1.7 Forest Road Construction

Forest road construction on the flat terrain very often have a surface of earth or sandy clay with, occasionally, a top dressing of gravel. In hill region where cutting has to be made into the hillside, the subgrade may be of some harder formation such as earth and gravel, soft limestone, and etc. Economy is often a primary factor in road construction and, In the forest there are various soil formations which give a good wearing surface for light traffic, provided the road surface has been initially compacted and that provision has been made to drain off surface water.

There are various soil formations, in the form of decayed rock which stand with very well to light traffic. For an earth road to give any reasonable service, however, it is essential that the road surface should be consolidated and well drained. The soil types and foundation value for road bed formation is shown in Table 2.

1.7.1 Road Formation Construction

The road line is marked out, either by pegs or by marking the trees on each side of the clearnce area. If it is possible to carry material to the stream crossings, culverts should be constructed well ahead of the dozer. Unless the grade is critical, or in some exceptional cases, it is not necessary to insert any level pegs to aid the dozer operator. Where the grade is not acute the actual level of the finished formation is not very important, so long as it is smooth and even.

The dozer, which should start work at the highest point on the proposed road line, cuts the required formation, including camber, crossfall, and super-elevation. Usually the dozer is used with its blade angled. The side drain is taken out with the blade dipped and angled. The dozer works its way along a hillside by building a platform of soil and casing the cut out wards and onwards. The most efficicnt size of dozer is the D6, D7 or D5C. The D4 is very useful but lacks power for the heavier work and speedy production. The D2 is too small and almost useless for road construction work. The D8 is too large and cumbersome. When the formation nears the required level an cven surface is obtained by backblading. If the excavation occurs in a well graded material suitable for a base, care should be taken not to waste much of it by pushing it over the side. It should be brought forward by the dozer to cover nearby softer patches, or may cven be transported elsewhere by dumper or lorry.

The work for the whole year should be diveded into dry-weather and wetweather work. Certain jobs can be done only in summer, whereas some be tackled all the year round, as would be the case in well drained soils. By taking this factor into account in the planning of the programme, a minimum of waste time will be achieved.

Table 2 Soil types and foundation value for road bed formation guide

Soil types	Foundation value
Coarse grained soils	Very good
Sands and sandy soils	Good
Fine grained soils	Fair
Organic soils	Useless

Sources: Modified from Highway Department (1978); Keller and Sherar (2003)

1.7.2 Road Base

If one measured the tyre contact areas and the weight of a vehicle one would, theoretically, by referring to the bearing capacity, be able to determine whether a soil would be sufficiently strong to withstand the pressure from the vehicle.

Table 3 Safe load of subgrade materials

Material	Safe load in tons per m^2
Hard rock	300
Average rock	200
Soft or weathered rock	100
Dry clay	45
Sand and gravel, compacted	45
Chalk	20-45
Loam and alluvial soils	3-8
Average firm earth	10

Sources: Modified from Highway Department (1978); Keller and Sherar (2003)

The pressure exerted from the tyre on the soil spreads out at an angle of approximately 45 degrees each side, and so it is possible, by adding a layer of material as a base, to spread the load over a larger area. The deeper the base coat the less will be the resultant pressure on the subsoil. Therefore, according to the bearing power of the load. The base coat may be of many different materials, though in the forest it is likely to be of some local material, such as weathered rock. The safe load of subgrade materials are shown in Table 3.

1.7.3 Road Surface

On top of the road formation is laid the road surface. A very geneal statement is to say that this top layer is of the best material available. For many forest roads abroad, lack of funds or dearth of suitable material necessitate only a top dressing of earth being spread and consolidated. Earth roads very readily cut up and ruts and potholes form on the surface. The surface drinage is a major problem.

The stabilization of soils is a mater of great importance for forest roads where so many roads have an earth foundation and an earth surface. Earth cuts up readily but is permeable. A mixture of sand and loam is stable under certain conditions, where the proportion of water is not too high. A sand and silt soil stands with well when moist, but cuts up badly when dry. Dried, is very unstable, but when sand is wet each grain is coated with a thin film of water. This film has sufficient surface tension to hold particles together, thereby greatly increasing the load which the road surface can bear. As the sand dries the surface tension disappears and the sand grains then move apart.

A clay soil, when dry, is hard and stable but very unstable when wet. Clay if used alone in a road, always gives trouble. Clay has a very great affinity for water and rapid absorption and hence its weakness and instability. The cohesive strength of clay is high and a mixture of sand and clay binds well, had good wearing qualities and has a certain degree of permeability. The materials should be thoroughly mixed and proportioned to get the best results but these ideal conditions have to be governed by local circumstances and are difficult to achieve for forest roads. The addition of gravel to a sand-clay road adds considerably to its wearing.

A thorough binding results in a satisfactory road for light traffic. Compacted earth, whatever its composition, will absorb water much more slowly than loose soil. On any beaten footpath or road, even after a heavy down pour, it will be found that the ground is wet only to a slight depth, whereas the soil on either side of a footpath may be quite soft after rain. The compacted surface stratum forms a waterproof coat. If the road surface is given a camber or a slope, enabling the rain water soaking through the upper crust. In a road of path, however, animals' hoofs and tyres of vehicles break up this hard compacted crust and the rain water penetrates deeper. Thus the point is again stressed that it is essential to give adequate drainage to the road surface and to take all measures possible to get water out of the ruts.

Manufactured road surface dressings are seldom used in the forest, due to their expense. In most cases the road base and wearing surface are the one and same thing. Normally, even on low standard public roads, a base of stone would be placed on the sub-soil formation and covered with a surface dressing, designed to form a wearing and waterproof surface. The most popular surface dressing for public roads today is tarmac. It consists of a graded hard stone mixed with tar or bitumen to form a sticky mass. The processing is generally carried out at the quarry where there is mixing plant installed. The stone is heated prior to the hot bitumen being poured over it and remixed. It can be laid by hand or spread mechanically. It gives a long wearing, smooth surface, which is anti-skid.

Bitumen and tar compounds are used as surface dressings, very often in the work maintenance.

1.7.4 Weathered Rock as a Road Base

Weathered rock can often be used to advantage, especially if it has to be excavated in any case to make the formation of a nearly section of road. Naturally crusted rock may sometimes be found, which has been fragmented by heat and pressure long ago, so providing a satisfactory source of cheap road stone. Shale weathers easily and provides a useful supply. For forest roads, the fact that shale is soft is turned to advantage. Part powders down under traffic and causes the whole to bind into a solid carpet. Broken shale fragments, spread over the road in thickness varying from 3 to 20 cm, have proved very satisfactory. If a dozer operator, during his excavation work, unearths a supply of broken stone or good material, the engineer in charge should make full use of it. Very often, when a suitable supply is found, just a little is used, and then the source is covered up and forgotten. It is fully realized that gaping excavations on the roadside in the forest do not add to the beauty of nature, but such a supply can be worth several thousand pounds. The area can be left tidy, and the space used to form a passing place.

1.7.5 Gravel as a Road Base

Strictly speaking, gravel is defined as stone varying in size from 0.2 to 2 cm. If the majority of the particles are of the same size, then gravel is unsuitable for a road base. Material of equal sized grains would be, by itself, unstable, and the vehicle's wheels would spin and rut the surface. The same effect happens with a base of crushed stone if the size is small and the grading not varied.

For a gravel base to be satisfactory the gravel should be angular, of varying grades, and made into a solid mass by the addition of some fine material, preferably a clay mixture.

1.7.6 Hardcope as a Road Base

This name is given to rubble from demolished buildings, or to any material of a like nature. It may contain broken brick or stone rubble. It can form a good road base, especially if it is well graded and not too high a percentage of "fines" laid in one place. It should be surfaced if the broken brick is inclined to crumble, otherwise, with rain, it will powder into a soft patch. Some times the stone is too large and has to be broken. Because of that reason and the fact that it is not policy to surface-dress forest roads, it is not satisfactory for forest use. The demolition work is often carried out by excavator, which results in the loads being very badly mixed, some with a large quantity of decayed mortar and plaster, which, by itself, is useless. The supply is limited and often distributed over a wide area, making loading expensive. It can be spread by machine or by hand, but in no case would it be hand placed as with "pitching".

1.7.7 Pitching

"Pitching" strictly means the placing of stone by hand so that the narrower end is placed on the ground and the longer side of the stone is standing a little off vertical. The size of the stone for road making should be from 15 to 30 cm on its longest dimension. The projecting points are broken off by sledge hammer and the voids filled in with a smaller gauge stone. The road is then rolled with a heavy roller, working in from the edge. For greater accuracy, level pegs should be put in every 3 to

6 m. A pitched road is very strong but, due to the need to use strong hard stone and hand placing it is expensive, and not often seen in the forest.

1.7.8 Repairs to Unmetalled Roads

Repairs to ruts, potholes, etc., in the road should be carried out as soon as possible. In the tropics, it is too often the custom to carry out road repairs at the close of the rainy season and during one period in the year. Admittedly at that time the soil is soft and can readily be worked and consolidated, but if any pothole or rut, breaking the top hard compacted crust, is left unattended for months, the resulting damage to the road and the general cost will be much greater.

Rather than carry out repairs all at the one time, it is much sounder policy and cheaper practice, to patch the road surface as soon as there are signs of wear. Where a stretch of road is in constant use, much better and cheaper results are obtained in road maintenance by dividing the road up into suitable stretches and keeping a permanent repair gang working on repairs up and down their particular stretch.

A permanent road gang not only maintain the road surface, increasing general efficiency and reducing the total cost of repairs, but they can maintain the drainage system and keep the drains and culverts clear. A culvert choked during one heavy downpour may cause a lot of damage to the road and upset the drainage scheme generally if not cleared before the next flow of flood water.

For repairs on an unmetalled road, there is a temptation to use materials other than the soil of the road surface for filling up ruts and potholes. The patching material should be the same as that of the road bed, otherwise an uneven surface is likely to result. The soil for repairs should be free from any vegetation. Patches and ruts which have been repaired should be thoroughly rammed or rolled to ensure the maximum consolidation.

1.7.9 Cement Stabilization of Soil

Experiments have been carried out on soil stabilization, using cement as a stabilizer, by various public bodies. While satisfactory results have been obtained on actual works and fairly large scale experiments, this construction appears to be still somewhat in its experimental stage.

As has already been discussed, many soils can be compacted under particular moisture conditions to give a very satisfactory bearing surface for wheeled traffic. It might be noted that a satisfactory "bearing" surface is not quite the same as a satisfactory "wearing" surface. We all know too well, conditions to be met with in forest earth roads, which, for some months, may be well consolidated but in the rains are inches deep in mud and, in the very dry weather, inches deep in dust; both abnormal conditions raising traffic difficulties, Where earth roads have, perforce, to be as widely used as in the forest works, this matter of soil stabilization, if economically feasible, would be of very great importance. Whichever method of stabilizing the soil is used, the aim in all cases is the same, to get a firm soil which will remain reasonably firm for some time. The addition of cement is acting as a binder and giving the soil added resistance to wear and to the softening action of water.

Soil moisture content-For any soil there is an optimum moisture content, under which conditions satisfactory compaction may be achieved. Each grade of soil will have natural moisture content. There can be no stability of the moisture content in soils by any drainage system because some soils will retain moisture despite all attempts at drainage, whereas other soils will readily drain themselves dry. In the case of a soil with low moisture content there will be a high air content and a successful compaction cannot be brought about. A soil with high moisture content will have a much lower air content but the increase in the water content will tend to keep the soil particles apart and prevent satisfactory compaction. Once a soil has been properly compacted under optimum moisture conditions it will absorb much less water during rains than a soil not so compacted and the question is to decide the optimum moisture content for any particular classification and grade of soil. The natural moisture content of that soil has to be raised (or, on occasion it might be, lowered) to the optimum moisture content.

Grading of soils-It is laid down that soil, for cement stabilization should be free from any organic matter, be friable at a low moisture content and should be well graded. Each classification and grade of soil will have its optimum moisture content.

As a general rule, it can be stated that predominantly sandy soils require least cement and finish up hard and compact. They require 6-12 percent. of cement. Silty soils require at least 8-12 percent of cement and harden well. Clayey soils require 10-15 percent of cement and harden reasonably well.

Much of the actual and experimental stabilization work appears to have been carried out on areas such as aerodromes and assembly yards where the work could be concentrated and where expense was of less importance than expendiency. For forest roads expense will rule out much of what should be done in the way of regrading the soil. Soils with too much clay or too much gravel would require some of the undesirable material removed but, for forest roads, that would hardly be a practical proposition and the most that could be done to improve the grading would be the addition of some imported soil such as sand, The best results would appear to be with a soil having a mixture of silt, sand and gravel. The soil should contain a fairly high proportion of sand with a well graded gravel content. There will be much more variation in the soils to be considered for soil stabilization than for the various coarse aggregates to be used in various concrete mixes and, for any stretch of road of any importance, there would have to be a preliminary testing of the soil to decide what could reasonably be done to improve the grading and to find out the natural moisture content of the soil and its optimum moisture content.

Regrading of the soil-As in the case of concrete laid on a sub grade, the “concrete earth” would have to be laid on a soil reasonably well compacted. It would be best to roll an earth road well, before any regrading were done, in order to make sure that the subsoil were well compacted. The top soil to a depth of about 15 cm would then have to be dug up or ploughed up and any clods brocken up by means of mattocks or harrows. In a work of this nature, disc harrows drawn by a tractor would give the best results but, for forest roads, seldom would mechanical agricultural implements be available and shift would have to be made with hand labor. The proportion of sand and gravel which it was decided should be added, would then be spread and thoroughly mixed in. It appears to be difficult to say what is the ideal mixture as regards the soil, but 2 parts of soil (largely sandy) to 1 part of graded gravel appear to give satisfactory results. The cement in the required proportion, 10 per cent. to 12 percent., would be spread on top and then thoroughly mixed in down to a depth of at most 15 cm. The mixing is carried on until the soil has a more or less even color. In experiments carried out, the mixing of the cement was done by mechanically operated cultivators and disc harrows which would be much more effective then mixing by hand.

Watering – Water has to be added, sufficient to bring the natural moisture of the soil up to the optimum moisture content and, on hot and windy days, an extra proportion of water of about 2 percent given as an allowance for evaporation. The water would be added by spraying either from a water cart or from watering cans fitted with a hose. At the time of adding the required extra water, further mixing would be done. The wet mixing would be followed by rolling. For forest roads a ballast roller would have to make do but repeated rollings with a ballast roller would give a “sheepsfoot roller” which is a special type or roller with projections, enabling the soil to be packed before being rolled to an even surface with the ordinary type of road roller.

As in the case of ordinary concrete, “earth concrete” requires to be cured and, after the surface had been well rolled with the ballast-roller, the surface would require to be kept damp for some days.

The earth concrete would not give sufficient bearing surface and would be deficient as regards wearing qualitities but would give much better resistance to wear if given a top dressing of quarry chips or broken gravel and hot tar. Any stabilized soil has a very short life if it is not surfaced.

As an alternative to stabilization of the soil by using cement, a top dressing of a lean mix concrete could be given. A surfacing consisting of a 14 : I lean concrete mix (that is l part cement to 14 parts of fine aggregate) would materially assist in waterproofing and would give some sort of a bearing and wearing surface.

Wherever cement is used one of the main dangers to be guarded against is damage by forest and any probable trouble from such a cause would have to be considered when and where cement earth was being considered as a road construction material.

1.7.10 Gravel Roads

A road subject to much traffic requires a harder wearing surface than can be given by any earth surface. Where gravel is available, a top dressing of gravel gives the road surface extra wearing qualities and resistance to abrasion. Gravel alone does not bind well and requires the addition of sand and of clay for binding. Gravel in situ is usually mixed with sand and clay but if there is less than 10 per cent. of clay in the mixture, extra clay should be added to give the required minimum proportion and the whole thoroughly mixed.

For economy the width of the road to be graveled need not exceed 1.8 to 2 m, sufficient for a single track road. Shallow trenches should be cut from the outside of the width tailing off to ground level at the centre of the road, these trenches helping to confine the gravel to the actuac road. With gravel there will always be a tendency for the gravel to be pushed off the road at the haunches. The finished cutting will be of the shape of the proposed finished camber.

