INTERNATIONAL SYMPOSIUM
International Union of forestry research organisations
MAY 13-15 1999
FACULTY OF FORESTRY - PRAGUE

Land evaluation for a forestry route system on the Falterona and Tufone Mountains (Tuscany-Italy)[1]

Paolo Gajo (2) – Claudio Fagarazzi(3) - Enrico Marone(4)

Department of Agricultural and Forest Economics
University of Florence

---

[1] Prof. P. Gajo project co-ordinator. Author-study contributions are as follows: Dr. C. Fagarazzi for paragraphs 1, 2 & 4; E. Marone for paragraphs 3 & 5.

[2] Professor at the Department of Agricultural and Forest Economics of Florence University.

[3] PhD student at the Naval University Institute of Naples.

[4] Associated Professor at the Department of Agricultural and Forest Economics of Florence University.

Abstract

The present study has evaluated, the possibility to identify the best route alternatives in a forestry district in relation to its economic convenience and presupposes an evaluation of its impact on the land as well. Different project alternatives have been evaluated in consideration of the multiple functions which a route system can encompass. In particular, the productive and tourist-recreative functions and fire control, as well as the impact on the hydrogeological system and the countryside that the different project alternatives proposed can accommodate. The methodology applied for the purpose of evaluating the different project alternatives has been selected within the multicriteria analysis framework. Firstly the project technique evaluations were developed that have determined the courses of the different alternative routes (technical constraints). Successively, a discrete number of alternative projects to analyse utilising the multiattribute analysis model were identified. Once the technically feasible alternatives were determined, there followed an appraisal of the value (calculated as a function of the length of the accessibility realised) assumed by each objective function resulting from the different project alternatives accomplished.

Keywords: Land economic – Forest route system - Multicriteria analysis

Contents

1 INTRODUCTION 3

2 THE STUDY AREA AND HYPOTHESISED SILVICULTURAL MANAGEMENT 4

3 STUDY METHODOOGY 6

4 EVALUATION OF THE OBJECTIVE FUNCTIONS 9

4.1 Evaluation of the Economic Functions. 9

4.2 Evaluation of the fire control function 12

4.3 Evaluation of the water control function 15

4.4 Evaluation of the tourist-recreation function 17

5 THE RESULTS 20

BIBLIOGRAPHY 25

1 INTRODUCTION

Improvements to forest accessibility represents one of the necessary interventions needed to render the harvesting of many of the forest crop in Italy economically convenient. In fact, it is often the case that many of the woodlands, whilst offering good growing stock, are not utilised due to high harvesting costs resulting from the topographic conditions of the land.

The construction of a forest road or improvements to forest district accessibility, besides providing productive, environmental, landscape and recreation functions, cannot be evaluated only in relation to its economic convenience but presupposes an evaluation of its impact on the land as well.

The forest complex taken into consideration is situated in the central Apennines, on the slopes of Mt. Falco at an altitude varying from 600m to 1658m. The surface area of the complex is 2250 hectares and forms an integral part of the State-owned Casentine Forests (7300 ha). The present study, projected as an Access Improvement Project, has tried to identify the best Route Project combinations in a forest district characterised by zones in which the harvesting costs, given the absence of adequate accessibility, have not allowed for the utilisation of available stands with high yields.

Generally, evaluation of such projects is done by determining the "optimum route density" in respect to, the logging costs and the construction costs of skidding roads (Normadin, 1978 e Id., 1984; Marinelli - Marinelli, 1986; Hippoliti, 1990).

Instead, this work has taken into consideration the multiple functions which a route project accomplishes for the evaluation of the different project alternatives. In particular, the economic function has been taken into consideration as well as the tourist-recreation, fire control and hydrogeological functions that the different project alternatives proposed can accommodate.

The availability of a geographic information system (GIS) has allowed us to elaborate a database containing for each of the 229 stands of the study area, relative information on the type of woodland, ground condition, average slope stand, geometric barycentre of the stand utilised for the calculation of the *pre* and *post* skidding road distances, type of management, growing stock and the technical-silvicultural rotations.

The methodology applied for the purpose of evaluating the different project alternatives has been chosen within the multicriteria analysis framework. In particular, the analysis has developed from technical project evaluations that have defined the different route projects. Afterwards, a discrete number of alternative projects were identified for a multiattribute analysis.

Once the technically feasible alternatives were determined, there followed an appraisal of the value assumed by each objective function resulting from the different project alternatives accomplished. As far as concerns the productive function we have made use of financial indicators based on the evaluation of ground and forest crop value, and of the annual construction and maintenance costs of the roads. For evaluation of the tourist-recreation function, we have made use of accessibility to forestry information with different recreation capabilities; whilst for the fire control function, we have considered both the accessibility and the risk classes of the various forest communities. Instead, hydrogeological instability has been evaluated utilising indicators that consider the *curve number* provided by the U.S. *Soil Conservation Service*, for the definition of surface flows.

2 THE STUDY AREA AND HYPOTHESISED SILVICULTURAL MANAGEMENT

The woodland in examination are situated in the central Apennines, on the slopes of Mt. Falco at an altitude varying from 600m to 1658m. The area is State-owned property and covers an area of 2250 ha and from 1991 forms part of the National Casentine Forest Park of Mt. Falterona and Mt. Campigna.

The physical environment is characterised by hilly topography with average slopes of 40% and a maximum of 79%. The geological formations are characterised by the Tuscany series; ranging from the Chianti and Mugello hardstones to the Vicchio and Pievepelago marls. In general, the majority of the soils belong to the acid-browns, that certainly represent the prevalent soils above 700-800m (*cfr*.AA.VV.1980).

Climatically, the Mediterranean influence effects the seasonal distribution of rainfall, with heavy autumn-winter rainfall and typical summer minimums.

The typical plant associations of the higher altitudes occur within the warm parts of Pavari's *Fagetum* zone**,** with frequent and ample tracts belonging to the Pavari's *Castanetum* zone**,** especially below 1000 metres. The main types of woodlands are the mixed fir-beech formations (30% of the area), the beechwoods (18%), the sweet chestnuts (14%) and the black and Douglas pine formations (12%) *(cfr*, Fig.2.1).

