RESULTS AND DISCUSSION

The results of studied were defined according to purposes of study as following:

1. The study results of the park road planning and design, road construction, road performance, and park road density in National park indicated that;

1.1 The study of tourist statistics and from field data collecting showed that during 1991-2002, the total tourist was 750,422 per year or 2,055 per day. The highest daily amount of tourist was 1,946 in February, and lowest tourist was 1,225 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.

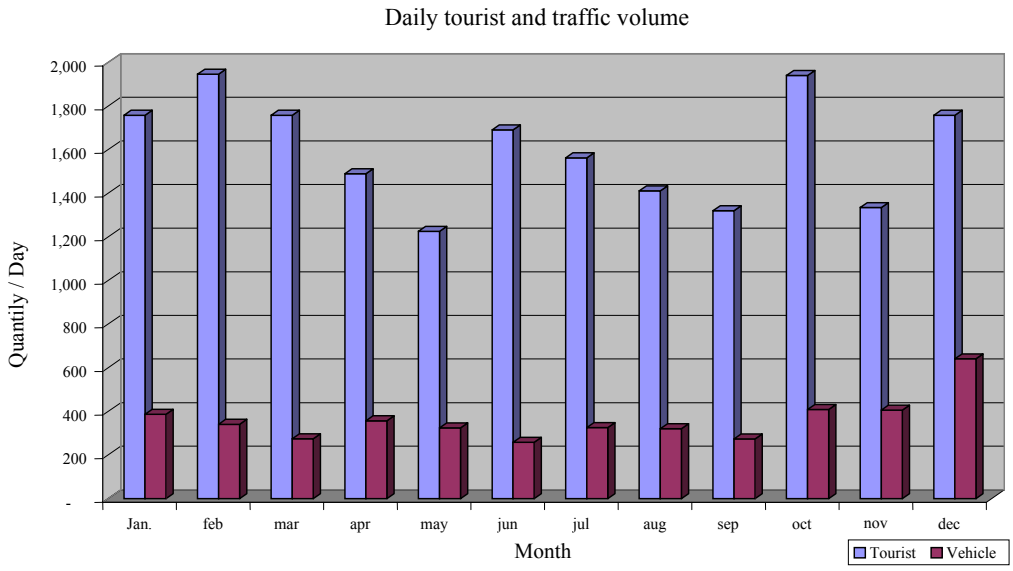

Figure 18 Daily tourist and traffic volume in Khao Yai National Park during 2000- 2002.

The maximum daily traffic(ADT) was 641 vehicles per day in December, and minimum ADT was 258 vehicles per day in June as shown in Figure 18. 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 may highly effect to wildlife, nature, and ecological condition of National park. The RFD introduced ecotourism practice into park management in Thailand since then by mean of park roads planning.

1.2 The increasing of tourist and volume traffic each year caused Khao Yai National Park congested. In remedy this critical situation, the park planning for forest road utilities were tentatively planned. Beside for traveling purpose, park roads were built to serve as forest fire protection, inspection paths, bike path, forest trails, and park boundary line since 2004.

1.3 The forest roads were a multi-purposes structure in forest work. Besides traveling purpose as mention earlier, they served as boundary line for national park and wildlife sanctuary or forest plantation. Also, they served as earth dam to detain surface water for wildlife, or earth berm for flooding protection, as a berm in mangrove forest.

Unpaved forest road

Paved forest road

Figure 19 The unpaved and paved forest roads in Khao Yai National Park.

1.4 The results of forest roads studied in Khao Yai National Park showed that there were two types of forest roads, unpaved and paved road existed in the park as shown in Figure 20. The unpaved road was the earth road with compacted laterite soil surfacing, 5.0 meters width and 356 kilometers long, along the park boundary built during 1996-1997 as shown in Figure 19. It served for traveling path for park inspection duty for all park officials 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, as shown in Figure 19 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.