The supporting sub-grade should be improved where necessary by compacting the sub-grade where required and by filling up and soft pockets with some compacted material. The gravel should be spread in layers of not more than 7.5 cm in thickness and each layer should be well rolled, water being used in the consolidation. The quantity of water to be used will depend somewhat on the composition of the sub-grade but as a general rule about 5 litre of water is used for each square meter of surface. If rolling can be done this should be from the sides or hauches towards the centre of the roadway to prevent any gravel being forced on to the berms. Very often funds permit only of the gravel being spread on the surface and of leaving the traffic to work the gravel into the soil. Where two or more layers can be spread, the gravel can be partly graded, the coaser gravel being at the bottom and the finer gravel on top. For a road with a foundation of gravel, a top dressing of bitumen or cement mixed with sand and stone chippings gives a satisfactory binder course with good waterproofing qualities.

1.7.11 Roads in Swampy Areas

Forest roads in some special case have to be taken across swampy stretches. With the sub-grade far from stable, some construction has to be given to ensure there being an adequate foundation. Where stone is available, large soling can be hand placed with the broadest face of the stone resting on the sub-grade to give the maximum bearing. No figure can be given as to what depth the foundation course should be and, in marshy ground, where the road has to be kept open, it might be that this foundation course of large soling might be as much as 2.4 m in depth forming a sort of underground stone causeway before the bottom soling was resting on anything of a firm footing. The soling need be only for the actual road width and the sides of the road can be made up with earth. The top dressing can be taken across the full width of the made-up bund.

An alternative to the use of stone is to use timber to form a bearing carpet to rest on the soft sub-grade. One form of construction is to have a layer of logs, 45 cm or more in diameter, at right angles to the line of the road. These logs are somewhat longer than the proposed width of the road, and the distance apart at which they are laid varies from side by side to about 1.8 m centre to centre, according to the bearing capacity of the soil. On these cross logs, longitudinal logs are laid side by side in the line of the road. These longitudinal logs would vary in size according to the traffic load and the distance spart at which the cross logs were laid and normally are 10 to 20 cm in diameter. The joints are staggered, that is, broken. To hold these long logs in place, either the cross logs can be notched on their upper surface, for a width equal to the width of the road, or these logs can be nailed down. The outside logs must be kept from spreading and the outside to prevent any lateral movement. Across these long logs is laid a layer of brushwood, reeds, canes or any such packing. Some wearing surface is required, and this can be either a layer of small poles or a layer of bamboo matting. With poles as a top layer, a side pole would have to be fixed along each side of the track to help keep the poles in place.

For construction of this nature, there tends to be rapid decay of the timbers and species with the maximum resistance to decay should be used in the lower layers. A top dressing of earth is not recommended. The earth is not a good wearing surface and very readily cuts up. It holds the moisture, greatly speeding up decay in the timbers and an earth surface requires greater tractive effort than a surface of poles or bamboo matting. The poles present some difficulty for animals but a top dressing of grass, reeds, etc., will help to fill up the interstices.

The laying of poles side by side across the width of the road and at right angles to the line of the road is usually known as “corduroying”. Such a layer can be laid direct on the ground where the soil has reasonable bearing and where the road is only in very temporary use. In a temporary construction of that sort, added bearing can be given by having a layer of brushwood, of varying depth, below the corduroying. Alternatively, fascines can be made from brushwood and laid on the soft soil.

1.7.12 Tracks Over Soft Sand

A temporary track across soft sand can be made for wheeled transport by laying bamboo mats. These mats are made from woven split bamboo and can either be in lengths of 3 to 3.6 m with a width of 1.8 or 2.1 m or have a width of 0.75 to 0.9 m, laid in two tracks. These mats are pegged down by long wooden pegs driven into the sand. They will stand up to normal wear and tear for a matter of weeks and it is a simple matter to make any replacements. Bamboo mats of this nature are much more quickly cut up by iron tyred vehicles than by motor tyred.

An alternative track on sand is to have a carpet of grass, rushes, palm leaves or any such temporary surface dressing to distribrute the load on the tyres over the sand and give an abrasion surface for the tyres to grip.

1.7.13 Bulldozer

1.7.13.1 Bulldozer

The bulldozer is probably the most useful piece of engineering plant in the forest; many a forest road has been constructed by bulldozer alone. There are various sizes and makes of this type of machine, and they all have a place in the forest. The heavy machines are mostly used in forest road construction shown in Table 4.

The bulldozer is not a special unit in itself. It is a tractor with a bulldozer blade attachment. The same tractor can, and more often than not does, have a winch attachment at the rear, which can be used for power hauling or for operating a scraper unit which is towed behind. The bulldozer blade is moved by hydraulic power, or by wire ropes powered by the winch. The former type is now more common than the latter. The blade, which can be raised or lowered by the plant operator using a lever, be placed at an angle manually. This results in the blade giving a sideways thrust as the machine moves forward.

1.7.13.2 Tractor Range

Some tractors, suitable for bulldozer attachments, grouped according to available flywheel horse power

Table 4 Tractor types in road construction

Available Flywheel Horsepower PS	Caterpillar	International	Komatsu	Mitsubishi
200-400	D9 24,494		D-250 31,600	BD33 32,300
150-200	D8 18,109	TD24 18,404	D-80 17,500	BD19 18,600
100-150	D7 11,779	TD18 11,999		BD17 17,000
66-100	D6 7,770	TD14 8,241	D-50 10,000	BD11 11,000
46-65	D4 4,706	TD9 4,957	D-30 4,700	BD7 6,900
10-45	D2 3,254	TD6 3,556		BD2 2,400

Sources: Modified from Highway Department (1978); Keller and Sherar (2003)

1.7.13.3 Main Use of a Bulldozer

a) Short Haul Excavation. It is efficient up to a distance of approximately 50 m, over which the work becomes uneconomical. For short distances there is no better machine.

In general, the standard operating distance is commonly 20 m. An examination of output figures shows how efficient the machine is, and how great the saving of labour.

b) Leveling. The process of leveling or grading is carried out either by the blade being made to skin the ground as the dozer moves forward, or by "back blading" , when the blade is allowed to drop on the ground, with the dozer moving in reverse, se drawing the soil, and at the same time leveling it.

c) Clearing. For light scrub the dozer is most efficient. Tree butts with large roots are more difficult, and often other methods have to be adopted, such as the rooter or explosives.

d) Stone Spreading. The smaller machines are useful for spreading stone on a road formation, especially when the in-flow of material is large. Under suitable conditions the tracks help to consolidate the road base.

e) Tree Felling. Quite large trees can be felled by dozer, though this process lowers the value of the timber. To fell a tree of diameter 0.2 to 0.4 m a cut is made around the base of the tree, severing as many of the roots as possible. Then a ramp is made by the dozer from the already excavated soil on the side of the tree opposite to which it is required to fall. The tree can then be pushed over by the dozer from the already excavated soil on the side of the tree opposite to which it is required to fall. The tree can then be pushed over by the dozer moving up the ramp, and with the blade raised as high as possible to obtain maximum leverage.

f) Loading from Ramp. When excavators are not available, loading may be done by construction a ramp, under which lorries can run. The soil or other material is loaded into the vehicles by the dozer pushing the material over the ramp. Seldom is this a practical proposition; it is also uneconomical unless the quantity of material to be loaded is sufficient to justify the building of a workable ramp and loading bay.

1.7.13.4 Methods of Excavation by Dozer

Excavation by dozer is carried out by pushing the soil forwards, or to one side. The blade is equipped with a cutting edge at the bottom, and with a shoe on each of the bottom corners. Cutting edge and shoes are used to cut into the soil, which is then pushed by the blade itself. Angle dozing is also used on level ground where it is desired to move the top soil to one side. When it is required to push soil a long distance, there is a tendency, even with a straight blade, for the soil to spill off the sides of the blade and so greatly slow down the work. But on the other hand, when also the dozing distance is too short, there is same tendency, because the blade is not yet filled with soil. This is best overcome by cutting a channel the same width as the dozer blade, and to keep pushing the soil forward within that channel. One of the chief rules for working a dozer is that it should work downhill wherever possible. It is nearly always possible to get the machine to the top of the road, even if it means a long detour. The increased efficiency will more than make up for a long journey.

1.7.13.5 Dozer Output

The output of a bulldozer depends on the type of material, the grade of the ground, both in the direction that the plant is working and the side grade, the length of the haul, and the skill of the operator. All the figures for average soil utput are shown in Table 5.

Table 5 Average soil output of tractor machine in forest road construction

Length of haul (m)	Soil volume (m^3)			
	D-80	D-50	D-40 NTK-4	CT-35
10	70	40	35	35
20	50	27	25	20
30	35	20	18	15

Sources: Modified from Highway Department (1978); Keller and Sherar (2003)

The above figures are for forest roads construction, and are obtained by the next formula.

$$q = \frac{5(B.We.60^2)}{8(2.5D+26)} \ (m^3/h)$$

where q = soil output of tractor (m^3/h)

B = surface area of blade (m^2)

D = soil moving distance by bulldozer (m)

We = working efficiency

The working efficiency is determined by the hour of network, dozing distance, kind of work and condition of soils. It varies 0.2 – 0.8 by the above-mentioned factors and 0.4 will be taken for the most suitable figure. The hourly composition of earth work in per cent, efficiency of net working hour, capacity of blade of each tractor type, decreasing ratio of working volume, working efficiency coefficient of blade, soil factor, fuel and lubricating oil consumption are shown in Table 6, 7, 8, 9, 10, 11, 12, respectively.

Table 6 Hourly composition of earth work in per cent

Daily Arrangement	Net work	Moving	Waiting	Resting	Repair
8	61	3	9	17	2

Sources: Highway Department (1978); Modified from Keller and Sherar (2003)

Table 7 Efficiency of net working hour

Working hour %	40	50	60	70	80
Rating	Bad		Normal	Good	Very good

Sources: Modified from Highway Department (1978); Keller and Sherar (2003)

Table 8 Capacity of blade of each tractor type

Type	Size of blade (mm)		Blade area (m^2)	Capacity of blade (m^3)
D6	844	3200	2.70	1.4
D4	698	2362	1.64	1.3
D-50	750	3000	2.25	1.5
NTK-4	700	2900	2.03	1.3
Ct-35A	650	2440	1.75	0.8
BD-7	750	2900	2.18	1.4

Sources: Modified from Highway Department (1978); Keller and Sherar (2003)

Table 9 Decreasing ratio of working volume

Working distance, (m)	4	8	12	16	20	24
Decreasing ratio	0.5	0.8	0.9	1.0	1.0	1.0

Sources: Modified from Highway Department (1978); Keller and Sherar (2003)

Table 10 Working efficiency coefficient of blade

Activities	Coefficient
Banking, normal excavation	0.8
Scraping of road surface	0.6
Excavation of rocky soil	0.5

Sources: Modified from Highway Department (1978); Keller and Sherar (2003)

Table 11 Soil factor

Condition	Dry	Wet
Sand	0.5	0.5
Sandy soil	1.0	0.4
Loam	1.0	0.4
Clayey soil	0.5	0.3
Rocky soil	0.6	0.3

Sources: Modified from Highway Department (1978); Keller and Sherar (2003)

Table 12 Fuel and lubricating oil consumption

	Unit	NTK-4	D-80	D-50	D-40
Gasoline	1	0.15	0.20	0.15	0.15
Light oil	1	3.00	8.00	5.00	4.00
Mobile oil	1	0.17	0.25	0.25	0.20
Grease	1	0.15	0.15	0.15	0.15
Gear oil	1	0.20	0.25	0.25	0.20

Sources: Modified from Highway Department (1978); Keller and Sherar (2003)

The output of the bulldozer is affected somewhat by route grade, weather conditions or skill of driver, but there are no clear differences on grades of under 10 % Bad weather must be avoided for it cuts the output by 50 % and moreover the quantity of oil consumption increases; further it makes keeping the bulldozer clean in that condition a serious difficulty. The skill of the driver proved another influential factor. A driver with five year experience was superior by 15 % in his output when compared to a driver with only a year inexperience.

1.7.13.6 Ditching by Dozer

On earth roads the dozer is capable of butting in the side drain at the same time as it grades the surface of the road. This is done by dipping one side of the blade, which may be either angled or straight. The soil excavated is pushed across the road formation. A device, designed to be attached to the corner of the blade for digging, deepening and cleaning side drains was manufactured a few years ago and tried in the field. It was not a success, largely because it had no automatic lifting mechanism, so that when it encountered a deeply embedded stone the dozer slewed, and the engine stalled, before the operator had time to raise the blade.

Deep ditching in open level country is also possible with the dozer, but is seldom as satisfactory as when done by a suitable plough. Part of the excavation for culverts can be carried out by dozer, as well as all the back filling. For the latter job the dozer has no equal.

1.7.13.7 Dozer Maintenance

Sufficient time must be afforded to the operator to carry out the necessary maintenance on the machine. He should be in possession of and instruction chart, and have available all the necessary oils and greases required. To have a set time each day and each week for maintenance makes it more satisfactory for everybody concerned. Probably the best times are first thing in the morning and each Saturday forenoon. Each day he will have to carry out minor maintenance on the chassis, and engine lubrication. Each week, or after 50 hours of working a medium maintenance is essential. In the case of the chassis, a major maintenance is required after 250 hours work; in the case of the engine, after 100 hours, 250 hours, and 500 hours. The agents of manufacturers will provide the necessary maintenance schedules.

A close watch should be kept on the cutting edge and the shoes of the blade. If they are removed at the right time they can be rebuilt. If the shoes are allowed to wear through to the blade, damage is done to the blade metal, resulting in the blade having to de sent off to the workshops to be built up. Wear is particularly heavy when cutting in shale or some like hard material. However, if the rock is first loosened, or broken up, by explosives.

During the winter months an anti-freeze mixture should be added to the cooling system. With most modern machines it is impractical to drain the radiator. The machine should be parked at night on a dry hard area and covered with a tarpaulin. Very often the dozer is working at a high altitude, where it is much colder at night than in the sheltered valleys.

1.8 Forest Road Maintenance

Road maintenance is necessary and must always be included in road construction plan. The purpose of road maintenance is to keep the road in good condition, and on the standard (Odier *et.al.*, 1971). Good roads certainly reduce the on – the – road accidents. The maintenance cost must be estimated according to the type of work, not higher or lower than the requirement. Use the concept of the least expense but the most economical. Maintenance and improving forest road can be done in the following steps (Keller and Sherar, 2003):

A. Use laterite soil surface road for low traffic volume.

B. Use thin asphaltic surface or single surface treatment where traffic volume is moderate.

C. Where the traffic volume grows higher than maintenance situation. Overlay the surface of the road will save the maintenance cost.

Surface and each layer of the road need good care, since the structure of road deform little by little. Due to the fluctuation of temperature, moisture, traffic and earth surface movement. Therefore, in forest road maintenance, it is important to inspect the road regularly and carefully. If little or small defect is found, it should be immediately repaired. Little damage such as surface crack which is scarcely noticed at the first time, will be expanded and get more damage if it was not discovered soon enough. Inspection by pacing is the most effective way to discover small crack. Sometime, it is necessary to dig the corrupted area in order to inspect the foundation structure.

The road maintenance can be classified as follows:

1.8.1 Daily Maintenance.

This type of maintenance is to keep the road in a good condition, for instance, smoothen road surface, cleaning the drainage pipe, side ditches and roadsides.

1.8.2 Periodical Maintenance.

This type of maintenance is to improve the corrupted road which caused structural failure after the long period of use. These types of works are: overlay the laterite soil, asphalt surface, and traffic surface,

1.8.3 Particular Maintenance.

This kind of maintenance is mainly foe the safety of the users, including the aesthetic of roads, roadsides, and nearby area landscape, the installation of traffic signs, etc. Some other emergency works related to the road, such as improving an asphalt pave for the road in the community area, traffic surface widening or road shoulder widening.

The maintenance types can also be classified by the type of traffic surface as follow:

A. Laterite soil surface
B. Surface treatment road
C. Asphaltic concrete or penetration macadam

The planning and duration of road maintaining are depending on various factors such as type of traffic surface, traffic volume, type of material and wear out rate, etc. So, the same type of the road but different in traffic volume, will cost differently in maintenance. It is therefore necessary to consider each case separately.

Laterite Soil Surface

General Maintenance. The works are grading and re-compacting. The frequency of maintenance is upon traffic volume directly, and the minor factors are gradient of road and rainfall intensity in that area. Some research discovered that the grading must be done when traffic volume increase up to 6,000 passes. In Thailand, the specification for the relation between traffic volume and number of grading are show in the Table 13 below.

Table 13 The traffic volume and number of grading relation

Average traffic volume (vehicles/day)	Numbers of grading in 1 year	Grading Interval (weeks)
0 - 150	2.5	20
150 - 400	9	6
400 - 750	18	3
> 750	30	1.5

Source: Highway Department (1978)

The traffic volume in forest road is generally considered to be low (less than 100 vehicles/day). So, the grading should be done only once in a year, after rainy season. But if the traffic volume is more, the grading must follow Table 13.

