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A Framework for the Evaluation of Infrastructures' Serviceability

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***Abstract*—**Aging infrastructures became a serious social problem. This brought out the increased need for the legislation of a new strict guideline for infrastructure management. Although existing guidelines provided basics of how to evaluate and manage the condition of infrastructures, they needed improvements for their evaluation procedures. Most guidelines mainly focused on the structural condition of infrastructures and did not properly reflect service aspects of infrastructures such as performance, public demand, capacity, etc., which were significantly valuable to public. Regardless of the importance, these factors were often neglected in infrastructure evaluations, because they were quite subjective and difficult to quantify in rational manner. Thus, this study proposed a framework to properly identify and evaluate the service indicators. This study showed that service indicators could be grouped into two categories and properly evaluated using AHP and Fuzzy. Overall, proposed framework is expected to assist governmental agency in establishing effective investment strategies for infrastructure improvements.

***Keywords*—**Infrastructure, evaluation, serviceability, fuzzy.

I. Introduction

NOWADAYS, aged infrastructures and their improvements are considered as key items to secure national competitiveness. To properly cope with these issues, governments established a guideline for infrastructure management, and they regularly conducted inspections as well as evaluation of infrastructure based on the guideline. However, most evaluation processes mainly focused on structural deficiencies and other important aspects of infrastructure such as performance, public demand, capacity, etc., were often neglected regardless of their importance. This was because those factors were too subjective to evaluate in rational manner. Thus, this study proposes a framework to properly evaluate the importance of the subjective factors regarding serviceability of infrastructure using AHP and Fuzzy approaches. Overall, this work is utilized as primary tool for infrastructure evaluation and further assists governmental budget planning.

II. Current Status of Infrastructure Evaluation

A. Infrastructure Evaluation (Korea)

As a part of asset management, infrastructure evaluation is important in that it allows the manager to monitor their assets and make them provide appropriate services for national economies [1]. In Korea, inspection and evaluation of infrastructure was primarily conducted based on the 'Guidelines for the safety inspection and test of infrastructure [2].' According to the guideline, there are eight species of infrastructures including road, railroad, harbor, dam, water facility, building, slope, and river facility, which should be inspected and evaluated on a certain schedule depending on the condition level of the infrastructure [2]. Although the guideline provide the agency with basics how to evaluate and manage the infrastructure, it should be improved because it mainly focused on the structural defects and corresponding safety without considering the serviceability aspects of infrastructure in the evaluation process. This could lead to wrong decisions in the budget allocation for infrastructure investments.

B. Infrastructure Evaluation (Other Countries)

In other countries, evaluation processes rarely include service ability indicators but they have somewhat different meanings for each agency. It is also different depending on the type of facility. For example, WAT which is the water services regulation authority) in UK, defined service ability as "the capability of a system of assets to deliver a reference level of service to customers and to the environment now and in the future" [3]. UKWIR indicated that quality output and operating capability were contributing factors for the serviceability of pipeline [3]. In case of WRc (water research center in UK), they assessed condition of sewer pipe with structural and operational defects [4]. Table I shows WRc coding for sewer pipeline.

TABLE I
WRc Coding for Sewer Pipeline (Adapted from [4])

Structural defects	Operational defects
crack, fracture, deformation, joint defects, collapse, break, sag, surface damage, corrosion, hole	root, debris, encrustation, protrusion, infiltration

On the other hand, FHWA (Federal Highway Administration) defined the conditions of bridges based on structural condition without considering serviceability indicator. Nevertheless, FHWA indicated that functional obsolescence of the bridge resulted from the changing traffic demand [5]. After reviewing the best practices for infrastructure management, we concluded that serviceability of infrastructure deeply related with quality aspect and operational capacity of infrastructure fitting to public demand.

C. Improvement of Infrastructure Evaluation

To improve existing practices for infrastructures evaluation, the followings should be considered. First, service aspects of infrastructure should be considered in evaluation criteria. Most

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practices for infrastructure evaluation, including Korea, have focused only safety and structural condition of infrastructure. Second, systemic approach for the evaluation of service aspect should be established, because indicators for service criteria are subjective and hard to be quantified. Third, infrastructures should be evaluated on the network level. Currently, worst-first approach for repair and rehabilitation policies was prevalent in most cases of infrastructure improvements. However, this approach would not properly prioritize the infrastructure and this would prevent effective strategies for governmental budget allocation. On the other hand, network level of infrastructure evaluation could support the comprehensive management of national infrastructure.

III. Theoretical Backgrounds

A. Fuzzy Approach

Fuzzy set theory was first introduced by Zadeh [6] and has been widely applied to solve the problems regarding the ambiguity of the human-thinking. Fuzzy set theory provided a mathematical framework in which imprecision of human language, judgement and opinion could be adequately evaluated with crisp number [7]. Thus it was particularly effective in translating the subjective things into objective ones. Han [8] estimated the relative weights of the factors influencing the construction period using fuzzy approach. Lee [9] utilized fuzzy theory to develop a methodology of ranking fuzzy numbers.