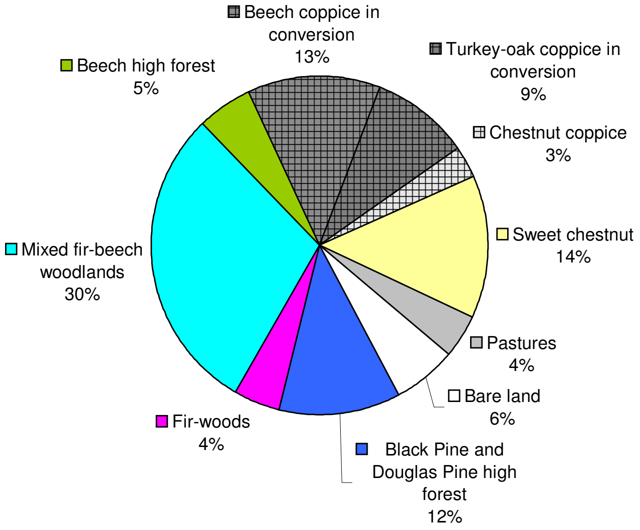

Figure 2.1. Area Breakdown of the woodlands

As far as concerns the silvicultural aspects, it has been necessary to subject the different woodland types to some constraints that would allow for a long term evaluation of the investments in forest accessibility. These concern assumptions that, in some cases, can occur in contrast with the foreseen planned proposals within a national park[5].

The first assumption, relevant from a silvicultural point of view, is that the areas concerning each woodland type are perpetuated in time[6]. The second assumption is that the intermediate and final cuttings take place on the whole stand surface area[7]

On the basis of such considerations, and seen that the application of the land impact evaluation model, based on the realisation of an expert system that operates on georeference data; necessitates for its working, simplified forest regulations; it evidently appears that the basis of "natural silviculture" *(cfr.* Ciancio & Nocentini, 1995) finds little application in this first phase of the model.

In particular, for the fir-woods, beechwoods, mixed fir-beech woods, beech coppice in conversion, turkey-oak coppice in conversion and black pine and *douglas pine* high forest; the hypothesised treatment foresees clear-cutting with *post* artificial regeneration, while for the chestnut coppice it is hypothesised a clear-cut treatment.

Regarding the sweet chestnut woods, they have not been included in the productive function in consideration of the variability and uncertainty of the incomes derived from them [8], even if a rotation period of 150 years has been hypothesised.

At present , some simplifications concerning the management choices and forest regulations have been done that would allow for the identification of a valid multicriteria model. In this specific case, we have assumed that the rotations were defined on the basis of forest regulations , considering the rotations usually practised in the Casentinese market and the commercial assortments in the area. In particular, the hypothesised rotation and age in which to carry out the intermediate and final cuttings in each type of woodland, are presented in Table 2.1.

---

[5] The model proposes simplifications that can be overcome including a transition planning model

[6] Such an assumption does not necessarily contrast with the park objectives, since its institution in recent times (1991) is certainly a symptom of the fact that the pre existing forest communities have a relevant environmental value.

[7] Such constraints appear easily surmountable through definition on the cartographic scale (GIS) of sub-stand sizes less than those limits imposed by the regulation concerned (maximum guidelines and forest policies, park regulations, etc)

[8] Although within the study, the evaluation of the average income per hectare derived from the sale of fruits and wood obtained from final cutting , it is necessary to consider the extreme fragility of this species to damages from *Endothia parasitica* (Murr.) and *Phitophthora cambivora* (Petri) that in some cases can lay to waste the investments in a fruit project.

Economic Class	Age 1st Thinnings	Age 2nd Thinnings	Rotation
Fir-woods	30	80	110
Mixed fir-beech woods	30	60	90
Chestnut coppice			14
Turkey-oak coppice in conversion	25	50	80
Sweet chestnut			150
Beech high forest	30	60	90
Beech coppice in conversion	20	50	100
Black Pine and Douglas Pine high forest	20	50	80

Table 2.1. Hypothetical interventions in the different woodland types

To calculate the estimation of extractable volumes from the various woodland formations, in the absence of forest mensuration data for the determination of forest yield; it was necessary to assimilate the same woodland formations to similar woodland stands of normal density. In this way, it was possible to use the yield tables (*cfr.* Cantiani, Bernetti, 1962) for volume determination per hectare area, intermediate and final cuttings . In the mixed cases, such as the mixed fir-beech woodlands, the estimated yields correspond to the average value of the above ground yield of the two species.

3 STUDY METHODOOGY

The multiple functions of the forest resources, as well as constituting a peculiarity for all woodlands , assumes particular relevance when the object of surface improvement interventions falls within a protected area such as a national park. Evaluation of the impact following route enlargement within the district study area, has to be able to measure the effects of such interventions on the multiple functions that the woodlands provide (*cfr.* Casini, 1998). The choice to use the multicriteria analysis tool arises from the understanding that, both from a methodological as well as an application point of view; this constitutes the most appropriate instrument for an evaluation of the effects from route enlargement on the multiple functions provided by the district forest (*cfr.* Zeleny, 1982).

In fact, Multicriteria Analysis (MCA) has developed with the end purpose of making explicit the possible conflicts that emerge in the use of woodlands and is proposed as a methodological tool capable of providing the necessary elements to the evaluation of land planning interventions (*cfr.* Romero – Rehman, 1989). Within the MCA, a multiplicity of methods have been developed in service of the different functions that from time to time are to be achieved; following however, a common approach to the different evaluation procedures, those phases that are always considered can be summarised as follows:-

- an informative first phase that foresees the identification of the objectives to be achieved and the evaluation indexes (*cfr.* Lazarsfeld P.F., 1969).
- a second phase of strict analysis to identify the efficient alternatives from a Pareto point of view and to evaluate the level obtained from each objective for each of the alternative projects proposed.
- a third and last phase that has identified the most satisfactory district solutions between the management alternative proposed within the multiattribute framework.

