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DETERMINING BICYCLE ROUTE PRIORITIES: THE KOREAN EXPERIENCE

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ABSTRACT

This study proposes a feasible methodology for prioritizing alternative bicycle routes which are a key to supporting a national bicycle road construction plan. The procedure facilitates consideration of the differing characteristics of bicycle and vehicular traffic. This can be efficiently employed; 1) when future bicycle demand forecasts are considered unreliable due to several reasons such as insufficient data and a wide range of alternative paths for bicycle traffic, and 2) when policy judgments such as the opinions of professionals, decision-makers, or local community residents are considered more important than future bicycle demand. The approach proposed here can be applied to prioritize alternative bicycle routes on national highways in South Korea as a pilot study. The results showed that our methodology provided reasonable priority considering local, social, and economic characteristics of various alternative routes. We believe, therefore, if the proposed methodology is adapted to each specific location, it can assist with planning of appropriate new, improved or extended routes.

***Keywords**:* Bicycle routes, Analytical hierarchy process, Daily living zones, Active transportation, Priority

I. INTRODUCTION

Bicycles were first introduced in South Korea in the late 1950s. They were accepted as a useful means of transportation, one that is available to anyone regardless of age or gender, because of their lower cost of ownership compared with motorized vehicles. Although they gained additional popularity in the 1960s and 1970s, bicycle traffic had a lower priority than vehicular traffic, due to South Korea's vehicular traffic-oriented policies. Since the mid-2000s, however, the importance of bicycle traffic has sharply increased as a means of increasing active transportation. These efforts are consistent with the notion of "carbon reduction" and "green economy" which has gained interest globally. In addition, since quality of life tied to national economic development in South Korea, has increasingly improved, people have become much more interested in their own health and the surrounding environment, thereby leading to a natural increase in demand for bicycling. As existing bicycle routes continue to carry increasing numbers of cyclists, the central and local governments face the growing challenge of demand for bicycle facility construction. Accordingly, since 2011, they have been working on establishing a national plan for bicycle facilities to actively address increasing bicycle demand. In order to support this plan, the Korean government performed a pilot study on national highways with a total of 20 candidates' routes for bicycle within Korean cities and towns.

Toward that end, our study proposes a specific methodology for prioritizing bicycle routes. The approach facilitates consideration of the differing characteristics of bicycle and vehicular traffic. It is generally accepted that the feasibility and priority of construction for vehicular traffic is determined on the basis of the predicted future travel demand. Various ways of forecasting future bicycle travel demand have been studied. Lewis and Kirk (1997) estimated bicycle demand through comparison studies. For example, it was assumed that, if bicycle demands were observed in a certain area then, the same demand would also be found in other areas with similar characteristics. The study of Wigan et al (1998) also performed comparison studies by developing a GIS database of two existing off-road bike paths in Australia. The biggest shortcoming of this method is that the demand forecasting results can be misinterpreted. Waldman (1977) tried to predict bicycle demand in the United Kingdom using an aggregate behavior model after comparing cities of similar size based on the cycling rate and geographical features. Because the model relies on regression, it is integral to identify the correlation between bicycle demand and the explanatory variables. However, the drawback of that model is that it cannot be applied to other cities whose characteristics are completely different from the cities observed in this study. In the study of Brög et al (1983), a hierarchical elimination approach was used to identify traffic demand. In that study, it was crucial to distinguish between four types of "situational constraints" because they showed what made people reluctant to ride bicycles. However, that study was limited in that it was difficult to divide people's characteristics into only four types of situational groups. Goldsmith (1997) introduced the concept of a "travel shed" to estimate bicycle demand on specific facilities. This defines the potential demand zone. There was a case where this method was applied to a whole city (Katz, 2000). In that study, elasticity of demand was estimated for bicycle facilities currently in the planning phase. In addition to the studied above, Gotschi (2011) proposed a cost-benefit analysis of bicycle road construction in terms of monetized valued of health benefits, healthcare cost savings, and value of statistical life savings. Results of the study showed that in many cities in the U.S, bicycle road construction was cost-effective even when the benefits were selected in a limited way. Barnes and Krizek (2005) employed the National Household Travel Survey (NHTS) to examine the population of bicycle users in the U.S. In that study, a simple regression model was developed to estimate a ratio of bicycle use per inhabitant in many major cities and states including Minnesota. Regional transport models are the mainstays of integrated urban transport planning.Traditionally they have been carried out in a four-stage process of Trip generation, Trip distribution,Mode split and Network assignment.These models are used in many cities internationally. They provide for themedium to long term planning of the transport network. However, there is a critical disadvantage that they require various input data for forecasting bicycle demand and some of these data are typically unavailable (Katz, 2003). The U.S. has researched and published guidelines for analysis of investment in bicycle facilities (NCHRP Project, 2005). This provided a tool to transportationplanners to estimate costs of different types ofbicycle facilities. Heinen et al (2010) provides an excellent review of the literature on the determinants of bicycle commuting. More recently, NCHRP Report 770 developed a guidebook that enable to support both transportation and community planners account more effectively for pedestrian and bicycle demand in plans and projects (TRB, 2014). Thisguidebook is the output of NCHRP Project 08-78, which wasspecifically performed to deal with these deficiencies with more strong methods to satisfy the needs of a growingand diversified body of practitioners and planning applications.

