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MULTI-OBJECTIVE MATHEMATICAL PROGRAMMING MODELS AS DECISION SUPPORT SYSTEM FOR PARK ROADS MANAGEMENT

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ABSTRACT

The park roads are built every year in the national parks of Thailand. New-built park roads are rarely based on sound road standards. The maximum gradient often exceeds allowable safety standards. A low road safety quality usually causes high road accidents. Presently, new park roads construction has high cost of investment and maintenance but relatively short life span of use. Excessive clearing, grubbing and tree felling usually causes large open areas which then damages the ecosystem. Therefore, a multi-objective criterion for park roads planning and design in National Parks of Thailand using multi goals programming was applied to minimize conflicting goals. The study models were applied to the Thai existing park road data in Khao Yai National Park. These developed mathematical models for park roads construction can be applied to control park roads design and construction in National Parks. The results indicated that the model of the less environmental impact criteria resulted in the highest cost of construction. While, the model of the maximum traveling safety and the minimum environment impact criteria resulted not much difference in construction cost. Thus, the decision maker of park road planning and design should take these two criteria into account in preparing the proposed Park Roads Standard for controlling park roads design and construction in national parks.

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INTRODUCTION

The National Park, Wildlife and Plant Conservation Department is urgently constructing many park roads and improving existing roads to serve tourism purpose. A thousand kilometers of park road are built every year in the national parks of Thailand. New-built park roads are rarely based on sound road standards(Royal Forest Department, 2001). The carriageway and surfacing width vary from project to project. The maximum gradient often exceeds allowable safety standards. Excessive clearing, grubbing and tree felling has resulted in a large area of forest land being exposed which then damages national resources (Chomitz and Gray, 1996). Heavy cuts and fills of road construction may cause negative impacts (Anderson and Simons, 1983). A lack of soil protection structures, such as retaining walls, slope protection or improperly drainage structures may result in high erosion effects. Furthermore, there is a low traveling safety for tourists and may frequently cause many road accidents (Highway Department, 1982). These newly built park roads have very high maintenance costs and a short performance life. In general, park roads are multipurpose permanent investments. Besides providing many positive kinds of economic, social and environmental effects, they may cause negative impacts as well. For instance, erosion may be caused by new park roads and their construction can destroy stream and river ecosystems down below if these activities are not properly managed (Reid and Dunne, 1984). The negative effects on park values about wildlife habitat and mobility, drainage, stream flow, and the climatic effect should be minimized as much as possible (Jones and Grant, 1996; Sauer *et al.,* 1982). Moreover, preserving the integrity of the landscape, respecting ecological processes, insuring a fully rewarding visitor experience is the main purpose of park roads (National Park Service, 1984). Therefore, a multi-objective criterion for park road planning and design in National Parks of Thailand is needed (Bonczek *et al.,* 1980; Little, 1970; Moor and Chang, 1980).

MATERIALS AND METHODS

The study was carried out at Khao Yai National Park, Nakhon Ratchasima province. The procedure composes of field data collection, data analysis, park road standard development for Thailand and models for park road construction and management. All activities were summarized step by step as following;

Data Collection

1. Literatures of all previous works of forest road standards including laws, Acts, regulations, limitations, announcements of the Royal Forest Department were reviewed for designing the park road models.

2. The secondary data for all road

construction in forest area such as tourist statistics, traffic volume, climates, topography, forest and vegetation type, soil type, stream flow, and geology were collected and studied.

3. Field data of existing park roads in Khao Yai National Park were observed with special emphasized on road characteristics data and using data. The collected field data are:

(a). Route location survey, horizontal and vertical alignment, maximum gradient.

(b). Data collecting of road geometric design such as typical section, carriage width, surfacing design, surfacing materials, road structures, super elevation.

(c). Traffic volume collecting, speed, type and quantity of vehicle per day at study points.

(d). Data collecting of road drainage structures, type and quantity checking, capacity evaluation, and adequate number of structure checking.

(e). Traffic sign and safety checking.

Data Analysis

The first step of data analysis is to create the goal objective functions. The field raw data were calculated and transformed to suit the multi-goal mathematical programming model. For types of the goal objective functions were tested;

1) Minimize construction cost model
2) Minimize maintenance cost model
3) Minimize environmental impact model
4) Maximize safety traveling model.