Of the planning models cited in the literature, we have considered the discrete alternatives planning model, the most adapt to the evaluation of route improvements in the district study area. Evaluation of the forest route systems represents in fact, one of those cases in which a mathematical model continues to be practically impossible. Furthermore, in the multiobjective analysis it is possible to consider more decisional groups, that in the case in question, can identify themselves into the following groups:

- those groups interested in maximising the productive-economic returns derived from the exploitation of the forest standing volume;
- those groups interested in maximising the recreation functions of the woodlands;
- those groups interested in the wildlife and landscape aspects of the area;
- those groups interested in the hydrogeological protection of the area.

The approach utilised is based on a ranking method that has allowed for the identification of the most satisfactory Route Projects in respect of the objectives proposed.

The study, therefore presupposes from the start that the district forest in question, although included within a national park, has to however carry out a multifunctional role within the socio-economic context of the Casentine region. Seen that many of the stands whilst offering high wood production are not actually utilised, both from management choices made by the park authority as well as high harvesting costs that do not allow positive stumpage values to be obtained; determines the need to improve accessibility to the district woods that would allow the last constraint to be overcome.

This study therefore evaluates the impact that an increase in the productive functions of the woodlands, made possible only through enlarging pre-existing routes, can have on the other functions that the area offers in the sphere of the Casentine Forest Park.

Improvements to accessibility has been conceived through a preliminary technical type of study that presents a series of route projects (RP) capable, thanks to the reduction of forest logging costs, to profitably increase the number of exploitable stands. The length and development of the different RP has been determined in such a way as to render the maximum potential area available according to exclusively technical criteria. The basis of the analysis is such as to make the RPs complimentary between themselves in that each stand is served by only one RP. We have then stipulated that each RP is not divisible and therefore in decisional matters, it is foreseen that this is more or less accepted according to the contribution that it is able to provide relative to the different objective functions taken into consideration.

The Improved Route Project plan foresees the realisation of nine different RP, that serve a total area of 361 ha and extends for a total length of 14.5 km according to the outline indicated (*cfr.* Tab. 3.1):-

Alternative Project	Length (Km)	Area served	% Area served	Area per Km
1	0,8	43,8	1,9%	54,8
2	2,1	58,2	2,6%	27,7
3	1,1	62,2	2,8%	56,5
4	1,4	15,4	0,7%	11,0
5	2,8	45,9	2,0%	16,4
6	0,5	15,0	0,7%	30,0
7	2,8	65,3	2,9%	23,7
8	1,3	30,0	1,3%	23,0
9	1,8	25,3	1,1%	14,5

Table 3.1. Route Projects

For the identification of the functions obtained from the forestry route network, it has been necessary to consider two distinct factors; on the one hand the services offered by the district forest, whilst on the other hand the total efficiency of the different RPs proposed. In particular, attention was given to associate to the different RPs the functions obtained from the pertinent standing woodland to each of them. This allowed within the available financial constraints, the identification of all the RPs capable to maximise the *increase* of direct and indirect benefits of the forest complex concordantly to the minimum impacts on the forest communities. Particularly, the development of forest routes within the forest complex was estimated to the growth of financial support from public management bodies. The effects taken into consideration, have been those relating to the following functions[9].

1. **economic function**
2. **fire control function**
3. **water regulation function**
4. **tourist-recreation function**

There followed, for each objective function the resolution of a linear programming model to “whole numbers” (cfr. Bernetti, 1994). This type of model is very adapt to the case in question in that it allows the activation of the RPs thanks to decisional variables that can assume values 1 and 0 (binary variables).

If the binary variable assumes value 1 in correspondence of the *y-nth* RP it means that the whole *y-m* RP is realised and therefore the values assumed by the objective functions come to be evaluated following the activation of the pertinent stand to that RP. Instead, if it assumes value 0 the *y-nth* RP is not realised. Furthermore, in the absence of technical-construction constraints to the realisation, on the same route way, of different road types (skidding roads or forest roads), there followed the resolution of the four objective

---

[9] At the moment we have abstained from evaluating aspects relative to the impact on the naturalistic value of the forest, and on the landscape. It concerns in fact, functions that we will evaluate at a later moment with the use of procedures adopted from different authors (*cfr* .Canter & Hill , 1976) favourably adapted to the local situations and based on the identification of the parameters that make up logical indexes. Such evaluations require in fact forest surveys for the determination of species number, social position, above ground structure (single-storied, two-storied , etc) the presence of renewal and other determinable data through the realisation of stand transects.

functions tied to the different construction type of RP and to the easy or difficult conditions for its realisation (land slope angle, soil characteristics, etc). Such functions are in fact effected by the diverse realisation and maintenance costs, , time of forest logging operations , time and speed of fire-control interventions, surface run-off, recreation impact, etc.

The nine RPs that have therefore been considered in the two forms of construction: skidding roads or forest roads; give rise to the duplication of the chosen options (18 options for a total of 324 combinations).

The choice of road type in view of the objective functions considered, has been somewhat tied to financial support from the managing body, for the construction of forest routes.

The variation in a regular manner, of the constraints of construction costs of the forest routes, has led us, through the use of liner programming directed towards the maximisation and/or minimisation of the objectives, to the construction of a series of *pay-off* matrices corresponding to the different levels of cost constraints. Such matrices have allowed us to check eventual conflicts between the different objectives.

Furthermore, for the resolution of the multiattribute model the ideal distance point method has been adopted to define the best alternative management practices of those proposed. Relative to the choice of the metric to adopt in light of *compromise programming*, the presence of compensation between the objectives, or contrarily its absence, allow the choice of the most appropriate metric to adopt in the model.

In our case, and in general experience of natural resource planning, particularly that of forestry (cfr. Krawiec et al.- 1990) the application of metric with $p > 1$ allows more coherent results to be obtained with less distortion. In fact, it is difficult to demonstrate that the productive type of benefits determined by the realisation of improved access can compensate the relative negative effects, for example, the regulation of water from the district examined. On the basis of such considerations a metric based on the Chebisev distance, that is L_∞ metric was adopted.