Our study develops a methodology that can reflect policy judgments as well as the forecasted future bicycle demand. The most significant reason for developing this methodology is that it can be efficiently employed; 1) when future bicycle demand forecasts are considered unreliable due to several reasons such as insufficient data and a wide range of alternative paths for bicycle traffic, and 2) policy judgments such as needs of professionals, decision-makers, or local community residents are considered more important than future bicycle demand. The approach proposed here can be applied to prioritize alternative bicycle routes on national highways in South Korea as a pilot study. The results showed that our methodology provided reasonable priority considering local, social, and economic characteristics of various alternative routes. The description of the overall methodology is presented in the next section. A specific application of the proposed methodology with bicycle route construction projects in South Korea is provided in Section 3. Finally, a summary of this study and future research issues are discussed in Section 4.

II. DESCRIPTION OF OVERALL METHODOLOGY

The procedure proposed in this study consists of two main approaches which are considered simultaneously. These are a quantitative approach where economic feasibility for project implementation is reflected and a qualitative one where policy judgments of decision-makers are considered. The structure is as follows:

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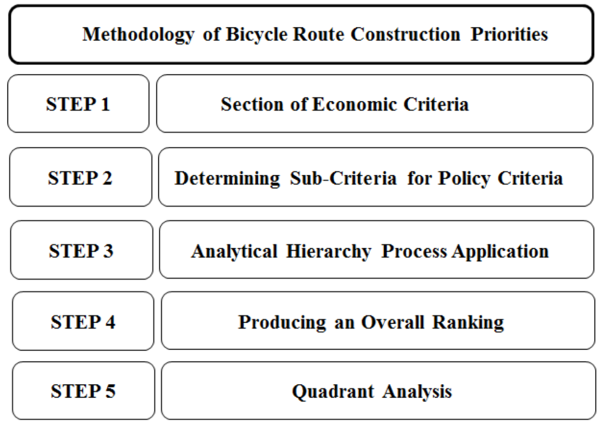

Figure 1. The structure of the proposed methodology

Step 1. Selection of economic criteria

As mentioned in the literature review, many efforts to predict future bicycle demand have been attempted. However, this method has few drawbacks in estimating bicycle demands, and thus can be easily used by all. For the quantitative standpoint (economic feasibility) in our methodology, we use the results of a Cost Benefit analysis, demand forecasting, and/or project cost with regard to bicycle facility construction, regardless of which forecasting method is used. This helps decision-makers to select the most reasonable approach for their situation.

Step 2. Determining sub-criteria for policy judgments

For qualitative policy judgments, three main criteria should be considered: connectivity of existing bicycle routes, degree of bicycling safety, and bicyclist convenience. This is because that these are generally accepted as evaluation criteria, especially when a bicycle facility construction plan is considered using a preliminary feasibility plan for what are known as Social Overhead Capital (SOC) projects in Korea. They can be adopted others if different countries or communities desire to employ other criteria. Our methodology allows decision-makers to select the most appropriate sub-criteria corresponding to each of the criteria, taking into account local, social, and economic characteristics of various alternative bicycle routes. We believe this ensures flexibility in order to reflect various factors influencing project implementation. For example, according to the study of Nankervis (1998), bicyclists were affected by short-term and long-term weather conditions and seasonal variance under several assumptions.

Step 3. Analytical Hierarchy Process (AHP) Application

Once detailed sub-criteria associated with three criteria are determined as shown in Step 2, relative importance of those sub-criteria should be estimated. In this phase, the AHP method is employed and the overall hierarchical structure is depicted the figure 2.