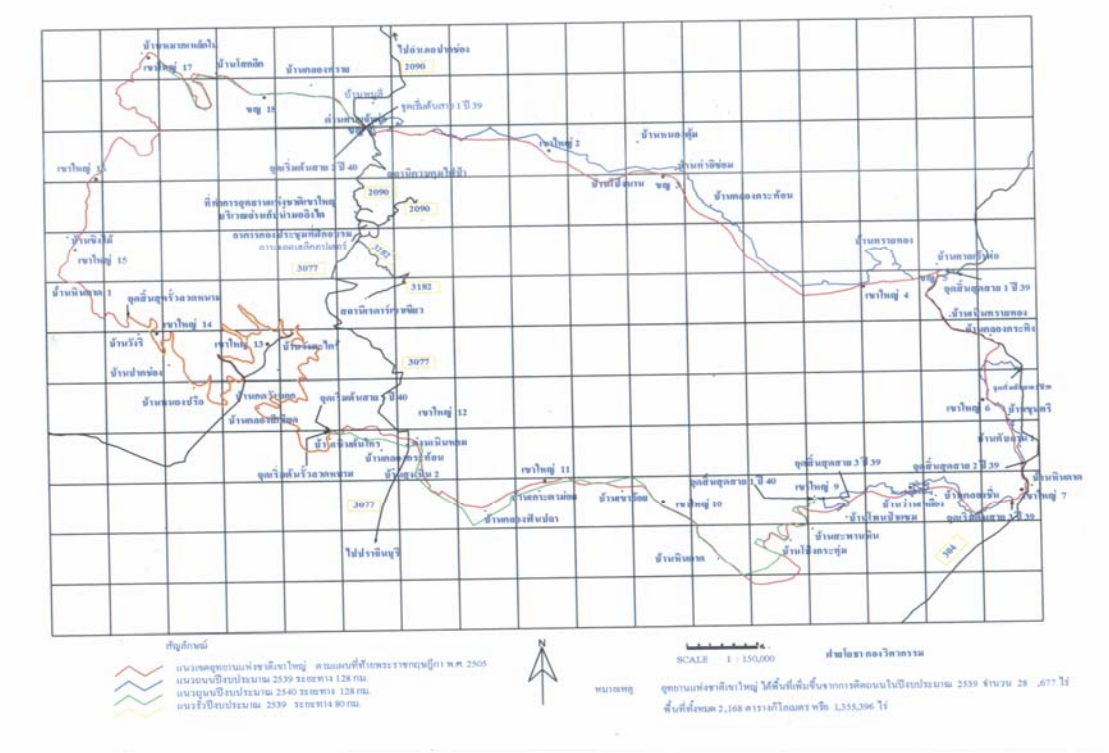

Figure 20 Forest roads in Khao Yai National Park.

1.5 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 according 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 guideline for road design and controlling.

1.6 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, as shown in Table 28 and Figure 21, indicated that;

Table 28 Forest road density in Khao Yai National Park classified by management zones

Management zone	Area (km^2)	% of total area	Forest road length (km)	Forest road density :FRD (km/km^2)
1.Intensive use zone, Outdoor recreation zone	89.82	4.14	72.058	0.802
2.Strict nature reserve zone	5.67	0.26	0.000	0.000
3.Special use zone	14.75	0.68	15.000	1.017
4.Recovery zone	184.37	8.50	315.000	1.709
5.Primitive zone	1,874.34	86.42	0.000	0.000
Total	2,168.96	100.00	402.060	0.185

1.6.1 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.

1.6.2 The special use zone, where the 7.50 kilometers long provincial highway was accessed, the forest road density was 1.017 km/km^2.

1.6.3 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.

1.6.4 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.