B. AHP (Analytic Hierarchy Process) Method

AHP method was developed by Saaty [10]. It was evaluation method to facilitate the decision making by analyzing the mutual dependence of components. To obtain their goal, AHP utilized knowledge, intuition and experience. AHP method was an effective tool to accommodate multilateral criteria for various opinions of decision makers. Thus, it was extensively applied to assist pairwise comparison of considering factors. Using AHP method, [11] determined the suitable areas for crop cultivation and [12] estimated the importance of the evaluation index regarding design competition of architecture. In this study, AHP was applied to determine the importance of each factor using survey.

IV. Infrastructures' Service Ability Evaluation

A. Framework for Service Ability Evaluation

To properly evaluate the overall condition of infrastructure, both structural condition and level of service should be considered. While structural condition represents the structural deficiency of the structure, level of service implies customer's satisfaction or operational performance of facility. In other words, structural condition affects the service life of facility and serviceability impacts on the usage of facility. Although most countries have their own way (condition rating system) to evaluate the structural condition of infrastructure, few rating system exists for the evaluation of service level. Without considering the service level of facility, proper evaluation for infrastructure investment could not be achieved and this can result in erroneous budget allocation of infrastructure investment. Thus, this study proposes a framework which adequately evaluates the service level of infrastructure using AHP and Fuzzy approach. A proposed framework for the evaluation of infrastructures' serviceability is composed of four steps: identification, classification, weight-assessment and evaluation. Each step is explained in detail in following sections. Evaluation procedures of the framework are illustrated in Fig. 1.

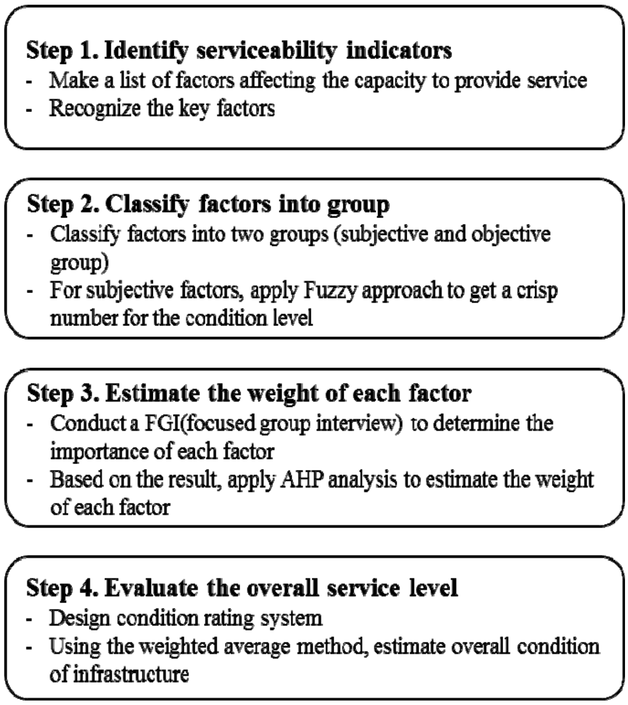

Fig. 1 Framework for evaluation of infrastructures' serviceability

B. Identification of Service Ability Indicators and Their Classification

To identify serviceability indicators, the definition of service for each infrastructure should be established. For example, the objective of water pipelines is to provide users with high-quality of water without intervention. Thus, service indicators for water pipeline would be about the customer's satisfaction such as acceptable pressure, interruption of water supply, water quality, leakage levels, etc. These indicators are too diverse that every service indictors could not be considered in the evaluation process. Thus, the list of indicator should be reduced to recognize key factors. After reviewing the existing practices for infrastructure, we concluded that it can be categorized into two groups: subjective and objective group. Table II shows the example of the service indicators and their classification in water pipeline.

While subjective groups included the indicator regarding quality level of service, objective group included the indicator regarding operational capacity. The condition level of operational capacity is rather clear. Thus, the indicators in objective group could be easily estimated and the condition level would also be established. However, subjective indicators were hard to be quantified and thus the condition level was established using surveys of involving experts. To solve the problems, fuzzy approach was applied. Previously indicated, fuzzy approach was useful to translate ambiguous human thinking into a crisp number which represented a certain service level. Table III shows the examples of service indicators in various infrastructures.