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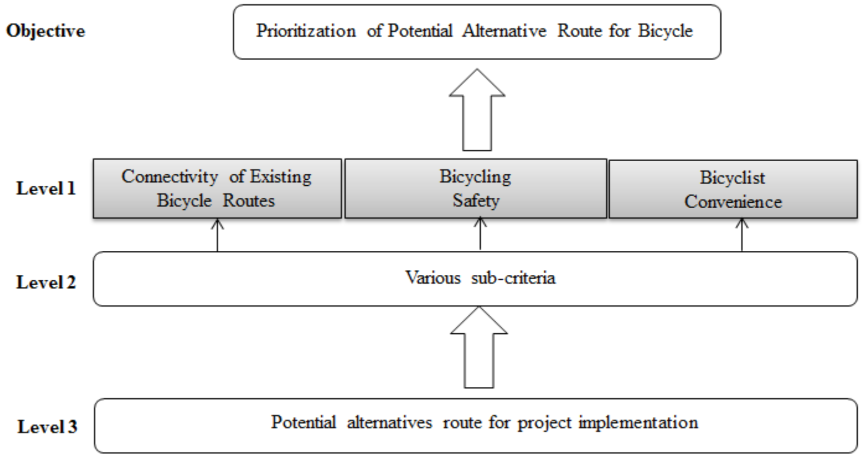

Figure 2. Hierarchical structure for qualitative analysis

To estimate the relative importance among criteria and sub-criteria in level 1 and 2 of the hierarchy, a survey from various groups such as transportation professionals, general bicyclists, local residents and practitioners could be conducted. In transportation engineering, priority decision-making applying the AHP has proven to be useful, and it has also been widely applied in many other areas. Some examples from the transportation literature include Holguin-Veras (1995), Kim and Bernardin (2000), Tanadtang, Park and Hanaoka (2005), Mahmoud, M., and Hine (2012), Lee et al (2013), Yang and Regan (2013(a)), Yang and Regan (2013(b)), and Yang and Regan (2014).

Step 4. Producing an overall ranking

Since it is infeasible to directly compare qualitative and quantitative results, they need to be mathematically normalized. There are three types of typical normalization methods such as the z-score, the difference of max and min value, and the ratio between before and after value. Decision-makers are able to choose a proper method for their analysis (Rardin, 1997 and Hines et al, 2003).

Step5. Quadrant analysis

The normalized values obtained in Step 4 are plotted in the quadrant as shown in Figure 3, in which the x-axis represents the result of quantitative analysis (economic feasibility) and the y-axis represents the qualitative analysis (policy judgment).

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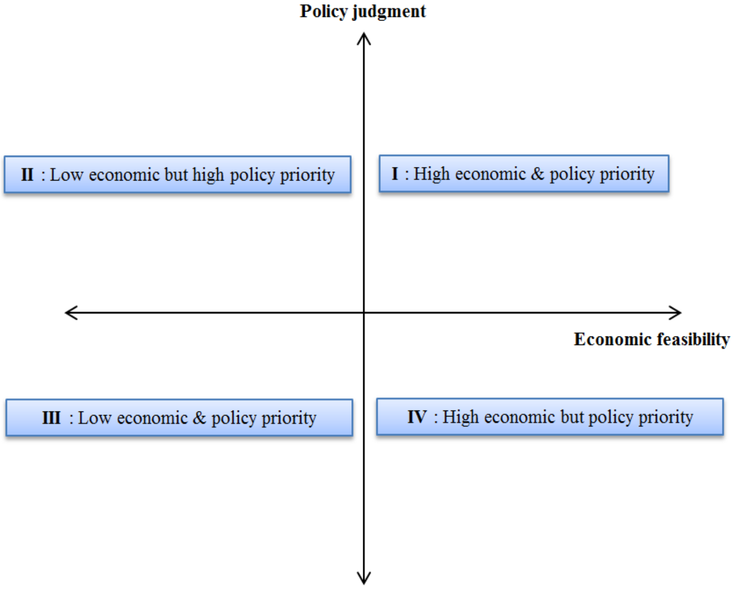

Figure 3. Definitions of Quadrants

Quadrant I is considered an area where immediate construction is needed from the standpoint of both the quantitative and qualitative perspectives. This is because both values lay mathematically positive side on the x- axis and y-axis. However, Quadrants II, III, and IV lack quantitative and/or qualitative support to some degree because at least one value has mathematically negative. Therefore, future changes such as increased bicycle demand should be considered before construction for these routes is implemented.

