned out to be sensitive, and in the community groups, socio-economic and environmental factors. Environmental factors were commonly considered very important factors among all stakeholders, which implies the changed circumstances around transport investment.

5. Regarding the comparison with the results of KOTI project, there is no direct way to compare them because of different alternatives and objectives to be assessed. In KOTI project, they used their subjective assessment considering all costs and benefits for tangible criteria, and the figures or verbal expression for intangible criteria for a final decision. The results of KOTI project showed that alternative 2 was the best one, but overall ranking was not given.

6. Nevertheless, if we attempt to compare the results derived with the result from KOTI, there are some differences in prioritising alternatives and assessment process. These results also imply a difference between the CBA and the multiple criteria evaluation method, especially AHP approach, themselves. In the KOTI project, they incorporated all the quantifiable criteria in the CBA and the other non-quantifiable attributes were considered without attempting to combine them.. While the analytic hierarchy approach for the research incorporated quantitative and qualitative judgements into a framework. This can be a great difference between the two methods.

7. The analytic hierarchy approach through the application provided much wider scope in attributes to be assessed than the conventional evaluation method, and it also provided a consistent framework in which all possible transport responses to transport policy and objectives may be judged with the distribution of weights on all stakeholders. By some subjective criteria for assessment of the suitability of the analytic hierarchy approach, the followings were confirmed (see section 6.3.2.1~6.3.3) :

- The AHP has the great advantage of incorporating qualitative information without transforming them into a monetary dimension because it was designed to evaluate the qualitative decision problem. In this research, qualitative and quantitative information were tried to be combined in the evaluation process, which is different from the normal AHP process (see section 6.3.2.1).
- The AHP can be easily understood by the decision maker compared with other multiple criteria decision making methods even though it has the same drawbacks of multiple decision making methods which make it difficult for the decision maker or stakeholders to understand compared with conventional evaluation method such as CBA
- The analytic hierarchy approach showed a systematic framework to elicit public opinion and organise them in the process. This is the major reason why the analytic hierarchy approach is used in this research.
- From the result, it showed the applicability of the analytic hierarchy approach to transport projects due to its ability to combine qualitative and quantitative information into the framework, and to elicit public preference into the evaluation process. As the case considered in the research was a project with conflicting attributes and many stakeholders affected by the project, it needed the multiple decision making methods. The analytic hierarchy approach based on the conventional cost-benefit analysis showed the capability of encompassing a variety of primary effects resulting from the implementation of transport projects.

8. Despite many advantages of the analytic hierarchy approach, it also showed some drawbacks to be overcome in the application such as a large amount of data and information requirement, inherent difficulty in survey implementation, limitation in structuring a hierarchy, especially in checking the homogeneity. This could make the application of the AHP worse than traditional evaluation methods despite the great advantages mentioned above unless the first step, structuring the problems in a hierarchy, is done properly under the brainstorming or group consensus. This is because this technique was highly dependent for its validity on the hierarchical structure and the comparative judgement of every pair of its elements.

Chapter Nine

Conclusions and Recommendations

9.1 Conclusions

Because of increasing demands for better transport services and better quality of life from economic development, Korean society has met the various demands of interest groups. But the conventional, popular economic analysis technique emphasises economic efficiency and it could not provide a consistent framework in which all possible transport responses to transport policy and objectives may be judged with the distribution of weights on all stakeholders.

To solve these problems, one might introduce MCDM techniques which are able to involve the decision makers in the decision process and include various factors of them. Through the comparison of traditional evaluation method with multiple criteria decision making methods, the method appropriate for the case in this research was selected.

Among many MADM methods, the AHP method finally was chosen as the proposed methodology which provided the means for structuring and analysing a complex problem with multiple decision makers and their various interests. This technique is highly dependent for its validity on the hierarchical structure and the comparative judgements of every pair of its elements. This model includes the knowledge and experience of transport experts, and the preference as input data from the public directly or indirectly related with the transport investment projects. Highlights of the model are:

- Model ties strategy and tactical goals of interacting units to the selection process.

- Model handles multicriteria, tangible and intangible factors.
- Model involves the preference and opinion of various interests groups in the evaluation process.
- Model decomposes the complex problem into small problems, so it is relatively easy to understand.
- Model gives results very quickly and accommodates " what-if" type questions.

The AHP has advantages of incorporating qualitative information without transforming them to a monetary dimension because it was designed to evaluate a qualitative decision problem. However, this research required the evaluation of qualitative and quantitative information in a framework to overcome the following constraints from both methods (traditional method and AHP), a lack of distributional incidence and of involvement of various interests from multiple stakeholders in traditional analysis, and its large dependence on subjective human judgements rather than monetarisation in AHP for a decision.

Therefore, it has been attempted to pick out advantages from each method, then to combine each advantage of CBA and the AHP in the evaluation process within a framework. The main point is to blend quantitative information with qualitative information, i.e. to use monetarisation and human experience and judgements to elicit public opinion and organise them in the process. It is different from other normal AHP process. That is why this is called as an analytic hierarchy approach.

As applied to the case study, the model has four levels of hierarchical structure with three interest groups and six objectives and eleven factors. Alternatives were based on a real project by the Government, but they were modified according to the pilot survey. A total of 615 respondents from transport experts, supplier (mainly Government officials), user (Seoul-Pusan corridor transport users) and community members (Kyongju city dwellers) answered the survey questionnaire. A total of 137 from the expert survey were used as data to derive the stakeholder's role, and 478

cases were used as data for analysing the preference of each element from the questionnaire survey.

The results of derived weights of all elements in the model indicate some interesting facts:

1. From the expert survey, user's opinion (51.5%) was considered most important, and secondly was the community members (34.2%), while supplier groups (14.4%) opinion was considered least important in deciding the best railway route in the historic city of Kyongju. This indicates that the role of the supplier should be reduced compared with the role in the past as a single decision maker, while various interests group's opinion, especially community group for the future, should be more involved in the evaluation process for transport investment such as this case.

2. For the transport investment in Kyongju, *Minimising adverse environmental effects*, and *Maximising socio-economic benefits* and *Improving comfort & convenience* turned out to be the main factors to be considered for investment. This proves the changed circumstances in the decision environment and some change in socio-economic status.
   - the supplier group emphasised the importance of transport service such as the quality of transport service with environmental and socio-economical factors.
   - the user group gave great concerns on the improvement of transport service such as comfort with travel time and cost, and the environmental factors also were considered important by the user group.
   - community members emphasised both the environment and socio-economic circumstances (52%) more than the other groups (supplier: 46%, user: 49%).

3. *Minimising adverse impacts on cultural assets* and *ecological circumstances* were considered most important among many environmental factors for all stakeholders in this case, whilst community members regarded *Min. ecological factors* as a

more important element than the other environmental factors. This may be caused by the fact that it is more related to the quality of life than the others.

4. As the best alternative, alternative 2 showed the highest priority with the relative priority 39%, which is caused by the fact that it is able to compromise the conflicts of the transport efficiency and conservation of environmental assets including historic culture. Alternative 3 came next and alternative 1 showed the lowest priority.
   - Each group showed some different preference against alternatives. The supplier group preferred alternative 1 which had been rejected by the strong objection of some cultural experts in local area to alternative 3, and community members also preferred alternative 1 to 3, the same with supplier group. These emphasised the necessity of involvement of various interest groups, and also drawing and combining public opinion in the evaluation and decision process.

5. In order to investigate the robustness of the results and prepare for the change of preference, in this research, the incremental change of the stakeholder's role and the objectives' weights were examined to identify which stakeholder or objective has a greater impact and would be sensitive to the decision of the best alternative. These were firstly assessed by the weights derived from the survey, then confirmed by the KL measurement. This is useful for a selection of stakeholder and objectives for a future transport investment plan. This sensitivity was to analyse the sensitive relationship with the priority of alternatives.
   - Sensitivity analysis of each stakeholder's role showed that community member's opinions were most sensitive to the results. It means that it is becoming more important to obtain their views for the right decision because their participation in the decision process becomes necessary and their views may change the ranking of alternatives.
   - Sensitivity results about factors showed that the sensitivity of objectives were somewhat different between the stakeholders except the consideration on

environmental factors and the quality of transport service. These few following factors turned out to have more impact on the priority than others.

- supplier group: quality of transport service and environment factors
- user group: comfort, travel cost and time, environmental factors
- community: socio-economic and environmental factors

6. Regarding the comparison with the results of KOTI project, there are some differences in the ranking of the alternatives and assessment process, yet it was difficult to compare because the alternatives were different from each other. Therefore, the difference is converged to the difference between the CBA and the multiple criteria evaluation method, especially the analytic hierarchy approach. The main differences through the application of the analytic hierarchy approach for the same project implemented by the government are summarised as follows:
   - With regard to prioritisation of alternatives in this research, two groups, supplier and user group, among all stakeholder groups preferred alternative 1 to alternative 3 even though it is least favoured in the global priority. This implies that any single decision made could provide some different results from the decision which multiple decision makers are involved in. The result of the KOTI project did not provide the preference order of alternatives except the best alternative recommended.
   - Regarding judgement incorporation, the analytic hierarchy approach provided greater scope of aggregating the data than current evaluation method, and allocated due weights to the objectives and elements.

7. The analytic hierarchy approach through the application provided much wider scope than the conventional evaluation method, and also provided a consistent framework. Via some subjective criteria for assessment of the suitability of the analytic hierarchy approach, the followings were found:
   - The analytic hierarchy approach showed a systematic framework to elicit public opinion and organise them in the process.

- From the result, it showed the applicability of the analytic hierarchy approach to transport projects due to its ability to deal with complex problems with conflicting attributes and many stakeholders affected by the project, and the analytic hierarchy approach can incorporate advantages from the conventional cost-benefit analysis.
- The analytic hierarchy approach showed the capability of encompassing a variety of primary effects resulting from the implementation of transport projects.

8. Despite many advantages of the analytic hierarchy approach, it also showed some drawbacks to be overcome in application such as a large amount of data and information requirement, inherent difficulty in survey implementation, limitation in structuring a hierarchy, especially in checking the homogeneity.

For the evaluation and selection of the best alternative in Kyongju, we found that it was necessary for the evaluation method to find the appropriate evaluation method which is able to involve various interests and multiple stakeholders affected by the project, then to solve a complex problem.

This demands multiple criteria decision making methods to quantify all the factors and gives the appropriate weights distribution to each factor as a harmonised figure among all groups involved.

This could be achieved by the combination of the advantages of each method, for example, the advantage in quantifying the tangible factors of CBA and in deriving the weights of the factors of the analytic hierarchy process. In this respect, it was attempted to draw the best solution in this research and the analytic hierarchy approach proved to be an effective tool in implementing these goals. This could be the solution to overcome or complement the drawbacks of each evaluation method.

9.2 Contributions

Through this research, it is expected to be able to prove the validity of the Multiple Criteria Decision Making methods and be able to contribute academically to the field of multicriteria evaluation. In addition to these, diverse interests such as multiple factors including environmental, socio-economic concerns and public discontents of multiple decision makers were involved in the evaluation process, and so decision makers were presented with useful and understandable information and flexible alternatives for appropriate decisions. Therefore, this could contribute to the efficient and logical transport investment planning considering multiple criteria and decision makers in practice in Korea.

It is perceived that this research makes the following contributions:

1. to combine the conventional evaluation method and the AHP method. In the research, qualitative and quantitative evaluation items were blended in a framework using monetarisation (CBA) as well as human judgement (AHP) to elicit public opinion and organise them in the process.

2. to demonstrate the application of the analytic hierarchy approach to railway network development alternative selection in the transport field. In Korea, any attempts were not made to evaluate the project in such a way with many criteria and multiple stakeholders with the analytic hierarchy approach. This research demonstrated the applicability to transport projects with complex problems.

3. to include diverse multiple factors in transport investment evaluation. In the past, economic efficiency has been considered the most important for transport investment, so a whole range of impacts which need to be taken into account in project evaluation have not been considered or considered just as secondary factors not in a framework due to the difficulty of monetarisation and a lack of evaluation framework. In this research, all evaluation attributes were attempted to be included

in the decision process using monetarisation and pairwise comparison with human experience and judgements, and moreover within a framework.

4. to show how to extend the scope of decision makers to multiple decision makers and to involve various interests groups in the evaluation process. In Korea, the Government's views have been most important in the decision during last decade as with many developing countries. However, as the country's socio-economic status has been changing, many projects were faced with the interests from various interest groups. It required public participation in the evaluation and decision process. This research showed how to involve various interests from multiple interest groups and how to organise their views in the evaluation process from the beginning to the end in a framework.

5. to examine the degree of impact of stakeholders' role and their objectives of the decision (priority of the alternative). Due to the uncertainty of the future around transport investment, it is necessary to prepare for the changed circumstances (mainly stakeholder's role and their preference for objectives), which could help more flexible judgements in the decision for the decision maker. It might be useful to classify multiple stakeholders and set up the objectives for transport investment planning.

6. to contribute to the improvement of existing transport investment evaluation method with problems and controversy in the application. The analytic hierarchy approach provided much wider scope in which all possible attributes should be judged with the distribution of weights on multiple stakeholders incorporating qualitative and quantitative information in a consistent framework. All of these had been the weakness and drawbacks of the current evaluation method in Korea causing costly indecision and incomplete evaluation. This research might be useful for improving current evaluation and making progress in transport investment appraisal.

9.3 Recommendations for Further Research

From the results of this research, the followings are recommended for further study.

Firstly, it is recommended that further work should set up the criteria for investigating the difference between evaluation methods and the axiomatisation of evaluation methods should be more developed because it was found to be very difficult to classify the evaluation methods and to select the most suitable one according to the needs of the decision makers.

Secondly, it was found that the priority was dependent on the hierarchy in the AHP application, especially factors to be compared at same level, and it was very difficult to arrange the attributes at each level of the hierarchy in structuring a hierarchy. As the weights are dependent on how many numbers and which attributes are at each level, further work should be undertaken to check the homogeneity of the factors at the same level

Finally, some of the multiple criteria methods were found to be very good on some aspects of the decision problems, while others proved to be better on others. It would be quite interesting to undertake research with a view to developing a model combining the advantages of several advanced multiple criteria decision making methods.

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APPENDICES

1. **Pilot Survey Questionnaire**

2. **Main Survey Questionnaire**

3. **Sensitivity Test Results of Objectives**

Appendix 1: Pilot Survey Questionnaire

Dear Sir,

I am undertaking research into the evaluation of transport investment projects in Korea. This research is considering the four railway network alternatives for developing a high speed railway network passing through/by the oldest historic city, Kyongju in Korea. In order to achieve as a good decision as possible, this case really needs a systematic analysis which is able to consider various factors such as environmental factors, especially cultural assets, and various interest groups involved in the project. The multiple criteria decision making method is applied to this research.

To evaluate and select the best network alternative by a multiple criteria decision making approach, this research particularly needs your preference on the degree of importance of the role of each decision maker and each element related with this network development project in Kyongju. Based on the information about survey scheme and alternatives given on the front of the questionnaire, please base the answers to this questionnaire on your knowledge, experience and subjective judgements. Your answers are valuable for future transport investment planning and evaluation in Korea.

