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Estimating road management equipment inventory needs and associated purchase costs

Choong Heon Yang [a,*], Amelia C. Regan [b], In Su Kim [a]

[a] Highway & Transportation Research Division, Korea Institute of Civil Engineering & Building Technology, 2311 Deahwa-Dong, Ilsan-Gu, Goyang-Si, Gyenggi-Do 411-712, Republic of Korea
[b] Department of Computer Science and Institute of Transportation Systems Engineering, University of California, Irvine, 4068 Bren Hall, Irvine, CA92627, USA

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ABSTRACT

This paper presents a method for estimating road management equipment inventory needs and associated purchase costs. The primary feature of this method is to consider historical operations records by road management equipment type and weights by work type based on subjective preferences of the public agencies. The Analytical Hierarchy Process (AHP) is employed as the main tool to reflect the relative importance of a day-to-day road management activity. In order to examine the appropriateness of our method, we performed a case study with 18 regional transportation offices in South Korea. The estimated cost of equipment purchases across these offices was approximately 41 million US dollars based on the 2011 year (when apply average unit cost by equipment), while the actual equipment purchase costs during the same one-year period were about 44 million US dollars. The main reason for the differences of estimates across offices is due to unit cost by equipment, road conditions, relative importance of management tasks, and omission of unused equipment in inventories and use of labor. We also developed estimates using the maximum unit costs by equipment, in order to provide an upper bound to the authorities. Using those values we estimated the annual cost at approximately 60 million dollars. The estimates developed can provide useful information to road authorities when they establish annual plans for road management.

1. Introduction

Road authorities try to improve the quality of transportation systems for road users by managing new road construction as well as performing regular maintenance of existing roads. Since the late 1980s, investment in road maintenance rather than construction had increased markedly in accordance with the change in national road planning priorities in South Korea (MLTM, 2010). The primary goal of investment is to improve the efficiency of road management operations through available resources and to provide high-quality public road service for travelers. Day-to-day road management work varies according to each road and its needs. In South Korea, the following tasks are classified as a day-to-day road management: snow removal operations, cleanup of roads, drains and facilities, flood prevention, and pavement repairs (MLTM, 2013). The main issues addressed in this study are that each road management requires appropriate equipment in order to perform maintenance works. Equipment has its own life cycle but this differs from equipment type and work force. Therefore, road authorities want to change and/or purchase regularly within their budget (Yang and Regan, 2013b). The government-department of budget planning needs to have accurate information on those needs before performing actual budget allocation. Sometimes, these concerns may conflict when they negotiate each fiscal year. Namely, road authorities want to obtain sufficient resources while the budget planning department has to consider budget allocation efficiency. In order to use sound logic, road authorities need a specific method that enables to improve estimation of road management equipment inventories and associated purchase costs. The primary characteristics of the method is to consider historical operations records by road management equipment as a quantitative aspect and weights by work type based on subjective preferences of the public agencies as a qualitative aspect. The Analytical Hierarchy Process (AHP) is employed as the main tool to reflect weights of a day-to-day road management work. AHP is frequently used to determine investment and management priorities in transportation. Saaty and Vargas (1981) suggested an arbitrary rating scale with ranging from 1 to 9 based on psychological experiments. These results show that people cannot

* Corresponding author. Fax: +82 31 910 0746.
E-mail address: chyang231@gmail.com (C.H. Yang).

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compare more than seven objects, allowing plus and minus two without being confused. The suggested scales are ordinal scales because they just describe the order of the relative importance between criteria. A scale of 1 indicates no difference in relative importance between two criteria. On the other hand, a scale of 9 indicates that one criterion is of absolute importance compared to the other.

$$A = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{mn} \end{bmatrix}$$

Rule 1: Suppose that a_{ij} is an entry of the matrix. If $a_{ij} = b$, then $a_{ji} = (1/b)\,(i \neq j)$

Rule 2: If two criteria, i and j, are identically important, then $a_{ij} = a_{ji} = 1$