III. PILOT STUDY

Our methodology can be applied to prioritize alternative bicycle route construction on the national highways in South Korea as depicted in figure 4.

Figure 4. Examples of bicycle route on the national highways

This project plans to construct a bicycle route connecting key small and medium-size cities and towns; the total length is about 172.5km that is distributed across 20 cities. This plan is for bicycle routes in the "daily living zone". That connects an interval of about 5 to 10km in order to absorb bicycle traffic demand for activities of daily living such as commuting for work or school, shopping, and family-oriented leisure, etc. This connects residential areas via the national highways surrounding the cities, communities, and industrial complexes. Figure 5 demonstrates the concept of "daily living zone" in rural areas. Basically, these zones were designated by public officials working in the 18 regional transportationmanagement agencies.

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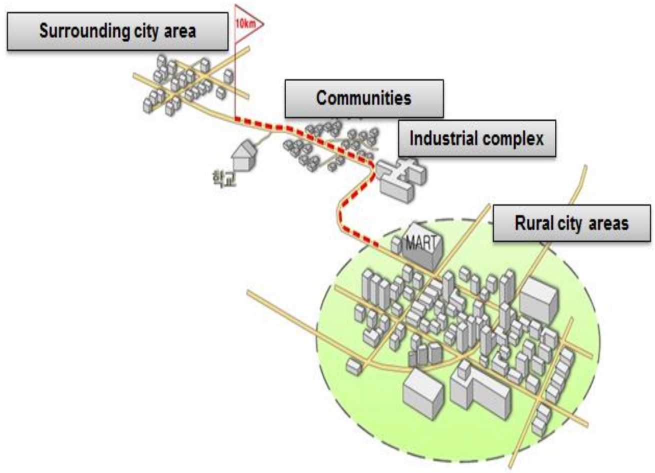

Figure 5. The Concept of Daily Living Zone in Rural Areas

- **Step 1) Selection of economic criteria**

In our study, the cost benefit analysis results represent the quantitative standpoint for alternative bicycle route construction project. They were treated with considerable detail in an official research report performed by the Ministry of Land Infrastructure and Transport (MLIT, 2010). According to that report, the demand forecast for alternative bicycle routes was performed by combining the following two considerations: (1) "current trend demand" obtained by applying in the traditional four-step demand forecasting model except for mode choice, and (2) "potential demand" in which derived demand is forecasted according to the respective bicycle routes. Benefits described in the report, included reduction in vehicle operation cost, reduction in air pollutants, and medical cost reduction. As for costs, the construction cost and incidental expenses per design type, and the land acquisition cost were estimated for each alternative route and applied. The following table 1 shows the benefit/cost analysis results for total of 20 cities and towns.

Table 1. Cost -Benefit analysis results of 20 cities and towns

Number	Cities and Town	Route Number	Number of lanes by Direction	Total Length (km)	Total Cost (100million)	Total Benefit (100million)	B/C Result
1	KyongJoo	7	4	8.7	77.8	157.5	2.02
2	SeoSan	29	4	7	45.6	89.9	1.97
3	WonJoo	42	4	12	93.5	171.9	1.84
4	Moonkyoung	34/59	2~4	10.4	64.2	114	1.78
5	Pohang	7	4	8.2	83.2	138.3	1.66
6	Yongin	45	4	12.2	98.1	156.6	1.6
7	Okchun	4/37	4	9.2	54.2	85.9	1.58
8	Sokcho	7	4	7.7	41.7	65.6	1.57
9	HongChun	44	4	5.8	41.1	63.6	1.55
10	Sokcho	7-1	4	5.9	45.1	68.7	1.52
11	Chilgok	4	4	21	176.2	258.7	1.47
12	YangGu	31/46	2~4	2.4	6.3	9.15	1.46
13	PyeongTaek	38	4	9.8	95.6	130.3	1.36
14	Wando	77	2~4	2.8	4.7	6.4	1.35
15	PyeongTaek	77	4	3.5	107.1	138.3	1.29
16	Cheolone	43	4	12.9	71.2	90.6	1.27