4 EVALUATION OF THE OBJECTIVE FUNCTIONS

4.1 EVALUATION OF THE ECONOMIC FUNCTIONS.

Evaluation of the impact of the alternative routes on the “economic” objective functions has been done through the definition of an objective function (O.F.) represented by the variation of the value of the woodland, that is the value variation of the ground as well as the forest crop of the pertinent stand to each *y-nth* ($y=1,\ldots,18$) RP net of the construction and maintenance costs of the forest routes.

The choice of an index based on a differential value, is the result of the substantial variation in the specific composition of the district forest; in fact an index based only on the value of the wood of the area concerning each RP, would have favoured the RP to service those areas with more valuable species.

For the determination of this index some basic hypothesis have been considered:-

the district forest is composed of even-aged woodland stands ;

the stands are all technically accessible, also those whose stumpage value, in respect to pre existing accessibility, results negative;

investment in forest routes, if subject to periodic maintenance, have an unlimited time span;

In this case, the O.F. is based on a mixed technical-logical evaluation methodology, since, in the forest model logical operator are present that express the reasons for the choice of harvesting methods most suited for use in each stand in relation to average diameter of the woodlands, to stand slope angle, route distance; as well as for the determination of the realisation and maintenance costs of the roads in relation to the type of road constructed (forest, harvesting) and to the average slope angle (easy/difficult conditions).

To arrive at the determination of woodland value it has been necessary to evaluate the stumpage values of the forest crop, and therefore estimate the pertinent returns and costs to each stand in the two conditions: pre-accessibility and post- accessibility.

For the determination of the first component (returns), pertinent to each stand, we have assumed that these stands have a full stocking, other than having the same age . In this way it has been possible to utilise the yield tables to determine the area volumes per hectare of the intermediate and final cutting yields. With the successive use of assortment tables (relative to each forest species) and with the corresponding prices coming from the different wood assortments on the Casentine market, the obtainable returns from the various cuts were determined.

As far as concerns the age at which to carry out the intermediate and final cuts, these have been determined from previous silvicultural choices outlined (*cfr.*par.2)

Relative to the second component (costs) estimation of the probable costs of logging each stand appear decisive. The elaboration of an Expert System has allowed the evaluation of such costs through distance and stand slope criteria, and on the dimensions of the trees (*cfr.* Tab. 4.1 and Fig. 4.1).

CRITERIA		**LOGGING METHODS**
Diameter <= 15 cm	slope <= 30 %	forward logging
	slope > 30 %	dry slide logging
Diameter > 15 cm	slope <= 40 %	skidder tractor logging
	slope > 40 % distance <= 0.3 Km	free slide logging
	slope > 40 % distance > 0.3 Km	skyline cable logging

Table 4.1. Choice criteria for logging systems.

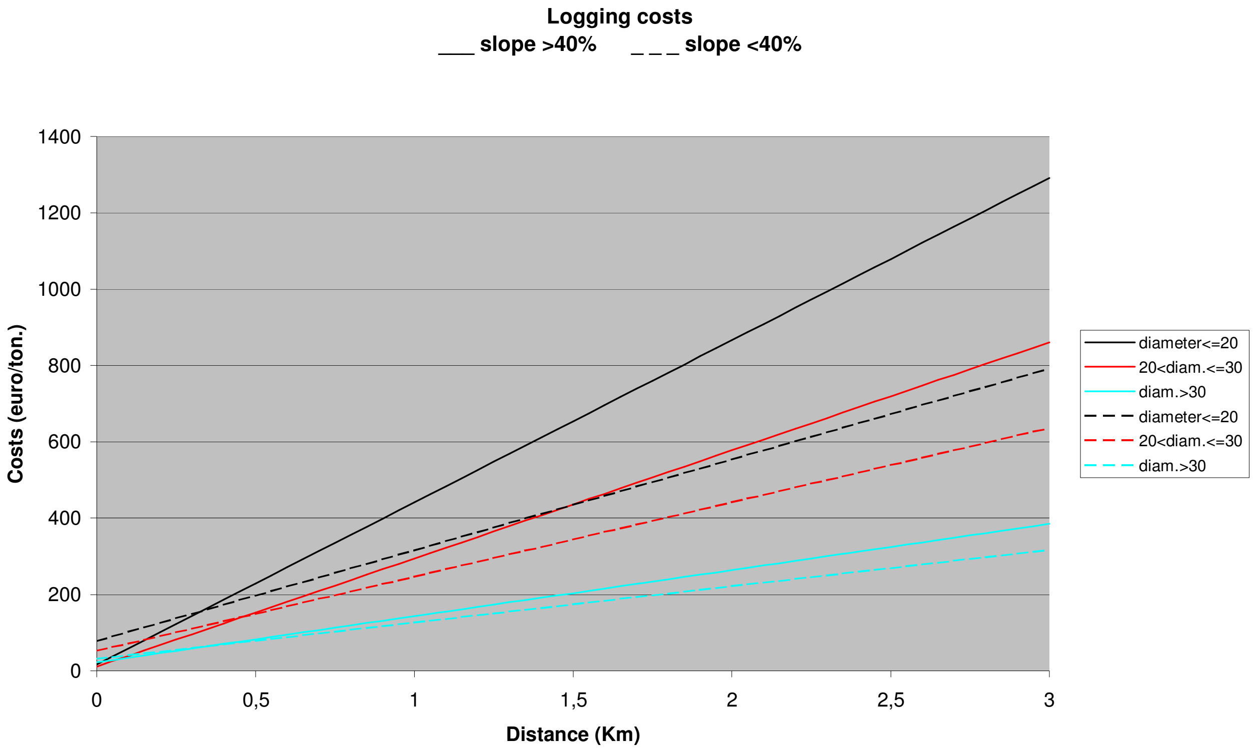

Fig. 4.1. Logging costs in relation to distance

The formula of the model selected for the economic function is as follows:-

$$\max_{y}\ \Delta BN = \left\{ \max_{y} \sum_{y} \left[\sum_{i=1}^{n} \left(Bn_i^y - Bn_i^x \right) - \left(C^y + \frac{M^y}{r} \right) \right] \right\} \qquad \forall\ y = 1,....,18 \qquad \textbf{(1)}$$

S.T.

$$\sum_{y} C^y \le K$$

where:

ΔBN = variation of the woodland value net of the construction and maintenance costs;

n = number of stands with n=229;

$Bn^y{}_i$ = value of the ground as well as forest crop of the *i-nth* stand (with *i*=1,…229) post-realisation of the *y-nth* RP;

$Bn^x{}_i$ = value of the soil as well as forest crop of the *i-nth* stand (with *i*=1,…229) pre-realisation of the *y-nth* R.P;

C^y = construction cost of the *y-nth* R.P.;

M^y = maintenance cost of *y-nth* R.P.;

r = capitalisation rate;

K = financial support from firms with investments in forest routes.