Periodical Maintenance. This work is overlaying the laterite soil surface of road. Each time overlay should be about 10 cm. The specific time for overlaying is depending on the wear out rate. This rate is depending on the amount of dust, when vehicles pass or eroded by rain.

The wear out rate of laterite soil each year can be computed by the formula:

$$L = F.\frac{T_a^{\ 2}}{T_a^{\ 2}+50}.\left(4.2+0.92T_a+3.5R^2+1.88V_C\right)$$

Where: L = yearly wear out rate of laterite soil in mm.

F = 0.94 for dry laterite soil

T_a = No. of vehicles in both directions for one year [in thousand units]

R = Annual rainfall in meter.

V_c = Road gradient in percent.

Of the relationship between traffic volume and duration of maintenance, the time for the overlaying can be specified as the Table 14 below.

Table 14 The duration time for traffic surface overlaying

Average traffic volume (vehicles/day)	Duration for surface overlay (years)
0 - 150	5
150 - 400	4
400 - 750	3
> 750	2

Source: Highway Department (1978)

The table above showed that if the bidirectional vehicles are more than 450 vehicles per day. The surface should be improved to surface treatment which is more economical.

Surface Treatment

General Maintenance. The works are patching potholes and cracked surface repairing. The destruction of surface treatment is related to axle – load direction, standard of road construction and strength of the road itself.

The estimation of the repaired surface area was shown in the Table 15 below.

Table 15 The estimation time for traffic surface repairing

Average traffic volume (vehicles/day)	Service life maintaining area (m^2/km)	Annual maintaining area (m^2/km)
60	6.3 (A)	1.30
150	17.2 (A)	3.40
300	37.6 (A)	7.50
750	252.0 (A)	50.40
1500	1138.0	227.60
3000	1138.0 (B)	517.27

Remarks: A) in first 5 years of service life.
B) Improve to double surface treatment.

Source: Highway Department (1978)

If the length of cracked surface is more than 5 m. per 1 m^2 the reparation must be done through sub base layer.

Particular Maintenance. Generally, the surface treatment can prevent the soubise layer in first 5 years of using, or when the standard axle – load not exceed 1.5

million times. If exceeding. The over all surface should be repaired because it is cheaper than keep maintaining. The following cases must be taken into consideration:

A. In case of the average traffic volume less than 1000, the single surface treatment is sufficient and the maintenance period can be specified by not exceeding the following conditions:

- Surface crack length more than 1 m. in 1m^2
- Service performance time longer than 5 years.

B. In case of the average traffic volume more than 1000, the double surface treatment is needed and the maintenance period can be specified the same as the first case.

Asphaltic concrete or penetration macadam

General Maintenance. The general work is surface repairing, patching potholes or cracked surface. The maintaining area estimation could be considered by traffic volume and standard axle – load as shown in the Table 16 below.

Table 16 Traffic volume and standard axle – load relation

Average Traffic volume (vehicles/day)	Service life maintaining area (m^2/km)	Annual maintaining area (m^2/km)
1,500	10.8	2.2
3,000	21.7	4.3
6,000	37.5	6.5
15,000	37.5	13.4
30,000	37.5	25.0

Source: Highway Department (1978)

Particular Maintenance. When the road surface get damages and can not serve the traffic. The surface overlay should be considered. The overlay should be done in the following cases:

1. Surface cracking occurred in wheel line exceed 1.0 m. in 1m^2 of surfacing area

2. Service age exceed 7 years

3. When the axle – loaded serviced more than 1.5 million times. Each overlay should not exceed 5 cm. for asphaltic concrete and not exceed 7 cm. for penetration macadam surface.

1.9 Cost Estimation in Forest Road Construction

The cost estimation is to specify construction budget for budget planning or for construction control. Cost estimation is depended on the following factors :

1.9.1 Location of construction indicates construction materials, transportation, and fuel cost.

1.9.2 Topographic characteristics control clearing and grubbing cost, of those are:

a. Paddy field, grass land or small forest, not more than 125 trees/rai

b. Few and dense forest, 125 – 250 trees/rai

c. Very dense forest, more than 250 trees/rai

1.9.3 Type of heavy equipments used in construction process depended on :

a. Topographic condition

b. Horse power of equipment

c. Efficiency of operator and the machine.

1.9.4 Other controlling factors, e.g. climate, construction problem, construction time and distance of laterite borrow pit. These factors affect the actual cost, so unexpected cost must be considered at least 5% of total cost.

1.9.5 Heavy equipments used in forest road construction. In forest road construction, simple equipments and manpower are normally used. Animal power like cows and buffaloes can be applied. Generally, road construction equipments are :

a. Bulldozers, good for forest clearing and grubbing, open cut excavation, and surface opening, e.g. D4, D5, D6, D7, D8.

b. Motor grader, for earth spreading, surface finishing and side ditch cutting, e.g. CAT 120G, T500A.

c. Pay loader, for short distance earth excavation or loading material into dump truck for long distance. There are pneumatic type and track type of pay loader, 50 – 170 horse powers.

d. Scraper, for opening cut earth excavation and road materials spreading.

e. Dump truck, for earth hauling form borrow pit to construction site and stock piling.

f. Compaction equipment, for compacting earth filled materials. There are many types of compactor, e.g. pneumatics type, tractor roller, sheep foot roller, dynamic compactor.

g. Water truck, for hauling water from storage or river to construction site.

h. Farm tractor, for dragging pneumatics type roller for earth filled compaction.

Others equipments are back hoe or excavator, trailer for moving equipments, pick up car, inspection car, and etc.

1.9.6 Cost estimation for forest road construction. There are many methods for construction cost estimation, depending on what the purpose, e.g. cost estimation for budget request, cost estimation for bidding or cost estimation for construction controlling. Estimation can be computed by roughly estimate construction cost per year. The cost must be estimated slightly higher than actual cost. Another method is done by estimating cost from each work item, e.g. estimate wages and salary, material and managing cost, and etc. The estimation cost is normally stated per one kilometer.

1.9.6.1 Soil investigation and soil testing for construction. Soil investigation is to determine soil properties and type of road foundation where the road will cross, e.g. if natural soil is clay or muddy soil, the improvement method causes high cost, so alternative choice such as excavation and refill with better material is reasonable. Field observation can be me do directly by field measuring, e.g. shear cone test, and soil sampling for laboratory test. Construction inspection and control can be me do by compaction test and sand cone test to find field compaction density and then comparing with standard specification. Cost of soil testing must include soil sampling, soil transportation, and material cost. Latest estimate per 1 kilometer length of the road must be provided.

1.9.6.2 Clearing and Grubbing work. Two groups of tree size are considered, first trees less than 0.30 meter diameter and second those greater than 0.30 meter. Equipment ability in clearing and grubbing are shown in Table 17. Equipment efficiency must be considered as below.

Time efficiency 50 minute/hr	= 0.83
Operating efficiency	= 0.80
Overall efficiency	= 0.66

Table 17 Equipment ability in clearing and grubbing for tree less than 0.30 meter diameter

Bulldozer	Quantity of work rai/hr. (1 ha = 6.25 rai)		
	dense	medium	loose
D8	0.56	1.10	1.60
D7	0.45	0.91	1.30
D6	0.31	0.61	1.11

Source: Rural Development Department (1980)

Table 18 Working time for forest clearing by bulldozer for tree larger than 0.30 meter diameter

Type	Base time	Working time min/tree			
	min/rai	30 – 60 cm	60 – 90 cm	90 – 120 cm	120 – 180 cm
D8	30	0.80	3.1	6.7	16.5
D7	36	1.30	4.2	10.5	27.0
D6	45	2.20	7.8	19.6	–

Source: Rural Development Department (1980)

Efficiency of bulldozer shown in Table 18 can be used to calculate working hour, when knowing equipment rental rate per hour, it can evaluate total cost including wages and determine cost per rai.

1.9.6.3 Top soil removal cost can be evaluated by computing total distance of cutting area. Normally, depth of cut will be 15 – 20 centimeters to extinguish weed or soft material, but if natural ground is dense laterite soil, surface removal is not necessary. For forest road construction. surface opening width must be more than 3 times of carriage width along the road. The cost of surface opening can be evaluated by computing cutting volume, divided by equipment out put, the result will be equipment working hour, working hour is used to determine equipment rental cost If equipment rental cost includes with wages cost, it becomes surface opening total cost. average per cubic meter will be surface opening unit cost.

There are three kinds of earth volume for earthwork cost estimation. natural volume or bank volume, loose volume and compacted volume.

Earth cutting

bank volume x 1.3 = loose volume

bank volume x 0.75 = compacted volume

Earth filling

compacted volume x 1.7 = loose volume

Laterite Soil

Compacted volume x 1.7 = loose volume

Bank volume x 1.5 = loose volume

1.9.6.4 Earth cutting works are :

- Road side cutting
- Cutting and hauling to other place
- Earth fill of cut material
- Foundation compaction
- Water spreading for compaction

Calculate all kind of cut volume and estimate the cost. Cost estimation of earth cut are road side cutting and cutting to stock pile for hauling to other place. Equipment efficiency will relate to haul distance. Table 19 and 20 show cutting volume of different machine type vary to haul distance for K = 0.66

Table 19 Cutting volume m^3/hr/machine for efficiency K = 0.66.

Bulldozer	Blade type	Haul distance (m)							
		15	20	25	30	35	40	45	50
D8	S	181	143	117	100	87	77	69	63
D7	S	143	113	93	79	69	61	55	49
D6	S	133	106	86	74	64	57	51	46
D5 D, PS	S	87	68	56	48	46	46	43	41

Remark Blades are 3 types :

S = Straight blade, U = Universal blade, A = Angle blade

Source: Rural Development Department (1980)

Table 20 Cutting volume capacity for stock piling in m^3/hr/machine for efficiency (K = 0.415)

Bulldozer	Blade type	Haul distance (m)							
		15	20	25	30	35	40	45	50
D8	S	114	90	74	63	55	48	44	39
D7	S	90	71	58	50	43	38	34	31
D6	S	84	66	54	46	40	36	32	29
D5 D, PS	S	60	47	39	38	30	26	23	21

Source: Rural Development Department (1980)

1.9.6.5 Rock Blasting

Sometime, road constructed passing through mountain area. Cost of rock removable must be included by using bank volume change into loose volume and divide by output of equipment loading into dump truck and hauling away to other place or nearby area. Rock blasting cost must include wages cost and processing cost and average per bank volume.

1.9.6.6 Earth Fill

Calculate all earth filled volume from plans and change it into loose volume for compute equipment cost and average per loose volume. The earth filled processes are:

(1) Road side borrow
(2) Earth fill from borrow pit
(3) Spreading and compacting
(4) Spreading water

Cost estimation of earth fill need break down in each detail, e.g. side borrow use soil from both side of embankment by using bulldozer, earth fill from borrow pit need equipment for stock piling, loading and hauling. So, it is necessary to manage how many dump truck need to match loading time of pay loader for no wait state. Loading time and transportation time of each truck must be considered to know how many trucks required in the process. The solution are listed as follows:

1. Transportation time in minute

$$= \frac{\text{haul distance (km)} \times 60}{\text{hauling velocity (km/hr)}} + \frac{\text{return distance (km)} \times 60}{\text{return velocity (km/hr)}}$$

$$+ \text{dumping time}$$

2. Excavation time = time in item 1. + loading time
3. Number of truck = time in item 2. / loading time
4. Loading time to fill dump truck is shown in Table 21.

Table 21 Loading time filling up dump truck

Bucket capacity m^3	Loading volume m^3 in min		
	3	4.5	6
0.76 – 1.14	2.6	3.25	-
1.14 – 1.33	1.95	2.60	3.25
1.33 – 1.52	-	2.60	3.25

Source: Rural Development Department (1980)

On the other hand, loading time can determine from;

Loading time = truck volume x 0.65 / bucket volume

Spreading and compaction times can be used to compute working hour of motor grader.

Spreading

$$\text{Volume of work } (m^3/hr) = \frac{E \times W \times D \times S \times 1000}{N}$$

where:

E = equipment efficiency

W = width of spreading in meter.

D = spreading thickness meter.

S = spreading velocity km./hr.

N = number of pass for requiring thickness

Grading

$$\text{Quantity of work } (m^2/hr) = \frac{W \times S \times 1000}{N}$$

e.g. Use motor grader for spreading line width 3.0 m. thickness 0.10 m. pass for each line. Average velocity 5 km./hr. If equipment efficiency 0.6, quantity of work can be determined by:

$$\text{Quantity of work } (m^3/hr) = \frac{0.6 \text{ x } 3 \text{ x } 0.1 \text{ x } 5 \text{ x } 1000}{10}$$

$$= 90 \ m^3/hr$$

Compaction volume per hour for each type of compactor can compute by:

$$\text{Quantity of work } (m^3/hr) = \frac{S \text{ x } E \text{ x } W \text{ x } E \text{ x } D \text{ x } 1000}{N}$$

Where:
E = efficiency of equipment = 0.83
S = compaction velocity km/hr
W = compaction line width in meter
N = number of pass
D = layer thickness meter

Rubber Tired Roller

e.g. E = 0.83, D = 0.15 m., S = 5 (km/hr)
N = 10 passes, W = 1.20 (m)

$$\text{Quantity of work } (m^3/hr) = \frac{5 \text{ x } 1.20 \text{ x } 0.83 \text{ x } 0.15 \text{ x } 1000}{10}$$

$$= 75 \ m^3/hr$$

Sheep foot Roller

e.g. E = 0.83, D = 0.20

S = 5 km/hr, N = 12 passes,

W = 1.0 m.

$$\text{Quantity of work } (m^3/hr) = \frac{5 \times 1.0 \times 0.83 \times 0.2 \times 1000}{12}$$

$$= 65\ m^3$$

Watering of earth fill can calculate by this method:

Water truck contain water 15,000 gallon = 5,680 liters

Use 0 3 pump flow rate	=	300	liters / minute
time for spray water	=	410	liters / minute
turning time	=	1	minute

$$\text{Fixed time} = \frac{\text{contain volume}}{\text{flow rate}} + \frac{\text{contain volume}}{\text{spray rate}} + \text{turning time}$$

$$= \frac{5,680}{800} + \frac{5,680}{410} + 1 = 21.95 \text{ unit}$$

$$\text{Travel time} = \frac{\text{travel distance} \times 60}{\text{hauling velocity (km/hr)}} + \frac{\text{travel distance} \times 60}{\text{return velocity (km/hr)}}$$

Cycle time = Travel time + Fixed time

e.g. Water truck above run to storage at 50 km/hr and hauling at 40 km/hr, travel distance is 3 km.

$$\text{Travel time} = \frac{3 \times 60}{50} + \frac{3 \times 60}{40} = 8.10 \text{ minute}$$

Cycle time = 8.1 + 21.95 = 30.05 minute

Time efficiency = 50 min/hr
= 50 / 60 = 0.83
Cycle / hr = 50 / cycle time = 50 / 30.05 = 1.66
= 1.66 x 5680 = 9428 liter/hr/truck
= 9.428 m^3/hr/truck

1.9.6.7 Laterite Soil Surface

(1) Temporary road construction to laterite borrow pit that is forest clearing and grubbing, cost per kilometer is 3000 – 5000 baht.

(2) Forest clearing and surface opened cutting for laterite borrow pit. Knowing require compacted volume of laterite from plan, change into bank volume and estimate size of laterite borrow pit in length and width. Change bank volume into loose volume to evaluate stock pile cost and hauling cost.

(3) Cutting, stock pile, loading and hauling cost estimate the same as earth fill estimation.

(4) Spreading, compacting and mistuning, estimate as earth compaction.

1.9.6.8 R.C. Pipe Culvert and Drainage

Cost of this part is depended on type of drainage structures. The R.C. pipe culvert, cost including price of pipe, transportation, foundation preparing and earth fill compaction, cost average per meter of pipe. The cost is varied depend on construction site and topography. For box culvert, the cost is included material cost, cement powder, reinforce steel, aggregate, sand, formwork and wages cost. More expensive cost for bridge construction and also high maintenance cost. For example, temporary timber bridge with reinforce concrete pier 10 meters long will cost more than 1 kilometer of road construction (Highway Department, 1970, 1975, 1978). Thus, avoid bridge construction by using many rows of box culvert instead, or changing road alignment, were the most practical in forest road construction (Keller and Sherar, 2003).

1.9.6.9 Equipment Moving Cost

When moving equipments to construction site, the expense include wages cost or fuel consumption cost for trailer hauling equipment to the site. The cost varies as hauling distance and number of equipments to be moved.

