CONCLUSION AND RECOMMENDATION

Conclusions

The study of forest roads in national parks were never done before in the past study of Thailand. Even though forest roads were the simple structure, but served as a multi-objectives usages structure, directly and indirectly effected to parks management and ecology. Besides serving as communication routes, forest roads also were served as other objectives such as, as national park or wildlife sanctuary boundary line, as forest fire protection line, as earth dam or earth berm for flooding protection purpose, as earth berm bank of digging canals in mangrove forest. In addition, they also served as inspection path or nature study trail in national park for ecotourism purposes. However, forest roads might caused negative impacts to environment of forest areas if road construction and management were not properly managed. Thus, this research emphasized to study forest roads management and planning, forest roads design and construction, road usages, and road density in Khao Yai National Park. Moreover, the effects of forest road geometric design were included in the investigation. The mathematical models of road construction cost data were used to formulate multi-goal mathematical programming models to obtain optical values for park roads design geometry.

From the results of this study, could be concluded that Khao Yai National Park was the first national park in Thailand, later became ASEAN Heritage Park and nominated as a World Heritage Site in 14 June 2005, located at latitude 14 degrees 5 minutes to 14 degrees 15 minutes north, and longitude 101 degrees 5 minutes to 101 degrees 50 minutes west. The topography was varied from flat terrain, hilly, to mountain terrain. Therefore, the park was suitable for case study area of forest roads standard site. The national park with a total area of 2, 168.64 square kilometers or 1,355,400 rais occupied some part of Nakhon Ratchasima, Nakhon Nayok, Prachin Buri, and Sara Buri provinces.

The tourist statistics during 1991-2002 was 750,422 per year or 2,055 per day. The highest daily amount of tourist was in February, and lowest tourist was in May. Therefore, the average daily tourist at Khao Yai National Park was quite high. The annual traffic volume during 2000-2002 was 131,367 vehicles per year. The maximum daily traffic (ADT) was 641 vehicles per day in December, and minimum ADT was 258 vehicles per day in June. With these high ADT, the park roads were severe damaged during high tourist season. Therefore, the park roads were closed for traffic surface repairing by the Royal Forest Department during 1999-2001. The very high amount of tourist at 1,946 per day was highly effect to wildlife, nature, and ecological condition of National Park. Since then, the RFD introduced ecotourism practice into park management in Thailand by mean of park roads planning.

The results of forest roads study in Khao Yai National Park showed that there were two types of forest roads, unpaved and paved road existed in the park. The unpaved road was the earth road with compacted laterite soil surfacing, 5.0 meters width and 356 kilometers long, along the park boundary build during 1996-1997. It served for traveling path for park inspection duty for all park official and staffs to inspection point offices scattered along park boundary. It also served as nature trail, bike path for tourist, berm for earth dam, forest fire protection line, and park boundary line. The paved roads with permanent surfacing material, asphaltic concrete surface 5.50 meters width were highway 2090, 3077, and 3182 which total length of 72.092 kilometers built by Highway Department as provincial highway connecting Prachin Buri and Sara Buri provinces. Since 1993, the highways were delivered to Royal Forest Department for park service and maintenance, and closed for surfacing overlay during 1996-1997. The unpaved park roads, gravels or laterite soil road, in Khao Yai National Park were used mainly for park boundary purpose. The paved roads with surface treatment, or asphaltic or asphaltic concrete, or concrete pavement surfacing were mostly used for main roads of national parks. The carriage width of park roads including shoulders was less than 7.0 meters. The maximum gradient of the park roads was less than 12 percentage of grade according to the provincial rural highway standard.

The study of forest road standard for design, Park Road Standard of USA, Low Volume Road of UNESCO, Provincial Highway Standard of Thailand, and Forest Road Design Guide Line of RFD found that the standards were varied to objectives of road usages, and limitations in each standard. The forest road in National Park or park road in Thailand did not have any standard or guide line for road design and controlling.

The forest road density study in Khao Yai National Park, results classified by park management zones according to Khao Yai National Park Management Master Plan 1993, indicated that the Intensive use zone and the outdoor recreation zone, where the 72.058 kilometers long provincial highway was in-service, the forest road density were 0.802 km/km^2. The Special use zone, where the 7.50 kilometers long provincial highway was accessed, the forest road density was 1.017 km/km^2. The Recovery zone where the forest area had been disturbed or destroyed by villagers along the park boundary, there were the unpaved forest roads with laterite soil surfacing 315 km. long. The forest road density in this zone which was the highest one in Khao Yai National Park, was 1.709 km/km^2. The Strict nature reserve zone and the primitive zone, where the area were wilderness with no road, the forest road density were 0.0 km/km^2. The average forest road density of the total Khao Yai National Park was 0.185 km/km^2.