In consideration of the multiplicity of the stands and of the age variations present in them, the value of Bn_i has been evaluated according to the fictitious cycles approach, that is:

$$Bn_i = \frac{Ps_i\, q^{t-s+h} + (Pt_i - R_i)q^h + Pm_i\, q^{h-m}}{q^t - 1} \qquad \mathbf{(2)}$$

where:

Pt_i = is the stumpage value for year t of end rotation of the *i-nth* stand;
Ps_i^y, Pm_i^y = are the stumpage values for year s and m of the *i-nth* stand;
R_i^y = forestation costs of the *i-nth* stand;
q = unitary amount (1+r);
t = rotation of the *i-nth* stand;
h = forest crop age of the *i-nth* stand at the moment of the estimation.

For the capitalisation rate (r), this has been estimated on the basis of the alternative investment choices available to the manager relative to the conditions of the study object area. In our case a capitalisation rate has been estimated equal to 2%. As already seen in Table 2.1., the rotations taken into consideration for the different woodland types are of a technical-silvicultural nature.

4.2 EVALUATION OF THE FIRE CONTROL FUNCTION

For the estimation of this function, definition of a combined technical index capable to determine the extent of the areas saved from fire following the construction of the different RP was done. Such a function, is evaluated both in relation to susceptibility to fires of the forest crops concerning each RP, and in relation to increased promptness of the extinction operations following the realisation of each R.P.

Susceptibility to fires is the result of a synergetic action between stationary and anthropological factors. In the case in question, we have taken into consideration the main variables that influence this phenomena, that is the ignition of the vegetation, evaluated through the fire propagation speed in the different forest communities, and the slope of the stand (evaluated thanks to GIS.).

On the basis of research done in Italy (cfr. Bovio & Camia, 1990) notable differences have been identified in the fire propagation speed between different categories of soil cover. In fact, this varies in proportion to the presence of woodlands and to the different forms of silvicultural system adopted (*cfr.* Tab.4.2).

Propagation class	*Average value of fire propagation mq/min.*	*code*	*woodland types*
0	*0,00*	TN	Bare ground
1	*121,85*	CA	Chestnut grove
2	*148,85*	CC FC F CF	Turkey-oak coppice in conversion Beech coppice in conversion Beech hight forest Sweet chestnut
3	*167,75*	A BM PD	Fir-woods Mixed fir-beech woods Douglas Pine
4	*258,90*	CE	Bushes
5	*364,80*	PA	Pastures

Table 4.2. Fire Propagation Classes

Considering that such propagation coefficients vary in relation to the slope of the stand (*cfr*. Calabri, 1984), we made the specification of the propagation speed functions that define the propagation values from the flame front for each propagation class was added (*cfr*.Tab.4.2). On the basis of the discrete values relative to the different propagation speeds in relation to the slopes proposed in the literature, there followed an estimation of a function capable to constantly estimate the propagation speed values in relation to the slope for each type of woodland. The best function capable to estimate such values is given by the following speed propagation function:

$$VP(\delta) = a + \left(1/\left(b + e^{-c(\delta - d)}\right)\right) \qquad \textbf{(3)}$$

with:

$VP(\delta)$ = value assumed from the propagation speed functions in relation to the slope δ= average slope of the stand;
a = parameter that identifies the intercept of the function;
b = parameter that influences the maximum value of the function;
c = parameter that influences the slope of the function;
d = parameter that identifies the flex point of the function.

In respect to the five propagation classes identified, the parameter *a* assumes from time to time, the value of the propagation speed in absence of slope (*cfr.* Fig. 4.2) while parameter *b,* becomes a function of *a* (where b=1/3a). Instead the parameters *c,* and *d* are the same for all the propagation classes identified, because they are determined only by slope, and not from the different propagation classes.

The factor susceptible to fire has therefore been evaluated through the average value of $VP(\delta)$ for each single RP.