1.9.6.10 Management and Work Control Cost

This cost must be provided for fuel expense in construction managing, controlling and accomplishing. The cost must be included officials podium and supervision fee in the field checking (Highway Department, 1970).

1.9.6.11 Unexpected Cost

This is to preserve unknown work that may be effected the whole construction work. This cost normally is prepared for 5 % of total cost. In case of estimation for bidding, it is necessary to include benefit and tax for contractor. At present, tax approximate 5-6 % of total cost. Benefit is up on difficulty of work and total cost e.g. total cost not exceed 5 million baht, benefit will be 10 - 15 %

Cost estimation of road construction depend vary much on fuel cost, material cost in each local and difficulty of work. So, these factors must be considered. The estimation of future year must be preserved increasing of materials cost. The lists below shows official cost for estimate forest road construction of National forest land management division in 1974 that almost sites were in ruin forest, flat area, laterite borrow pit mot more than l kilometer from site. The cost of drainage structures is varied place to place up to topography of construction site and transportation cost.

2. Road Density

Roads provide access which gives rise to a range of pressures on the natural environment (e.g. ecosystems system, fluvial, and karstic terrain.). It is often a precursor to changes in land use and land cover. In addition, the roads themselves have significant effects on runoff rates, slope drainage patterns and flow regimes, as well as soil erosion rates and runoff turbidity. Changes (which will normally be increased) in road density within a region will imply a higher likelihood of adverse impacts on the natural environmental processes within that region. Environmental management systems in road design and construction can assist in protecting natural systems.

Road density can be used to help understand the potential for impacts from road surface erosion, drainage, and sediment delivery to streams. Many factors affect the degree of impact to natural resources from roads, and there can be a greater possibility of adverse impacts as road density in a forest increases. However, research indicates the relationship between the degree of impacts to natural resources and road density is not simple and linear. Nonetheless, road density may be used as an indicator variable.

Road density, measured as length of forest road per forest area, in km/km^2, has been proposed as a useful, broad index of several ecological effects of roads in a landscape (Forman, 1995; Forman and Hersperger, 1996; Forman *et.al*., 1997). Effects are evident for faunal movement, population fragmentation, human access, hydrology, aquatic ecosystems, and fire patterns.

A road density of approximately 0.6 km/km^2 appears to be the maximum for a naturally functioning landscape containing sustained populations of large mammals. (MacGurk and Fong, 1995; Forman *et.al*., 1997). The mammal populations decreases with increasing road density (Forman *et.al*., 1997; Lyon, 1983). These species are differentially sensitive to the road kill, road-avoidance, and human-access dimensions of road density. Species that move along, rather than across, roads presumably are benefited by higher road density (Forma, 1995).

Human access and disturbance effects on remote areas tend to increase with higher road density (Lyon, 1983; Forman, 1995). Similarly, human-caused fire ignitions and suppressions may increase, and average fire sizes decreased.

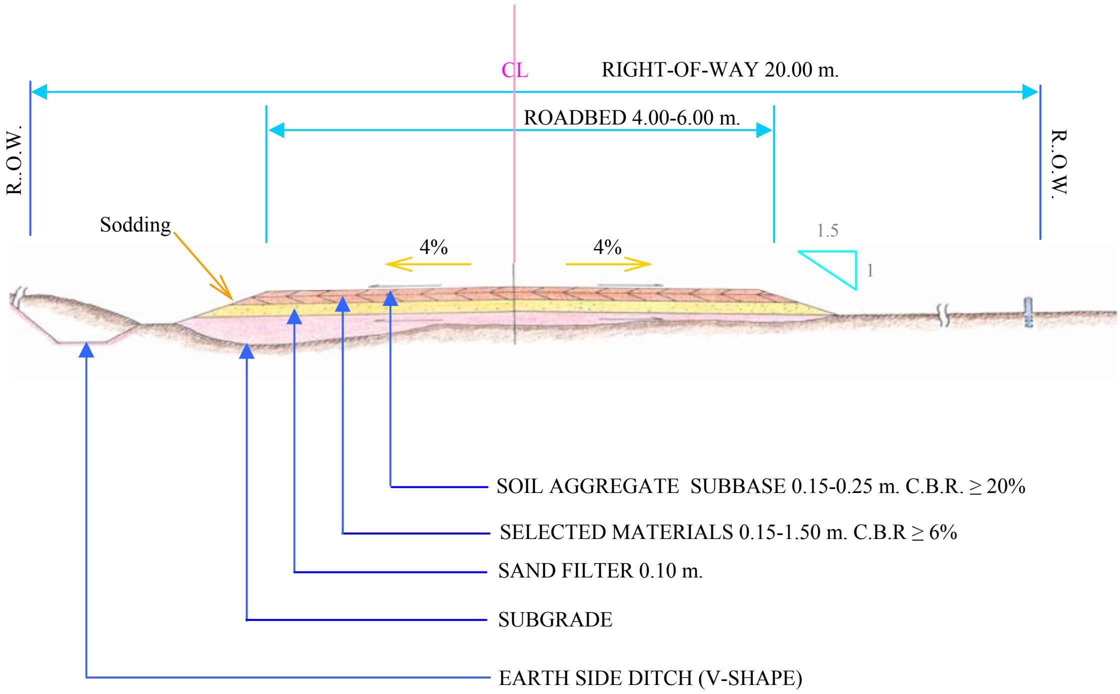
Aquatic ecosystems are also affected by road density. Hydrologic effects, such as altered groundwater conditions and impeded drainage upslope, are sensitive to road density. Increased peak flows in streams may be evident at road densities of 2–3 km/km^2 (Jones and Grant, 1996). Detrimental effects on aquatic ecosystems, based on macro-invertebrate diversity, were evident where roads covered 5% or more of a watershed in California (MacGurk and Fong, 1995). In southeastern Ontario, the species richness of wetland plants, amphibians/reptiles, and birds each correlated negatively with road density within 1–2 km of a wetland (Findlay and Houlahan , 1997).

Road density is an overall index that averages patterns over an area. Its effects probably are sensitive to road width or type, traffic density, network connectivity, and the frequency of spur roads into remote areas. Thus network structure, or an index of variance in mesh size, is also important in understanding the effect of road density (Forman, 1995; MacGurk and Fong, 1995). Indeed, although road density is a useful overall index, the presence of a few large areas of low road density may be the best indicator of suitable habitat for large vertebrates and other major ecological values.

3. <u>The Park Road Standards</u>

3.1 Forest roads and Park roads

Park roads are defined as forest roads that were constructed within National Park. Forest roads in forest work of Thailand are classified as paved and unpaved roads (Royal Forest Department, 2001). The unpaved roads, or earth roads, are very common used in forest areas such as fair weather road, inspection paths, and secondary road, with soil aggregate or compacted earth surfacing as shown in Figure 7. The paved roads with surface treatment, or asphaltic or asphaltic concrete, or concrete pavement surfacing are mostly used for main roads or park roads as shown in Figure 8. The carriage width including shoulders of forest roads is not more than 7.0 meters and maximum gradient is less than 16 percent.



<u>Figure 7</u> Typical cross section of unpaved surfacing forest roads.

Source: Royal Forest Department (2000)

Forest roads are one of the necessary parts of land and forest management. Construction of forest roads frequently results in changes of the landscapes where the road accesses. New roads in forested landscapes often lead to economic development as well as deforestation and habitat fragmentation (Chomitz and Gray, 1996). Of all the forestry activities, improperly constructed and inadequately maintained forest roads are the principal human-caused source of erosion and sediment. Road failures and surface erosion can exert a tremendous impact on natural resources and can cause serious economic losses, by blocking the water ways, ruining spawning sites, lowering soil productivity, and damaging property.

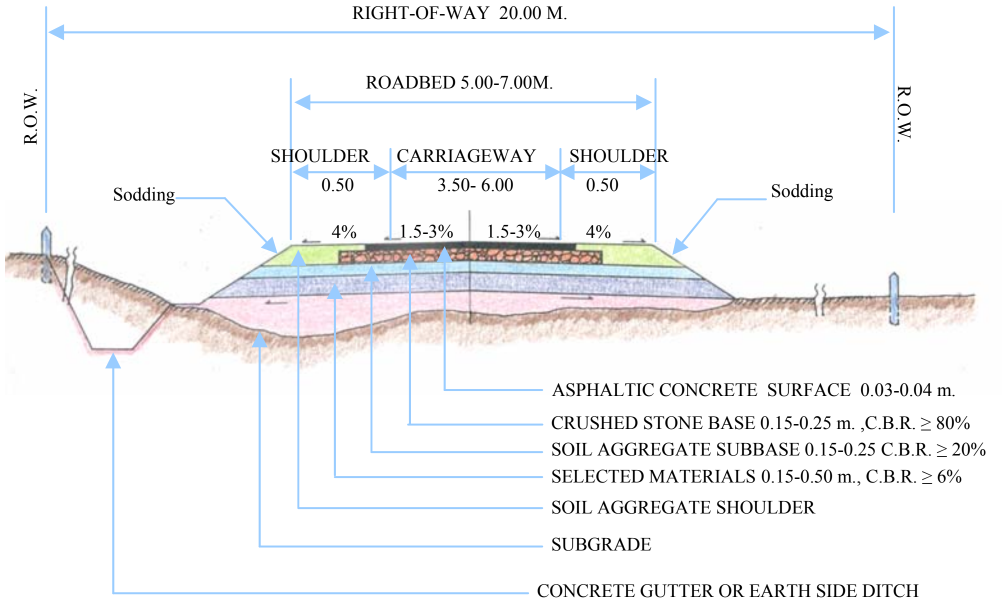


Figure 8 Typical cross section of paved surfacing forest roads.
Source: Royal Forest Department (2000)

Forest roads often significantly contribute sediment, by road surface erosion and mass soil movement. The compacted surfaces of forest roads, trails and forest fire lines often carry surface run-off when heavy storms occur. Forest removal results in lower evapotranspiration and water-storage capacities, but roads alone may increase peak discharge rates (Jones and Grant, 1996). Also, flood frequency apparently correlates with the percentage of road cover in a basin (Harr *et al.*, 1975; Sauer *et al.*, 1982). Forest road surfaces are generally a significant source of sediment in forests up to 29.216 tons/rai/year (Khunrattanasiri, 2002) because of surface run-off in the rainy season. Sediment yield is determined by road geometry, slope, length, width, surface, and maintenance (Anderson and Simons, 1983), in addition to soil properties and vegetation cover (Horner and Mar, 1983). Road surfaces, cutbanks, fillslopes, bridge/culvert sites, and ditches are all sources of sediment-transport capacity of increased hydrologic flows, result in higher erosion rates and sediment yields (Reid and Dunne, 1984). Thus, the results of these impacts are high maintenance cost and low traveling safety.

The purposes of park roads are completely different from those of highways system. Park roads are not continuations of the highways network. They should neither be designed-nor designated-to serve as connecting links (National Park Service, 1984). The road standards using in Thailand are highway standard, low cost road standard, and forest road standard. There is no park road standard in Thailand. A review of forest road design for national park areas in Thailand in the past indicates that there is relatively little information about forest road standards. The forest 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. The forest roads in Khao Yai National Park were built by the Highway Department since 1981 as provincial highways network to connect Nakhon Ratchasima and Prachin Buri province together (Highway Department, 1982) not for tourism purposes. There are highways numbers 2090, 3077 and 3182, which the total length within Khao Yai National Park area is 72.082 kilometers. The Highway Department transferred ownership of these three highways to the Royal Forest Department for routine road maintenance in 1993 to ensure the safety of road users in national parks (Royal Forest Department, 1993).

The forest road standards and guide line commonly used for road design and construction in the forest areas are listed as follow.

3.2 The US Park Road Standards

The park roads can be classified by the standards into five types as major, minor, special-purpose, interpretive (motor nature), administrative, and parkways (National Park Service, 1984).

The details of the standard can be summarized as shown in Table 22.

Table 22 Design standards criteria of the US Park Road Standards

No.	Descriptions	Areas Type		
		recreation	natural	general
1	Design speed (km/hr)	67.50	37.50	22.50
2	Minimum turning radius (m)	〈---------- ASSTHO ---------〉		
3	Maximum gradient (%)	7 (8,9,10)		
4	Surfacing materials			
	a. soil aggregate	✓	✓	✓
	b. asphaltic	✓	✓	✓
5	Shoulder (m)			
	a. soil aggregate	-	-	-
	b. asphaltic	0.90	0.90	0.90
6	Carriage width (m)	7.30	6-6.75	3.50-4.50
7	Right of way (m)	〈--------- ASSTHO ---------〉		
8	Non Passing Sight Distance (m)	〈--------- ASSTHO ----------〉		
9	Super Elevation Rate- SE (m/m)	〈--------- ASSTHO ----------〉		
10	Widening (m)	〈--------- ASSTHO ----------〉		
11	Crown Slope , Cr%	〈--------- ASSTHO ----------〉		
	a. soil aggregate			
	b. asphaltic			

Table 22 (Continued)

No.	Descriptions	Areas Type		
		recreation	natural	general
12	Wheel Load (kg)	〈---------	ASSTHO	----------〉
13	Traffic volume VPD			
	a. Primary roads			
	b. Secondary roads			

Source: National Park Service (1984)

3.3 The UNESCO Low Volume Road Standards

The standards suggested for different classes of low volume roads are related to traffic intensities in the following ranges (Odier *et al.*, 1971):

Primary roads	100 – 5,000	vehicles per day
Secondary roads	50 – 800	vehicles per day
Feeder roads	Less than 100	vehicles per day

The details of the standard can be summarized as shown in Table 23.

Table 23 Design standards criteria of the UNESCO Low Volume Road Standards

No.	Descriptions	Terrain type for secondary roads		
		flat	hilly	mountain
1	Design speed (km/hr)	60-80	50-60	35-50
2	Minimum turning radius (m)	110-190	75-110	35-50
3	Maximum gradient (%)	5	5-7	7-9
4	Surfacing materials			
	a. soil aggregate	✓	✓	✓
	b. asphaltic	✓	✓	✓
5	Shoulder (m)			
	a. soil aggregate	2-2.6	2-2.6	1-1.70
	b. asphaltic	2-2.6	2-2.6	1-1.70
6	Carriage width (m)	6-6.8	6-6.8	6-6.8
	a. traffic volume < 100 VPD			
	b. traffic volume < 50 VPD			
7	Right of way(meters)	30	30	30
8	Non Passing Sight Distance (m)	⟨------- ASSTHO ------⟩		
9	Super Elevation Rate- SE (m/m)	0.10	0.10	0.10
10	Widening (m)		0.60-1.20	
11	Crown Slope , Cr%			
	a. soil aggregate	3	3	3
	b. asphaltic	2-3	2-3	2-3

Table 23 (Continued)

No.	Descriptions	Terrain type for secondary roads		
		flat	hilly	mountain
12	Wheel Load (kg)			
13	Traffic volume (VPD)			
	a. Primary roads	-	-	-
	b. Secondary roads	〈----------50-800---------〉		

Source: Odier *et al.* (1971)

3.4 The Provincial Highway Standard of Thailand

The provincial highways standards which applied to all forest roads that were previously built in the national park of Thailand, mostly as a provincial highways to connect different provinces together and not for tourism purposes.

The details of the standard can be summarized as shown in Table 24.

Table 24 Design standards criteria of the Provincial Highway Standard of Thailand

No.	Descriptions	Terrain type for provincial highway(F4)		
		flat	hilly	mountain
1	Design speed (km/hr)	60-80	45-60	30-45
2	Minimum turning radius (m)	-	-	-
3	Maximum gradient (%)	8	10	10
4	Surfacing materials			
	a. soil aggregate	-	-	-
	b. asphaltic	✓	✓	✓
5	Shoulder (m)			
	a. soil aggregate	0.75-1.0	1-.75	1-.75
	b. asphaltic	1-.75	1-.75	1-.75
6	Carriage width (m)	5.50	5.50	5.50
7	Right of way (m)	20-40	20-40	20-40
8	Non Passing Sight Distance (m)	〈------- ASSTHO --------〉		
9	Super Elevation Rate- SE (m/m)	-	-	-
10	Widening (m)	-	-	-
11	Crown Slope , Cr%			
	a. soil aggregate	-	-	-
	b. asphaltic	-	-	-
12	Wheel Load HS20 (kg)	8,200	8,200	8,200
13	Traffic volume (VPD)			
	a. Primary roads	〈-------300-1,000--------〉		
	b. Secondary roads			

Source: Highway Department (1982)

3.5 The RFD Guide Line for Forest Road Design

The Royal Forest Department (RFD) forest road guide line for design and construction of forest roads was mainly for forest village projects purpose only. The forest roads in the forest village served as a shortest route to communicate between resident areas and crop fields or other villages. The guide line was based on low volume road standard (Odier *et.al*., 1971; Robinson and Snell, 1987) but slightly adjusted some design values and limitations to fit to Thai's forest conditions.