17	Ichun	42	4	15.4	133.7	158.9	1.19
18	Yongin	42	4	8.1	174.4	200.3	1.15
19	YeaSan	21	4	6.4	66.8	70.2	1.05
20	Pohang	14	2	3.1	111.1	113.2	1.02

- **Step 2) Determining sub-criteria for policy criteria**

Qualitative criteria, connectivity of existing bicycle routes, bicycling safety, and bicyclist convenience, were set to level 1 of the hierarchy. Table 2 presents the sub-criteria associated with each of the criteria. The sub-criteria were selected to represent the characteristics of each alternative bicycle route by comprehensively considering practitioners, local resident opinions, and transportation professionals'recommendations. Therefore, sub-criteria can differ by project-type, applied areas, and so on. In our study, they are applied uniformly across 20 candidate routes. The values for the selected sub-criteria were determined using in-person survey results and various national statistical indices.

Table 2. Qualitative criteria and their sub-criteria

Qualitative Criteria Level 1	Level 2	Details
Connectivity	Existing and designed bicycle routes	Connect with existing or designed bicycle routes
	School roads (school zone)	School zone for link with school roads
Safety	Traffic accidents related bicycling	The number of bicycle traffic accidents that have occurred in the administrative districts including the sections in the past three years (the number of accidents per km)
	Traffic accidents related pedestrian	The number of pedestrian traffic accidents that have occurred in the administrative districts including the sections in the past three years (the number of accidents per km)
	Traffic volume	Annual Average Daily Traffic at the targeted sections
Convenience	Convenience of use of public transit	The number of public transit services such as bus
	Weather effect	Days except those that are snowy, rainy, high and low temperature days

- **Step 3) Analytical Hierarchy Process (AHP) Application**

To estimate "weights" that represent the relative importance used for both qualitative criteria and their corresponding sub-criteria, a survey was conducted of total 35people, including 15 transportation professionalsconcerned with cycling, 10 practitioners, and 10 local residents. They selected the sub-criteria that they considered most crucial in the first level of the hierarchy. The survey question was "What are the most critical sub-criteria to reflect three main criteria for this project? (Multiple answers are allowed)". The survey results showed that connectivity with existing bicycle routes was selected as the most important by 43% of the survey participants in the first level while degree of bicycling safety was selected by 37% followed by degree of convenience selected by 20% in the second level of the hierarchy. After that, a pair-wise comparison matrix wasdeveloped based on following fundamental procedures (Saaty, 1990; Saaty and Vargas, 1981).

1) Define the problem and determine its goal
2) Structure the hierarchy from the top throughthe intermediate levels to the lowest level whichusually contains the list of alternatives
3) Construct a set of pair-wise comparison matrices($n \times n$) for each of the lower levels with onematrix for each element in the level immediatelyabove by using the relative scale measurementshown in Table 3
4) There are $n(n-1)$/judgments required developingthe set of matrices in 3), and thusreciprocals are automatically assigned in each pair-wise comparison

5) Hierarchical synthesis is now used to weight theeigenvectors by the weights of the criteria and thesum is taken over all weighted eigenvector entriescorresponding to those in the next lower level ofthe hierarchy

6) Having made all the pair-wise comparisons, theconsistency is determined by using the eigenvalue, λ_{max} , to calculate the consistency index, CI as follows: $CI = (\lambda_{max} - n)/(n-1)$, where n is thematrix size. Judgment consistency can be checkedby taking the consistency ratio (CR) of CI with theappropriate value in Table 4. The CR is acceptable, if it does not exceed 0.1. If it is more, thejudgment matrix is inconsistent. To obtain a consistent matrix, judgments should be reviewed andimproved

7) Steps 3-6 are performed for all levels in the hierarchy

Table 3. Pair-wise comparison scale suggested by Saaty

Numerical rating	Verbal judgments
1	Equal importance
3	Marginally strong
5	Strong importance
7	Very strong
9	Extremely strong
2,4,6,8	When compromise is needed (Fuzzy condition)

Table 4. Average random consistency (RI)

Size of Matrix	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

After developing the matrices, validation can be performed by examining the consistency ratio and consistency index described in the text. In that phase, we can use commercial software or our own code for the mathematical procedure. In our study, we employed our own code using MATLAB to produce the eigenvalues and corresponding eigenvectors. Weights for each level can be determined with a set of eigenvectors corresponding to the largest eigenvalue. After applying the consistency tests based on Saaty's rules mentioned above, consistency ratios (CRs) were obtained with regard to the first and second level of the hierarchy. Table 5 shows estimated weights for the first and second level of the hierarchy. After consistency tests, the same CR value at level 1 (3%) and level 2(3%) are presented. Since the CR is less than 10% in both levels, the developed pair-wise comparison matrices appear to be logically valid.