The application models were :

The Proposed Mathematical Model:

$$Y_{pw} = f(A,X)$$

where

Y_{pw} = dependent variable such as construction cost per kilometer of road length in Baht

A = unit price of each variables

X = independent variables such as road length (x_1), carriage width including shoulder (x_2), width of clearing and grubbing (x_3), side slope ratio (H:V) for soil cutting (x_4), side slope ratio (H:V) for soil filling (x_5), subgrade level (x_6), percentage of grade G from PVC.STA. to PVI. STA. in% (x_7), percentage of grade G from PVI.STA. to PVT. STA. in% (x_8), length of vertical curve (x_9), subbase thickness (x_{10}), base thickness (x_{11}), traffic surfacing thickness (x_{12}), number of culverts installation points (x_{13}), number of rows of culvert installation points (x_{14}), number of culvert in each row (x_{15}), culvert diameter (x_{16}), rip rap thickness (x_{17}), length of earth side ditch (x_{18}), length of concrete side ditch (x_{19}), number of guide posts, milestone post (x_{20}), etc.

Multi-Goal Mathematical Programming Model

$$Z_0 \leq C'X_{ij} \quad (1)$$

$$AX_{ij} \leq b_0 \quad (2)$$

$X_{ij} \geq 0$ (3)

Goal Objective Functions

$$Optimal\_Z = \sum_{i=1}^{n} \sum_{j=1}^{m} A_i X_{ij}$$

1. Minimize construction cost model (Z_1)

$$Minimal\_Z_1 = \sum_{i=1}^{n} \sum_{j=1}^{m} a_i X_{ij}$$

The minimize construction cost (Z_1) objective function is subject to following constraints such as ;

1.1 Minimum soil cutting
1.2 Minimum soil embankment
1.3 Minimum drainage structures
1.4 Minimum soil protection structures
1.5 Shortest route layout

2. Minimize maintenance cost model (Z_2)

$$Minimal\_Z_2 = \sum_{i=1}^{n} \sum_{j=1}^{m} b_i X_{ij}$$

The minimize maintenance cost (Z_2) objective function is subject to following constraints such as ;

2.1 Maximum thickness of surfacing layer and adequate surfacing material
2.2 Adequate drainage structures
2.3 Maximum soil protection structures
2.4 Adequate soil compaction
2.5 Foreseen traffic intensity within the expectation range
2.6 Adequate routine maintenance

3. Minimize environmental Impact model (Z_3)

$$Minimal\_Z_3 = \sum_{i=1}^{n} \sum_{j=1}^{m} c_i X_{ij}$$

The minimize environmental Impact cost (Z_3) objective function is subject to following constraints such as ;

3.1 Minimum clearing and grubbing
3.2 Minimum soil cutting
3.3 Minimum soil embankment
3.4 Maximum soil protection structures
3.5 Maximum drainage structures
3.6 Adequate routine maintenance
3.7 Maximum thickness of surfacing layer and adequate surfacing material
3.8 Foreseen traffic intensity within or less than the expectation range
3.9 Well design and construction process

4. Maximize traveling safety model (Z_4)

$$Minimal\_Z_4 = \sum_{i=1}^{n} \sum_{j=1}^{m} d_i X_{ij}$$

The maximize safety cost (Z_4) objective function is subject to following constraints such as ;

4.1 Maximum horizontal curve alignment
4.2 Adequate vertical curve align ment
4.3 Maximum stopping distance
4.4 Adequate traffic sign and road sign facilities
4.5 Maximum carriage width
4.6 Maximum thickness of surfac ing layer and adequate surfac ing material
4.7 Foreseen traffic intensity within or less than the expec tation range
4.8 Well design and construction process
4.9 Maximum drainage structures
4.10 Low gradient
4.11 Adequate routine maintenance

The second step is to create the recommended mathematical model. The proposed mathematical models were :

1. Data analysis and computer simulation.
2. Develop and establishing mathematical modeling of park road by using multi-goal programming.