The details of the standard can be summarized as shown in Table 25.

Table 25 Design standards criteria of the RFD Guide Line for Forest Road Design

No.	Descriptions	Terrain type for forest road		
		flat	hilly	mountain
1	Design speed (km/hr)	60	40	30
2	Minimum turning radius (m)	75-10	40-75	25-35
3	Maximum gradient (%)	6	10	12
4	Surfacing materials			
	a. soil aggregate	✓	✓	✓
	b. asphaltic	✓	✓	✓
5	Shoulder (m)			
	a. soil aggregate	-	-	-
	b. asphaltic	0.50	0.50	0.50
6	Carriage width (m)			
	a. traffic volume < 100 VPD	5-5.5	5-5.5	5.0
	b. traffic volume < 50 VPD	4.5	4.5	4.5
7	Right of way (m)	20	20	15-20
8	Non Passing Sight Distance (m)	110	30	30
9	Super Elevation Rate- SE (m/m)	0.10	0.10	0.10

Table 25 (Continued)

No.	Descriptions	Terrain type for forest road		
		flat	hilly	mountain
10	Widening (m)	1	1	1
11	Crown Slope , Cr%			
	a. soil aggregate	4	4	4
	b. asphaltic	3	3	3
12	Wheel Load (kg)	8,000	8,000	8,000
13	Traffic volume (VPD)			
	a. Primary roads	<100	<100	< 100
	b. Secondary roads	< 50	< 50	< 50

Source**:** Royal Forest Department (2000)

4. Environmental Effects of Forest Roads

Forest roads are multipurpose permanent investments. Besides providing many positive kinds of economic, social and environmental effects, they may cause negatively impacts as well. For instance, erosion may be caused by new forest roads and their construction if these activities are not properly managed (FAO, 1977; Forman and Alexander, 1998).

Forest roads often significantly contribute sediment, by road surface erosion and mass soil movement. The compacted surfaces of logging roads, skid trails and fire lines often carry surface run-off when heavy storm occurred (FAO, 1979). Road surfaces are generally a significant source of sediment in forest because of surface run-off (Reid and Dunne, 1984). The environmental consequences of forest road construction will be discussed in this chapter, and aiming at suitable criteria in planning and designing forest roads to minimize those impacts.

4.1 Interaction of Roads and Environment

Forest road is one of a necessary part in land and forest management. Construction of forest road frequently results in changes of the landscapes where the road accesses (Forman, 1995; Forman and Alexander, 1998). Of all the forestry activities, improperly constructed and inadequately maintained logging roads are the principal "human-caused" source of erosion and sediment. Road failures and surface erosion can exert a tremendous impact on natural resources and can cause serious economic losses, by blocking the water way, degraded water quality, destroyed bridges and road rights-of-way, ruined spawning sites, lowered soil productivity, and property damage, etc.

4.2 Forest Road Planning and Design Criteria to Minimize Environmental Impacts

Road planning and design are regarded as the most important phases of forest road development. The general procedures in planning and design are; evaluation of soil credibility, the potential for mass movement, and the potential for sediment transport must be made (Bureau of Land Management, 1978; FAO, 1979). These three evaluations may confirm the proposal of opening a new route, changing the forest harvesting system, or finally may come to the conclusion of no road construction.

Engineering criteria in planning, designing, constructing and, maintaining of forest roads, aiming at minimize sedimentation are parts of the total engineering criteria needed. Minimizing surface erosion and sedimentation are normally started with the appropriate design of slope, and continue with the consideration of ditch size, culvert intakes, culvert integrity and culvert outlets. Then, the sediment criteria will be used as critical criteria in designing and constructing of forest road.

Sediment control design criteria may be the same as other design criteria which results in an efficient economic forest road system for sounded forest land management.

The strategies used for designing forest road (U.S. Forest Service, 1979; Puangchit, 1986; RFD, 2001) are:

4.2.1 Considering of natural resources; including reforestation, forest fire protection, wildlife sanctuary, watershed management, and forest villages development project.

4.2.2 Considering the current and future timber harvesting systems.

4.2.3 Considering the details specifications which is appropriate and necessary to convey to the road builder or contractors; including the scope of the project, and thus allow the preparation of construction plans and procedures, time schedules, and cost estimation.

4.2.4 Specify the precise instructions of the design decisions so as to minimize the opportunity for changes which may happen during the construction with consequences of money and time.

4.2.5 Analyzing specific road elements for up-front cost versus annual maintenance cost (PCA, 1964; Kezdi, 1979; U.S. Forest Service, 1979; Punmia *et.al*., 1992). For instance;

- culvert and embankment reparations versus bridge installation,
- ditch pavement or lining versus ditches in natural soil,
- paved or lined culverts versus unlined culverts,
- sediment trapping devices (trash racks, catch basins, or sumps) versus culvert cleaning costs,
- retaining walls or end hauling side cast versus placing and maintaining large embankments and filled slopes,
- roadway ballast or surfacing versus maintenance of dirt surfaces,
- balanced earth quantities versus waste and borrow.

4.3 Forest Roads Erosion Process

Forest roads erosion can be broadly categorize as surface and mass erosion. Surface erosion is defined as movement of individual soil particles by combination of other forces and gravity force such as overland flow or runoff, raindrop impact, and wind (Sauer *et.al*., 1982; Reid and Dunne, 1984). Dry creep or dry ravel, the movement of individual particles resulting from wetting and drying, or mechanical disturbance, is considered as a surface erosion process. Mass erosion includes all erosion where particles tend to move en masse primarily under the influence of gravity. It includes various types of landslides and debris torrents.

4.4 Erosion Control Factors of Forest Road

Factors that might be considered as erosion control factors of road construction and subsequent development of site (Krag, 1981; Keller and Sherar, 2003) are:

4.4.1 Soil and geology

- soil physical and chemical characteristics
- geological conditions (stratigraphy, mineralogy, etc.)
- groundwater occurrence and movement
- slope stability
- seismic characteristics

4.4.2 Climate and Precipitation

- beginning and end of rainy season
- intensity and duration of storms
- occurrence of summer storms
- seasonal temperature
- wind erosion
- runoff before and after construction

4.4.3 Topography

- slope angle
- slope aspect
- slope length
- density and capacity of drainage
- suitability of sites for sediment basins

4.4.4 Vegetations

- type and location of native plants
- fire hazardous
- ease in establishing
- adequacy of existing plants to reduce erosion

4.4.5 Manner of development

- percent grade and layout of roads
- density of road
- distribution of open space
- structures affection erosion
- number of culverts, stream crossings
- size of areas, duration and time of the year when ground is barely exposure

Topographical consideration is very important in road location. Among these factors are steepness, slope length, slope aspect and distance to stream channels.

Road should be located in stable land, apart from streams or water way in order to minimize stream sedimentation (Schiess *et.al.*,2000). Landscape of steep slope, narrow canyons, slide areas, naturally dissected terrain, mashes of wet meadow, ponds, or along natural drainage channels should be avoided.

4.5 Forest Road Surface

Road surface must be kept well crowned or sloped for good drainage (Antola, 1988; Keller and Sherar, 2003). Surface balding should be preferably accomplished when the moisture content of the material show neither dust nor mud from the balding operation. Particular attention should be accorded with the crown of slope just before the rainy season.

Road subject to traffic during the wet season will require continual monitoring for surface condition including ability to drain, presence of rutting and loss of ballast (Keller and Sherar, 2003). Provisions should be made for ballast replacement where necessary as a condition to continuing operation on the road. Road sufficiently ballasted for dry weather operation may not be satisfactory for all seasons.

4.6 Forest Road Surface Erosion

The construction of forest road is the major cause of stream sedimentation in the forest harvesting system (Bureau of Land Management, 1978; FAO, 1977, 1979). Large quantities of sediment are produced from roads as a result of surface erosion and mass wasting. There are clear indications that approximately 80 % of the total accumulated erosion over the life of the road occurs within the first year after construction (Reid and Dunne, 1984; Forman and Alexander, 1998).

In order to minimize erosion during the construction, the following factors must be taken into account:

4.6.1 Keep construction time as short as possible, especially time for exposure of unprotected surface

4.6.2 Plan construction activities for the dry season. Construction activities during heavy or extended rainfall should be halted

4.6.3 Install drainage facilities right away. Once started, drainage installation should continue until completed

4.6.4 Construct filter strips at the top of fill slopes to catch earth slumps and sheet erosion

Renegotiation of areas disturbed by forest road construction is the most effective means of reducing sediment production. Mulches, chemical soil stabilizers and mechanical treatment measures are often required initially to help establish vegetation and to reduce erosion during this critical period. The various types of slope stabilization procedures and their effectiveness in reducing sedimentation are discussed in the fallowing sections.

4.7 Seeding and Planting

The forest cover was among the most effective vegetation in maintaining and protection soil from erosion. This cover reduced the effects of raindrop impact; decreases runoff velocity and erosion power, increases granulation, soil porosity, and biological processes associated with vegetative growth, and dry soil by evapotranspiration (Anderson and Simons, 1983; Forman and Hersperger, 1996; Jones and Grant, 1996).

Forest road construction commonly removed natural vegetation and exposes soil that had unfavorable properties for plant growth. Renegotiation by seeding and transplanting could be a successful method for stabilizing backslope and fills, putting road to bed which is no longer used, filtering sediment of water flowing into water courses.

4.8 Forest Road Drainage Structure

A major contributor to both acceleration of surface soil erosion and mass soil failures were the lack of adequate drainage. Drainage included practices which prevent concentration a water, and move dispersal of water into stabilizes land areas and into stabilized stream channels (American Iron and Steel Institute, 1979; Keller and Sherar, 2003). Failure or improper of road drainage facilities involved in all roads were traditionally connected to storm damage.

To minimize sedimentation from forest roads, special design planning; and construction of drainage facilities (Keller and Sherar, 2003) must be executed for certain condition and not being a generalized one.

4.9 Ditches and Culverts

Ditches, culverts and catch basins must be kept free of debris and obstacle (Highway Department, 1975; American Iron and Steel Institute, 1979). One new construction, catch basins mass required frequent cleaning, perhaps after each heavy storm. Grass in ditches should not be removed during cleaning operation. Shoulder and bank undercutting must be avoided. Damaged culverts should be repaired or replaced.

Culverts and inlets structures should be cleaned by flushing downstream only if adequate filters for protecting watercourse is available. Debris from cleaning operation should be hauled to a stable waste site to remove from any watercourse.

Live stream with culverts should be completely free from moving debris, at least 50 meters away from the upper stream. If the initial construction did not consider in debris deflectors on trash rock, and are later on required. It can be included as a part of the maintenance. Debris should be removed from streams or channels by grapples or tongs rather than by heavy equipment in the stream bed.

4.10 Retaining Walls

Retaining walls are used to bring about an abrupt change in grade, or enable the utilizations of steep overall slope, and then would otherwise be possible in a particular soil or rock mass (Odier *et.al*., 1971). Two types of retaining walls are commonly available in Thailand, including gravity and crib walls (Puangchit, 1986; RFD, 2001).

In Thailand, gravity walls are usually constructed by mixing sand and concrete at ratio 1:10, and put in plastic bags. The weight of the structure acts as counterbalance and resists earth pressures. This type of wall is usually the simplest and easiest to construct but generally can be used only relatively low walls with moderate soil pressures.

A crib wall is essentially a gravity type structure made of timber which forms an open structure of same dimension. When this opened structure is filled with soil or stone, it becomes relatively large and massive. This type of wall is usually suitable for small to moderate-light walls subjected to only moderate earth pressures. Crib walls are usually flexible enough to be used where settlement is a particular problem (U.S. Forest Service, 1979).

All retaining walls are expensive in design and construction. Crib walls are probably the cheapest for forest applications. The great expense of retaining walls reemphasizes the need to study all possibility alternative of the locations of roads in areas of potential mass wastage.

4.11 Conclusions

A review of erosion control from road construction in Thailand indicates relatively few information in sedimentation which can probably be minimized if proper engineering design, planning, construction, and maintenance are applied. To minimize erosion and control sedimentation, slope protections follow with necessary alignment of ditch size, culvert intakes, as well as culvert integrity and outlets are needed.

There is an abundance of information available on the subject of minimization the creation and transposition of sediment occurring in forest road construction. Other sources of information are individuals experiencing in design, construction and maintenance of these roads.

The value of a through planning and reconnaissance program for a proposed road is emphasized by many authorities. No amount of design or construction expertise can recover from an approach base upon inadequate reconnaissance information. Field reconnaissance evaluation must include attention to the potential of mass movements as well as surface erosion. In steep terrain, it is likely that the engineering investment to ensure a stable road will be much exhaustive than a gentle terrain.

The general approach to road design must be the classical engineering approach without a specific rule, depending on the individual practices under a certain circumstances.

Drainage designs are frequently appeared to be done without paying attention into the following features.

- Determination of the amount of flood
- Evaluation of the potential for debris blockage
- Choice of stream crossing method
- Attention to the installation of drainage requirement in both design and construction steps to insure the structural integrity

Minimizing surface erosion and sedimentation begins with the appropriate treatment or design of slope protection, and continues with the particular attention to ditch size, lining culvert intakes, culvert integrity and culvert outlets (Reid and Dunne, 1984; Schiess *et.al*., 2000; Keller and Sherar, 2003). Under most conditions, vegetation and other forms of permanent cover seems to be efficiently prevent excessive surface erosion from cut and slopes. Vegetation establishment should be initiated soon after the construction, before soil is disturbed.

Although inclusion of design criteria for erosion control may increase initial capital outlay, it is not necessarily increase total annual cost over road life.

5. Eco-tourism in Thailand

5.1 Definition and Ecotourism Principles

The International Ecotourism Society (TIES) defined ecotourism as "responsible travel to natural areas that conserves the environment and improves the well-being of local people." This means that those who implement and participate in ecotourism activities should follow the following principles

1) Minimize impact
2) Build environmental and cultural awareness and respect
3) Provide positive experiences for both visitors and hosts
4) Provide direct financial benefits for conservation
5) Provide financial benefits and empowerment for local people
6) Raise sensitivity to host countries' political, environmental, and social climate
7) Support international human rights and labor agreements

Ecotourism: Responsible travel to natural areas which conserves the environment and improves the welfare of local people

Over the past three decades, major losses of virtually every kind of natural habitat and the decline and extinction of species have occurred. Many of the ecosystems in decline provide attractions for tourism development. These include coastal and marine areas, coral reefs, mountains, and rainforests, which support a wide range of activities, including beach tourism, skiing, trekking, and wildlife viewing.

Increased human activities, such as logging, clearing land for agriculture, hunting and gathering fuelwood, are degrading both protected areas and the land surrounding them

As a non-extractive activity, ecotourism offers a sustainable way of using these areas and an opportunity to promote sustainable social and economic development.

Policy Planning and Working with Local Partners

Tourism, when properly planned and managed, can contribute to effective conservation and to the economy by directly capitalizing on biodiversity assets and by indirectly reducing the vulnerability of the poor to environmental degradation.

According to the Quebec Declaration on Ecotourism, ecotourism was "embraces the principles of sustainable tourism... and the following principles which distinguish it from the wider concept of sustainable tourism:

1) Contributes actively to the conservation of natural and cultural heritage,
2) Includes local and indigenous communities in its planning, development and operation, contributing to their well-being,
3) Interprets the natural and cultural heritage of the destination to visitor,
4) Lends itself better to independent travellers, as well as to organized tours for small size groups".

In May 2000, as part of the side events on the **8th session of the United Nations Commission on Sustainable Development** (CSD 8), a group of Indigenous Peoples Organizations, NGOs and other members of Civil Society provided a proposal on guidelines for ecotourism. Although the final result could not be incorporated into the official papers due to procedural aspects, UNEP recognizes its value as a statement of genuine concerns from primary stakeholders.

Ecotourism is sustainable tourism, which follows clear processes that:

- Ensures prior informed participation of all stakeholders,
- Ensures equal, effective and active participation of all stakeholders,

Acknowledges Indigenous Peoples communities' rights to say "no" to tourism development - and to be fully informed, effective and active participants in the development of tourism activities within the communities, lands, and territories, and

Promotes processes for Indigenous Peoples and local communities to control and maintain their resources.

The definition of ecotourism adopted by Ecotourism Australia is:

"Ecotourism is ecologically sustainable tourism with a primary focus on experiencing natural areas that fosters environmental and cultural understanding, appreciation and conservation".