TABLE II
GROUP OF SERVICE INDICATOR IN WATER PIPE

Group	Factors
Subjective (Quality)	Odor, Acceptable pressure, water quality
Objective (operational capacity)	Leakage level, number of service interruptions

TABLE III
SERVICE INDICATOR IN VARIOUS INFRASTRUCTURES

Type	Group	Factors
Water pipeline	Subjective (Quality)	Odor, Acceptable pressure, water quality
	Objective (operational capacity)	Leakage level, number of service interruptions
Pavement	Subjective (Quality)	Smoothness, noise, skid resistance, drainage
	Objective (operational capacity)	Peak hour volume, # of required lane, saturation flow rate
Tunnel (Road)	Subjective (Quality)	Smoothness, luminance, air quality, drainage
	Objective (operational capacity)	Peak hour volume, average speed
Bridge (Road)	Subjective (Quality)	Smoothness, lighting, vibration serviceability
	Objective (operational capacity)	Peak hour volume, average speed
Slope (Road)	Subjective (Quality)	Subjective risk, safety distance
	Objective (operational capacity)	Traffic volume
Tunnel (Rail)	Subjective (Quality)	Noise, vibration, luminance
	Objective (operational capacity)	#of trains per day
Bridge (Rail)	Subjective (Quality)	Noise, vibration
	Objective (operational capacity)	#of trains per day
Dam	Subjective (Quality)	Water quality, stability of operation
	Objective (operational capacity)	Flood control, reservoir capacity

The types of infrastructures were divided based on the current version of 'Guidelines for the safety inspection and test of infrastructure.' Groups of indicators were divided using survey. As shown in Table III, there was a little difference between service indicators of road tunnel and those of railway tunnel. This was because although the facilities had similar appearance and function, the structures adopted different users which had different viewpoints of their satisfaction.

When the service indicators were grouped, condition level for each factor should be defined. To accomplish this task, various standards and certification system were reviewed. In addition, solid basis was prepared to support the official application of the evaluation process. Table IV shows example of condition rating system for average speed in Tunnel (road). This condition rating system was designed based on the opinions of governmental agencies. In addition, the capacity could be varied by size and location of facility, this study constructed the condition level in a proportional manner.

TABLE IV
CONDITION RATING SYSTEM FOR AVERAGE SPEED IN TUNNEL (ROAD)

Level	Descriptions
5	Average speed is over design speed
4	Average speed is 90~100% of design speed
3	Average speed is 80~90% design speed
2	Average speed is 70~80% design speed
1	Average speed is 70% or less design speed

C. Estimate the Weight of Each Factor

Although important factors were identified in previous step, the weight of each factor should be defined, because the factors did not provide same impact on the service level. In addition, depending on the type of infrastructures and users, the weight could be varied. For example, quality aspects could be more important in water pipe line but operational capacity would be more important in road or bridge due to varied viewpoints of satisfaction. To properly estimate the weights, this study applied the AHP analysis based on FGI (focused group interview). The results of AHP analysis was also reviewed by infrastructure management committee.

D. Evaluate the Overall Service Level

After weight of each factor is estimated, the decision maker determines the overall condition level. To obtain the level, the decision maker needs to combine all these factors into one condition level. This process is quite straightforward using weighted average method. Firstly, decision maker designed condition rating system for overall condition level. Table V shows the example of overall condition level with 5 scales. This 5scale of condition rating system is prevalent in existing guidelines.

TABLE V
OVERALL CONDITION LEVEL

Level	Descriptions
5	Excellent (service level is extremely satisfactory)
4	Good (service level is satisfactory)
3	Fair (service level is fair)
2	Poor (service level is unsatisfactory)
1	Failed (service level is extremely unsatisfactory)

Next step is a combination of each service level, this step can be easily achieved using weight average method (1).

$$LOS = \frac{\sum_{i=1}^{n} w^{i} f^{i}}{\sum_{i=1}^{n} w^{i}} \quad (1)$$

where, LOS= level of service, n = number of factors, w^i = weight of each factor, f^i = condition of each factor.

V. CONCLUSION

This paper proposed a framework which could be utilized for evaluation of infrastructures' serviceability indicators. The framework contributed to the existing body of knowledge in that the proposed evaluation process could properly translate ambiguous and subjective opinion regarding user's satisfaction into a crisp number. This would enable agencies to evaluate the subjective factors clearly and determine the overall service level of infrastructure objectively. In addition, this work provided idea about the service indicators for various infrastructures and corresponding condition rating system, because current version of guidelines for infrastructure evaluation did not properly reflect service aspects of infrastructures. Later, the service indicators and the evaluation processes are planned to be reflected in the amendment of 'Guidelines for the safety inspection and test of infrastructure' in 2017 version. To review the validity of indicators as well as to improve the applicability of the framework, we will perform a demonstration project coupled with survey, and get the feedback from governmental agencies. Overall, this work is expected to assist governmental agencies in evaluating their infrastructures and further facilitate the reasonable budget planning.

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