I should be grateful for your assistance and would appreciate it if you could answer this questionnaire. Thank you for your co-operation.

Sang-Min Lee

Senior Researcher in KOTI (The Korea Transport Institute),

Research Student in ITS (Institute for Transport Studies, University of Leeds)

1. Survey Scheme

The case considered for this pilot survey is to choose the best railway network passing by the oldest historic city, Kyongju, with very many historic cultural assets, as a part (68 km) of main railway (high speed rail: 426.2 km) from Seoul to Pusan.

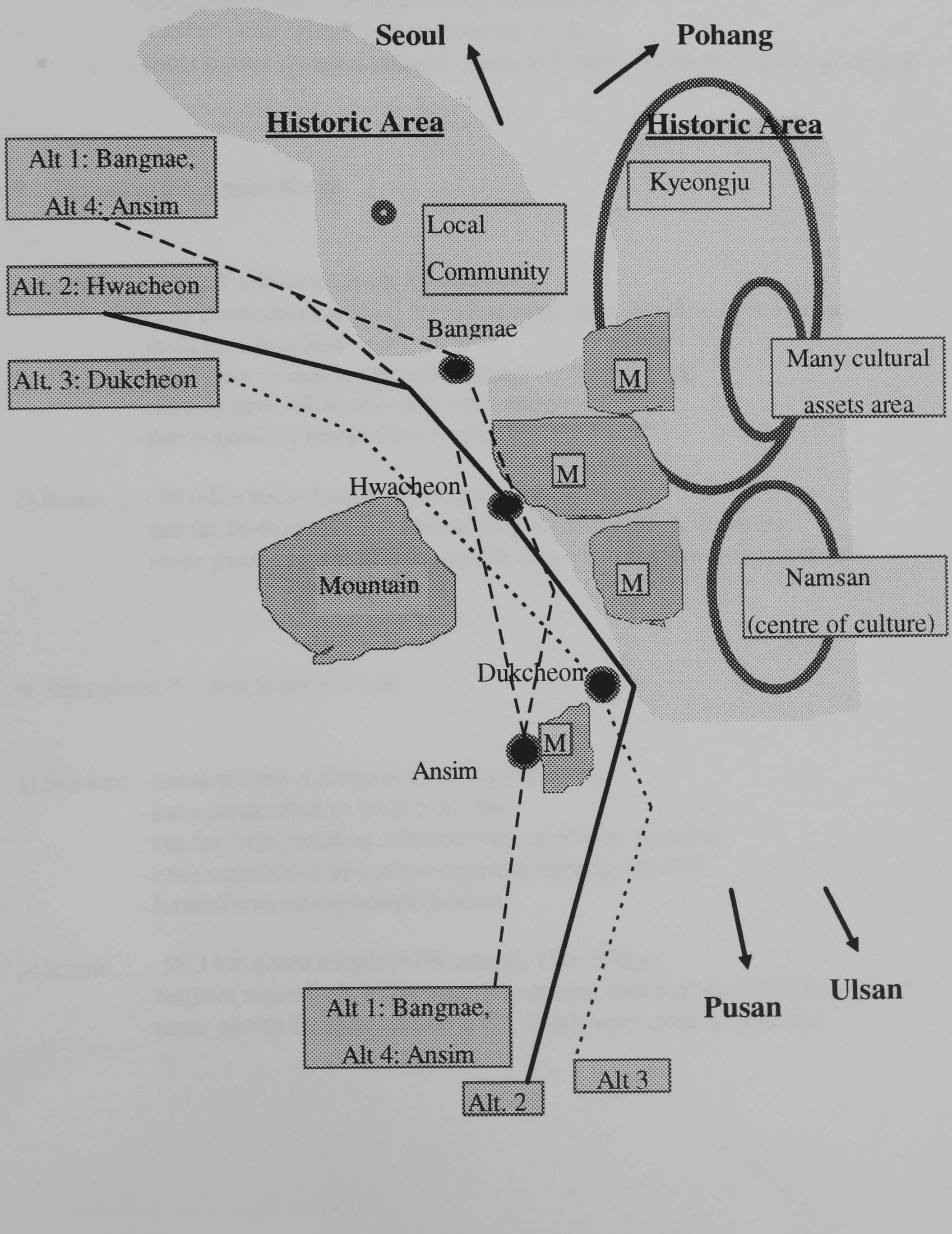
The main purpose of this high speed rail project is to increase the capacity for relieving the severe traffic congestion on the Seoul-Pusan main traffic axis (70% share of total regional traffic demand) and to provide better accessibility to the south-eastern part of Korea including Kyongju city, then to improve regional development of those areas through connecting a section of this railway network to this area.

For the remaining part of a whole high speed rail line excluding Kyongju area, routes and sites of stations have been selected without very much controversy because of the advantage of better accessibility and regional development. Whilst choosing the best railway network for the Kyongju area has been long debated across the whole country because the city has so many cultural assets as the oldest historic city in Korea. It is because that it is very difficult to meet both goals, "transport development for increased accessibility, and regional development" and "cultural asset conservation" when transport facilities are invested in that area.

For the conflict resolution and group consensus to get the best decision for the project, a multiple criteria decision making method which enables many decision makers to participate in the evaluation process is attempted to be applied to this case which requires consideration of various interests and stakeholders. Through this pilot survey, the procedure and methodology for application should be confirmed and modified, and then the findings from the results of this pilot survey will be used to make the method concrete for the application in the main research.

2. Alternatives

The alternatives given for this research are to choose the best one of the 4 alternatives for about 60 km of railway with different routes and stations through those area. A brief map of the alternatives given for this pilot survey is as follows:



◆ Alternative 1 : Bangnae Route

1) Station: - located very close to Kyongju city
- easy connection to local road, motorway
- need much relocation cost for connecting current regional railway network to this new main railway
- flat and wide area, but expansion limited due to cultural assets nearby

2) Route : - 59.5 km route length (48% through tunnels, 18% over bridges)
- closest to residential area among alternatives (1879 house within 250 m from the route)
- route passes by most cultural assets (35 sites), Namsan visually protected

◆ Alternative 2 : Ansim Route

1) Station: - located a distance from Kyongju city
- easy connection to local road, but away from junction of motorway, need new junction
- need long relocation for connecting current regional railway network to this new main railway
- surrounded by mountains, so expansion limited

2) Route : - 59.0 km route length (53% tunnel, 16% bridge)
- not far from residential area among alternatives(1650 house)
- route passes by cultural assets (26 sites), Namsan visually protected

◆ Alternative 3 : Duckcheon Route

1) Station: - located quite a distance from Kyongju city
- easy connection to local road, rail but far from junction of motorway, need new junction
- easy connection to current regional railway network
- limited site, so expansion limited

2) Route : - 58.3 km route length (67% tunnel, 15% bridge)
- furthest away from residential area among alternatives (1632 house)
- route passes by cultural assets (25 sites), very close to Namsan

◆ Alternative 4 : Hwacheon Route

1) Station: - located very close to Kyongju city
- easy connection to local road, motorway junction
- easy connection to current regional railway network
- extendible due to wide area nearby

2) Route : - 58.9 km route length (56% tunnel, 16% bridge)
- relatively close to residential area (1817 house within 250 m)
- route passes by fewest cultural assets (17 sites), Namsan protected

	Alternative 1 Bangnae	Alternative 2 Ansim	Alternative 3 Duckcheon	Alternative 4 Hwacheon
◆ STATION				
Site and its Circumstance	-wide area -limited extension due to cultural assets nearby	-surrounded by mountains -limited area for extension	-limited area for extension -very close to Namsan	-between the mountains -limited, but enough extension
Connection to				
local road	-easy connected	-easy connected	-easy connected	-easy connected
motorway	-easy connected to motorway junction and access road	-need new junction and access road	-need new junction and access road	-easy connected to motorway junction and access road
rail	-need many re-location of rail for connection	-need long connection	-easy connection	-easy connection
◆ ROUTE				
Length	-59.5 km	-59.0 km	-58.3 km	-58.9 km
Tunnel	-48%	-53%	-67%	-56%
Bridge	-18%	-16%	-15%	-16%
Grade	- ~ 17 ‰	- ~ 17 ‰	- ~ 12 ‰	- ~ 24 ‰
Distance from residential area	-very close -1879 house within 250 m	-far -1650 house	-very far -1632 house	-close -1817 house
from cultural area	-very close, but far from Namsan	-close -very far from Namsan	-far from historic area -but very close to Namsan	-not far from historic area -close to Namsan
Number of cultural assets nearby	-35 sites	-26 sites	-25 sites	-17 sites
House Replacement needed	- 430 house within 50m	-365 house	-304 house	-315 house

3. Stakeholders and Objectives

● Stakeholders

Stakeholders mean the people who have an interest so that their interest should be considered. Stakeholders are often at the policy level of decision making concerned with the programme goals and objectives, and the consequences of programme operations.

In this research, in order to identify and structure the value attributes important to the evaluation that people are interested in, and to assign importance weights to these attributes, three interest groups(stakeholders) are chosen for this project, suppliers, users and community, and surveyed via a questionnaire.

Supplier means the people responsible for the supply and investment for the transport facility. This role is fulfilled by government officials. Users are the people whose individual mobility is affected by the project through changes in travel time, cost, safety and convenience in using those facilities. The last group is the people, community members, who live in the area that are affected directly by the project. They are concerned about their living circumstances and environment individually or at a community level, and those matters are currently becoming more important social issues.

● Objectives

There could be various objectives related to the project along with the specified factors of each objective according to each stakeholder because the transport system affects people's quality of life in various ways. It influences not only life style but also social, economic, physical and environmental sectors.

All objectives and the elements possible considered for choosing the best railway route in the historic city, Kyongju and their measurement units for evaluation are as follows:

Objective		Definition & Measurement
Reduced Travel Time		• rail passenger travel time to next cities on HSR line + access time to destination
Improved Transport Network Connection		• connection to local road, regional railway and motorway
Improved Comfort & Convenience		• comfort measured by physical layout such as the roughness of rail route, constitution of route • for convenience, it depends on route condition such as tunnel, bridge, gradient, railroad crossing of each alternative, and the location of station
Min. Project Cost		• construction cost of railway, collector road to rail, relocation cost of existing railway for connection, and its operating cost • NPV
Urban travel cost		• generalised cost of Kyongju city on all roads caused by all of travellers for urban journeys according to the location of station
Max. Socio -Economic Benefits	***Developed Regional Economy***	• approximately same each alternative, but slightly different from site location & condition of station • subjective judgement by description
	Min. House Replacement	• measured by total numbers of replaced house against alternative routes within a predetermined distance
Min. Adverse Environmental Effects	**Noise**	• measured by total number of the exposed house against alternative routes within predetermined distance
	Ecological Impacts	• depends on railway route passing through the mountain, river • subjective judgement
	Min. Visual Intrusion	• assessed by the view from Namsan • subjective judgement
	Min. adverse impacts on Cultural Assets	• depends on number of cultural sites affected by the project within a predetermined distance • subjective judgement

4. Assessment

To make the pairwise comparison judgements, the fundamental scale of the AHP of nine point values in classical verbal descriptors is used. Using the ratio scale, the dominance of each element over the others with respect to each element of the immediately higher level of the hierarchy is assessed. Two examples show how to mark your subjective preference in pairwise comparison.

< Scale of verbal measurement used for this research>

Intensity of relative importance	Definition
1	Equally important or preferred
3	Slightly more important or preferred
5	Strongly more important or preferred
7	Very strongly more important or preferred
9	Extremely more important or preferred
2,4,6,8	Intermediate value

example 1> When Alternative A is considered ***strongly important (better), 5*** than Alternative B, circle 5 on the Alternative A half

Alternative	**← better**																	**better→**	**Alternative**
A	9	8	7	6	(5)	4	3	2	1	2	3	4	5	6	7	8	9		B

example 2> When Alternative B is considered ***strongly important (better), 5*** than Alternative A, circle 5 on the Alternative B half

Alternative	**← better**																	**better→**	**Alternative**
A	9	8	7	6	5	4	3	2	1	2	3	4	(5)	6	7	8	9		B

■ EXPERT SURVEY

PART 1 : GENERAL

This section refers to the general background.

1. What is your professional identity in the transport field ?

   ❑ Professor
   ❑ Researcher
   ❑ Planner
   ❑ Other (specify): [ ]

2. How long have you worked in transport field ?

   ❑ less than 3 years
   ❑ 4-6 years
   ❑ 7-10 years
   ❑ 11 or more years

PART 2 : IMPORTANCE OF ROLE

This section refers to the degree of importance for the role of each stakeholder involved in this specified transport project to get the relative importance of the following three interest groups,

supplier: people in responsible for the supply and investment for transport facility

user: people affected by the project directly or indirectly through the change of travel time, cost, safety, convenience using that facility (high speed rail)

community : people who live in the area that are affected by the project through the change of their living circumstances and environment (people in Kyongju area including nearby railway route of its area)

Please check and rate how much extent each stakeholder's opinion should be considered important and reflected in choosing the best railway network in the historic city, Kyongju according to your subjective judgements.

■ ***Which stakeholder's opinion should be considered more important and reflected in choosing the best railway route with respect to the railway network development in the historic city, Kyongju?***

Stakeholder	← more important more important →	**Stakeholder**
Supplier	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	User
Supplier	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Community
User	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Community

■ QUESTIONNAIRE SURVEY

PART 1 : GENERAL

This section refers to the general background.

1. What do you think which decision maker group you belong to ?

   ❑ Supplier
   ❑ User
   ❑ Community member
   ❑ None of any group

2. Which age group do you belong to ?

   ❑ less than 20
   ❑ 21-30
   ❑ 31-40
   ❑ 41-50
   ❑ more than 51

PART 2 : PREFERENCE

1. Relative Importance of each *Objective* with respect to the *Overall Goal*

This section refers to the preference for each objective as the major factor in railway network development project in order to evaluate and select the best railway network.

Please rate the relative importance of pairwise objectives with respect to overall goal in affecting the evaluation of this project according to your own preference.

■ ***Which objective for the evaluation in this transport project should be considered more important as the objective in choosing and developing railway network in Kyongju?***

Objectives	← more important more important →	Objectives
Reduced Travel Time	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Improved Transport Network
〃	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Improved Comfort & Convenience
〃	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Min. Project Cost
〃	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Urban Travel Cost
〃	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Max. Socio-Economic Benefits
〃	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Min. Adverse Environmental Effects
Improved Transport Network	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Improved Comfort & Convenience
〃	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Min. Project Cost
〃	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Urban Travel Cost
〃	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Max. S-E Benefits
〃	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Min. Env. Effects
Improved Comfort & Convenience	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Min. Project Cost
〃	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Urban Travel Cost
〃	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Max. S-E Benefits
〃	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Min. Env. Effects
Min. Project Cost	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Urban Travel Cost
〃	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Max. S-E Benefits
〃	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Min. Env. Effects
Urban Travel Cost	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Max. S-E Benefits
〃	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Min. Env. Effects
Max. Socio-Economic Benefits	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Min. Env. Effects

2. Relative Importance of each *Element* with respect to *Objective*

This section refers to the preference for each element with respect to several objectives, as the specified factor in railway network development project in order to evaluate and select the best railway network.