Ecotourism Australia believes that the ultimate definition of ecotourism is compliance with the core criteria stated within the Eco Certification Program.

Tourism operators in Australia who have their tour, attraction or accommodation accredited under the Eco Certification Program can geniunely claim to provide authentic ecotourism product.

Consequently, ecotourism has the potential to create support for conservation objectives in both the host community and the visitor alike, through establishing and sustaining between the tourism industry, local communities, and protected areas.

As social and environmental benefits are essentially interdependent, social benefits accruing to host communities as a result of ecotourism may have the result of increasing overall standards of living due to the localized economic stimulus provided for an increased visitation to the site. Similarly, environmental benefits accrue as host communities are persuaded to protect natural environments in order to sustain economically viable tourism. Local communities compromise groups with difference, and potentially conflicting interests. That is, not all groups want the same things. The tourist industry seeks a healthy business environment with financial security, a trained and responsible workforce, attractions of sufficient quality to ensure a steady flow of visitors who stay longer and visit more often as well as a significant return on investment.

Those interested in the natural environment and cultural heritage issues seek protection of the environment through prevention, improvement, correction of damage, and restoration and also to motivate people to be more aware and therefore care for rather than use up resources. Community members seek a healthy place in which to live with food, adequate and clean water, health care, rewarding work for equitable pay, education and recreation; respect for cultural traditions; and opportunities to make decisions about the future. Some concerns that each may hold in common include: issues of access, such as when, where and how tourists visit and move from place to place; host and guest issues, such as cultural impact or common use of infrastructure; land use issues, such as hunting wildlife habitat, agriculture, recreation, preservation and development. A number of reasons why local communities may consider ecotourism is a desire to be part of strong growth in tourism generally and see the potential of catering for special-interest tourism (niche markets), an awareness of the high value of natural attractions in the locale, empathy for conservation ideals and the need for sustainable tourism and a desire to responsibly rejuvenate the local tourist industry. However there are conflictual issues expressed by representatives of host communities to tourism development and generally fall into a number of interrelated categories.

These include the lack of opportunities for involvement in decision-making relating to ecotourism; inadequate responses from governments when administrative or legislative mechanisms have been established to involve them in such decision-making; the lack of financial, social and vocational benefits flowing to these communities from projects that commercially exploit what they regard as their resources; the need to establish better tools for evaluating socio-cultural impacts and ensuring this is completed over the more emphasized environmental impacts on the natural environments which are usually of more interest to the outside investors and conservation groups; impacts on community cohesion and structure as well as the rapidity of tourism development that in many cases significantly accelerates social change.

These concerns embrace a wide range of issues relating to the management of natural resources adjacent to these communities. The central issue is the inadequate levels of participation perceived by these communities in the management of what they regard as their traditional domains. In view of the significance of wildlife conservation on its own and its tourism value, wildlife-human conflicts will remain a permanent problem in the neighborhoods of protected areas. As such, the role of policy is to reduce the conflicts to a tolerable level. This involves dealing with problem wildlife and devising mechanisms to allow local people to derive direct benefits from wildlife-based tourism. Such an approach is likely to encourage the residents of those areas to conserve the fauna and the flora.

Wikipedia, the free encyclopedia defined **Ecotourism** as ecological tourism, where ecological has both environmental and social connotations. It is defined both as a concept-tourism movement and as a tourism (specifically sustainable tourism) sector. Born in its current form in the late 1980s, Ecotourism came of age in 2002, when the United Nations celebrated the "International Year of Ecotourism". The International Ecotourism Society defines ecotourism as "responsible travel to natural areas that conserves the environment and improves the well-being of local people". However, this is a vibrant, new movement and there are various definitions.

Eco-tourism focuses on local cultures, wilderness adventures, volunteering, personal growth and learning new ways to live on our vulnerable planet. It is typically defined as travel to destinations where the flora, fauna, and cultural heritage are the primary attractions. Responsible ecotourism includes programs that minimize the adverse effects of traditional tourism on the natural environment, and enhance the cultural integrity of local people. Therefore, in addition to evaluating environmental and cultural factors, initiatives by hospitality providers to promote recycling, energy efficiency, water re-use, and the creation of economic opportunities for local communities are an integral part of ecotourism.

Many global environmental organizations and aid agencies favour ecotourism as a vehicle to sustainable development.

Ideally, true ecotourism should satisfy several criteria, such as

1) conservation (and justification for conservation) of biological diversity and cultural diversity, through ecosystems protection
2) promotion of sustainable use of biodiversity, by providing jobs to local populations
3) sharing of socio-economic benefits with local communities and indigenous people by having their informed consent and participation in the management of ecotourism enterprises.
4) increase of environmental & cultural knowledge
5) minimization of tourism's own environmental impact
6) affordability and lack of waste in the form of luxury
7) local culture, flora and fauna being the main attractions

For many countries, ecotourism is not so much seen as a marginal activity intended to finance protection of the environment than as a major sector of national economy and as a means of attracting tourists. For example, in countries such as Kenya, Ecuador, Nepal, Costa Rica and Madagascar, ecotourism represents a significant portion of the gross domestic product.

The concept of ecotourism is widely misunderstood and, in practice, is often simply used as a marketing tool to promote tourism that is related to nature. Critics claim that ecotourism as practiced and abused often consists in placing a hotel in a splendid landscape, to the detriment of the ecosystem. According to them, ecotourism must above all sensitize people with the beauty and the fragility of nature. They condemn some operators as "green-washing" their operations — that is, using the label of "ecotourism" and "green-friendly", while behaving in environmentally irresponsible ways.

Although academics argue about who can be classified as an ecotourist, and there is precious little statistical data, some estimate that more than five million ecotourists — the majority of the worldwide population — come from the United States, with other ecotourists coming from Europe, Canada and Australia.

Currently there are various moves to create national and international ecotourism certification programs, although the process is causing controversy.

One criticism against ecotourism is that the air travel to often remote places is not included in the "environmental impact calculation". A journey to a place 10,000 km away and home consumes about 700 litres of fuel per person. Another problem is that some of the destinations visited by ecotourists are extremely sensitive to environmental impact from human use (e.g. Antarctica, bird breeding colonies) and can be damaged even by careful travellers.

Tourism Authority of Thailand (TAT) defined the definition and concept of Ecotourism as

“Ecotourism is responsible travel in areas containing natural resources that possess endemic characteristics and cultural or historical resources that are integrated into the area’s ecological system. Its purpose is to create an awareness among all concerned parties of the need for and the measures used to conserve ecosystems and as such is oriented towards community participation as well as the provision of a joint learning experience in sustainable tourism and environmental management.”
(Tourism Authority of Thailand, 1997)

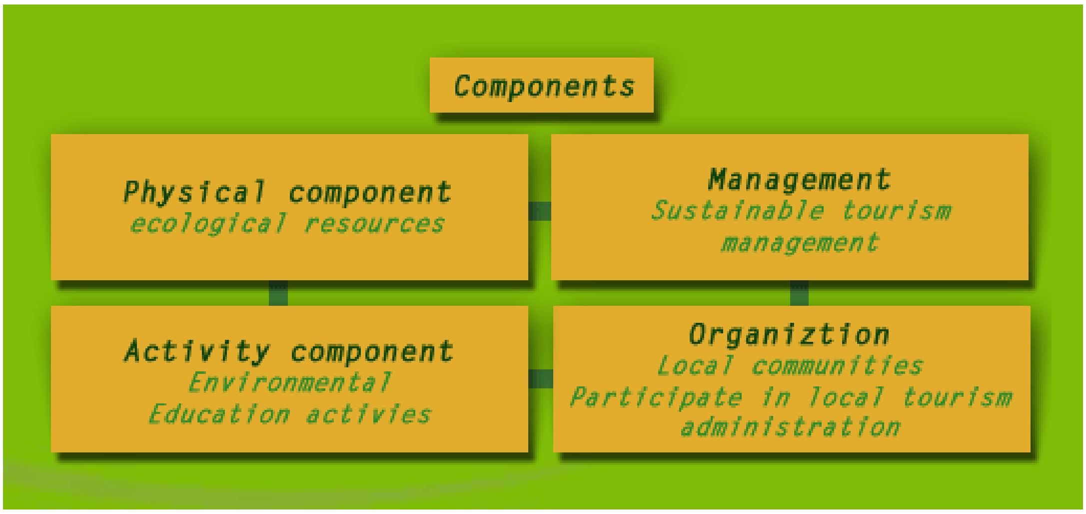


Figure 9 The component ecotourism of Thailand.

Source: Tourism Authority of Thailand (1995)

Ecotourism should be characterized by the followings:

1) Tourism activity is carried out in a relatively undisturbed natural setting.

2) Negative impacts of tourism activity are minimized

3) Conserves natural and cultural heritage

4) Actively involves local communities in the process, providing benefits to them.

5) Contributes to sustainable development and is a profitable business

6) Education/appreciation/interpretation component (of both natural and cultural heritage) must be present"

Definition and Concept of Ecotourism

Ecotourism is seen as a symbiotic relationship between tourism and nature conservation. The criteria that the ecotourism development should meet are:

1) The activity must be nature based. It does not imply that the setting must be pristine or unmodified. It does not exclude settings that include exotic species or are substantially or totally comprised of introduced species. It does not imply any specific level of physical activity. It means that the motivation for undertaking the

activity in a particular setting is provided by expectations of satisfaction that are directly related to the natural qualities of the setting.

2) The activity must be environmentally sustainable. It is this criterion that supports the contention that ecotourism is better understood as a process rather than a product. To ensure environmental impacts of tourism activities are sustainable it is necessary to have a process for monitoring environmental impacts and the ability (and willingness) to limit or mitigate the impacts of tourism and recreation within the limits of acceptable change.

3) The activity must make a contribution to nature conservation. The contribution to conservation may be measured by the degree to which the impact of local communities is reduced or it may be made directly by the tourism related activities, or indirectly by facilities provided with the funds generated from ecotourism.

5.2 Ecotourism Policy and Plans

During 1995-1996, the Tourism Authority of Thailand has established policies, Management Guidelines and action plan for ecotourism as the followings

The National Ecotourism policies

Management Guidelines

National Ecotourism Action Plan (2002-2006)

5.2.1 The National Ecotourism Policies

In 1997, the National Ecotourism Councils was set up composing of representatives of the public sectors, academic, private sector, and NGOs involving in ecotourism development. Its main mission was to oversee the development of National Ecotourism Policy and Action Plan as well as appointed the Sub-Committee on various aspects of ecotourism management. The goals, guiding principles, and policy aspects of the National activities Ecotourism Policy are summarized below. Its content guides ecotourism management in Thailand as well as Ecotourism Action Plan (2002-2007) already approved by the Cabinet in October 2001 (TAT, 2001)

5.2.1.1 Goals

The overall goals of ecotourism development are to develop a sustainable tourism industry, to maintain a healthy natural and social environment and to foster self-reliance of local communities. The specific goals of ecotourism development are:- Ensure that endemic natural resources and unique cultural resources and their surrounding ecological system have an appropriate management system that emphasizes conservation, rehabilitation and ecosystem maintenance. Carrying capacity and instituting a proper zoning scheme should do this.

- Promote people's awareness of how tourism can contribute to ecological sustainability. This would foster the comprehensive conservation the natural and social environments.
- Establish a management system that facilitates cooperation among all relate sectors. This should include local participatory management in tourism development.
- Establish tourism facilities and services that help protect the environment and are thus compatible with tourism resources. Environmental management should aim to maintain the natural and social characteristics of the areas and reassure the tourists' feeling of security.
- Attract quality foreign eco-tourists to visit Thailand. Attempts also be made to promote ecotourism to a broader market segment of Thai tourists, particularly Thai youth. Disperse of tourists from main tourist attraction to other tourism destinations throughout the country should be emphasized.

5.2.1.2 Principles of Ecotourism Development

- The tourism resources must be managed to maintain their natural conditions as far as possible, and to avoid or to refrain from traveling to sensitive area which are very fragile and adversely impact can be occurred and difficult to rehabilitate.
- Emphasize the natural characteristics of existing tourism resources into management consideration in determining appropriate tourism activities and to ensure the compatibility between ecotourism and the original activities carried out in the area. This should include the avoidance of being in serious conflict with other forms of tourism. The benefits of ecotourism should also flow to the wider tourism system.
- Educational development must be promoted and stimulation of awareness from all concerns to jointly maintain the ecosystem of the area must be done rather than focus on economic growth and income generation only.
- Ecotourism management must facilitate the involvement of the local people and local organization in the tourism development process, particularly in the management of the resources, services, and programs designed to transfer knowledge and community culture. This should include their participation in formulating tourism management plan. Local representatives should be encouraged at all tourism management levels.
- Determine the ecotourism management priority and provide all concerned organizations clear roles in promoting ecotourism. This can be done through appropriate budget allocation, personnel provision, and management system design.
- An ecotourism development plan should be incorporated into the development plan at all levels, namely district, provincial, and regional development plan, along with sufficient budget allocation to ensure effective plan implementation.
- The tourism research should be carried out to determine or improve management guidelines, to solve any problems which arise, and to improve the plans.

- Law should be enforced strictly to control and maintain good environmental condition of tourism resources by focusing on providing advises and cautions along with cultivating discipline among tourists.
- Operating guidelines or tourism code of conduct should be provided for all related parties.
- An ecotourism network should be established both vertically and horizontally, through the co-ordination of information and joint- management at all levels.

5.2.2 Management Guidelines

To achieve the objectives of the five main factors stated at the beginning, the following clear and accurate management guidelines are necessary:

5.2.2.1 Guidelines for the management of tourism areas, and the conservation of the environment:

- Considering the management of the tourism area by dividing it into different administrative sections in order to separate the activities of the tourism section from those of the conservation section.
- Considering measures to seriously limit the number of tourist in environmentally fragile areas.
- Clearly indicating the role of TAT in the conservation of environmentally fragile areas.
- Considering regulations/rules of behaviour imposed on tourists.

5.2.2.2 Guidelines for communicating and giving educational services:

- Producing tourism media in terms of nature, culture, and history.
- Considering allocating a budget for producing tourism media to the parties involved.

- Considering upgrading knowledgeable local people to the position of qualified and eligible specialist tour-guides; together with the development of a tourism curriculum to correspond with the recommendations for development.

5.2.2.3 Guidelines for encouraging participation from the local people and giving benefits to them:

- All the organizations concerned have to promote education by disseminating information and understanding in ecotourism through various media, both inside and outside the formal education system to the youth, people in general, and community leaders.
- Local tourism enterprises may be organized into the form of a club, an organization, or a co-op to collaborate in mapping the recommendations of development and conservation, as well as to strengthen the power in marketing negotiations. This will result in the sustainability of local enterprises. Private development organizations and academicians may be involved as advisors in management.
- In proceeding with any recommendation, all the local resources should be primarily taken into consideration, whether they are personnel, raw materials, folk wisdom, or local heritage.

5.2.2.4 Guidelines for the prevention of the negative impact on culture:

- Setting limits for tourists and business operators, realizing the impact on culture; for instance, avoiding to cause cultural disintegration by behaving in accordance with the local culture (not interfering with personal rights; not behaving in the way to offend local people, or treating them as inferior, but being polite and in accordance with the principles of equality and human rights).
- Being aware of the fact that any change may cause an impact on the way of life and culture of local areas, study carefully and keep respect for the local culture and folk wisdom.
- In presenting the genuine culture to tourists, being aware of accurate knowledge, approval of the local community, and particular rules of

behavior within the culture and rites; in addition, inappropriateness in the change of the culture and rites to suit the marketing directions, or only to please tourists.

5.2.2.5 Marketing guidelines:

- To promote an idea of ecotourism among the youth and visitors in general both the Thais and the foreigners.
- To set the standards of ecotourism management, putting more emphasis on quality than quantity of tourism arrivals.
- To enhance the active role of tour operators in the ecotourism.
- To promote, boost and facilitate the organizing of international conferences in connection with the ecotourism.
- To produce and disseminate audio visual materials for the promotion of the ecotourism.

5.2.2.6 Other guidelines:

- To consider the advantages, disadvantages, and limits of home stay accommodation.
- To disseminate the knowledge on ecotourism which is clear, easy to understand and comprehensive.

5.2.3 National Ecotourism Action Plan (2002-2006)

Ecotourism is a form of sustainable tourism which plays significant role in the overall travel industry of the country in terms of economy, environmental conservation and boosting the living standard of local people in the nearby areas of tourism attractions.