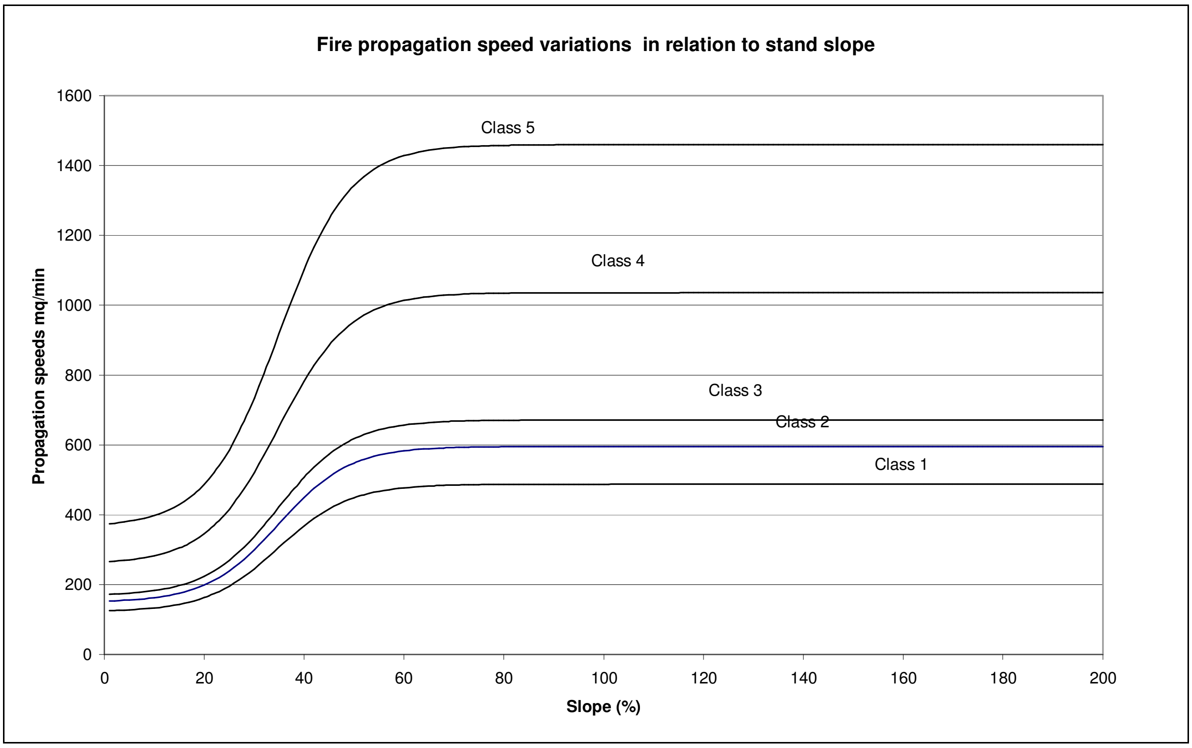

Fig. 4.2. Propagation speed from flame front

Relative to the other aspect, evaluation of increased promptness of the extinction interventions following the realisation of each R.P., has been based on the calculation of the time taken variations between post-realisation and pre-realisation situations.

The formula for the objective function "fire control" is as follows:-

$$\max_y I^y_{ANT} = \max_y \sum_y \Delta T^y_I \cdot VP^y = \max_y \sum_y \sum_{i=1}^{n} \left\{ \left[\frac{d^x_i}{Vu} - \left(\frac{l^y_i}{Va} + \frac{d^y_i}{Vu} \right) \right] \cdot \frac{\left(VP(\delta)^y_i \cdot S^y_i \right)}{S^y} \right\} \qquad \forall \; y = 1,.....,18$$

(4)

S.T.

$$\sum_y C^y \leq K$$

where:

I^y_{ANT} = efficiency index value in the reduction of fires;

ΔT^y_I = time intervention variation;

VP^y = average value of $VP(\delta)$ considered on the area served by the *y-nth* RP;

d^x_i = pre-project route distance between the stands that will be served by the *y-nth* RP and the old route;

l^y_i = post-project distance taken by vehicles on *y-nth* RP to reach the *i-nth* stand;

d_i^y = post-project route distance between the stands served by the *y-nth* RP and the RP itself;
Vu = average man speed
Va = average vehicle speed on forest or logging road;
$VP(\delta)^y{}_i$ = propagation speed value of the *i-nth* stand served by the *y-nth* RP;
S_i^y = area of the *i-nth* stand served the *y-nth* RP;
S^y = total area served by the *y-nth* RP.

The value of this function allows furthermore to evaluate the area saved from fire, expressed in mq, relative to the different RP activated.

In the specific case the use of the GIS in the definition of such indexes permits rapid dismissal of stationary data to include in the equation, distance between the barycentre of the stand and accessibility, slope stands, etc, and to produce cartographic maps for useful interpretation (fire risk maps, time access maps, etc).

4.3 EVALUATION OF THE WATER CONTROL FUNCTION

An effective method of evaluation for surface down flow following precipitation has been elaborated by the Soil Conservation Service (S.C.S) of the United States. One of the main requirements of many hydrological forecast models, is to provide suitable transfer functions for the transformation of precipitation values into useful flows *(cfr.* Borselli, 1995).

Such functions are represented by Curve Numbers, defined through a standard criteria designed by the S.C.S. Preliminary data are obtained by the operator making reference to a precise table, through subjective values of the pedological characteristics of the soils in question; the characteristics of soil use and the degree of surface vegetation. In the determination of CN the first order to assign is the class belonging to the soil in question, that in our case is represented by the road surface. In the procedure codified by the S.C.S. there exists 4 classes (A,B,C,D) of distinct soils on the basis of the response to hydrological potential (*cfr.* Tab. 4.3).

Anderson class	Soil hydrological Groups	Soil Classes				
		A	B	C	D	W
11	Developed – high intensity	57	72	81	86	100
12	Developed – low intensity	36	60	73	79	100
21	Cultivated land – woody	30	58	71	78	100
22	Cultivated land – herbaceous	30	58	71	78	100
31	Grass land – herbaceous	30	58	71	78	100
41	Woodland – deciduous	36	60	73	79	100
42	Woodland – evergreen	36	60	73	79	100
43	Woodland – mixed	36	60	73	79	100
51	Bare land – clayey	72	**82**	**87**	**89**	100
52	Bare land – sandy	72	**82**	**87**	**89**	100
53	Bare land – rocky	72	**82**	**87**	**89**	100
71	Moist woodlands – deciduous	30	58	71	78	100
72	Moist woodlands – evergreen	30	58	71	78	100
73	Moist woodlands – mixed	30	58	71	78	100
81	Moist herbaceous lands	30	58	71	78	100
91	Moist lands without vegetation	72	82	87	89	100
100	Surface area covered with water	100	100	100	100	100

Table 4.3. Curve Number for hydrological groups

In the present work we have applied the C.S.C. classification to the areas transected by the RPs. In order to do this, the land on which the roads rest have been assimilated to bare land with different cover grades adding to the attribution of a CN value for each type of road (*cfr*. Tab. 4.4.).