1.6.5 The average forest road density of the total Khao Yai National Park was 0.185 km/km^2.

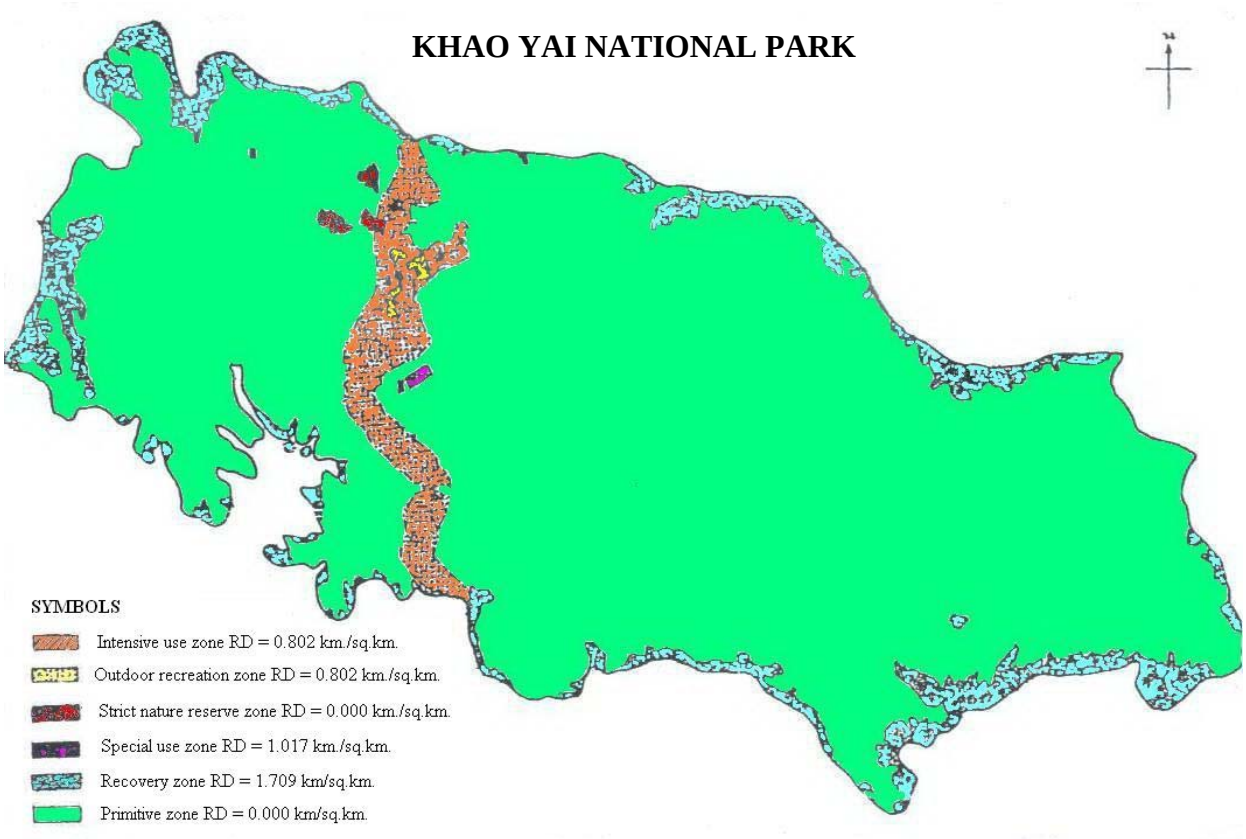

Figure 21 Forest roads density map in Khao Yai National Park classified by management zones.

1.7 The study of existing road design in Khao Yai National Park found that the three highways were provincial highway standard, rural type, class F4, with 5.50 meters carriage width, and 5 centimeters thick of asphaltic concrete pavement surfacing.

2. The geometric design of park road in national park area were studied on the three main highways 2090, 3182 and 3077 within Khao Yai National Park. The results of study were summarized as follows;

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

2.2 There were many sharp curves on highways 2090, 3182.

2.3 There was low traveling safety for tourist, or new visitors who were unfamiliar with the routes.

2.4 There was inadequate traffic signs for new visitors.

2.5 There was inadequate stopping sight distance.

2.6 There was inadequate passing sight distance.

2.7 There was inadequate headlight sight distance

2.8 There was inadequate sides parking or scenic overlook parking points for viewing scenery in safety.

2.9 There was inadequate drainage structures.

2.10 There was inadequate soil protection structures.

2.11 There was inadequate turning radius.

3. The multi-objective mathematical programming models as decision support tools for Park Roads management were formulated and optimized. The results of study were listed as follows;

3.1 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.

3.2 The forest road cost estimation in National park was determined estimated cost of all road construction items by area unit, by volume, by distance, by number of construction points, and so on by lump sum method. The overall total labor cost and materials were sum up for the whole project, then added up with operation, risk factor, percentage of profit, tax, in term of F-factor to obtain the total final construction cost of the project.

3.3 The mathematical model of forest road in Khao Yai National Park resulted for the minimum construction cost from this study as shown.

$$Y = 554{,}609.7043 + 225{,}570.671X_2 + 2{,}561X_3 + 100X_{18} + 500X_{19}$$

where:

Y = road construction cost(material cost + labor cost) in Baht/km.
X_2 = road width included shoulder width in meters
X_3 = clearing and grubbing width in meters
X_{18} = length of side ditch in meters
X_{19} = length of concrete gutter in meters

The optimal construction cost(material cost + labor cost) of forest road mathematical model was 1,239,005 Baht/km.

Therefore, the total construction cost (included F factor)

Total cost	= F x Y	Baht/km.
	= 1.4180 x 1,239,005	Baht/km.
	= 1,756,909	Baht/km.