RESULTS AND DISCUSSION

1. The park roads of Thailand are forest roads, can be classified as paved and unpaved roads.

Table 1. The goal mathematical programming models

Goals	Mathematical Models
Z_1	1,194,316.25. +2,151,892.21X_2 +37,256.66X_3 +1,087,325X_2X_{10} +1,613,450X_2X_{11} +18,940,500 X_2 X_{12} +2,500X_{35} +1,100X_{36} +950X_{37} +150X_{18} +470X_{19} +1,500X_{20} +10,000X_{22} +36,000X_{26} +1,400X_{30}
Z_2	2,647,328.84. +4,465,824.13X_2 +37,256.66X_3 +1,087,325X_2X_{10} +1,613,450X_2X_{11} +18,940,500 X_2 X_{12} +2,500X_{35} +1,100X_{36} +950X_{37} +150X_{18} +470X_{19} +1,500X_{20} +10,000X_{22} +36,000X_{26} +1,400X_{30}
Z_3	1,647,222.17. +1,883,364.86X2 +37,256.66X_3 +1,087,325X_2X_{10} +1,613,450X_2X_{11} +18,940,500 X_2 X_{12} +2,500X_{35} +1,100X_{36} +950X_{37} +150X_{18} +470X_{19} +1,500X_{20} +10,000X_{22} +36,000X_{26} +1,400X_{30}
Z_4	1,647,222.17 +5,498.33X2 +37,256.66X3 +1,087,325X_2X_{10} +1,613,450X_2X_{11} +18,940,500 X_2 X_{12} +2,500X_{35} +1,100X_{36} +950X_{37} +150X_{18} +470X_{19} +1,500X_{20} +10,000X_{22} +36,000X_{26} +1,400X_{30}
Z	2,314,250.17 +4,961,033.43X_2 +37,256.7X_3 +1,087,325X_2X_{10} +1,613,450X_2X_{11} +1,8940,500X_2X_{12} +59,150$X_{13}X_{14}$ +1,782X_{13} +810$X_{13}X_{14}$ +1,620$X_{13}X_{14}X_{16}$ +23,192.24X_{13} +19,384.35$X_{13}X_{14}$ -8,175.50$X_{13}X^2_{14}$ +150X_{18} +470X_{19} +10,000X_{22} +36,000X_{26};

2. The paved roads with surface treatment, or asphaltic or asphaltic concrete, or concrete pavement surfacing are mostly used for main roads of national parks.

3. The carriage width of park roads including shoulders is not more than 7.0 meters.

4. The maximum gradient of park roads is less than 16 percentage of grade.

5. The park roads that were previously built in the national park of Thailand, mostly by the Highway Department, as provincial highways to connect different provinces together and not for tourism purposes.

6. The formulated multi-objective mathematical programming models to obtain optimal values for park roads design are minimal construction cost, minimal maintenance cost, minimal environmental impact, and maximal traveling safety model.

7. The optimize solutions of mathematical programming is shown in the table 2.

8. The results in table 2 shown that the minimal construction cost of 3.0 meters carriage width is 3,666,131 Baht/Km. The park road construction cost for lowest maintenance is 4,512,298 Baht/Km, and 4,991,756 Baht/Km for less environmental impact. However, the maximal traveling safety for traveler is cost 8,229,441 Baht/Km in park road construction. In multi-objective or multi-goal mathematical programming analysis results, the park road construction cost per kilometer of road length are 4,192,537.04, 4,621,079.47, 4,906,186.00, and 4,903,563.33 Baht respectively.

9. The summation of goal deviation ($\sum(d^- + d^+)$) is 1,336,565.399 Baht/Km. indicate that the park roads construction cost increase 1,336,565.399 Baht/Km in using multi-objective programming for decision support system.

10. The decision maker has many other optional choices in making decision on variables should be used for a better road condition, such as increasing carriage width(X_2) from 3.0 to 4.0-7.0, but the construction cost will increase 1,395,000 Baht/Km.

Table 2. The optimize solution of mathematical programming

Objective	Construction cost Baht/Km	Goal deviation		Multi-goal construction cost Baht/Km
		+d	-d	
Z_1	3,666,131	942,936.849	0	4,192,537.04
Z_2	4,512,298	393,628.225	0	4,621,079.47
Z_3	4,991,756	0	0	4,906,186.00
Z_4	8,229,441	0.325017819	0	4,903,563.33
$\sum(d^+ + d^-)$		1,336,565.399	0	

CONCLUSIONS

This study was aimed at presenting overview of decision support system (DSS) for park road management, and road planning and design in National Park. The park road construction cost was employed in assessing and modeling. A general statement of system requirement for DSS had been conceptualized to provide a set of core requirement and behavior for DSS for multi-criteria decision making in park road management.

The cost of park road construction from Khao Yai National Park indicated that the less environmental impact criteria in road construction and management resulted a highest cost of construction. However, the maximum traveling safety and minimum environment impact criteria did not much highly difference in construction cost. Thus, the decision maker of park road planning and design making should take these two criteria into account in preparing the proposed for Park Roads Standard for controlling park roads design and construction in national parks.

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