In formulating the mathematical models of forest road, the construction cost estimation of each road items were used to form the models. The forest road cost estimation was included all construction activities since the beginning of construction survey of road layout, clearing and grubbing, road bed formation, cutting and filling work, compaction, drainage structures, traffic sign and guard rail, soil erosion protection structures, until cleaning uninstall the site office, and machine moving out from construction site. The formulated multi-objective mathematical programming models to obtain optimal values for park roads design were minimal construction cost, minimal maintenance cost, minimal environmental impact, and maximal traveling safety model. The results from study indicated that the minimal construction cost of

3.0 meters carriage width was 3,666,131 Baht/Km. The park road construction cost for lowest maintenance was 4,512,298 Baht/Km, and 4,991,756 Baht/Km for less environmental impact. However, the maximal traveling safety for traveler was 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 were 4,192,537.04, 4,621,079.47, 4,906,186.00, and 4,903,563.33 Baht respectively. The summation of goal deviation ($\sum(d^{-}+d^{+})$) was 1,336,565.399 Baht/Km. indicated that the park roads construction cost increase 1,336,565.399 Baht/Km in using multi-objective programming for decision support system. The decision maker had 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 would increaser 1,395,000 Baht/Km.

This study was aimed at presenting overview of decision support tools 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. Classes of decision elements for the analysis of decision problems and of other DSS components were identified.

The cost of park road construction from Khao Yai National Park indicate that the less environmental impact criteria in road construction and management result in the highest cost of construction. However, the maximum traveling safety and minimum environment impact criteria were not cost highly big difference in construction cost. Thus, the decision maker of park road planning and design will take these two criteria into account in preparing the proposed Park Roads Standard for controlling park roads design and construction in national Parks. The results of the studied were concluded in details as follows:

The main objective of this study was finding the optimum values of the decision variables in road construction. Those variables were carriage width included shoulder, clearing and grubbing width, subbase thickness, base thickness, surfacing thickness, numbers of culvert installation points, numbers of rows of culvert installation in each point, culvert diameter, length of earth side ditch, length of concrete side ditch, number of guide post, milestone post, numbers of traffic sign, numbers of installation places in slope protection construction, numbers of installation places in retaining wall construction, and length of guard rail.

The resulted optimum values of the decision variables in road construction implied that the carriage width for one-lane, two-direction traffic was 3.00 meters and for two-lane, two-direction traffic was 5.00 meters. The clearing and grubbing width for one-lane, two-direction traffic was 9.00 meters and for two-lane, two-direction traffic was 15.00 meters. The laterite or gravel subbase thickness for one-lane, two-direction traffic and two-lane, two-direction traffic were 0.25 meter. The crushed stone base thickness for one-lane, two-direction traffic and two-lane, two-direction traffic was 0.20 meter. The asphalt concrete surfacing thickness for one-lane, two-direction traffic and two-lane, two-direction traffic was 0.05 meter. The rigid pavement of reinforced concrete for one-lane, two-direction traffic and two-lane, two-direction traffic was 0.15 meter with 0.10 meter of sand cushion layer underneath. The numbers of culvert installation points, numbers of rows of culvert installation in each point, and culvert diameter were strictly depend on terrain characters, rainfall intensity, duration of rainfall, storm characteristics, soil type, and vegetation cover. Then those variables were varied to each different road construction site. The length of earth side ditch and concrete side ditch were varied to the amount of run off water on road surface. The number of guide post and milestone post were varied to the total length of road. The numbers of traffic sign and the length of guard rail were varied to topographic of construction site and road alignment. The numbers of installation places in slope protection construction and the numbers of installation places in retaining wall construction were varied to soil type, topographic characteristics, and road alignment.

The difficulties and complications of this study were there was a few researches study about forest roads in national parks of Thailand in the past. Hence, neither research data nor forest roads planning and design statistics were cited in this study. There was no sound engineering forest road design standard in the national park, the provincial rural highway standard was mostly used in designing. The forest roads in national parks mostly were the connecting provincial highway between provinces together for agricultural products transportation purpose. The common traffic volumes were heavy trucks, or agricultural products containers, slowly maneuver traffic, frequently causing accident. There were no speed, vehicles, or traffic control device, or any regulation and limitations to control park roads usages. Many decision variables such as retaining wall construction cost, slope protection structures construction cost, were varied to construction site topographic.

The introducing applications of mathematical programming techniques applied to park roads management and planning for sustainable management purposes were the strength of this research. Thus, the future researches should be done to extend this study.

Recommendation

This study was trying to identify an appropriate technique in order to establish basic standard for forest road design and construction in national park. It can be accepted to propose this technique to the other areas. However, it still needs to clarify in more concerned factors and procedures. However, this study was only covered in a small number of inland national parks. Therefore, further study with increasing number of national park and covering all types of inland and marine national parks should be considered and taking into scope of study in order to cover all types of national parks and climatic conditions.

