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A decision support system for determining the optimal size of a new expressway service area: Focused on the profitability

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ABSTRACT

Since the early 1990s, South Korea has been expanding its expressways. As of July 2013, a total of 173 expressway service areas (ESAs) have been established. Among these, 31 ESAs were closed due to financial deficits. To address this challenge, this study aimed to develop a decision support system for determining the optimal size of a new ESA, focusing on the profitability of the ESA. This study adopted a case-based reasoning approach as the main research method because it is necessary to provide the historical data as a reference in determining the optimal size of a new ESA, which is more suitable for the decision-making process from the practical perspective. This study used a total of 106 general ESAs to develop the proposed system. Compared to the conventional process (i.e., direction estimation), the prediction accuracy of the improved process (i.e., three-phase estimation process) was improved by 9.84%. The computational time required for the optimization of the proposed system was determined to be less than 10 min (from 1.75 min to 9.93 min). The proposed system could be useful for the final decision-maker as the following purposes: (i) the probability estimation model for determining the optimal size of a new ESA during the planning stage; (ii) the approximate initial construction cost estimation model for a new ESA by using the estimated sales in the ESA; and (iii) the comparative assessment model for evaluating the sales per the building area of the existing ESA.

1. Introduction

1.1. Research background and objective

Expressway Service Areas (ESAs) offer rest, convenience, and safety to drivers who make mid- to long-distance trips. According to the '*Expressway design handbook* (*Section 9. Service facility*) [1],' the ESA relieves drivers from fatigue and stress due to continuous expressway driving, resolves the physiological needs of the drivers, and offers them opportunities to refill their gas tanks and to check their cars for repairs. Recently, ESAs have likewise been required to provide additional amenities such as integrated IT services and eco-friendly resting places. From the four ESAs that were established in 1970, a total of 173 ESAs have been built in South Korea as of July 2013 [2,3].

Among these ESAs, however, 31 ESAs were closed due to financial deficits. It means that there were some problems in the conventional process for determining the size of a new ESA, which caused the huge initial investment for several years before any income is returned. For example, about 43.2 million dollars was invested for the construction of 'D' ESA in South Korea, which was used to verify the feasibility of the developed system. To prevent these deficits in the operation of a new ESA in advance, this study aimed to develop a decision support system for determining the optimal size of a new ESA, focusing on the profitability of the ESA.

1.2. Research scope and method

According to the current regulations [1,4,5], the functions of the ESA generally consist of three components: (i) convenient facilities (such as parking lots, restrooms, and green spaces); (ii) business facilities (such as restaurants, convenience stores, gas stations, and vending machines); and (iii) operation facilities (such as electric and communication facilities, water supply and sewage systems, and gas storage facilities). Among the three functions, the deficits in the operations of the ESAs are not directly related to the first component (i.e., the convenient facilities), but to the other two components (i.e., the business facility and the operation facility). Therefore, the scope of this study is limited for determining the optimal size of the building area (including both the business facility and the operation facility) of a new ESA, which does not include the convenient facility.

To develop the decision support system, this study collected the project characteristics on a total of 106 general ESAs out of 142 ESAs which were operated by Korea Expressway Corporation (KEC) as of 2013. Namely, 36 ESAs were excluded based on the following criteria: (i) since this study focused on the optimal size of the general ESAs, 11

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freight ESAs were excluded; (ii) since it is necessary to consider the '*passing traffic volume*' as independent variable, 14 ESAs, whose passing traffic volume were not surveyed, were excluded; and (iii) since it is necessary to consider the '*sales in the ESA*' as dependent variable, 11 ESAs, whose sales were not surveyed, were excluded.

This study was conducted largely in two steps: (i) this study conducted the statistical analysis to clearly identify the problems of the conventional process for determining the size of a new ESA; and (ii) based on the results of the statistical analysis, this study proposed the improved process for determining the optimal size of a new ESA, focusing on the profitability of the ESA. Meanwhile, this study adopted a case-based reasoning (CBR) approach as the main research method because it is necessary to provide the historical data as a reference in determining the optimal size of a new ESA, which is more suitable for the decision-making process from the practical perspective.