Forest Accessibility Classes	*Road width*	*CN*
asphalt forest road width >=6 m	9	*100*
well-gravelled forest road widht >4 m	7,5	*89*
well-gravelled forest road <=4 m	5,5	*87*
dirt forest track with slope 25-30% width = 3 m	4	*82*

Table 4.4. Curve Number for types of forest roads

The same type of evaluation has been done to determine the Curve Number values relative to each type of woodland, according to the values given in the following table (*cfr*. Tab. 4.5):

Hydrological groups of the woodlands	Soil Classes			
	A	B	C	D
Pastures Sweet chestnut	30	58	71	78
Turkey-oak coppice in conversion Beechwood coppice in conversion Chestnut Beech	36	60	73	79
Fir woods Douglas Pine	36	60	73	79
Mixed fir-beech woodlands	36	60	73	79
Bare land	72	82	87	89

Table 4.5. Curve Number for Woodland Type

The estimation of the water regulation function has therefore been done defining a technical index that through the use of the transfer functions conceived by the S.C.S. would allow determination of the accessibility impact on hydrological instability. In particular, the index is defined from the variation of Curve Numbers following road construction.

The "water regulation" objective, in the multiattribute planning model, will be directed towards minimisation of the following function; that is:

$$\min_y I^y_{IDRO} = \min_y \sum_y \left(CN^y - \frac{\sum_{i=1}^{n} L^y_i \cdot CN_i}{L^y} \right) \qquad \forall\, y = 1,....,18 \qquad \textbf{(5)}$$

S.T.

$$\sum_y C^y \leq K$$

where

I^y_{IDRO} = water regulation index of *y-nth* R.P.;
CN^y = curve number of the *y-nth* R.P.;
CN_i = curve number of the *i-nth* stand transected by the. *y-nth* R.P;
L^y_i = length of *y-nth* R.P. within the *i-nth* stand;
L^y = length of the *y-nth* R.P.

4.4 EVALUATION OF THE TOURIST-RECREATION FUNCTION

Evaluation of the alternative route impact on the tourist-recreation function has been done through the identification of a logical index.

On the basis of research carried out in Italy (*cfr.* Pettinà, 1992), there are numerous factors that influence the recreation potential of a forest complex; in our case the factors taken into consideration have been:, woodland crops type (size, degree of vegetation cover, crown colour and presence/absence of brushwood);

distance from paths and carriage roads

slope of the land

For the evaluation of the recreation value of the woodland types (Point i) a logical index has been estimated on the basis of interviews carried out on site, that have allowed an *appreciation grade* to be assigned to each type of woodland[10] (*cfr.* Tab.4.6).

Appreciation coefficient	***Value***	***code***	***Woodland crops type***
1	Very high	A F	Fir-woods Beech woods
0,8	High	BM CF	Mixed fir-beech woodlands Sweet chestnut
0,6	Medium	PD CA	Dounglas Pine Chestnut grove
0,4	Low	FC CC	Beech coppice in conversion Turkey-oak coppice in conv.
0,2	Very low	TN PA	Bare land Pastures

Table 4.6. Appreciation grades for the different woodland crop types

The same research conducted on site has provided the necessary elements to define, through the estimation of a logistical function (*cfr.*Zimmermamm, 1987) (*cfr.* Fig. 4.3 and 4.4), the useful parameters to evaluate the effects that stand slope and route distance can have on the recreation potential of the site (cfr. Bernetti, 1992).

$$f(d_i^y) = 1/\left(1 + e^{-a_1(d_i^y - b_1)}\right) \qquad \textbf{(6)}$$

$$f(z_i^y) = 1/\left(1 + e^{-a_2(d_i^y - b_2)}\right) \qquad \textbf{(7)}$$

with:-

$f(d^y{}_i)$ = recreation value in relation to distance from the *i-nth* stand;
$f(z^y{}_i)$ = recreation value in relation to slope of the *i-nth* stand;
$d^y{}_i$ = distance of the *i-nth* stand;
$z^y{}_i$ = slope of the *i-nth* stand;
a_1, a_2 = parameters that influence the slope of the usage function;
b_1, b_2 = parameters that identify the flex point of the usage function.

---

[10] An appropriate indicator for the evaluation of the recreation potential of the woodlands is represented by the number of visitors. In our case, this type of evaluation is subject to contamination following woodland usage. For such an application an investigation aimed exclusively on the evaluation of the qualitative characteristics appears more suitable.