In future research and studying of forest road to find out guideline or practical standard for forest road management in national conservation forest of Thailand, the recommendations for future work are suggested as following.

1. The other objectives of forest road construction such as forest road construction for boundary line purpose, for study trial purpose, for forest fire protection etc., should be taken into consideration for analysis and comparison.

2. Use the other difference areas such as wildlife sanctuary, high land watershed basin, national reserved forest, as the case study area for mathematical modeling formation.

3. The decision variables such as cut and fill volume were varied to road width fourth series, cut and fill length power three, and side slope square. Therefore, the nonlinear mathematical programming should be considered as alterable techniques to analysis the data in forest road construction.

4. The minimum maintenance goal, the minimum cut and fill goal, and the minimum gradient should be the alterable options in data analysis and formation the models.

5. Some decision variables such as gradient, road width, were varied in the certain range known value, hence the fuzzy mathematical programming (Lai and Hwang, 1992; Zimmermann, 1993, 1996) could be applied in the future study.

6. Besides modeling of forest road standards in the national park, the wildlife sanctuary area, the highland watershed area, and the national reserved forest could be needed of forest road standard for planning and controlling.

The study intended to recommend appropriate design standard for forest road in National Park of Thailand for eco-tourism purposes as proposed on the next topic.

The Proposed Park Road Standard

The proposed park road standard as a road guide line for design and construction in National Park of Thailand was prepared. These proposed park road standard is mainly for tourism purpose. The park roads in the National Park served as a communication way and a sight seeing route for tourist in National Park. The proposed standard is based on low volume road standard of UNESCO, Park Road Standard of USA (National Park Service, 1984), and provincial road standard of Highway Department of Thailand. Some adjustments of design values and limitations were made to fit to National Park regulation and limitations.

The details of the proposed standard can be summarized as shown in Table 31.

Table 31 Design standards criteria of the DNP for Park Road Geometric Design

No.	Descriptions	Terrain type for Park road			Remarks
		flat	hilly	mountain	
1	Minimum height of embankment above HWL. (m)	0.50	-	-	5 years cycle of storm
2	Design speed (km/hr)	40-60	30-40	20-30	
3	Minimum turning radius (m)	75-110	40-75	25-35	
4	Maximum gradient (%)	8	12	16	Max.allowable 17% in highly mountain or watershed area
5	Surfacing materials				
	a. soil aggregate	✓	✓	✓	
	b. asphaltic, concrete	✓	✓	✓	

Table 31 (Continued)

No.	Descriptions	Terrain type for Park road			Remarks
		flat	hilly	mountain	
6	Shoulder (m)				
	a. soil aggregate	✓	✓	✓	
	b. asphaltic, concrete	0.50	0.50	0.50	
7	Carriage width (m)				
	a. traffic volume > 10,00 VPD	6.0	5-5.5	5.0	
	b. traffic volume < 10,00 VPD	5-5.5	5-5.5	5.0	
	c. traffic volume < 300 VPD	4.5	4.5	4.5	
8	Right of way (m)	20	20	15-20	
9	Non Passing Sight Distance (m)	110	30	30	
10	Super Elevation Rate- SE (m/m)	0.10	0.10	0.10	
11	Widening (m)	1.0	1.0-1.5	1.0-1.5	
13	Wheel Load (kg)	HS20	HS20	3,000	
		8,000	8,000	- 8,000	
14	Traffic volume (VPD)				
	a. Main roads	<2,000	<1,000	< 300	
	b. Secondary roads, Feeder road	< 500	< 300	< 100	
	c. Special purpose, inspection path, etc.	< 300	< 100	< 50	

Limitations

A. Minimum Turning Radius

Flat terrain	75 – 110	meters
Hilly terrain	40 – 75	meters
Mountain	25 – 35	meters

B. Height of road bed above HWL. not less than 0.50 meters

C. Crown Slope not less than 4%

D. Design Speed 20 – 60 Km/hr(KPH)

E. Carriage width 3.50 – 6.00 meters

F. Maximum gradient in typical terrain shall not exceed 16%.

G. In highly mountain, or watershed area, or special extreme case by consulting of engineer, maximum gradient greater than 16% can be allowed by approval of NPD, but in any case shall not exceed 17%.

H. The vertical alignment grades greater than 12% road length shall not continuously longer than 500 meters and not shorter than 150 meters.

I. For unpaved road, if the vertical alignment grade greater than 12 %, road surface must be paved by soil cement, or asphaltic concrete, or concrete pavement, or other durable surfacing material by approval of NPD for erosion protection and safety purposes.

J. Tree cutting and felling within right of way is prohibited. Tree within right of way which diameter at breast height (DBH) greater than 30 centimeters shall be transferred to road side or given places.

K. Carriage width included shoulders shall not greater than 7.00 meters