Please rate the relative importance of pairwise elements with respect to this objective in affecting the evaluation of this project according to your own preference.

■ ***Which element should be considered more important as the main evaluation factor in minimising environmental adverse effects with respect to the railway network development in Kyongju?***

Elements	←more important									more important→								Elements
Noise	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Visual Intrusion
〃	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Cultural Assets
〃	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Ecological Impacts
Visual Intrusion	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Cultural Assets
〃	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Ecological Impacts
Cultural Assets	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Ecological Impacts

■ ***Which element should be considered more important as the main evaluation factor in maximising socio-economic benefits with respect to the railway network development in Kyongju?***

Elements	←more important									more important→								Elements
Improving Regional Development	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Minimising Adverse Effects such as house replacement

4. Relative Preference of each *Alternative* with respect to each *Elements (or Objectives)*

This section refers to the preference for each alternative with respect to each element (or objective) in order to evaluate and select the best railway network alternative.

Please rate the relative preference of pairwise alternatives with respect to each element (or objective) in affecting the evaluation of this project according to your own preference.

■ ***Which alternative is better than the other with respect to each element (or objective) for the evaluation of the railway network development in Kyongju?***

< Improved Comfort & Convenience >

Alternative	←better									better→								**Alternative**
Alternative 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Alternative 2
〃	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Alternative 3
〃	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Alternative 4
Alternative 2	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Alternative 3
〃	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Alternative 4
Alternative 3	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Alternative 4

<Improved Transport Network>

Alternative	←better									better→								**Alternative**
Alternative 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Alternative 2
〃	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Alternative 3
〃	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Alternative 4
Alternative 2	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Alternative 3
〃	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Alternative 4
Alternative 3	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Alternative 4

<Max. Regional Development>

Alternative	←better									better→								**Alternative**
Alternative 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Alternative 2
〃	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Alternative 3
〃	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Alternative 4
Alternative 2	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Alternative 3
〃	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Alternative 4
Alternative 3	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Alternative 4

<Noise>

Alternative	←better																better→	**Alternative**
Alternative 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Alternative 2
〃	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Alternative 3
〃	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Alternative 4
Alternative 2	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Alternative 3
〃	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Alternative 4
Alternative 3	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Alternative 4

<Visual Intrusion>

Alternative	←better																better→	**Alternative**
Alternative 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Alternative 2
〃	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Alternative 3
〃	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Alternative 4
Alternative 2	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Alternative 3
〃	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Alternative 4
Alternative 3	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Alternative 4

<Cultural Assets>

Alternative	←better																better→	**Alternative**
Alternative 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Alternative 2
〃	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Alternative 3
〃	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Alternative 4
Alternative 2	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Alternative 3
〃	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Alternative 4
Alternative 3	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Alternative 4

<Ecological Impacts>

Alternative	←better																better→	**Alternative**
Alternative 1	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Alternative 2
〃	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Alternative 3
〃	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Alternative 4
Alternative 2	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Alternative 3
〃	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Alternative 4
Alternative 3	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Alternative 4

Appendix 2: Main Questionnaire Survey

Dear Sir,

I am undertaking research into the evaluation of transport investment projects in Korea. This research is considering the three railway network alternatives for developing a high speed railway network passing through/by the oldest historic city, Kyongju in Korea. In order to achieve as a good decision as possible, this case really needs the systematic analysis which is able to consider various factors such as environmental factors, especially cultural assets, and various interest groups involved in the project. A multiple criteria decision making method is applied to this research.

To evaluate and select the best network alternative by a multiple criteria decision making approach, this research particularly needs your preference on the degree of importance of the role of each decision maker and each element related with this network development project in Kyongju. Based on the information about survey scheme and alternatives given on the front of questionnaire, please base the answers to this questionnaire on your knowledge, experience and subjective judgements. Your answers are valuable for the future transport investment planning and evaluation in Korea.

I should be grateful for your assistance and would appreciate if you could answer this questionnaire. Thank you for your co-operation.

Sang-Min Lee

Research Associate in KOTI (The Korea Transport Institute),

Research Student in ITS (Institute for Transport Studies, University of Leeds)

1. Survey Scheme

The case considered for this survey is to choose the best railway network passing through/by the oldest historic city, Kyongju, with a great number of historical cultural assets, as a part (68 km) of the main railway (high speed rail: 426.2 km) from Seoul to Pusan. The main purpose of this high speed rail project is to increase capacity for relieving the severe traffic congestion on the Seoul-Pusan main traffic axis (70% share of total regional traffic demand), and to provide better accessibility to the south-eastern part of Korea, and then to improve regional development of those areas through connecting a part of these railway network to its area.

For the rest of the whole high speed rail line excluding Kyongju area, routes and sites of stations could have been selected without a great deal of controversy due to the advantage of better accessibility and regional development, whilst choosing the best railway network of the area have long been debated throughout whole country because the city has so many cultural assets as the oldest historic city in Korea that it is very difficult to meet both goals, "transport development for increased accessibility, and regional development" and "cultural asset conservation" when transport facilities are invested in that area.

For the conflict resolution and group consensus in the project, a multiple criteria decision making method which enables many decision makers to participate in the evaluation process is attempted to be applied to this case which requires the consideration of various interests and stakeholders. Through this survey, the importance of each decision maker's role and their preference for objectives are to be found as a result. In addition, the applicability and suitability of multiple criteria decision making method are to be assessed and recommended for more efficient transport investment evaluation and planning in Korea.

2. Alternatives

The alternatives given for this research are to choose the best one among the 3 alternatives of the approximately 60 km railway with different routes and stations through those area. A brief description of the alternatives and data given for the application are as follows:

◆ Alternative 1 : Hyeongsan (Buknyeokdul) Route

The site of the station is located very close to Kyongju city, so its expansion for further development is limited, yet sufficient for the station development of the station site and vicinity. This site has advantages of easy access to the station and a very easy connection to local roads, motorway junction, and to the current railway network. This means that the existing transport network can be used for a new railway network with minimal cost. The route consists of 68.4 km, 48% through tunnels and 26% over bridges. This route is situated close to residential areas as well as cultural sites, so it has more impacts on cultural assets (28 sites) than the other alternatives. Moreover, as this route is close to Namsan, a national park with many cultural and environmental assets, is visually intruded upon by this alternative.

◆ Alternative 2 : Hwacheon Route

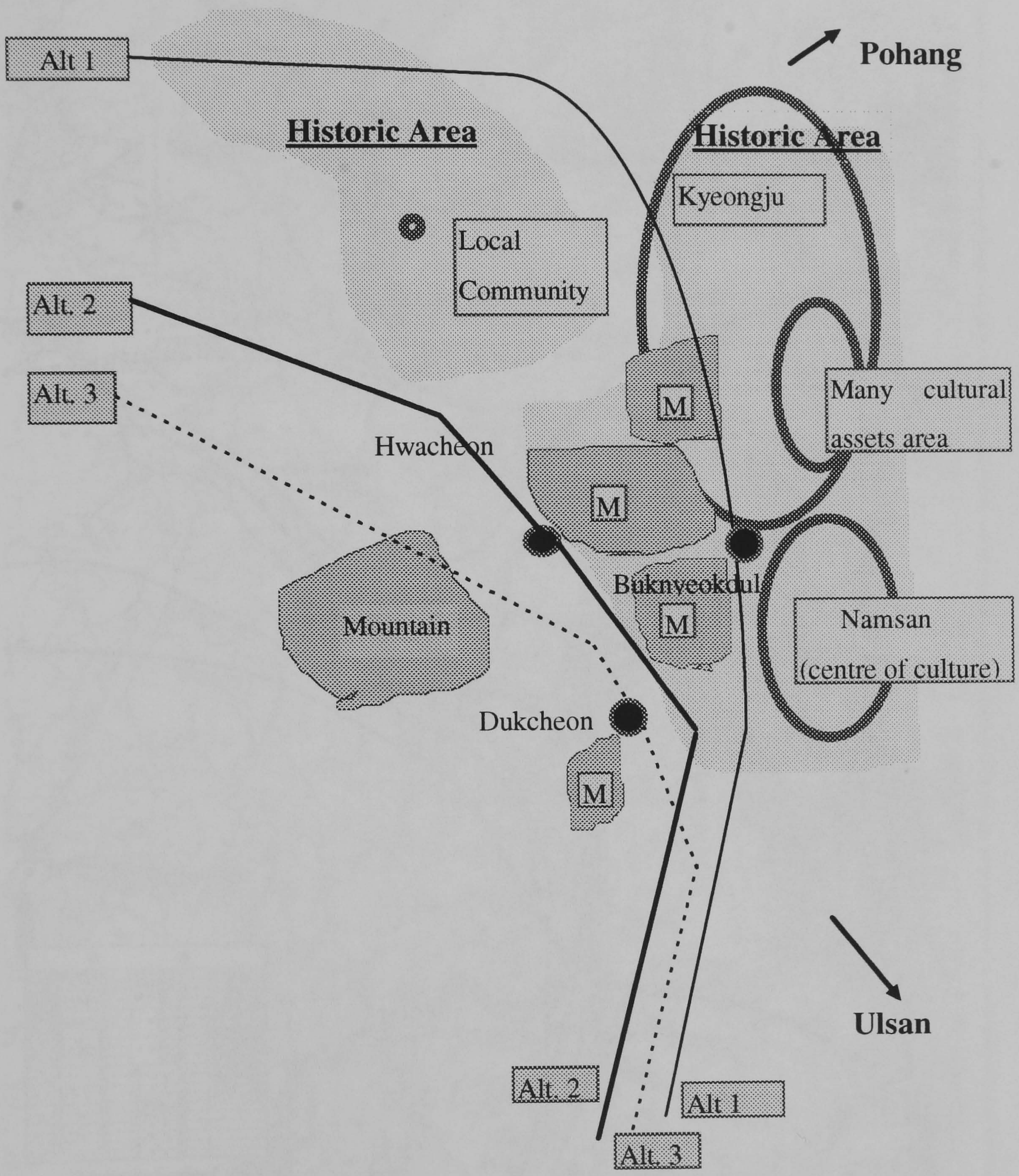
The site of the station is located close to Kyongju city and the site for further development is extendible due to the wide, plain nearby. This site also has relatively good access to the station and easy connection to local roads, motorway junction, and to the current railway network. The route consists of 58.9 km with tunnel (56%) and bridge (16%). This route is situated close to residential areas, but as there are less cultural assets (17 sites) than the other alternatives of the route, the impacts on cultural assets are less than the others. However, this route is relatively close to Namsan.

◆ Alternative 3 : Duckcheon Route

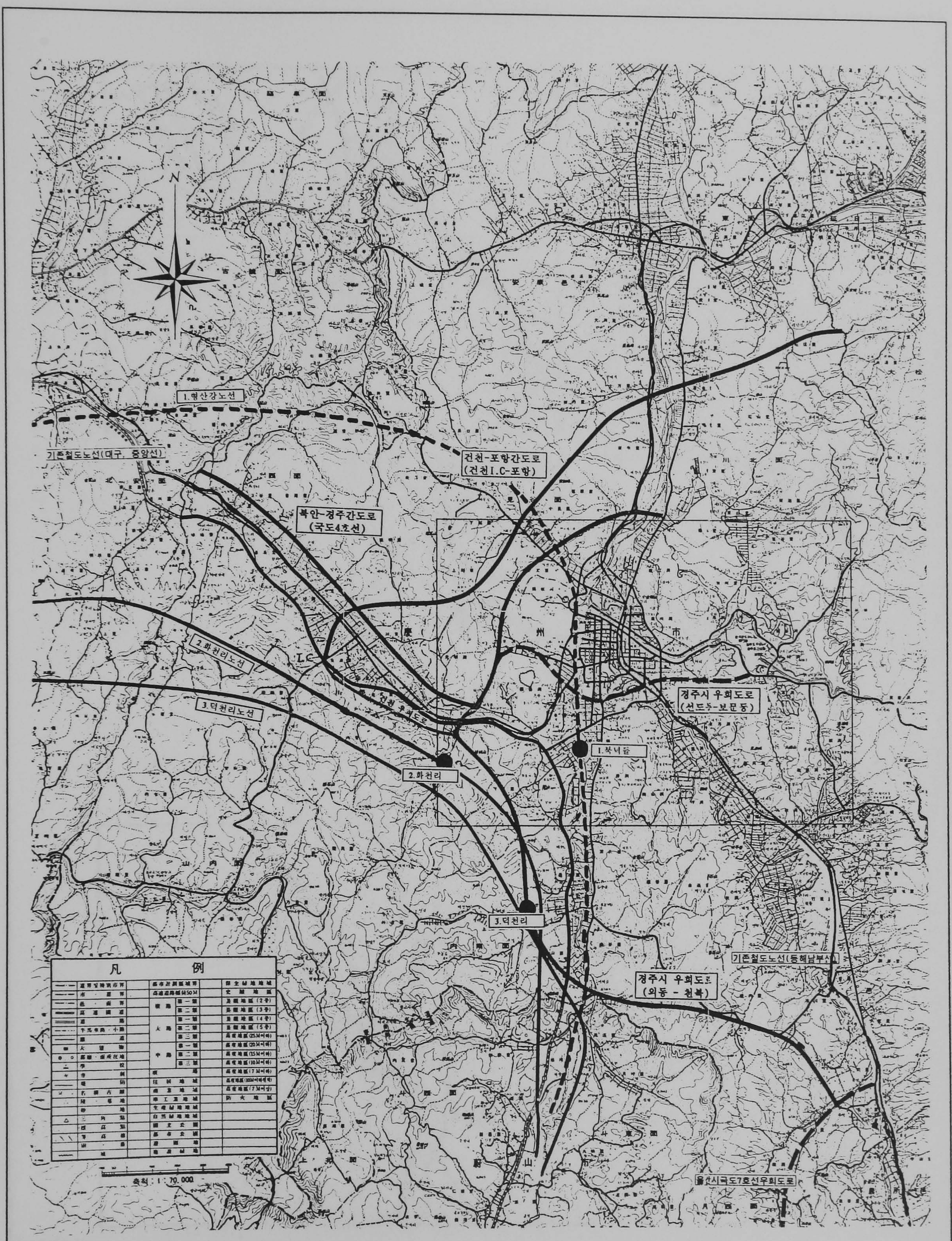
The site of the station is located farthest from Kyongju city, but the scope for further development is limited due to the mountains around the station. This site, therefore, does not have easy access to the station. But the access to local roads and the current railway is relatively good, while the connection to the existing motorway needs a new junction or access road because it is far from the junction. The route consists of 58.3 km with tunnel (67%) and bridge (15%). This route is farthest from the residential area, but not far from the cultural assets and Namsan.