Table 5. Estimated weight results for each level of the hierarchy

Level 1 Criteria	Estimated weight	Level 2 Sub-criteria	Estimated weight
Connectivity	0.582	Existing and designed bicycle routes	0.334
		School roads (school zone)	0.048
Safety	0.309	Traffic accidents related bicycling	0.162
		Traffic accidents related pedestrian	0.089
		Traffic volume	0.033
Convenience	0.109	Convenience of use of public transit	0.238
		Weather effect	0.096

Estimated weights do not fluctuate widely with small changes in cycling transportation professionals' preferences, though the eigenvalues of some matrices are sensitive to perturbations. Therefore, an inverse square law analysis was applied in order to test the sensitivity of the estimated weights for levels 1 and 2 as shown in table 6. Even though this analysis says that a specified physical strength (ρ) is inversely proportional to the square of the distance ($1/r^2$) from the source as described as below, it is believed to use well to other areas of perception or thought (Saaty, 1991).

Table 6. The results of an inverse square law analysis

Criteria	Num. of Responses	Normali-zation	Square of previous column	Reciprocal of previous column	Normalized reciprocal	Final values	Deviation b/w weights and previous column	Median of Deviation vector
Level 1								
Connectivity	15	0.429	0.184	5.444	0.144	0.428	-0.154	
Safety	13	0.371	0.138	7.249	0.192	0.404	0.095	0.059
Convenience	7	0.200	0.04	25.000	0.663	0.168	0.059	
Level 2								
Criteria	Num. of Responses	Normali-zation	Square of previous column	Reciprocal of previous column	Normalized reciprocal	Final values	Deviation b/w weights and previous column	Median of Deviation vector
Existing and designed bicycle routes	18	0.273	0.074	13.444	0.014	0.164	0.334	
School roads (school zone)	5	0.076	0.006	174.240	0.184	0.136	0.048	
Traffic accidents related bicycling	12	0.182	0.033	30.250	0.032	0.161	0.162	
Traffic accidents related pedestrian	10	0.152	0.023	43.560	0.046	0.159	0.089	0.04
Traffic volume	3	0.045	0.002	484.000	0.512	0.081	0.033	
Convenience of use of public transit	13	0.197	0.039	25.775	0.027	0.162	0.238	
Weather effect	5	0.076	0.006	174.240	0.184	0.136	0.096	

Deviations between final values and estimated weights are very small. In addition, the medians of each of the deviation values in Table 4 were all less than 0.1. Thus, it can be concluded that the sensitivity of the estimated weights for each level is very close to the original responses of 35 participants.

- **Step 4) Producing an overall ranking of the candidate sets**

To facilitate the comparison of the results of the quantitative and qualitative aspects, a z-score was used to normalize the data here. Equation 1 facilitates the subjective comparison between the two results using the mean and standard deviation.

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$$Z = \frac{X - \mu}{\sigma} \quad (1)$$

Where X , μ and σ represent the observed value, mean, and standard deviation, respectively. The following table represents the results of both the qualitative and quantitative analysis, as well as the relative priority of the project. If the observed values are greater than mean, a positive value is generated, and a negative value is produced when the observed values are lower than the mean. Table 7 summarized normalization results according to 20 cities and towns, representing qualitative and quantitative standpoints.

Table7. Summary results of normalization

Number	Cities and Town	Quantitative	Qualitative
1	KyongJoo	1.938	1.426
2	SeoSan	1.757	0.713
3	WonJoo	1.286	-1.272
4	Moonkyoung	1.068	-0.569
5	Pohang	0.634	0.112
6	Yongin	0.416	0.417
7	Okchun	0.344	-0.592
8	Sokcho	0.307	-1.041
9	HongChun	0.235	-0.470
10	Sokcho	0.126	1.176
11	Chilgok	-0.0543	1.929
12	YangGu	-0.090	-0.257
13	PyeongTaek	-0.452	-1.417
14	Wando	-0.489	-0.376
15	PyeongTaek	-0.706	-1.0256
16	Cheolone	-0.778	-0.518
17	Ichun	-1.068	0.841
18	Yongin	-1.213	1.854
19	YeaSan	-1.575	-0.932
20	Pohang	-1.684	0.002

- **Step5) Quadrant analysis**

The normalized values for each alternative bicycle route obtained in Step 4 were plotted on quadrant as depicted in figure 6.