For this reason, the Committee for Ecotourism Promotion and Development sees the necessity to set the certain action plans for ecotourism development. The plans are expected to be the guidelines for relevant agencies and the local communities to implement properly and lead to cooperation among each other in order to bring the efficiency and reach maximum mutual benefits.

The National Ecotourism Promotion and Development Committee then, appointed six sub-committee groups with their main task was development of Thailand's ecotourism action plans. The sub-committees proposed to adjust and reduce the plans from what was proposed in the study of Thailand Institute of Science and Technology Research in 1997 to be 14 plans and 43 projects and submitted to the National Ecotourism Promotion and Development Committee, which finally approved the main concept of the action plans for ecotourism in June 1999. The plans were proposed further to the TAT's committee for their consideration in March, 2000 which it requested revises on some projects before proposing it for the final approval from the minister cabinet.

Later on, TAT with cooperation from the Faculty of Forestry, Kasetsart University revised the action plan and had it approved by the minister Cabinet in October, 2001. The action plans for ecotourism was announced to be implemented at the national level and ordered all related agencies taking action according to the plans.

National Ecotourism Action Plan is a five year implementation plan starting from 2002 to 2006 which is in line with the 9th National Plan for Social and Economical Development. The Action Plan consists of 14 plans and 37 projects. It provides details of the projects needed to be implemented in order to fulfill the ecotourism policy of Thailand. The action plans correspond and support all six policies in ecotourism management as follows:

1) Tourism resources and environment management
2) Education and awareness building to the public
3) Cooperation among local people
4) Marketing promotion and tour guide
5) Basic infrastructures and ecotourism services development
6) Ecotourism investment support and promotion

6. Mathematical Modeling for Decision Making

There are two major thrusts in mathematical modeling with decision making environment: Optimization and simulation (Fotheringham and Rogers 1994, Stewart and Godchild 1994). Each represents a fundamentally different approach to problem solving. Broadly speaking, the output of optimization models is a prescription of strategy. Simulation, on the other hand, is a descriptive approach.

6.1 Optimization Modeling

Optimization is a normative approach to identify the best solution for a given decision problem (Wilson et. al.; 1981; Thomas and Huggett, 1980). An optimization method is a modeling method that seeks to find the best (maximum or minimum) solution to a well-defined management problem. A well-defined problem is one which has been structured in a way that the optimization method can utilize. Common to all optimization models is a quantity to be minimized or maximized. The quantity is often termed the objective or criterion function. The constraints define the set of feasible solutions. The solution to an optimization problem determines the values of decision variables subjective to a set of constraints. Thus, in the most general term an optimization model can be written as follows:

Minimize or maximize	$f(x)$
Subject to	$x €X$

Where f (x) is a criterion function, x is a set of decision variables, and X is a set of feasible alternatives. If the problem involves a single criterion function, the problem is referred to as a single-criterion decision model. When more than one criterion function is to be optimized simultaneously, the model is called a multi-criteria problem.

6.1.1 Linear Programming (LP)

One special type of optimization is linear programming (LP) (Greenberg 1978; Thomas and Hogget 1980; Killen 1983; Dykstra 1984). It is a tool developed for use in operations research, a science dealing with the development of mathematical decision models for management. In a linear programming model both the objective function and the constraints are linear and additive. The problem also assumes that the decision variables are linear and additive. The problem also assumes that the decision variables are of continuous type. Most linear programming problems have an economic objective function which seeks to optimize such economic concepts as profit, cost, or net present value. This objective function is comprised of a set of decision variables, each of which is multiplied by a constant coefficient. These coefficients correspond to each decision variable is contribution to the objective function value. Decision variables represent those portion of the total resource base that are allocated to particular activities. Some examples of decision variables that have been used in resource management are the mount of land allocated to specific activities, such as housing, recreation, or transportation; or the number of acres assigned to riparian area restoration, intensive timber management. The primary role of linear programming is to serve, as an allocate of scarce resources to competing activity demands (Goicoechea *et al.*, 1982; Dykstra 1984).

Because resources are not limitless and other potentially conflicting consideration need to be taken into account, a set of constraints are employed to restrict unlimited growth of the objective function in maximization problems and to force some activity occur in minimization problems. Like the objective function, these constraints are also linear and form a geometric space known as the decision space (or feasible region) which constraints very feasible solution to the linear programming problem. Any point outside this solution space is considered in feasible (i.e., a point that leads to a solution that violates one or more constraints and therefore can not be considered as a solution to the problem (The corner points of the solution space (i.e., points where two or more constraints converge) are the only candidates for solution consideration.

6.1.2 Network optimization (No)

Network optimization is one of the most widely applicable spatial decision models (Thomas and Hugget 1980; Ghost and Ruston 1986). A network consists of nodes (supply, demand, and transshipment point for resources) and arcs (paths over which resources flow between nodes) (Killen 1983; Malczewwski and Ogryczak 1995). Network flow models generally involve the optimization of a function of the flows of resources between nodes subject to a conservation of flows constraint (flows into a transshipment node must flow out of the node). The objective of network flow analysis is to determine the best allocation of resources among the nodes subject to resource availability and flow restrictions across arcs (Luien et al. 1987). Many linear programming problems can be formulated as network flow problem without a great deal of difficulty. However, conversion of other linear programming problems to network flow problems may be either too abstract to be of much value, or simply not be feasible to do. The two principal advantages of network flow models are vastly improved solution times over standard linear programming models and graphic representation of the network which can make problems more intuitive to users (Golden and Boding, 1986; Camm *et al.*, 1997).

6.1.3 Single and Multiple objectives

The problems associated with managing forest land, National Park, tourism objectives, and other resources have never been simple. The concept of park roads management which tries to compromise ecological tourism, socio – economic, and other impacts utilization in the system seems impossible to determine for the best management practice. Fortunately, there is an analytical process that be able to reduce those difficulties to manageable levels. The applications that have most fruitful are based on the mathematical programming model by means of optimization techniques (Haith, 1982). To solve the management problems, the following techniques must be understood.

6.1.3.1 Single Objective Programming

Linear programming is a mathematical technique provides only one objective function to be maximized or minimized. The program refers to the use of certain mathematical techniques to get the best possible solution to a problem involving limited resources. The models have certain characteristics in common. Thus, it is essential to understand those characteristics. The characteristics can be grouped into two categories: components and assumptions. The components relate to the structure of a model, whereas the assumptions reveal the conditions under which the model is valid (Levin *et al.*, 1982; Stevenson, 1992).

The characteristics of LP model are listed in Table 26. The following discussion will provide insight into the nature of linear programming problems and models.

1) Components of LP Model

In formulation of LP model, the following components must be understood.

Objective : The objective in problem solving is the criterion by which all decisions are evaluated. In linear programming models, a single, quantifiable objective called "Objective function" must be specified by the decision maker. According to the optimal solution, hence, it will be either a maximization problem or a minimization problem.

Decision variables : Decision variables represent choices available to a decision maker, usually with respect to the amount or quantity of either an input to a process or an output from a process. In terms of the LP model, the decision variables represent those unknown quantities.

Constraints : The ability of a decision maker to select values of the decision variables in an LP program is subject to certain restrictions or limits. The restrictions may reflect availabilities of resources (e.g. raw material, labor time), legal or contractual requirements (e.g. product or work standards), technological requirements, or they may reflect other limits based on forecasts, organization policies, and so on. In an LP model, the restrictions, are referred to as constraints. Only solutions that satisfy all constraints in a model are acceptable. These are referred to as feasible solutions. The optimal solution is the feasible solution that yields the best value in terms of the objective.

Table 26 Characteristics of linear programming model

Model validity	Model structure	Model validity
Components	1. Objective	
	2. Decision variables	
	3. Constraints	
	4. Parameters	
Assumptions		1. Proportionality
		2. Additively
		3. Divisibility
		4. Certainty
		5. Non – negativity

Source: Modified from Stevenson (1992)

Parameters : An LP model consists of a mathematical statement of the objective function, and a set of mathematical statements of the constraints. Those statements consist of symbols that represent the decision variables (for example, X_1, X_2, X_3) and numerical values called parameters. The parameters are fixed values that specify the impact that one unit of each decision variable will have on the objective and on any constraint, it pertains to as well as to the numerical value of each constraint.

2) Assumption of LP Model

The following characteristics are assumed in applying the LP model:

Proportionality: The proportionality requirement is that each decision variable has a linear impact in the objective function and in each constraint in which it appears. This means that change in activities proportionally affects outputs. Furthermore, the assumption implies that average value does not change as quantities change (Bell, 1977). This means, for example, that if the profit of x is $ 4 per unit, the same figure must hold regardless of the quantity of x_1: it must be true over the entire range of possible values of decision variable.

Additively: The terms of objective function and each constraint must be additive. Additively requires that activities be independent, So that the sum of the outputs of the individual activities will be equal to the output if these activities are combined.

Divisibility: In general, divisibility is not severely limiting. It means that all activities or variables in the problem may be divided into smaller and smaller parts.

Certainty: The LP solution is deterministic. For given inputs, one must be willing to assume that outputs will occur with certainty. If it does not produce certainty, a body of theory is available for dealing with uncertainty and risk in decision making (Bell, 1977). The certainty requirement involves two aspects of LP models. One aspect relates to the model parameters. It is assumed that these values are known and constant. In practice, production times and other parameters may not be truly constant. Therefore, the model builder must take an assessment as to the degree to which the certainty requirement is met. Another aspect is the assumption that all relevant constraints have been identified and represented in the model.

Non – negativity: The requirement is that negative values of variables are unrealistic and, therefore, will not be considered in any potential solutions; only positive and zero value will be allowed.

3) Limitation of LP Model

Linear programming allows only one objective function to be maximized or minimized, which is not suitable for real world conditions. It has become more and more difficult to see the world around us in a uni-dimensional way and to use only a single criterion when judging what it is. Things should be compared, ranked and ordered for the objectives of choice with respect to criteria. But only in a very simple, straightforward, or routine situation can be assumed that a single criterion of choice be fully satisfactory. On the other hand, using on criteria or too many criteria are both undesirable extremes and usually signal bad management. Usually decision criteria or objectives are not all equally important. Traditionally, different weighting schemes have been devised to address the problem of differential levels of important for objectives.

6.1.3.2 Multiple Objectives Programming

Today the problems are more complex and difficult than those of an earlier ear. All of these problems occur simultaneously and on a worldwide basis. In the multiple – use management of watershed resources, numerous and often conflicting objectives exist. To appreciate what is involved in the modeling process, certain concepts need to be understood clearly.

Romero and Redman (1989) explained some basic concepts of multi – objective modeling as follows:

1) Some Basic Concepts of Multi – Objectives Modeling

The first step is to establish the conceptual differences among attributes, objectives and goals, and also the distinction between goals and the conventional interpretation of constraints. After that, the idea of an efficient or a Pareto optimal solution is introduced, as it is essential to the development of the multi-objectives programming approach.

It should be pointed out that some of the concepts may have the same dictionary meanings, for example, goals and, in the context of some problems, can be used interchangeably without creating confusion. However, the meaning and use of some concepts in the analysis of a decision – making problem changes according to the theoretical structure, single or multi-objectives framework, within which the problem is being studied. The followings are steps to modeling the multi-objectives function:

(1) Attributes, Objectives and Goals

Attributes can be defined as a decision maker's (DM's) values related to an objective reality. These values can be measured independently from a DM's desires and in many cases can be expressed as a mathematical functions f(x) or in a ration formulation model of the decision variables. It can be clearly seen in terms of a set of inequality equations in the model structure.

The concept of an objective represents the direction of improvement of one or more of attributes. The improvement can be interpreted in the sense either "more of the attribute, the better" or "less of the attribute, the better". The first case means a maximization process and the latter situation minimization is at work. Therefore, objectives imply the maximization or the minimization of the functions representing one or several attributes reflecting the values of the DM.

A goal is an aspiration level or a target. A target is an acceptable level of achievement for any one of the attributes. On combining an attribute with a target will get a goal. In short then, in term of planning process will compose of many attributes or constraint, to maximize or minimize, an objective, and, to achieve a certain target, a goal. Finally, a criterion is a general term comprising the three preceding concepts. That is, criteria are the attributes, objectives or goals to be considered relevant for a certain decision – making situation.

(2) Distinction between Goals and Constraints

In fact, goals and constraints have the same mathematical structure and look exactly the same as both of them are inequalities. The difference between them lies in the meaning attached to the right – hand of the inequality. With goals the right – hand side is a target aspired by the DM, which may be achieve or not. With constraints, however, the right – hand side must be satisfied otherwise an unfeasible solution ensues.

6.1.4 Goal Programming (GP)

Goal programming (GP) is a variation of linear programming that can be used for problems that involve multiple objectives. This technique originally developed by Charnels and Cooper since 1960 which has been applied in various fields such as quality control, capital budgeting, resource allocation, manpower planning, project selection, etc. (Ignacio, 1983). GP models are quite similar to LP models, both are formulated under the same requirements and assumptions (e.g.) linearity, certainty, non – negativity…)

In the context of GP, multiple objectives are referred to as goals. Each goal relates to a target level of performance (Stevenson, 1992). The general aim of GP is simultaneous optimization of several goals. For that reason the deviations from the desired targets and what is actually achievable are minimized. The minimization process can be accomplished by several methods. Each method is a specific variant of GP. The most two widely used variants of GP are lexicographic goal programming (LGP) (Romero and Redman, 1989).

In LGP, higher priority goals are satisfied first, and only then are lower priorities considered. WGP, on the other hand, considers all goals simultaneously within a composite objective function composed of the sum of all deviations among the goals and their aspiration levels. The deviations are weighted according to the relative importance of each goals. (Romero and Redman, 1989). According to the latter, one comes up with a set of weights that truly reflect differences in importance. Some decision makers have found this process to be difficult and some what artificial. More recently, interest has centered on priority models (Stevenson, 1992).

It should be pointed out that there are two different types of goal. The first type are the goals which represent the decision maker is desires to reach a specific value and the second type of goals refer to the existence of limited resources. (Romero and Redman, 1989).

The setting of goals, targets, or aspiration level is an old and useful tactic in the pursuit of human objectives. Setting goals is an art. They should be neither too high nor to low. Everybody knows the agony and frustration of failing to achieve a goal set too high; everybody knows the disappointment and dissatisfaction which often sets in after one has “succeeded” in attaining a goal that was set too low. Given a portfolio of properly established goals, one tries to achieve them as closely as possible. Attaining a goal is necessary and sufficient prerequisite for setting a new goal it is not an end in itself (Zeleny, 1982)

It should be pointed out that there are two different types of goal. The first type are the goals which represent the decision maker is desires to reach a specific value and the second type of goals refer to the existence of limited resources. (Romero and Redman, 1989).

The setting of goals, targets, or aspiration level is an old and useful tactic in the pursuit of human objectives. Setting goals is an art. They should be neither too high nor too low. Everybody knows the agony and frustration of failing to achieve a goal set too high; everybody knows the disappointment and dissatisfaction which often sets in after one has “succeeded” in attaining a goal that was set too low. Given a portfolio of properly established goals, one tries to achieve them as closely as possible. Attaining a goal is necessary and sufficient prerequisite for setting a new goal it is not an end in itself.

GP needs to set some estimated targets for each of their goals and to put priorities on them that is to rank them in order of importance. The program tries to minimize the deviations from the targets that were set. It begins with the most important goal and keep on until the achievement of a less important goal would cause management to fail to achieve a more important one. However, typical f ranking goal can be divided into 3 models : A single – goal, Equally ranked multiple goals and priority ranked multiple goals (Levin *et al.*, 1982). Stevenson (1992) clearly explained some important aspects of the goal model:

In GP models, goals are expressed as constraints. However, goal constraints are somewhat different to those encountered in LP. In LP models, a solution would not be considered feasible if it violated any of the constraints. Because of the absolute requirement that constraints be satisfied and given as hard constraints. In contrast, goal constraints specify desirable levels of performance. These are treated as approximate rather than absolute amounts which should be achieved to the extent possible. Therefore, a goal constraint will be called as soft constraints or goal constraints.

The models may consist entirely of soft constraints (goal constraints), or a combination of soft and hard constraints. The solution to a GP model must also satisfy any hard constraints, although it may not necessarily achieve the target levels of the soft constrains. When one or more goals are not achieved by a solution, it is because there are conflicts either between goals or between goals and hard constraints. Deviations from goals are permitted if they are needed to obtain a solution. Thus, in GP, the objective is to satisfy the hard constraints. (if any) and achieve reasonably acceptable levels for the goal constraints. This is referred to as satisfy.