	Alternative 1 Hyeongsan	Alternative 2 Hwacheon	Alternative 3 Duckcheon
ROUTE			
Distance from city	very close	close	far
Site and its Circumstance	-sufficient extendibility	-between the mountains -limited, but sufficient	-limited site area -limited area for extension
Connection to local road	-easy connected	-easy connected	-easy connected
motorway	-easy connected to motorway	-easy connected to motorway and access road	-need new motorway junction and access road
rail	-very easy connection	-easy connection	-easy connection
Extendibility & Feasibility for Development	-limited due to visual intrusion on Namsan, but extendible	-extendible due to wide area nearby	-limited due to visual intrusion on Namsan
STATION			
Length	-68.4 km	-58.9 km	-58.3 km
Tunnel	-48%	-56%	-67%
Bridge	-26%	-16%	-15%
Distance from city	-very close	-close	-very far
from cultural area	-close to residential area -close to Namsan	-not far from historic area -close to Namsan	-far from residential area -very close to Namsan
Number of cultural assets nearby	-28 sites	-17 sites	-25 sites

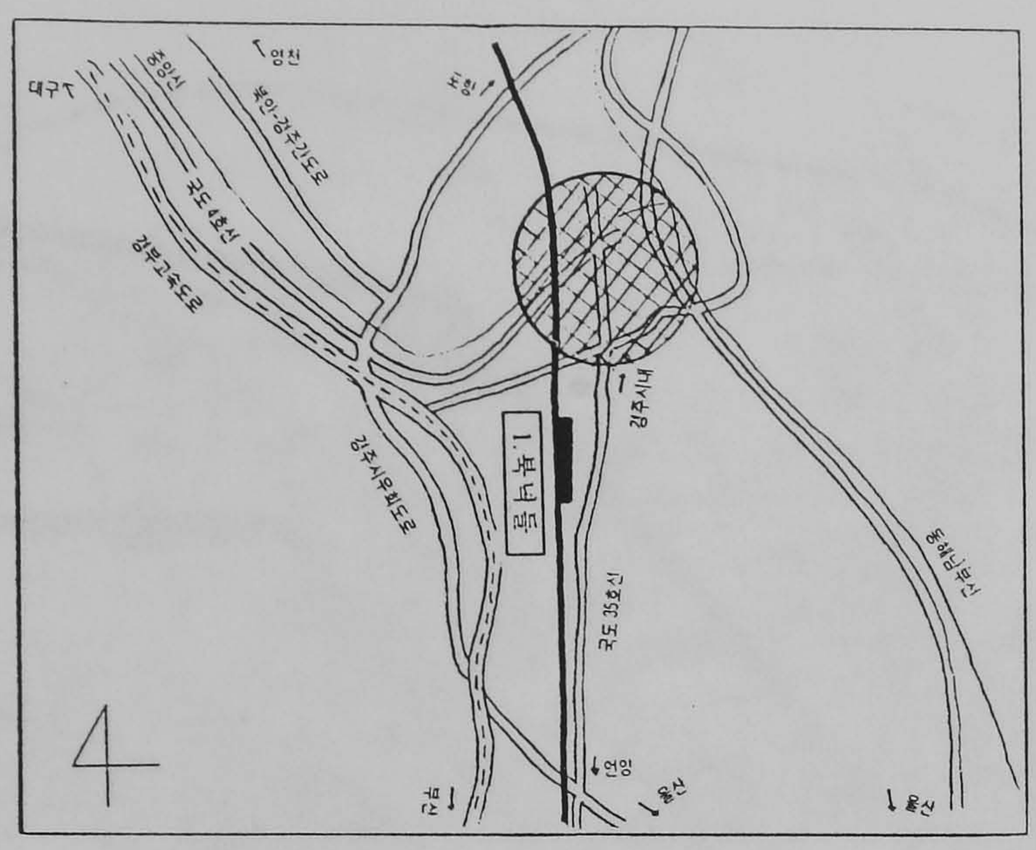
● Route Alternatives and its Circumstance

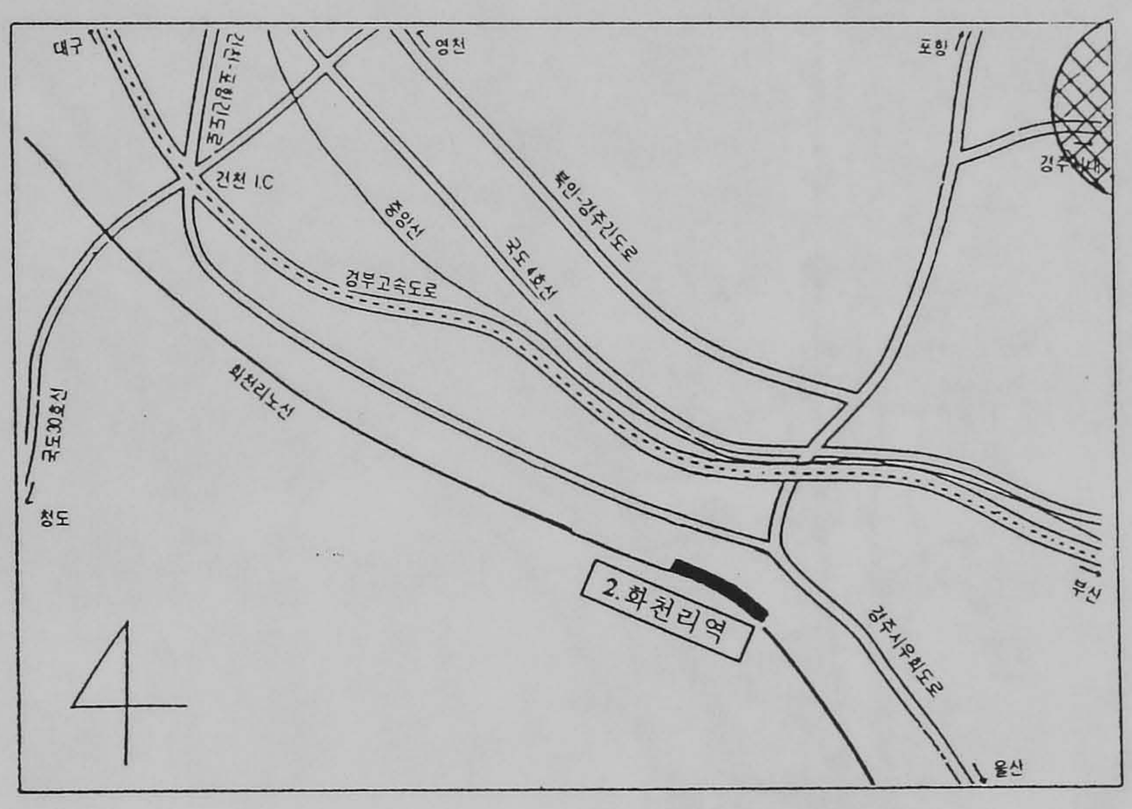


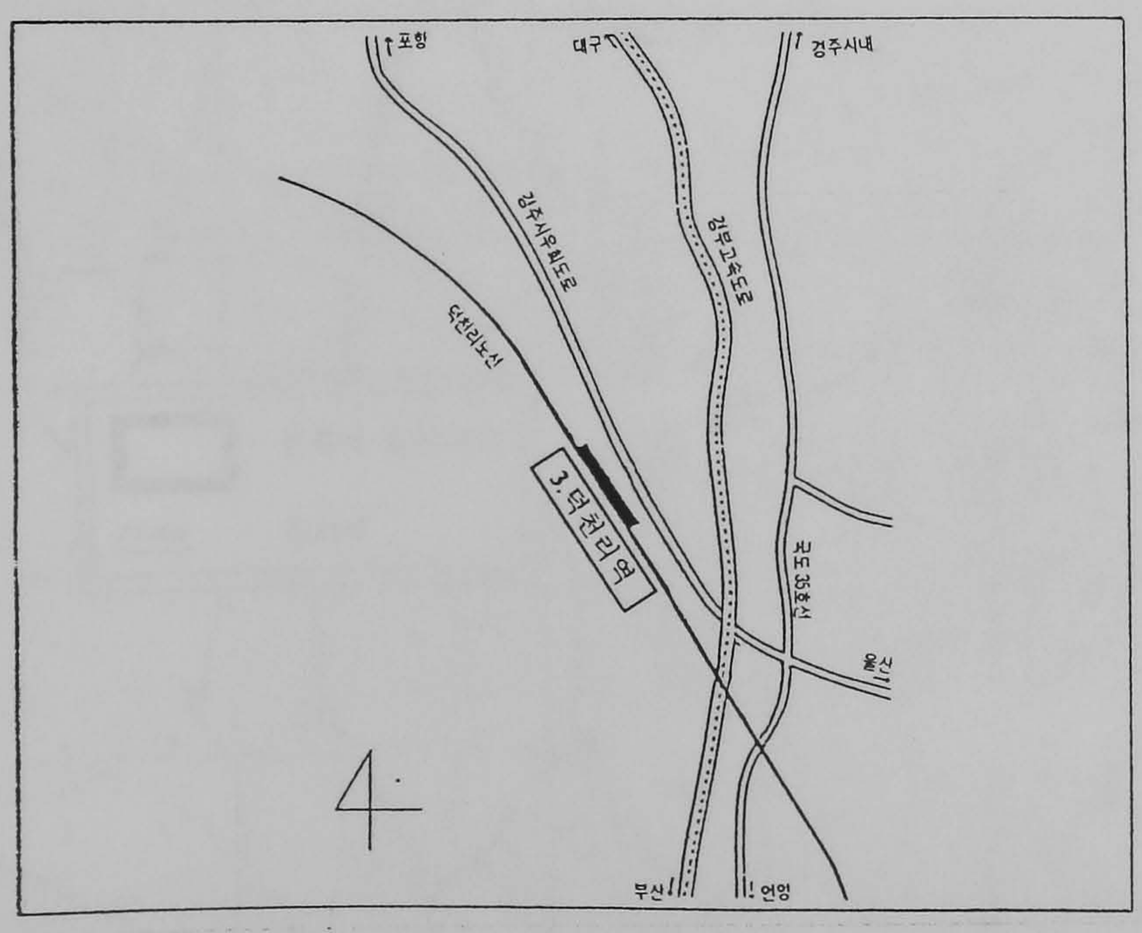
● Alternatives and its Transport Networks



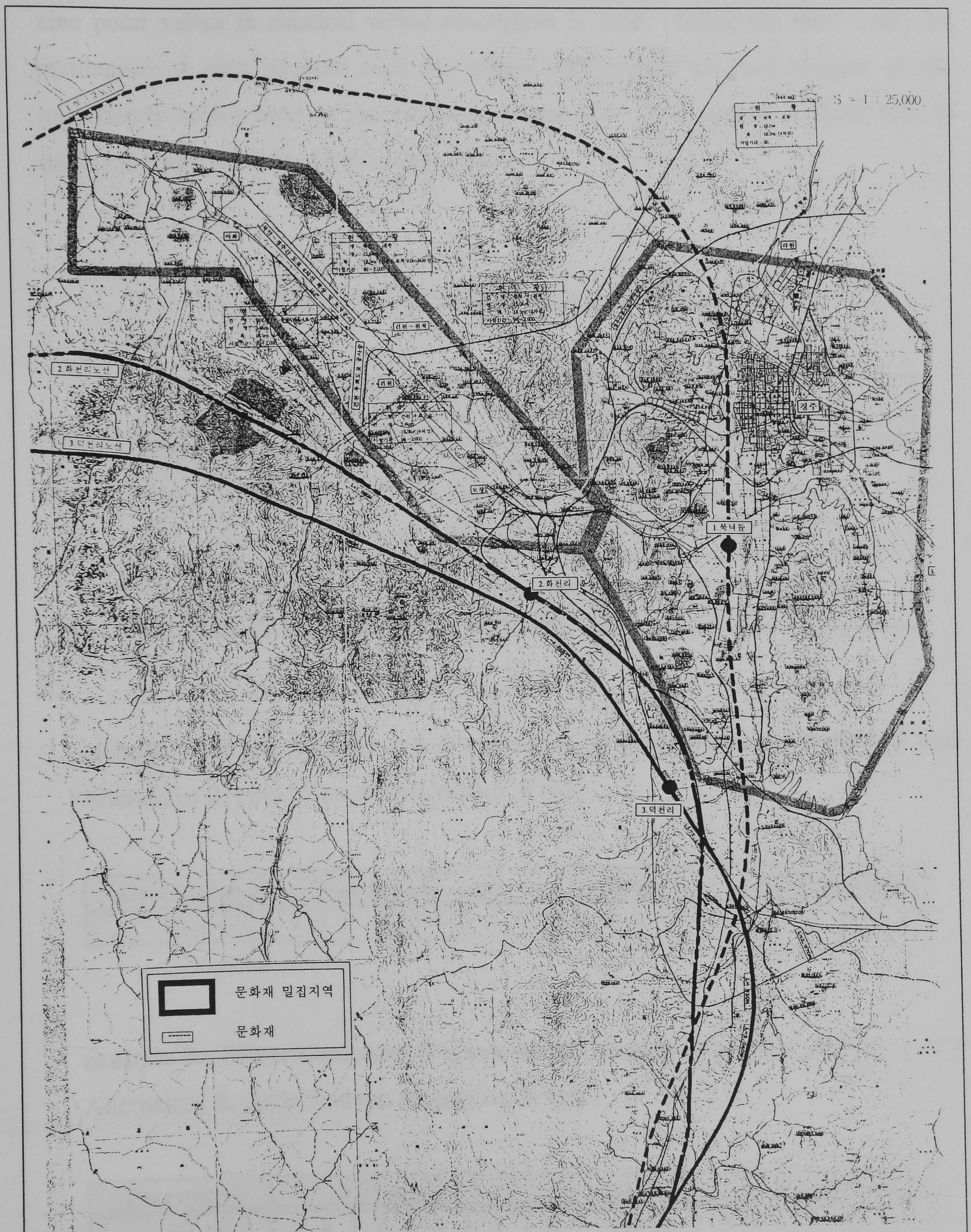
● A Detailed Map of Transport Networks







● Alternatives and Cultural Assets



3. Assessment

To make the pairwise comparison judgements, the fundamental scale of the AHP of nine point values in classical verbal descriptors is used. Using the ratio scale, the dominance of each element over the others with respect to each element of the immediately higher level of the hierarchy is assessed. Two examples show how to mark your preference in pairwise comparison.

< Scale of verbal measurement used for this research>

Intensity of relative importance	Definition
1	Equally important or preferred
3	Slightly more important or preferred
5	Strongly more important or preferred
7	Very strongly more important or preferred
9	Extremely more important or preferred
2,4,6,8	Intermediate value

example 1> When Alternative A is considered ***strongly important (better), 5*** than Alternative B, circle 5 on the Alternative A half.

Alternative	**← better**																	**better →**	**Alternative**
A	9	8	7	6	(5)	4	3	2	1	2	3	4	5	6	7	8	9		B

example 2> When Alternative B is considered ***strongly important (better), 5*** than Alternative A, circle 5 on the Alternative B half.