Further, AHP has gained acceptance as a well-understood multicriteria decision-making tool in South Korean governmental agencies. De Oliveira Almeida et al. (2012) employed a multi-criteria decision analysis to prioritize alternatives related to unpaved roadways. They first classified five groups of professionals based on their interests, and then individually interviewed them to identify their preferences for the evaluation criteria. Priorities were established based on AHP. Coulter et al. (2006) scheduled forest road maintenance and upgrade activities involving non-monetary benefits using AHP. Two mathematical programs were used in that study. The potential benefit of completing a given road maintenance or upgrade project was determined using the AHP. The measure of the benefit was combined with the economic cost of completing a given project to schedule the maintenance and upgrade activities for 225 km of road in a forested road system in western Oregon in the U.S. This combination of heuristics, cost–benefit analysis, environmental impacts, and expert judgment produced a road management schedule that better fits the current road management paradigm. In network-level pavement management, maintenance prioritization of pavement segments usually involves determining their relative priorities using several distresses of various types and severity levels. The AHP was previously applied to establish the relative pavement maintenance priorities of single pavement distress types with different severity levels (Farhan and Fwa, 2011). Generally, transportation agencies or decision-makers examine and prioritize numerous transportation projects at one time. Examples of AHP applied in this way can be found in Holguin-Veras (1995), Kim and Bernardin (2000), Sohn (2008), Tanadtang et al. (2005), Hassan et al. (2013), Yang and Regan, 2013a, 2013b). Moreover, in the previous study, we proposes a specific methodology to determine either to lend or borrow among regional offices or to consider purchase for both long and short term use (Yang and Regan, 2013b).

2. Methodology

Our method requires access to essential data such as historical operation records by equipment type and subjective preferences of public agencies for road management operations. Finally, these can be used to estimate appropriate equipment inventories and their corresponding estimated purchase costs. Fig. 1 shows the overall method.

2.1. Step 1: Data collection

Public agencies (and/or equipment experts) record equipment use in various forms. However, databases generally contain equipment identifier, number of operating days and accumulated operation time (or distance). Based on such data, the annual operation distance (or time) by individual equipment, and usage ratio by work type are produced using Eqs. (1) and (2), respectively.

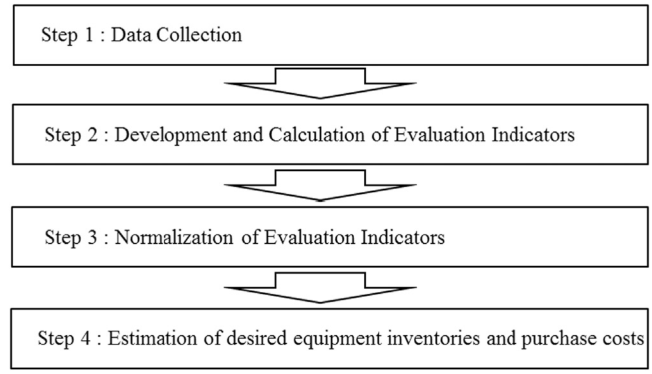

Fig. 1. The overall procedures of the proposed method.

Annual operation distance (or time)=
Accumulated distance (or time)
of the present year − accumulated distance
(or time) of the previous year (1)

Usage ratio by work and equipment type=
Total days of use by work and equipment type
/annual total days (2)

2.2. Step 2: Development and calculation of indices

Previous research (Yang and Regan, 2013b) provides two important evaluation indicators based on the data collected in step 1. Evaluation indicator I is based on the annual operating distance (or time) whereas Evaluation indicator II is based on equipment use. For evaluation indicator II, the AHP generated weights are used. These are shown in Eqs. (3) and (4).

Evaluation indicator I=
(operation distance (or time)
of equipment/total pieces of equipment)
/length of management area (3)

Evaluation indicator II = Σ (final weights)(operation ratio) (4)

2.3. Step 3: Normalization of evaluation indicators

The two indicators computed in step 2 differ both in their magnitude and in units. Therefore, the normalization is needed to facilitate comparison between them. Eq. (5) can be used to allow objective comparison of the indicators, performing normalization using the mean and standard deviation. If the observed values are greater than the mean, a positive value should be generated while negative value would be produced when the observed values are lower than mean.

$$Z = \frac{X - \mu}{\sigma} \quad (5)$$

where X, μ, and σ represent the observed value, mean, and standard deviation, respectively. Then, a 100-score conversion