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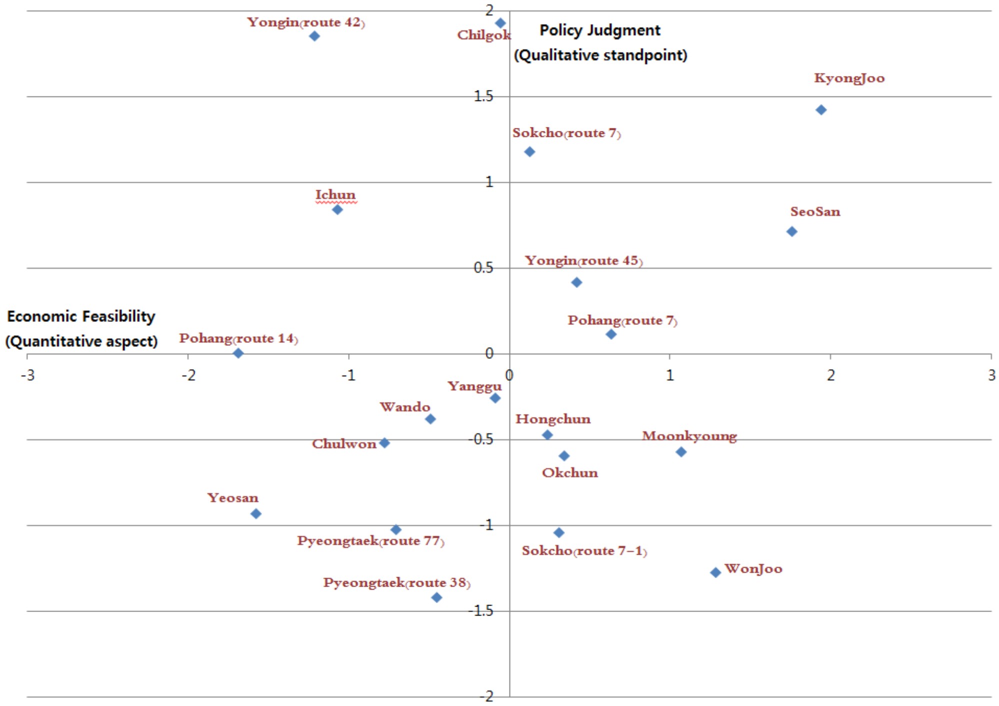

Figure 6. Results of Pilot Study in South Korea

The five alternative routes in Quadrant I are determined to be the highest priority whereas alternative routes in Quadrants II, III, and IV would be gradually developed considering changes in the surrounding environment, requests from local residents, and increases in bicycle demand in the near future.

IV. SUMMARY AND FUTURE RESEARCH

Increasing bicycle traffic is a key to the long term success of transportation systems. Therefore it would be a mistake to considerdeveloping alternative bicycle routes based solely on economic feasibility. In this research, a specific methodology that can determine priority of alternative bicycle route construction considering both economic feasibility and policy judgments was proposed and successfully applied to the fundamental construction plan on the national highways in South Korea. In the pilot study, the first priority is recommended immediately only in cases where both quantitative andqualitative standpoints are highly desirable, and thus bicycle route constructionis expected to distribute limitedresourceefficiently and to improve bicyclists'satisfaction in their use of bicycle facilities. According to the results for the pilot study, there are a common characteristic five routes where they have highest priority. That is connectivity with existing bicycle routes. In this case, economic aspect is very favorable in terms of reduced construction costs. Also, it seems to have great advantages with respect to policy standpoints if start and/end point is connected with existing bicycle routes. In addition, although our study considered quantitative andqualitative standpoints at the same time, bicycle traffic may vary by country or city in nature. If the proposed methodology is properly adapted in accord with the characteristics of each country and city, thiscould be applicable to a thorough review of practical possibility and needs before bicycle route construction is implemented.Although ourmethodology considersquantitative andqualitative standpoints at the same time, the nature of bicycle traffic varies by location. We believe, therefore, if the proposed methodology is adapted to each specific location, it can assist with planning of appropriate new, improved or extended routes.

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