Alternative	**← better**																	**better →**	**Alternative**
A	9	8	7	6	5	4	3	2	1	2	3	4	(5)	6	7	8	9		B

■ EXPERT SURVEY

Dear Sir,

I am undertaking research into the evaluation of transport investment project in Korea. This research is considering the railway network alternatives for developing high speed railway network passing by the oldest historic city, Kyongju in Korea. To evaluate and select the best network alternative, this research essentially needs your preference about a degree of importance of the role of each decision maker related with or affected by this project.

Please base the answer to this questionnaire, which includes three parts, on your professional knowledge. I hope for your assistance and would be appreciate if you could answer this questionnaire. Thank you for your co-operation.

Sang-Min Lee
Senior Researcher in KOTI (The Korea Transport Institute),
Research Student in ITS (Institute for Transport Studies, University of Leeds)

PART 1 : GENERAL

This section refers to the general background.

1. What is your professional identity in the transport field ?
   - ❑ Professor
   - ❑ Researcher
   - ❑ Planner
   - ❑ Other (specify): [ ]

2. How long have you worked in this field ?
   - ❑ less than 2 years
   - ❑ 3-5 years
   - ❑ 6-10 years
   - ❑ 11 or more years

PART 2 : IMPORTANCE OF ROLE

This section refers to the degree of importance for the role of each stakeholder involved in this specified transport project to get the relative importance of the following three interest groups,

supplier: people responsible for the supply and investment for transport facility (in this case Government Official),

user: people affected by the project directly or indirectly through the change of travel time, cost, safety, convenience using that facility (high speed rail),

community : people who live in the area that are affected by the project through the change of their living circumstances and environment (people in Kyongju area including nearby railway route of its area)

Please check and rate how much extent each stakeholder's opinion should be considered more important and reflected in choosing the best railway network in the historic city, Kyongju according to your subjective judgements.

■ ***Which stakeholder's opinion should be considered more important and reflected in choosing the best railway route with respect to the railway network development in the historic city, Kyongju?***

Stakeholder	←to be considered important									to be considered important→								**Stakeholder**
Supplier	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	User
Supplier	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Community
User	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Community

PART 3 : IMPORTANCE OF OBJECTIVE

This section refers to the preference for each objective as the major factor in railway network development project in order to evaluate and select the best railway network.

Please check and rate how much each objective should be considered important as main objectives as compared with other objectives for implementing the overall goal, the best railway network development in the historic city, Kyongju, according to your subjective judgements after reading the description as follows.

Objective		Description
Max. Capacity (Mobility Increase)		-increased transport capacity to south-east area
Min. Travel Time		-rail passenger journey time (travel time + access time) -travel and access time weighted by travel demand
Max. Accessibility		-accessibility to the area
Improved Transport Network Connection		-connection ability to local road, regional railway and motorway
Improved Comfort & Convenience		-comfort and convenience measured by physical layout such as the roughness of rail route, constitution of route such as tunnel, bridge, gradient, railroad crossing of each alternative and location of station
Min. Project Cost (Construction & Oper. cost)		-construction cost of rail, collector road to rail, relocation of existing railway for connection, and its operating cost
Max. Return on Investment		-the revenue of project
Min. Travel Cost		-travel cost of Kyongju city on all road caused by all of travellers for urban journey according to the location of station
Min. Energy Consumption		-fuel consumption by travel distance, travel time
Max. Socio-Economic. Benefits	Developed Regional Economy	-economic development of region by new project
	Min. Severance Effects	-the severance effects of neighbourhood relationship and urban social, economical relationship.
	Min. House Replacement	-total numbers of house replaced by the new project against alternative routes within predetermined distance
Min. Adverse Environmental Effects	Noise (sound pollution)	-total number of the exposed house against alternative routes by new project within predetermined distance
	Air Pollution	-air pollution of the area by new project
	Vibration	-vibration impacts on the area
	Ecological Impacts	-ecological impacts by railway route passing through the mountain, river
	Min. Visual Intrusion	-assessed by the view from Namsan against alternative routes
	Min. adverse impacts on Cultural Assets	-impacts on cultural assets on and nearby route by new project passing by historic cultural area

■ ***How much each objective of table below should be considered important as the main factor (objective) as compared with other objectives for implementing the overall goal, the best railway network development in the historic city, Kyongju?***

Objective		Degree of Importance				
		much less important	less important	important	more important	strongly important
Max. Capacity (Mobility Increase)						
Min. Travel Time						
Max. Accessibility						
Improved Transport Network Connection						
Improved Comfort & Convenience						
Min. Project Cost						
Max. Return on Investment						
Min. Travel Cost						
Min. Energy Consumption						
Max. Socio-Economic Benefits	Regional Development					
	Min. Severance Effects					
	Min. House Replacement					
Min. Adverse Environmental Effects	Noise (sound pollution)					
	Air Pollution					
	Vibration					
	Ecological Impacts					
	Min. Visual Intrusion					
	Min. adverse impacts on Cultural Assets					

■ QUESTIONNAIRE SURVEY

Dear Sir.

I am undertaking research into the evaluation of transport investment project in Korea. This research is considering the railway network alternatives for developing railway network through the historic city, Kyongju. To evaluate and select the best network alternative, this research essentially needs your preference (degree of importance) for each element. Your answering will be valuable for the future transport investment planning and priority.

Please base the answer to this questionnaire, which includes two parts, on your subjective judgement. I hope for your assistance and would be appreciate if you could answer this questionnaire. Thank you for your co-operation.

Sang-Min Lee
Senior Researcher in KOTI(The Korea Transport Institute),
Research Student in ITS(Institute for Transport Studies, University of Leeds)

PART 1 : GENERAL

This section refers to the general background.

1. Which age group do you belong to ?
   - ❑ less than 25
   - ❑ 26-30 years
   - ❑ 31-40 years
   - ❑ 41-50 years
   - ❑ more than 51

2. How long have you worked in this field ? **** supplier only**
   - ❑ less than 3 years
   - ❑ 4-6 years
   - ❑ 7-10 years
   - ❑ 11 or more years

3. Where do you live ?
   - ❑ Kyongju
   - ❑ Pohang, Ulsan, Yeongcheon, Kyeongsan
   - ❑ Daegu, Pusan
   - ❑ other < >

4. Please describe details where you live.
   <_____ si(gun), _____dong(eup)_____ myeon _____ri>

5. How often do you use Kyeongbu railway ? **** user only**
   - ❑ more than twice per month
   - ❑ once per month
   - ❑ once per every two month
   - ❑ less than 5 per year
   - ❑ less than once per year

PART 2: PREFERENCE

1. Relative Importance of each *Objective* with respect to the *Overall Goal*

This section refers to the preference for each objective as the major factor in railway network development project in order to evaluate and select the best railway network.

Please rate the relative importance of pairwise objectives with respect to overall goal in affecting the evaluation of this project according to your own preference after reading the description as follows.

Objective		Description
Min. Travel Time		-rail passenger journey time (travel time + access time) -travel and access time weighted by travel demand
Improved Comfort & Convenience		-comfort and convenience measured by physical layout such as the roughness of rail route, constitution of route such as tunnel, bridge, gradient, railroad crossing of each alternative and location of station
Min. Project Cost (Construction & Oper. cost)		-construction cost of rail, collector road to rail, relocation of existing railway for connection, and its operating cost
Min. Travel Cost		-travel cost of Kyongju city on all road caused by the location of station by all of travellers for urban journey
Max. Socio-Economic. Benefits	Regional Development	-economic development on region by new project including station site development
	Min. Severance Effects	-the severance effects of neighbourhood relationship and urban social, economical relationship.
	Min. House Replacement	-total numbers of house replaced by the new project within predetermined distance
Min. Adverse Environmental Impacts	Noise (sound pollution)	-total number of the exposed house by new project within predetermined distance
	Ecological Impacts	-ecological impacts by railway route passing through the mountain, river
	Min. Visual Intrusion	-assessed by the view from Namsan by alternative routes
	Min. Adverse Impacts on Cultural Assets	-impacts on cultural assets on and nearby route by new project passing by historic cultural area

■ ***Which objective for the evaluation in this transport project should be considered more important as the main factor in choosing and developing railway network in Kyongju?***

Objective	←more important									more important→								Objective
Max. Travel Time Savings	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Improved Comfort & Convenience
〃	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Min. Project Cost
〃	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Min Urban Travel Cost
〃	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Max. Socio-Economic Benefits
〃	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Min. Adverse Environmental Effects
Improved Comfort & Convenience	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Min. Project Cost
〃	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Min Urban Travel Cost
〃	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Max. Socio-Economic Benefits
〃	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Min. Adverse Environmental Effects
Min. Project Cost	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Min Urban Travel Cost
〃	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Max. Socio-Economic Benefits
〃	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Min. Adverse Environmental Effects
Min Urban Travel Cost	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Max. Socio-Economic Benefits
〃	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Min. Adverse Environmental Effects
Max. Socio-Economic Benefits	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Min. Adverse Environmental Effects

2. Relative Importance of each *Element* with respect to *Objective*

This section refers to the preference for each element with respect to several objectives, as the specified factor in railway network development project in order to evaluate and select the best railway network.

Please rate the relative importance of pairwise elements with respect to each objective in affecting the evaluation of this project according to your own preference.

< Maximising Socio-Economic Benefits >

■ ***Which element among several factors should be considered more important as the main evaluation factor in maximising socio-economic benefits on the area with respect to the railway network development in Kyongju?***

Element	←more important	more important→	Element
Regional Development	9 8 7 6 5 4 3 2 1	2 3 4 5 6 7 8 9	Min. Severance effects
〃	9 8 7 6 5 4 3 2 1	2 3 4 5 6 7 8 9	Min. House replacement
Min. Severance effects	9 8 7 6 5 4 3 2 1	2 3 4 5 6 7 8 9	Min. House Replacement

< Minimising Adverse Environmental Impacts >

■ ***Which element among several factors should be considered more important as the main evaluation factor in minimising adverse environmental Impacts on the area with respect to the railway network development in Kyongju?***

Element	←more important	more important→	Element
Noise	9 8 7 6 5 4 3 2 1	2 3 4 5 6 7 8 9	Ecological Effects
Noise	9 8 7 6 5 4 3 2 1	2 3 4 5 6 7 8 9	Visual Intrusion
Noise	9 8 7 6 5 4 3 2 1	2 3 4 5 6 7 8 9	Cultural Assets
Ecological Effects	9 8 7 6 5 4 3 2 1	2 3 4 5 6 7 8 9	Visual Intrusion
Ecological Effects	9 8 7 6 5 4 3 2 1	2 3 4 5 6 7 8 9	Cultural Assets
Visual Intrusion	9 8 7 6 5 4 3 2 1	2 3 4 5 6 7 8 9	Cultural Assets

3. Relative Preference of each *Alternative* with respect to each *Element (or Objective)*

This section refers to the preference for each alternative against each element (or objective) in order to evaluate and select the best railway network alternative.

Please rate the relative preference of pairwise alternatives with respect to each objective (or element) in affecting the evaluation of this project according to your own preference after considering thoroughly descriptions below given to you.

■ ***Which alternative is better than the other in the view of each objective (or element) for the evaluation of the railway network development in Kyongju?***

< Improved Comfort & Convenience>

-comfort and convenience measured by physical layout such as the roughness of rail route, constitution of route such as tunnel, bridge, according to each alternative and location of station, etc.

Alternative	←much better	much better→	Alternative
Alternative 1	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9		Alternative 2
〃	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9		Alternative 3
Alternative 2	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9		Alternative 3

< Regional Development>

- regional development including station site development and nearby

Alternative	←much better	much better→	Alternative
Alternative 1	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9		Alternative 2
〃	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9		Alternative 3
Alternative 2	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9		Alternative 3

< Min. Severance Effects>

-the severance effects of neighbourhood relationship and urban social, economical relationship.

Alternative	←much better much better→	Alternative
Alternative 1	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Alternative 2
〃	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Alternative 3
Alternative 2	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Alternative 3

< Min. Ecological Impacts>

-ecological impacts by railway route passing through the mountain, river and etc.

Alternative	←much better much better→	Alternative
Alternative 1	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Alternative 2
〃	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Alternative 3
Alternative 2	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Alternative 3

< Min. Visual Intrusion>

-assessed by the view from the historic site such as Namsan to protect historic area

Alternative	←much better much better→	Alternative
Alternative 1	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Alternative 2
〃	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Alternative 3
Alternative 2	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Alternative 3

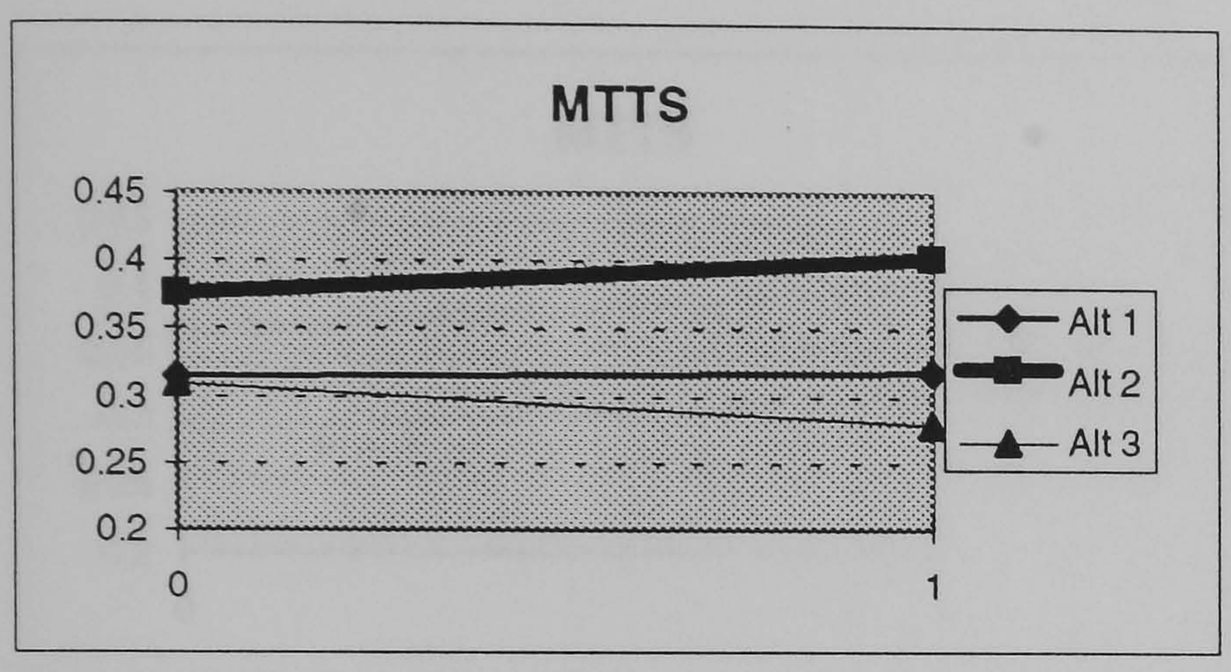
< Min. Adverse Impacts on Cultural Assets>