1.3. Literature review

1.3.1. Parking space demand

Previous studies considered the parking space demand as the main impact factors. Regarding the parking space demand, various studies have been conducted worldwide [6–21]. First, international studies on the parking space demand of the ESA were conducted as follows. Especially, this study focused on the U.S. Department of Transportation (DOT) and its specialized division, the Federal Highway Administration (FHWA). The FHWA has mainly developed several handbooks for a commercial truck's parking space demand [6,7]. Several state DOTs have developed prediction models to determine parking space requirements for the ESA. The Minnesota DOT (MnDOT) model was developed as a macroscopic-level parking space model for the ESA in 1979. This model was revised by the Virginia DOT (VDOT) based on the usage survey of the ESA in 1994. The MnDOT and VDOT's models only considered the passing traffic volume along the mainline to estimate the truck parking demand. Garber et al. [8] and Wang and Garber [9] considered the factors affecting the demand for commercial truck parking such as the percentage of trucks in the traffic stream, the distance from a truck stop to mainline, the distance from a truck stop to the nearest truck stop, and the facilities provided at the truck stop. In addition, several studies proposed the estimation models based on the law of supply and demand. FHWA [10] proposed two models: the capacity utilization model to evaluate the usage rate of the truck parking space in the operation stage of the ESA; and the truck parking demand model to evaluate the expansion size of the truck parking space. Gopi [11] developed recommendations that can provide parking facilities and the associated services based on the needs for commercial truck drivers in South Dakota DOT by using the truck parking demand model. FHWA [12] analyzed the commercial truck parking supply and demand balances, and then evaluated the adequacy of commercial truck parking facilities. Rodier and Shaheen [13] analyzed the expected truck parking shortages and illegal parking by considering the supply and demand for trucking parking within the study area. FHWA [14] analyzed the truck traffic volume and available parking space within the study area by using geographic information system, the results of which showed that the truck parking worked very well. Adams et al. [15] analyzed the supply and demand for trucking parking in Wisconsin DOT as follows: identified the parking issues for day-trip drivers; the operational issues causing the need for parking; where new or expanded facilities are needed; and low-cost solution to address trucking parking shortfalls. Based on the national research, other studies focused on the demand for truck parking space, the impact of the truck parking space on truck parking facilities, parking location, transportation infrastructure, safety, local economy, and environment. There were also several studies related to parking space, location and pricing, and rest area facility design [16–21]. As such, international previous studies mainly dealt with the truck parking space demand, of which focus was different from the ESAs in South Korea in terms of the type of ESA. Moreover, they presented a linear model such as an equation that uses conversion factors such as the usage rate, congestion rate, and turnover rate of the ESAs, which may cause an issue on the reliability of the estimation model.

Second, domestic studies on the parking space demand of the ESA were conducted as follows [22–25]. Several studies focused on the parking space demand of the general ESA by taking into account the impact factors such as vehicle types, daytime and night-time traffic volume, and traffic routes. In these studies, the conversion factors were used to estimate the parking space demand of a new ESA, which were established by using regression and cluster analyses [22–24]. Another study developed a model through regression analysis in order to estimate the parking space demand for freight vehicles. In the study, independent variables were extracted through factor analysis and correlation analysis [25]. As such, domestic studies were mainly limited to the parking space demand, merely suggesting a conversion factor or a linear model. Namely, various characteristics of ESAs were not considered, and thus it is limited in establishing the optimal size of a new ESA.

In summary, there were two major limitations in the previous studies: (i) the parking space demand was considered as main impact factor to estimate the size of a new ESA. The parking space demand was directly related to the size of convenient facility, but it was not directly related to the building area (including both the business facility and the operation facility). Accordingly, these approaches cannot estimate the optimal size of a new ESA, resulting in the deficits in the operations of the ESAs; and (ii) the conversion factors for determining the size of a new ESA were established as a fixed value based on limited survey results or a regression model based on limited historical data, which were not sufficiently validated. Accordingly, although the usage pattern of the ESA may be diverse depending on its characteristics, the previous studies cannot reflect enough characteristics to determine the optimal size of a new ESA.

1.3.2. Data mining technique

Various types of data mining techniques have been used for the purpose of prediction and classification (e.g., multiple regression analysis (MRA); artificial neural network (ANN); decision tree (DT); and CBR). In addition, the optimization process has been adopted to solve the complicated high-dimensional problems.

- As a statistical method, MRA can be relatively simple to implement, and is easy to understand. However, MRA is not suitable for the complicated problems [26–30].
- While ANN can solve the complicated non-linearity among various variables, it is not able to explain the process from which the final results are obtained, due to a hidden layer called the 'black box' [31–34].
- DT can form the clusters through the correlation analysis among the project's characteristics. Because the final result is provided in the form of a tree, it is easy to understand and simple to implement. However, in case that the correlation among the independent variables is too complicated, the prediction accuracy of DT model can decrease [35,36].
- CBR cannot only provide the prediction value based on historical data, but also present the retrieved cases as a reference for the decision-making. Namely, CBR has higher explanatory power. As with the continuous accumulation of the database, the prediction accuracy of CBR model can be improved. However, the prediction accuracy of the basic CBR model is relatively inferior to that of MRA or ANN model [37–39]. Therefore, when the CBR method is adopted to estimate some value, the prediction accuracy of the basic CBR model can be improved by integrating itself with the other techniques (e.g., MRA, ANN, and DT) and by implementing the optimization process (e.g., genetic algorithm (GA)) to improve its prediction accuracy.