The following details are the main steps in applying the GP model:

6.1.4.1 Deviation Variables

In order to account for possible deviation from goal, deviation variables are incorporated into each goal to represent the differences between actual performance and its target. There are two possible kinds of deviation from a target: being under the target amount (underachievement, u), and being over the target amount (overachievement, v). Deviation variables are included in each goal constraint. Adding these two deviation variables to a goal constraint create an equality because the deviation variables are equivalent to slack (amount of underachievement,) and being over the target amount (overachievement). Deviation variables are included in each goal constraint. Adding these two deviation variables to a goal constraint create an equality because the deviation variables account for any discrepancy between actual and target. In effect, the deviation variables are equivalent to slack (amount of underachievement,) and surplus (amount of overachievement, v). Hence, u is added and v is subtracted in a goal constraint. In addition, one of the two deviation variables in each goal constraint would equal zero in any solution because it would be physically impossible to be over and under a goal simultaneously. For more details Romero and Redman (1989) indicated that: A goal cannot be both underachieved (u) and overachieved (v). Hence, in a solution at least one of the deviation variables for each goal is zero. When a goal matches its aspiration level exactly then both u = v = 0. If a certain goal's achievement must be greater than or equal to its target then its deviation variable (u) must be minimized. If a certain goal must be less than or equal its target then the v deviation variable must be minimized. Finally, if a certain goal must be exactly equal to its target, then both u and v deviation variables must be minimized.

6.1.4.2 Model Formulation

A GP model consists of an objective and a set of constraints. The constraints may be goal constraints or they may be a mix of goal and no goal constraints. In addition, there is non – negativity requirement that all variables must be non – negative.

In priority models, the objectives indicate which deviation variables will be minimized and their order of importance. Thus, the objective is to minimize specified deviations from certain goals according to priority. The formulation steps of GP model would be as follows:

- Identified the decision variables
- Identified the constraints and determine shish ones are goal constraints
- Formulate the no goal constraints (if any)
- Formulate the goal constraints.
- Formulate the objective
- Add the non – negative requirement statement.

The following example illustrates the above ideas:

$$\textbf{Minimize } Z = P_1u_1+P_2u_2+P_3u_3$$

Subject to:

$a_{11}\, x_1 + a_{12}\, x_2$	$\leq$	b_1	Hard constraint
$a_{21}\, x_1 + a_{22}\, x_2 + u_1 - v_1$	$=$	b_2	$goal_1$
$a_{31}\, x_1 + a_{32}\, x_2 + u_2 - v_2$	$=$	b_3	$goal_2$
$a_{41}\, x_1 + u_3 - v_3$	$=$	b_4	$goal_3$

All variable ≥ 0

Where:

Z = Represent the objective minimization of the deviation variables or achievement function

P = The P's represent priorities, and their subscripts indicate order of importance

a_{ij} (i = 1…4, j = 1,2)	= coefficient of variable j in constraint i
x_j (j = 1,2)	= decision variable j
b_i (i = 1…4)	= right – hand side value of constraint i
u_j, v_i	= the deviations of under and over target level

6.1.4.3 Computer – assisted Solutions

GP problems can be solved using either a simplex method or a standard LP package. The above example can be examined by computer approach. The computer – assisted approach adds goals sequentially according to priority and generates a solution after each goal is added.

The process begins by solving a model that includes any hard constraints and one goal constraint. The goal constraint that contains the deviation variable that has the highest priority. The solution for that model fixes the value of deviation variable for the remainder of the analysis. Consequently, that variable is deleted from the model. This process is repeated using remaining deviation variable that has the highest priority and so on, until all priorities have been considered. The following example illustrates the 3 steps of the process.

From the above example:

$$\textbf{Minimize } Z = P_1u_1+P_2u_2+P_3u_3$$

Subject to:

$a_{11}\, x_1 + a_{12}\, x_2$	$\leq$	b_1	(Hard constraint)
$a_{21}\, x_1 + a_{22}\, x_2 + u_1 - v_1$	$=$	b_2	($goal_1$)
$a_{31}\, x_1 + a_{32}\, x_2 + u_3 - v_3$	$=$	b_3	($goal_2$)
$a_{41}\, x_1 + u_4 - v_4$	$=$	b_4	($goal_3$)

All variable ≥ 0

1) Focusing on the first priority ($goal_1$)

The first model must focus on the deviation variable with the highest priority, which is u1 in this problem. Consequently this first problem consists of hard constraint, first goal constraint and an objection function that includes all decision variables as well as the deviation variables in the first goal constraint. The model is:

$$\textbf{Minimize } Z = 0X_1+0X_2+u_1+0v_1$$

Subject to:

$a_{11}\, x_1 + a_{12}\, x_2$	$\leq$	b_1	(Hard constraint)
$a_{21}\, x_1 + a_{22}\, x_2 + u_1 - v_1$	$=$	b_2	($goal_1$)

Note that the decision variables are now represented in the objective function. All of the variables except the highest priority deviation variable have coefficients of zero. The zero coefficients reflect the fact that the quantities of these variables will have no impact on the objective, which is to minimize the amount of under – deviation on the first goal.

Suppose that the optimal Z = 0, that is $u_1 = 0$ then substitute this value into the first goal constraint and delete u_1 from the model. This, essentially, fixes the value of u_1 at zero for the remainder of the analysis.

2) Minimize the second priority ($goal_2$)

The next priority is to minimize u2, which is the second constraint. That constraint is now brought into the model, and the objective is modified accordingly. The revised model is:

$$\textbf{Minimize } Z = 0X_1+0X_2+u_2+0v_2$$

(u_1 is omitted)

Subject to:

$$a_{11}\, x_1 + a_{12}\, x_2 \quad \leq\ b_1 \text{ (Hard constraint)}$$
$$a_{21}\, x_1 + a_{22}\, x_2 - v_1 \quad =\ b_2 \text{ (subtracting the value of } u_1\text{) (goal}_1\text{)}$$
$$a_{31}\, x_1 + a_{32}\, x_2 + u_2 + v_2 \quad =\ b_3 \text{ (goal}_2\text{)}$$

Again, all objective function coefficients are zero except for the deviation variable being minimized. Note that the previous deviation variable, u_1 is now removed from the objective function, although v_1 still remains. The u_1 also has been removed from the first goal constraint. Thus, the revised model consists of the previous model with one additional goal constraint added, the previous deviation variable of interest has been deleted, and the objective function has been revised accordingly.

Suppose that the optimal solution Z = b5, so that u2 = b5. This information is used to modify the second goal constraint. Substituting the value of u2 = b5 into the constraint and then subtracting this amount from both sides gives:

$$a_{31}\, x_1 + a_{32}\, x_2 + b_5 - v_2 = b_3$$
$$a_{31}\, x_1 + a_{32}\, x_2 = b_3 - b_5$$

This puts the constrain on the right – hand side, and fixes the value of u_2 at b_5, so that, the value of u_2 cannot change as further solutions are generated.

3) Minimize the last priority (goal$_3$)

The third and last priority relates to deviation variable u3. Removing the previous variable, u2, for the model and incorporating the deviation variables for the third goal, the revised model is now:

$$\textbf{Minimize } Z = 0X_1+0X_2+0v_1+u_3+0v_2$$

Subject to:

$a_{11}\, x_1 + a_{12}\, x_2 \quad \le b_1$ (Hard constraint)

$a_{21}\, x_1 + a_{22}\, x_2 - v_1 \quad = b_2$ (subtracting the value of u_1) (goal$_1$)

$a_{31}\, x_1 + a_{32}\, x_2 + u_2 - v_2 \quad = b_3 - b5$ (subtracting the value of u_2) (goal$_2$)

Again, note that all variables in the objective function have coefficients of zero except the deviation variable that currently is being minimized, and all higher priority deviation variable, that were previously minimized are eliminated for the revised model.

Because all priorities have been accounted for at this point, this solution completes the analysis. The solutions can be concluded that only goal 1 reach to the achievement level according to the deviation variable (u_1) is equal to zero, but goal 2 and goal 3 are failed under their targets value by b_5 and b_6, as summarized in Table 27.

Note that once the value of a deviation variable is determined, subsequent solutions do not change it. The same fashion is not necessarily true for the decision variables; they may or may not change in value in subsequent solutions

Table 27 Summary of computer solutions showing the achievement and underachievement target levels

Model	Value of decision variables		Value of deviation variables		
	X_1	X_2	u_1	u_2	u_3
1.Hard constraint + goal1	$Value_1$	$Value_2$	0	-	-
2.Hard constraint + goal1+goal2	$Value_3$	$Value_4$	0	b_5	-
3.Hard constraint + goal1+goal2+goal3	$Value_5$	$Value_6$	0	b_5	b_6

Source: Variant (2000)

6.2 Simulation Modeling for Decision Making

In the broad sense, simulation is a methodology for performing experiments using a model of the real – world system (Rubinstein 1981; Matter 1991; England 1993). The primary difference between optimization and simulation is their starting point. Optimization procedures start with a definition of the system objectives and specify the actions that will satisfy those objectives at the optimum level. Once the optimum conditions are established, the vicinity of the optimal points is analyzed to determine the effect of variations in the system. Simulation modeling starts with the actions and studies their effects on the overall system objectives by testing different policies under various external conditions. Simulation s the exploratory approach to decision problems. It either reproduces a process or obtains a sample of many possible outcomes. Components of a system being simulated are defined mathematically and related to each other in a series of functional relationships. The results is a mathematical description of the complete decision process. The model is solved repeatedly using different parameters and different decision variables every time. As those values are changed, a range of solutions is obtained for the problem and the best solution is chosen from that range. This approach is similar in philosophy to post optimality analysis, except that it is not restricted to the neighborhood of the optimum point.

Given that simulation is based on a mathematical model, two classifications of simulation approaches can be identified: static versus dynamic and deterministic versus stochastic (Rubinstein, 1981) A static simulation is one in which experiments are performed on a model having variables and parameters that are not time dependent. A dynamic simulation includes systems that change over time. Deterministic simulations involve variables and parameters that are fixed and known with certainty, whereas stochastic simulations assign probability distributions to some are all of the variables and parameters. This type of simulation provides a powerful tool in solving probabilistic problems, where the distribution of the final results is more important that a point estimate for the result. Such simulations are also sometimes referred to as Monte Carlo simulation because of their use of random variables (Openshaw and Whitehead, 1985; Fisher, 1991; Openshaw, 1991).

6.3 Applicability of Liner Programming, Goal Programming in Natural Resources Management

Consideration of alternative use of forest and its products nearly always raises the question "What is the best way?" According to the number of alternatives, the complexity of the product interactions and the conflicting desires of the public, the optimal answer may be impossible to derive. Managing natural resources for multiple use requires complex decisions that involve many diverse aspects. Fortunately, some help has been provided for the manger by the decision tool known as mathematical programming called "Goal programming" (Bell, 1977; Schuler *et al.*, 1977).

6.3.1 Linear Programming (LP)

LP provides an excellent opportunity to introduce the idea of "what-if" analysis, due to the powerful tools for post-optimality analysis developed for the LP model. Linear Programming (LP) is a mathematical procedure for determining optimal allocation of scarce resources. LP is a procedure that has found practical application in almost all facets of business, from advertising to production planning. Transportation, distribution, and aggregate production planning problems are the most typical objects of LP analysis. In the petroleum industry, for example a data processing manager at a large oil company recently estimated that from 5 to 10 percent of the firm's computer time was devoted to the processing of LP and LP-like models.

Linear programming deals with a class of programming problems where both the objective function to be optimized is linear and all relations among the variables corresponding to resources are liner. This problem was first formulated and solved in the late 1940's. Rarely has a new mathematical technique found such a wide range of practical business. Commerce, and industrial applications and simultaneously received so thorough a theoretical development, in such a short period of time. Today, this theory is being successfully applied to problems of capital budgeting, design of diets, conservation of resources, games of strategy, economic growth prediction, and transportation systems. In very recent times, linear programming theory has also helped resolve and unify many outstanding applications.

It is important for the user to appreciate, at the outset that the "programming" in Linear Programming is of a different flavor than the "programming" in Computer Programming. In the former case, it means to plan and organize as in "Get with the program!", it programs you by its solution. While in the latter case, it means to write codes for performing calculations. Training in one kind of programming has very little direct relevance to the other. In fact, the term "linear programming" was coined before the word "programming" became closely associated with computer software. This confusion is sometimes avoided by using the term linear optimization as a synonym for linear programming.

Any LP problem consists of an objective function and a set of constraints. In most cases, constraints come from the environment in which we work to achieve our objective. When we want to achieve the desirable objective, we will realize that the environment is setting some constraints (i.e., the difficulties, restrictions) in fulfilling your desire or objective.

What is a function: A function is a thing that does something. For example, a coffee grinding machine is a function that transforms the coffee beans into powder. The (objective) function maps and translates the input domain (called the feasible region) into output range, with the two end-values called the maximum and the minimum values. When we formulate a decision-making problem as a linear program, we must check the following conditions.

The objective function must be linear. That is, check if all variables have power of 1 and they are added or subtracted (not divided or multiplied). The objective must be either maximization or minimization of a linear function. The objective must represent the goal of the decision-maker. The constrains must also be linear Moreover, the constraint must be of the following forms (>=, <=, or =, that is, the LP-constraints are always closed).

For most LP problems one can think of two important classes of objects: The first is limited resources such as land, plant capacity, or sales force size; the second, is activities such as "produce low carbon steel", "produce stainless steel", and "produce high carbon steel". Each activity consumes or possibly contributes additional amounts of the resources. "There must be an objective function, i.e. a way to tell bad from good, from an even better decision. The problem is to determine the best combination of activity levels. Which do not use more resources than are actually available. Many managers are faced with this task everyday. Fortunately, when a well-formulated model is input, linear programming software helps to determine the best combination.

6.3.2 Goal Programming (GP)

To date, many applications of GP have been outside forest management; they have included for instances: choosing optimal executive compensation plans; planning manpower management; scheduling production; employment; inventories to satisfy known demand over a finite time; and other applications to financial and market strategy. Recently they have been several applications in forestry; they have included selecting forest residue treatment alternatives; analyzing potential gains from tree improvement programs; and evaluating land – use planning decision on national forest (Schuler *et al.*, 1977).

In 1977, a pilot study by F.K. Martinson at the University of colorado implemented by the Bureau of Land Management (BLM) on a trial basis demonstrates the feasibility of using a multiple linear programming approach to help the area manager with his or her decisions. The following actual multiple-objective decision problems were pointed by Daellenbach *et al.*, (1983) as follows:

The Federal Land Policy and Management Act, passed by the 94th U.S. Congress in 1976, gives the following mandate to the Bureau of Land Management (BLM) for the management of the approximately 473 million acres of federally owned land under its jurisdiction:

- that the management to be on the basis of multiple use and sustained yield;
- that the land be managed in a matter that will

(a) protect the quality of scientific, scenic, historical, ecological, environmental, air and atmospheric, water resource, and archaeological values;

(b) where appropriate, preserve and protect certain public lands in their natural condition;

(c) provide food and habitat for fish, wildlife, and domestic animals; and

(d) provide for outdoor recreation and human occupancy and use.

Many of above objectives are in direct conflict with one another. For some tracts of land. the BLM will be under fire form different pressure groups to have their vested interest prevail. These groups included farm lobbies who want more grazing land, mining companies who what prospecting rights, and conservation groups who what to keep some areas in their natural state. How does the BLM resolve these conflicts?

Roughly, the BLM's current procedure consists of first compiling a detailed inventory of the area's topography, soils, vegetation, and other physical features and a description of existing use for each tract in the area. This is followed by an assessment of the unlimited potential of each tract for each possible use, without regard to any other uses by means of "MinMax approach" Independently of this, a socio-economic profile is compiled that provides relevant information on attitudes of current and prospective uses of the area, on special interest groups, and on economic factors relating to the importance of natural resources. Armed with these two basic documents, the area manager has to develop a compromise solution that reflects both the best intrinsic use of the various tracts and the relevant socio-economic factors.

In 1991, Cornett and Williams (1991) used goal programming technique for multiple land use planning on 16,000 acres in South Sierra Nevada at mineral King of California, USA. The model evaluated three levels of development: retaining the status quo, moderate development or intensive development. Multiple land use products were considered as goals, including both developed and dispersed outdoor recreation, timber production, livestock grazing and deer population management.

Comparison of the various solution sets revealed tradeoffs resulting from changing management priorities. Evaluation of modeling results and consideration of other environmental impact information showed that the intensive development alternative would have caused excessive degradation of existing watershed and cultural values. A more acceptable approach would be initiate a moderate scale of development following a conservative construction schedule, then closely monitor adverse impacts and compile an improve information base. Furthermore, it would your much more accurate projection of the consequences of further developments were desired.