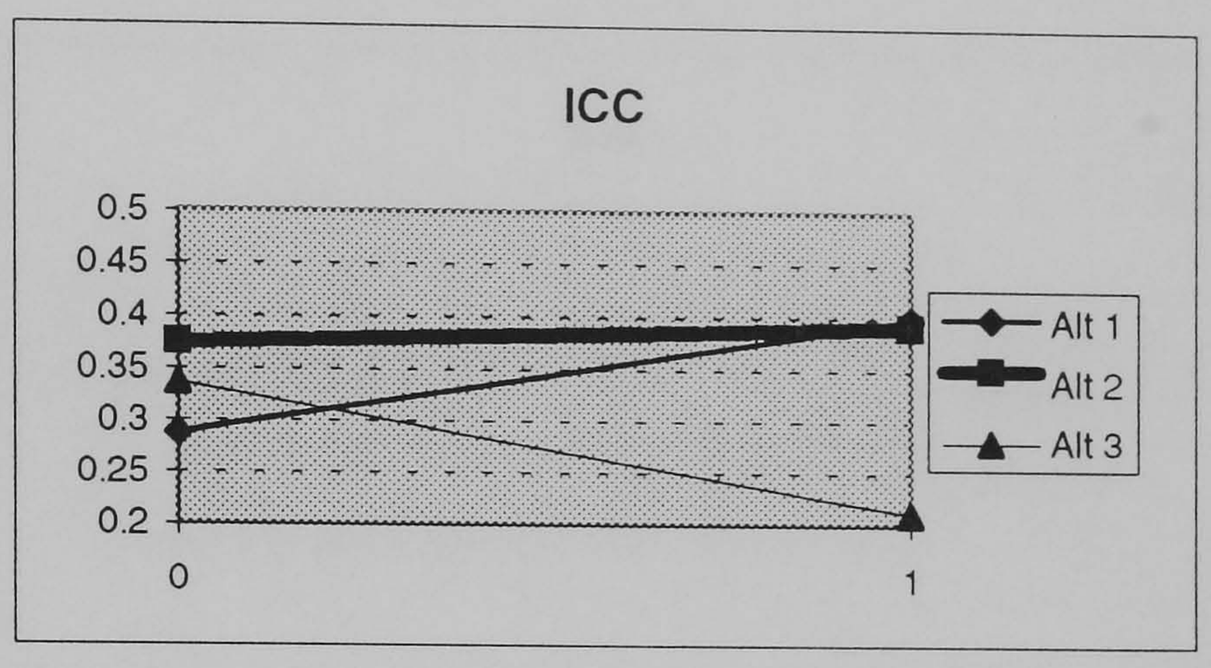
-impacts on cultural assets on and nearby route by new project passing by historic cultural area

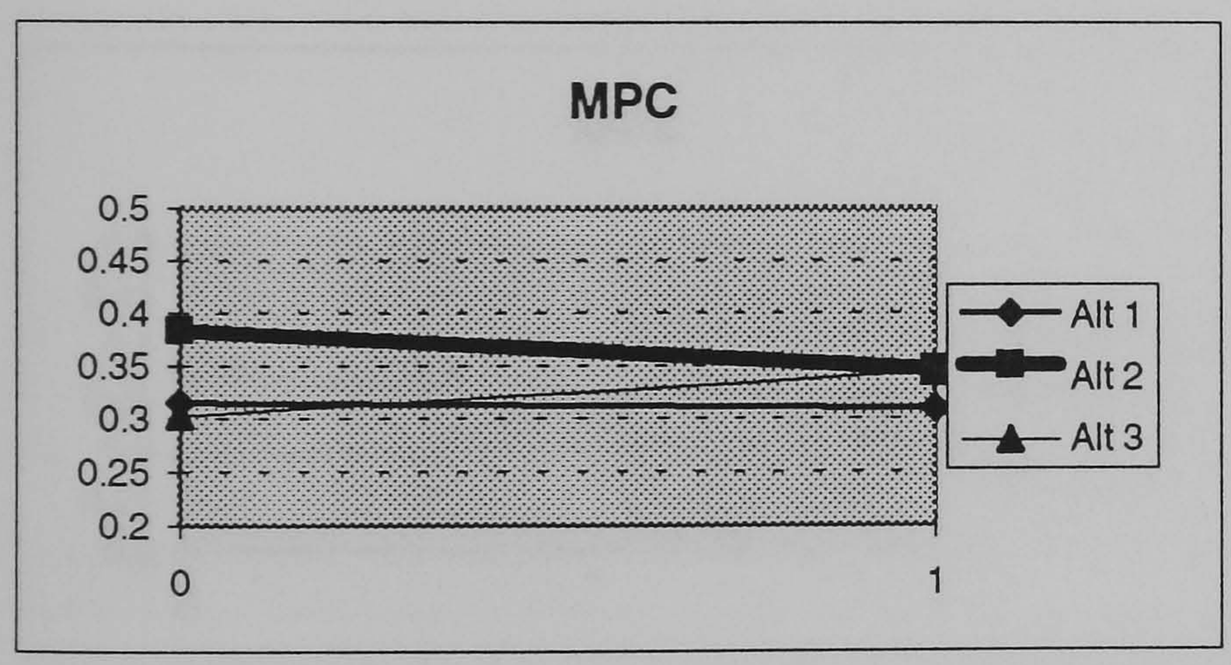
Alternative	←much better much better→	Alternative
Alternative 1	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Alternative 2
〃	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Alternative 3
Alternative 2	9 8 7 6 5 4 3 2 1 2 3 4 5 6 7 8 9	Alternative 3

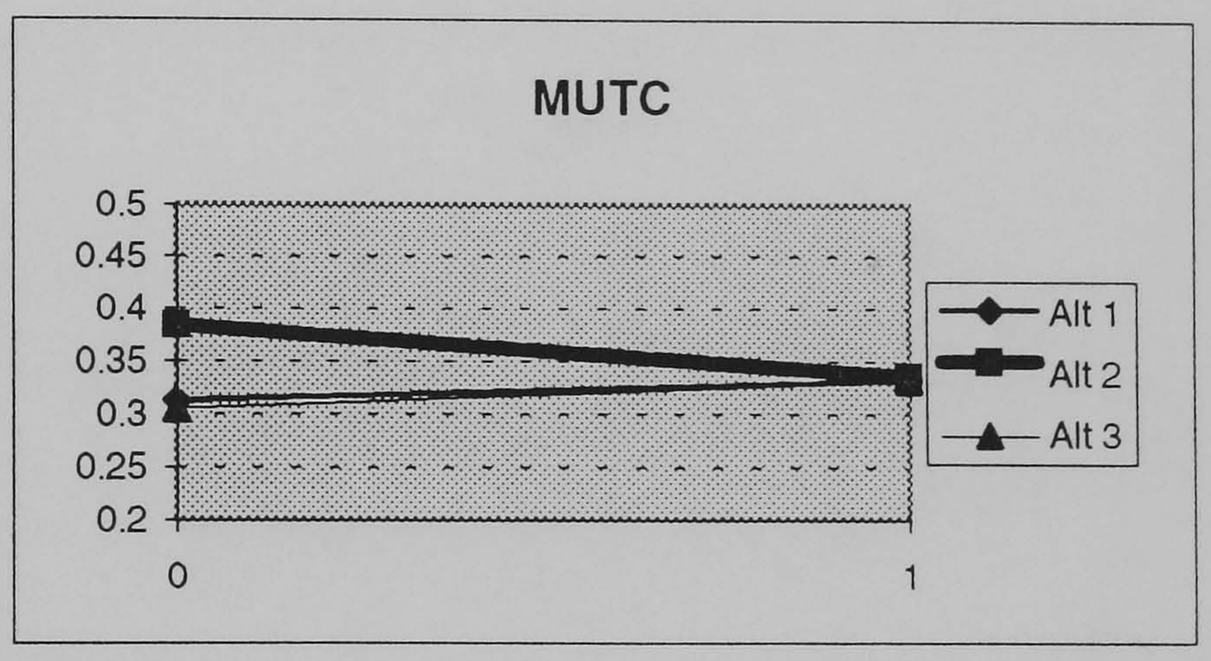
Appendix 3: Sensitivity Test Results of the Factors

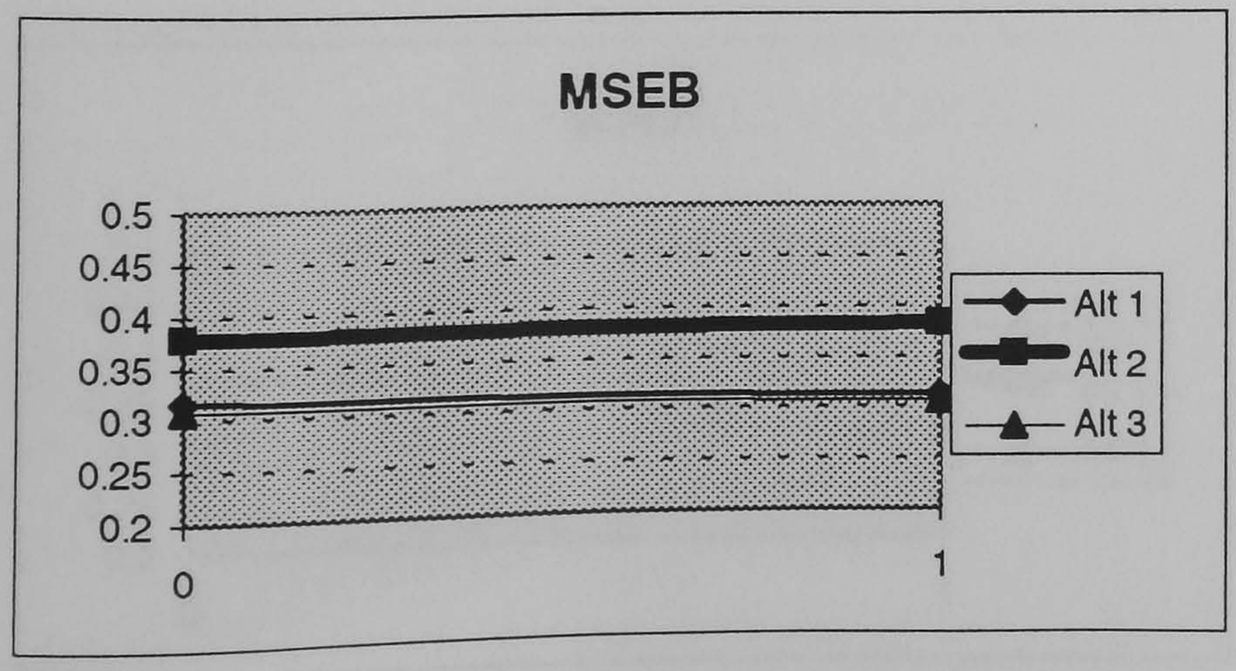
Sensitivity Test about the Factors of Supplier