Where the decision variables were;

3.3.1 The road width with surface pavement (X_2) = 3.0 m

3.3.2 The clearing and grubbing width of each side of roadbed (X_3) = 3.0 m

3.3.3 The length of side ditch (X_{18}) = 100 m

3.3.4 The length of concrete gutter (X_{19}) = 500 m

3.4 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.

Table 29 The Goal Mathematical Programming Models

Goals	Mathematical Models
Z_1	$1{,}388{,}250.17+4{,}961{,}033.36X_2+37{,}256.66X_3+1{,}087{,}325X_2X_{10}+1{,}613{,}450X_2X_{11}+18{,}940{,}500X_2X_{12}+45{,}500X_{13}X_{14}+4{,}550X_{13}X_{14}X_2+1{,}782X_{13}+810X_{13}X_{14}+1620X_{13}X_{14}X_{16}+23{,}192.24X_{13}+19{,}384.35X_{13}X_{14}-8{,}175.50X_{13}X^2_{14}$;
Z_2	$17{,}625{,}120.69+3{,}261{,}975X_{10}+4{,}840{,}350X_{11}+56{,}821{,}500X_{12}+59{,}150X13X_{14}+1{,}782X_{13}+810X_{13}X_{14}+1{,}620X_{13}X_{14}X_{16}+23{,}192.24X_{13}+19{,}384.35X_{13}X_{14}-8175.50X_{13}X^2_{14}+150X_{18}+470X_{19}$;
Z_3	$17{,}197{,}350.69+37{,}256.7X_3+3{,}261{,}975X_{10}+4{,}840{,}350X_{11}+56{,}821{,}500X_{12}+59{,}150X_{13}X_{14}+1{,}782X_{13}+810X_{13}X_{14}+1{,}620X_{13}X_{14}X_{16}+23{,}192.24X_{13}+19{,}384.35X_{13}X_{14}-8{,}175.50X_{13}X^2_{14}+150X_{18}+470X_{19}+10{,}000X_{22}+3{,}600X_{26}$;
Z_4	$9{,}405{,}912.42+2{,}277{,}778.5X_2+37{,}256.7X_3+3{,}261{,}975X_{10}+4{,}840{,}350X_{11}+56{,}821{,}500X_{12}+59{,}150X_{13}X_{14}+1{,}782X_{13}+810X_{13}X_{14}+1{,}620X_{13}X_{14}X_{16}+23{,}192.24X_{13}+19{,}384.35X_{13}X_{14}-8{,}175.50X_{13}X^2_{14}+150X_{18}+470X_{19}+1{,}100X_{21}+X_{22}+36{,}000X_{26}+1{,}400X_{30}$;
Z	$2{,}314{,}250.17+4{,}961{,}033.43X_2+37{,}256.7X_3+1{,}087{,}325X_2X_{10}+1{,}613{,}450X_2X_{11}+1{,}8940{,}500X_2X_{12}+59{,}150X_{13}X_{14}+1{,}782X_{13}+810X_{13}X_{14}+1{,}620X_{13}X_{14}X_{16}+23{,}192.24X_{13}+19{,}384.35X_{13}X_{14}-8{,}175.50X_{13}X^2_{14}+150X_{18}+470X_{19}+10{,}000X_{22}+$

$36{,}000X_{26};$

3.5 The optimize solutions of multi-goal mathematical programming were shown in the Table 30.

Table 30 The optimize solution of mathematical programming

Objective	Construction cost (Baht/Km)	Goal deviation		Multi-goal construction cost (Baht/Km)
		+d	-d	
Z_1	3,249,690	942,936.849	0	4,192,537.04
Z_2	4,512,298	393,628.225	0	4,621,079.47
Z_3	4,906,186	0	0	4,906,186.00
Z_4	4,903,563	0.325017819	0	4,903,563.33
$\sum(d^+ + d^-)$		1,336,565.399	0	

3.6 The results in Table 30 shown that the minimal construction cost of 3.0 meters carriage width is 3,249,690 Baht/Km. The park road construction cost for lowest maintenance was 4,512,298 Baht/Km, and 4,906,186 Baht/Km for less environmental impact. However, for the maximal traveling safety for traveler was 4,903,563 Baht/Km in park road construction cost. 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.

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

3.8 The decision maker had many other optional choices in taking decision variables such as increasing carriage width (X_2) from 3.0 to 4.0-7.0, but the construction cost would increased 1,395,000 Baht/Km.