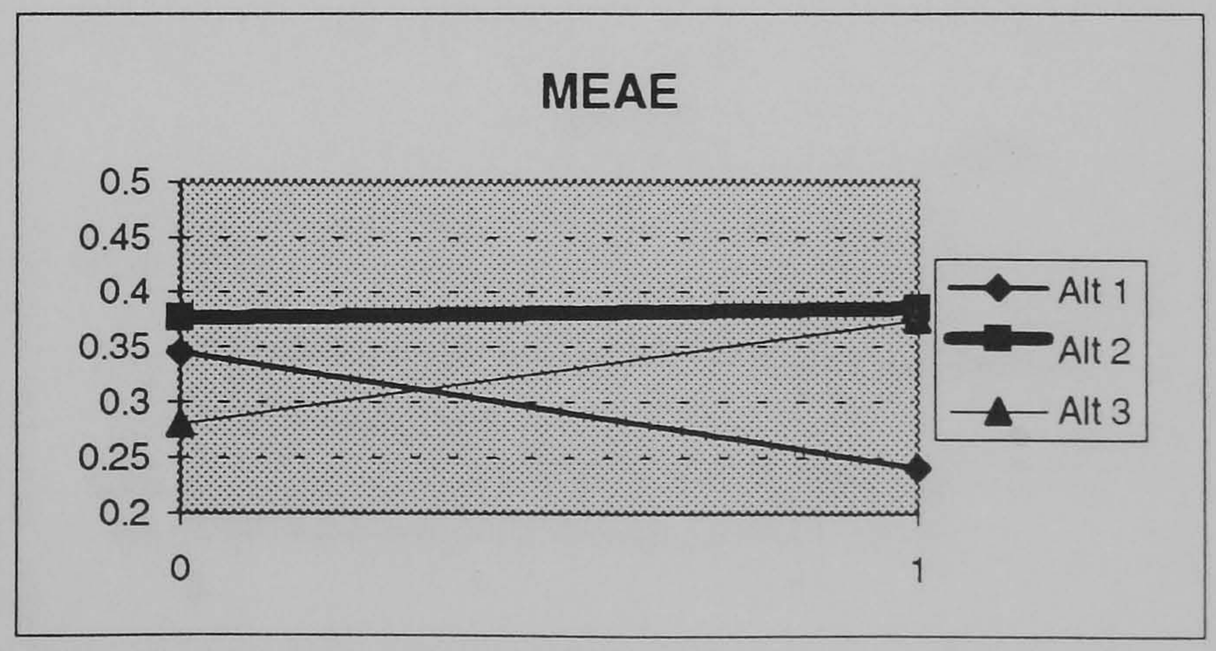




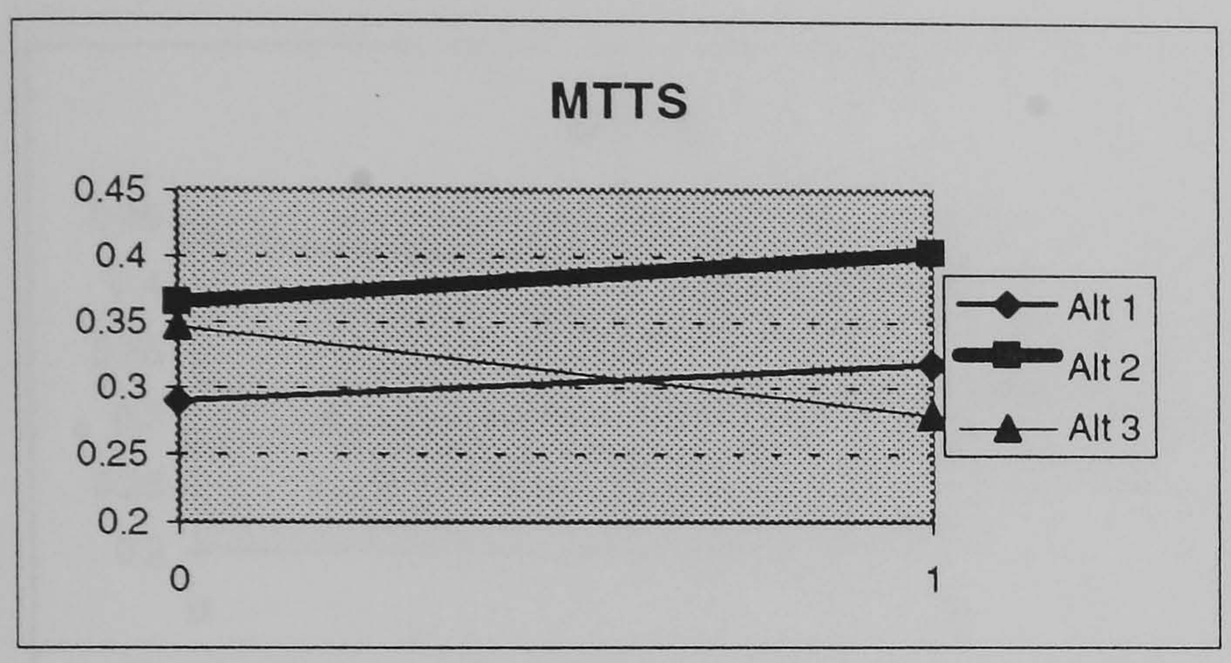


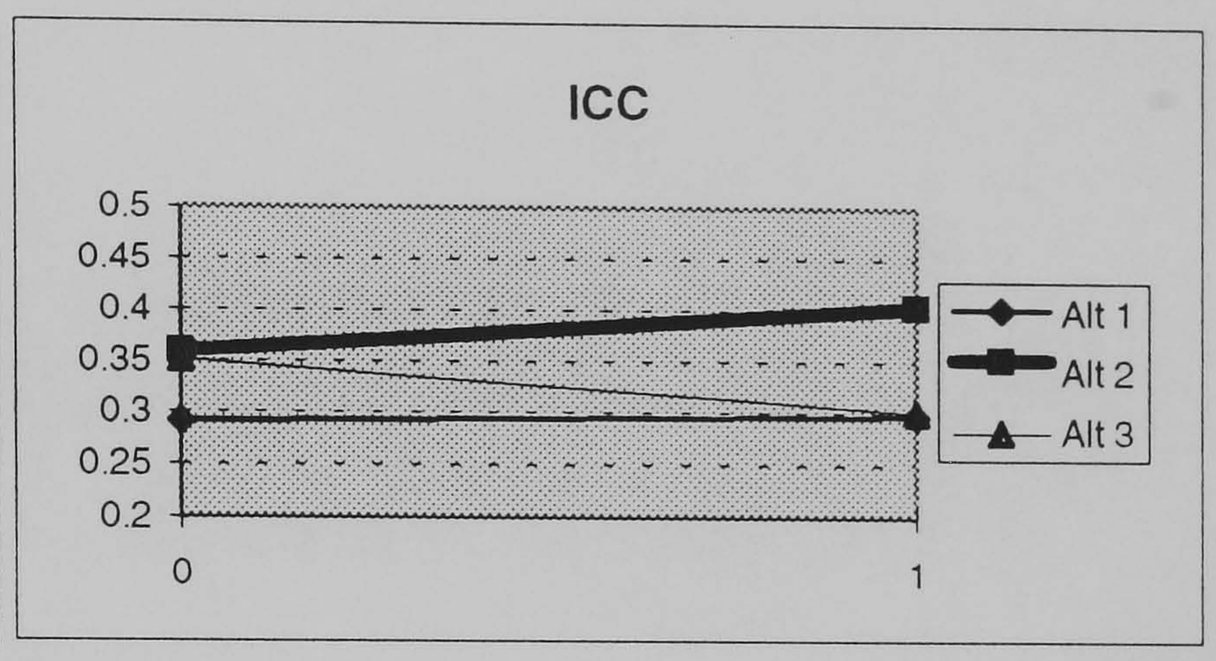


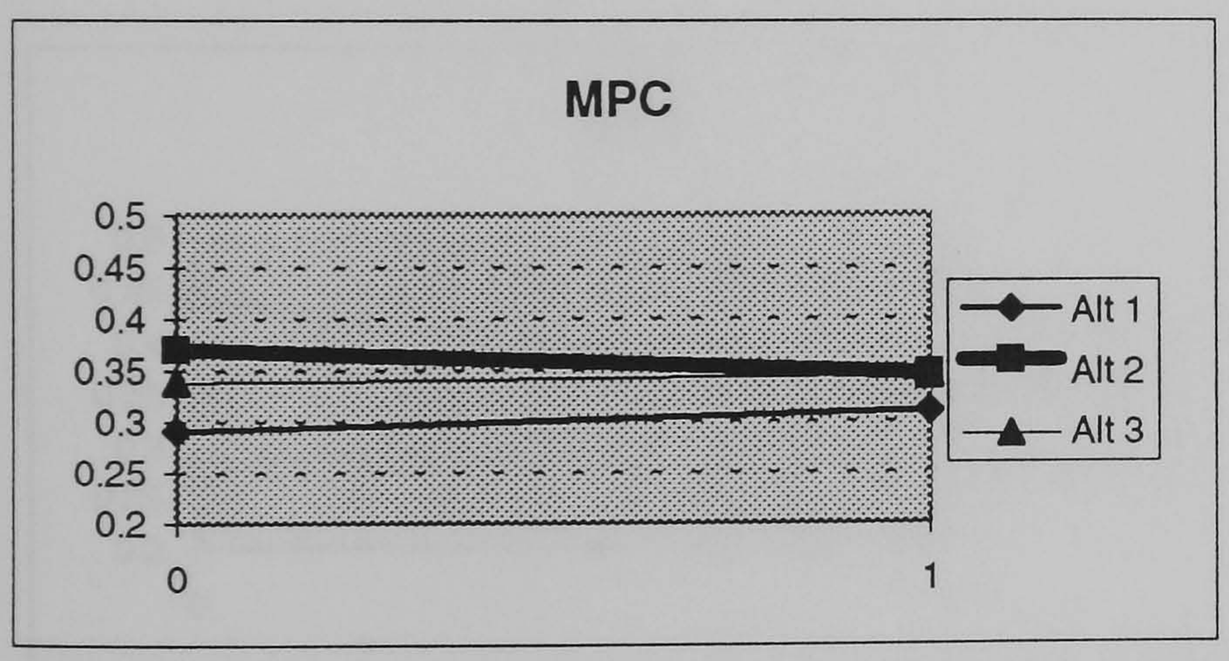


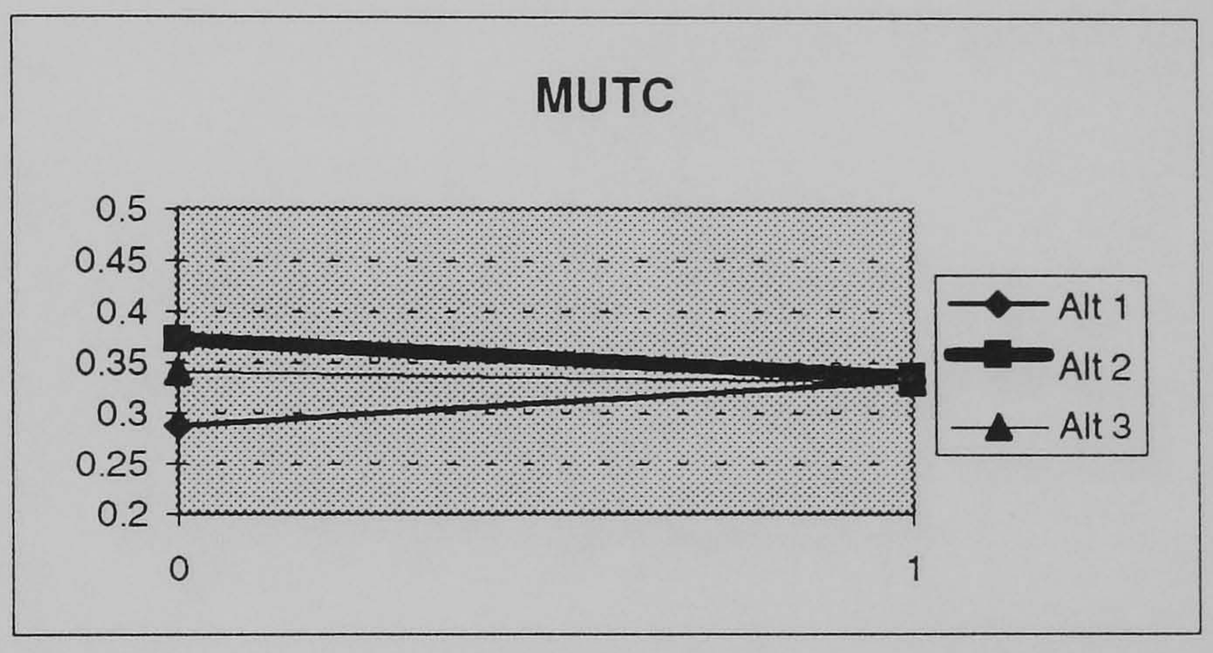


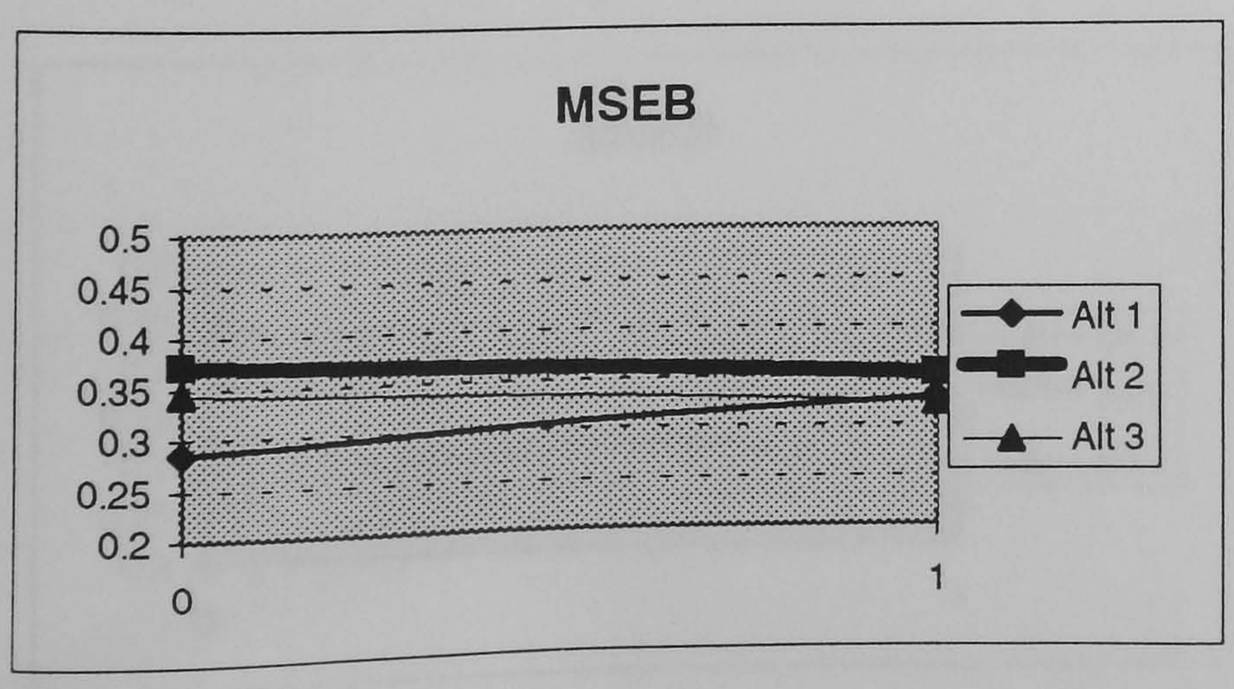
Sensitivity Test about the Factors of User

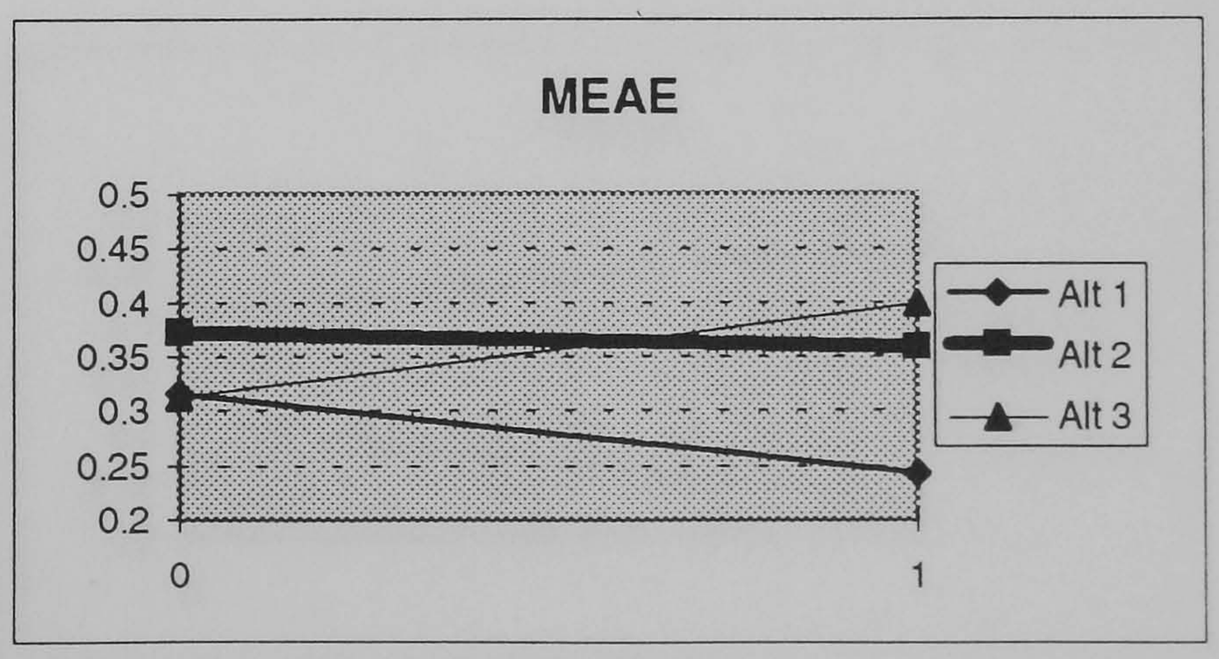
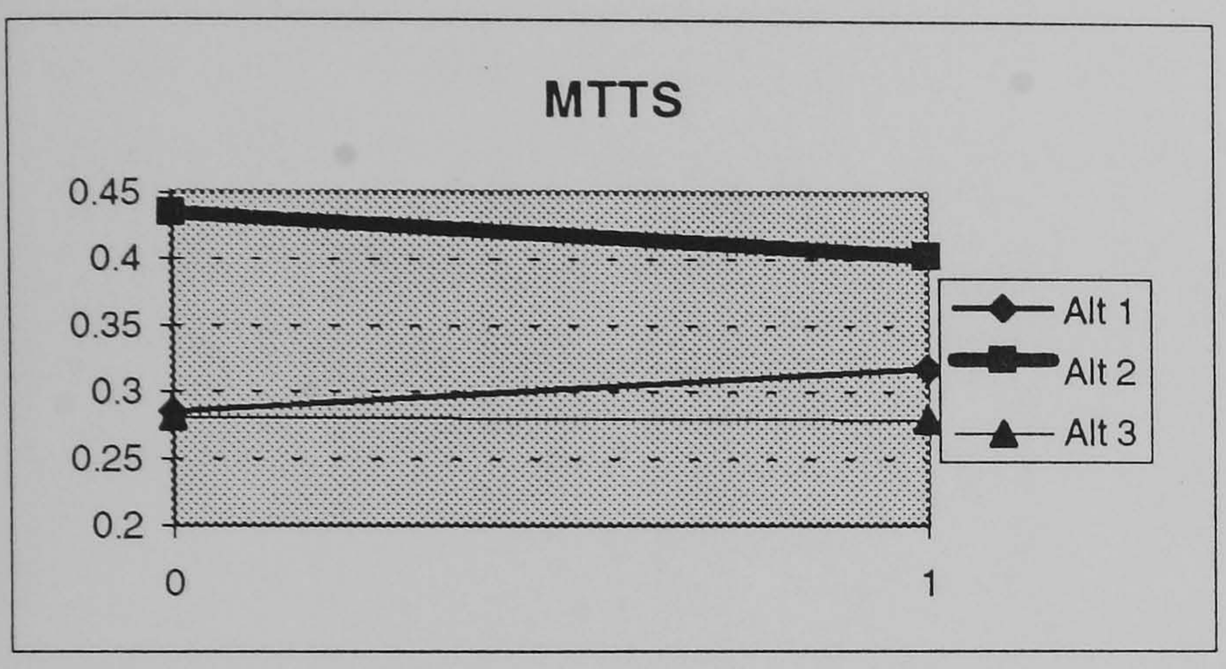
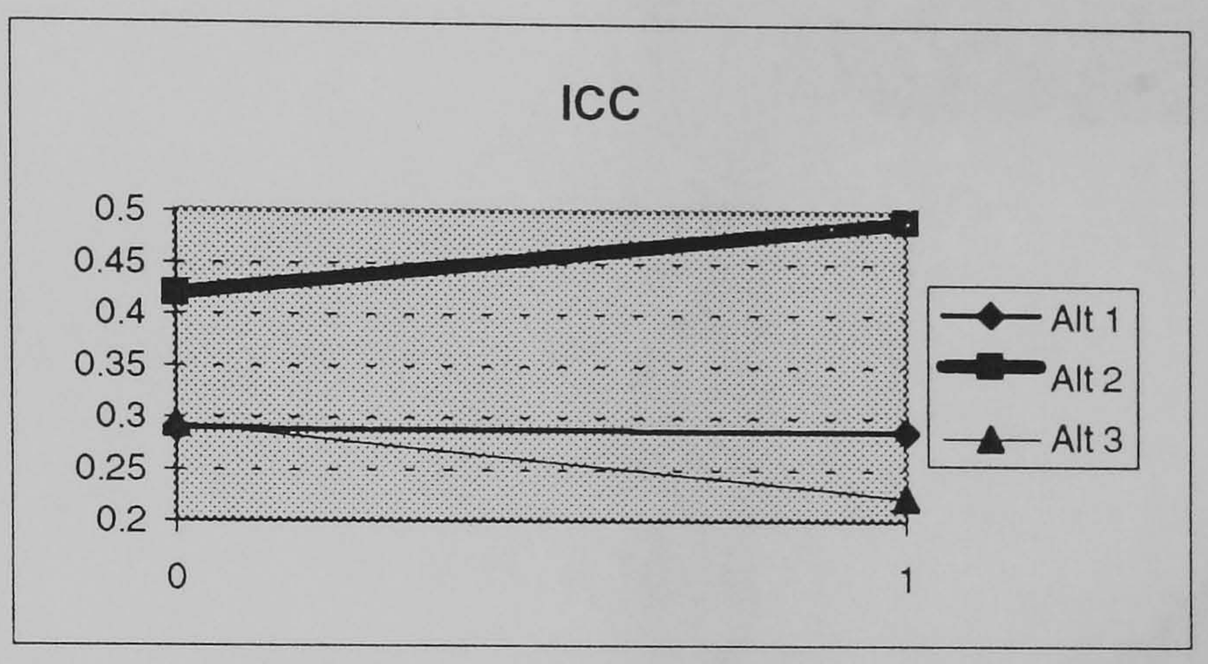
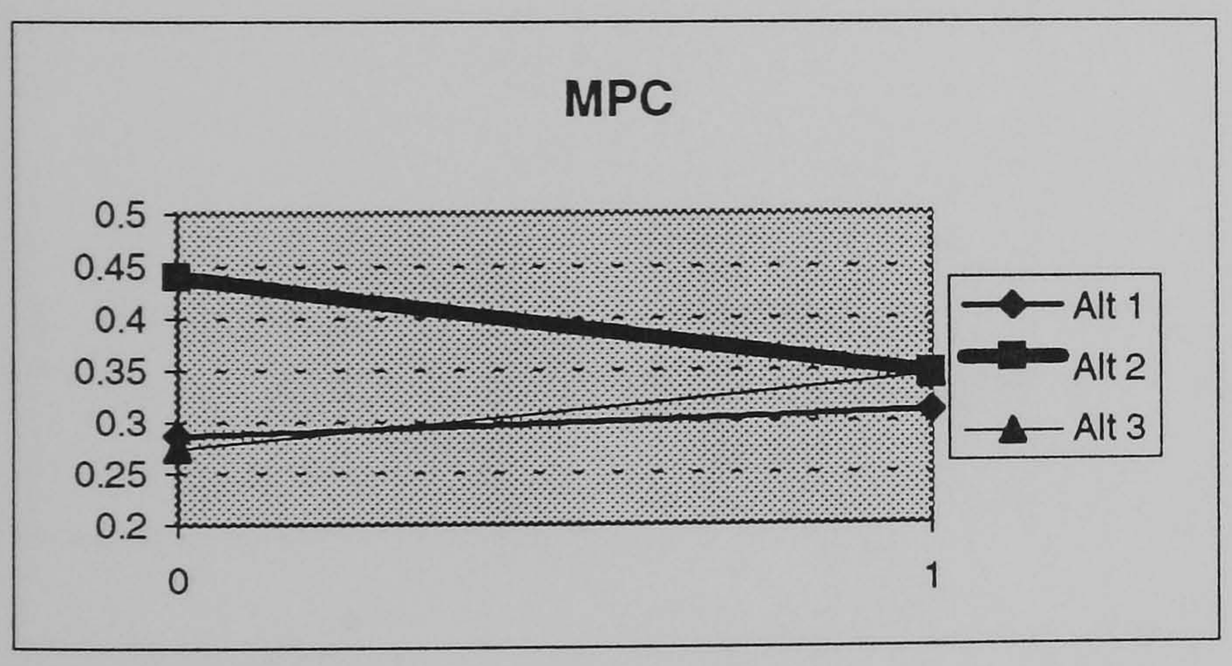
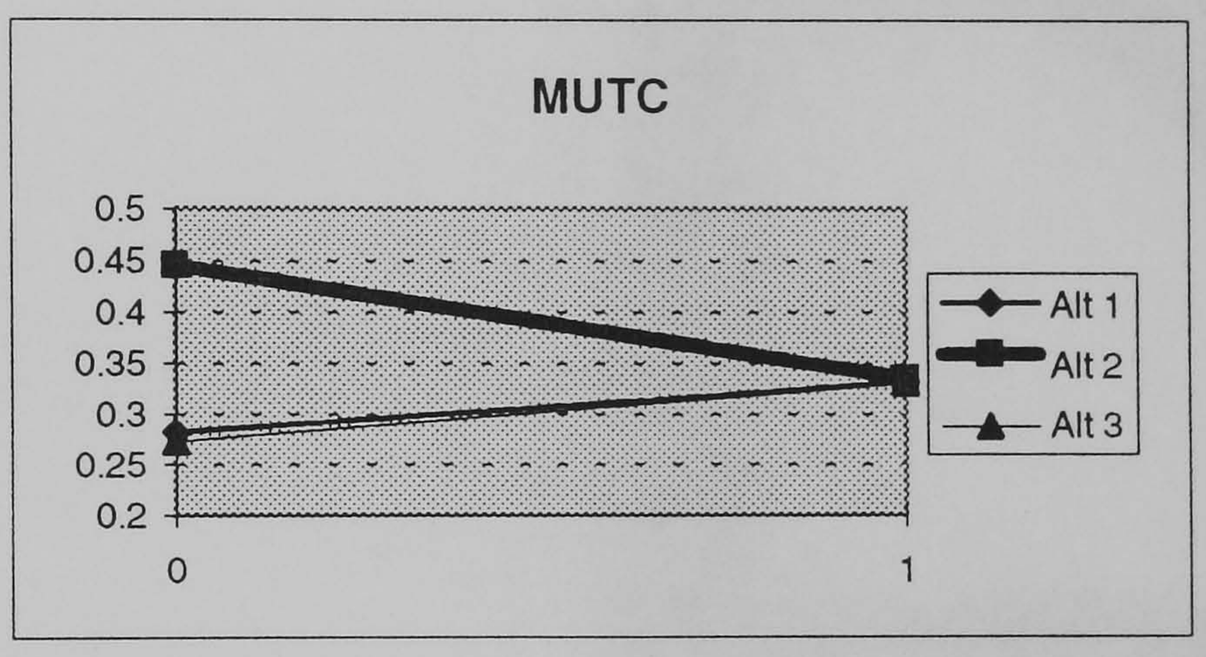
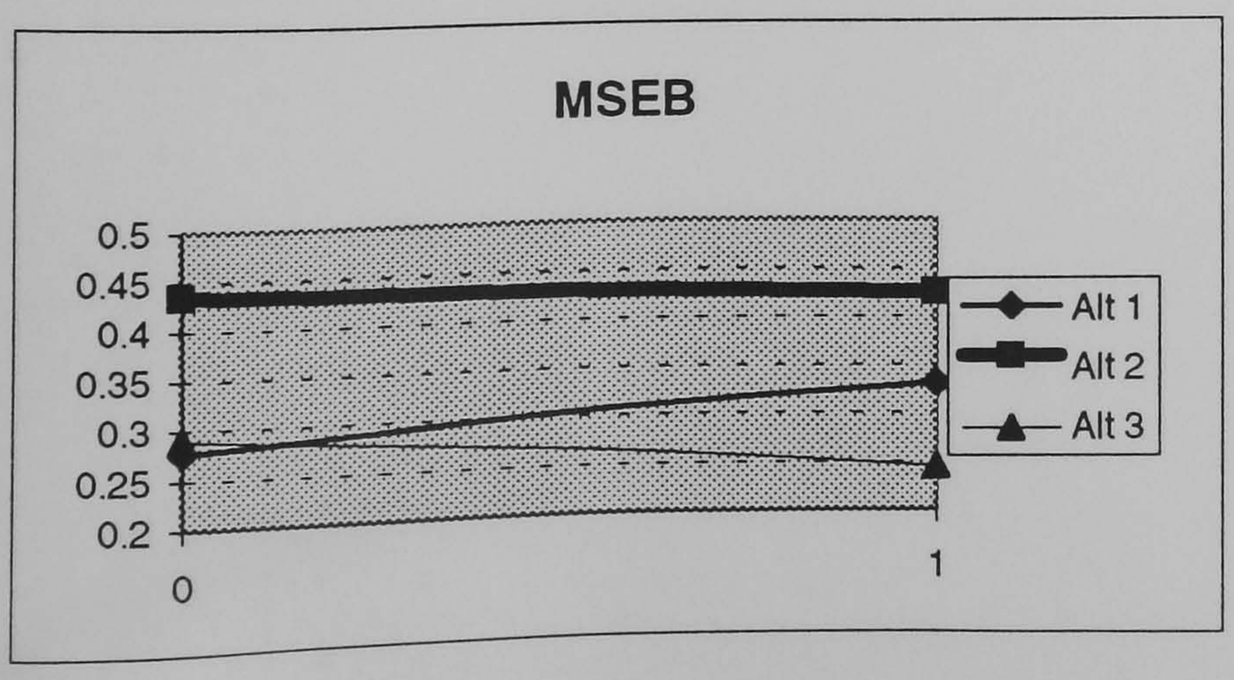
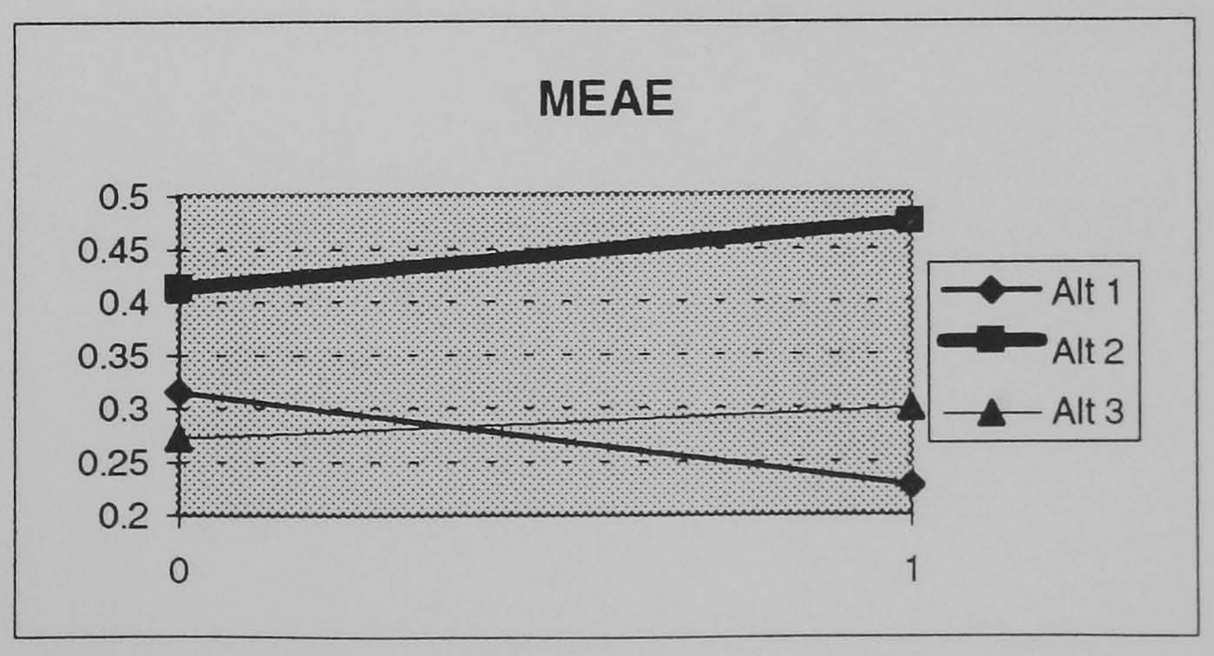












Sensitivity Test about the Factors of Community