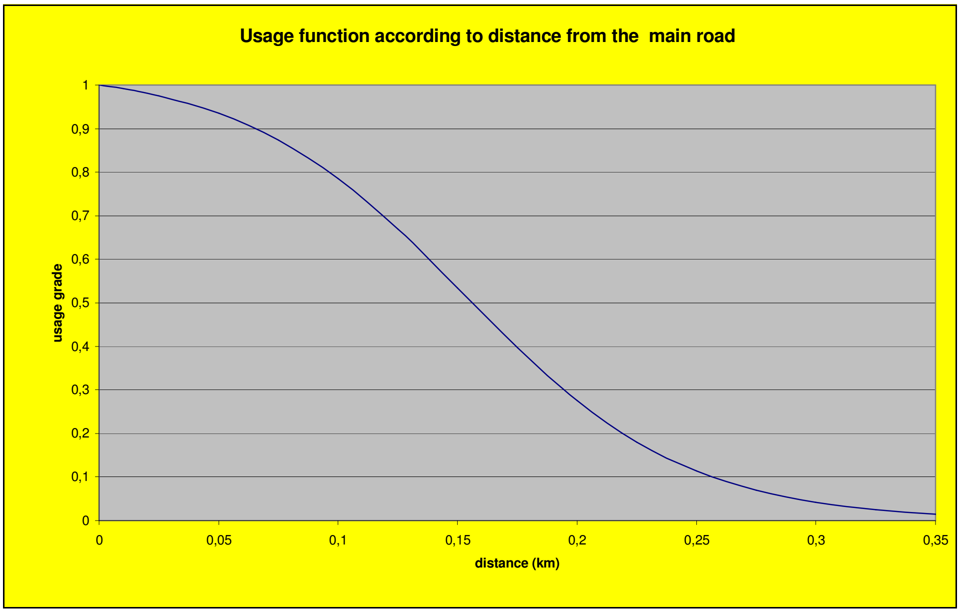

Fig. 4.3. Usage Function for Route Distance

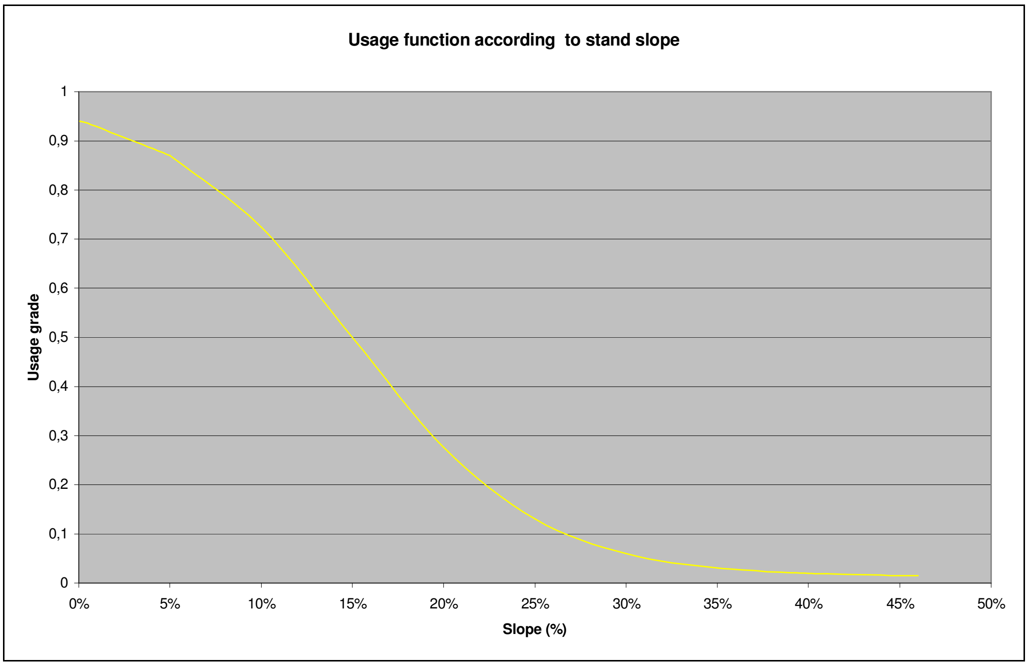

Fig. 4.4. Usage function for slope

The “tourist-recreation” objective in the multiattribute model will be directed towards the identification of the RP that maximises the increase of the function, according to the following formula:-

$$\max_{y} I_{RICR} = \max_{y} \sum_{y} \left\{ \sum_{i=1}^{n} \left[S_i^y \cdot C_i^y . f\left(d_i^y\right) \cdot f\left(z_i^y\right) \right] - \sum_{i=1}^{n} \left[S_i^y \cdot C_i^y . f\left(d_i^x\right) \cdot f\left(z_i^x\right) \right] \right\} \qquad \forall\, y = 1,.....,18 \tag{8}$$

S.T.

$$\sum_{y} C^y \leq K$$

where:

I_{RICR} = value of the recreation index for the *y-nth* R.P.;

S_i^y = area of the *i-nth* stand served the *y-nth* R.P.,

C^y = usage coefficient of the *i-nth* stand served by the *y-nth* R.P.;

$f(d^y{}_i)$ = post-realisation value assumed by the usage function of the distance for the *i-nth* stand;

$f(z^y{}_i)$ = post-realisation value assumed by the usage function of the distance for the i-*nth* stand regarding the *y-nth* R.P.;

$f(d^x{}_i)$ = pre-realisation value assumed by the usage function of the distance for the *i-nth* stand;

$f(z^x{}_i)$ = pre-realisation value assumed by the usage function for slope angle corresponding to the *i-nth* stand.

5 THE RESULTS

Resolution of the different objective functions indicated above allows us to obtain a set of *pay-off* matrices, consistent to the variation of the total construction cost constraints of the RPs. Five different construction cost constraints have been hypothesised varying between 50 million lire to 1 bilion lire, equal to the maximum value of the ΔBn_i obtainable.

The *pay-off* matrices allow us to observe that the objective relating to water regulation is always discordant in respect to the other objectives and its satisfaction is inversely proportional to the number of RPs activated. In the case of water regulation, the construction cost does not form a constraint in that the optimum level for that function coincides with the absence of forest accessibility. In this case the function relating to the regulation of water allows us to evaluate the impact derived from the activation of the different RPs according to the optimisation of the other objective functions.

From the analysis of the other three objective functions there emerged a complex connection, that shows the existent contrasts between such functions, also if their optimisation results in direct relation with the increase of forest accessibility. Specifically, also with different cost constraints, it is noted that the level of satisfaction reached by the economic, tourism-recreation and fire control objective functions, change according to the objective maximised. For example, in the case of the largest cost constraint (equal to the maximum availability of one bilion lire for the realisation of the different RPs) (cfr. Tab. 5.1) if the economic objective is maximised the level of satisfaction of the recreation function reaches 97%, while those relating to the fire control function is equal to 54%. In the case where the recreation function is optimised the economic objective reaches 74% and for fire control 89%. Lastly, in correspondence to the maximisation of the fire control function, the level reached of the productive and recreation functions is nil for the first and equal to 84% for the second.

	Economic object.	Hydrog. defence object.	Recreation object.	Fire control object
Economic object.	100%	16%	74%	0%
Hydrog. defence object.	30%	100%	7%	0%
Recreation object.	97%	0%	100%	84%
Fire control object	53%	0%	89%	100%

Table 5.1 Level of satisfaction for each objective in the case of the largest cost constraint

The explanation of these differences is attributable to the identification, for each objective function maximised, of different combinations of RPs. The maximisation of the economic function privileges the choice of skidding roads , that allow to optimise the difference between route construction costs and maintenance and the increase of Bn, while for the fire control function the choice is orientated towards types of forest roads that allow an increased speed of movement for assistance vehicles. Instead, the case of the recreation objective differs from the economic principally for the numerous RPs selected, that in this case are greater; if in fact, in the economic case the objective is realised in comparison between costs and benefits, in the recreation case the choice orientates towards the maximisation of the areas served by the route, privileging the skidding roads types that have a greater level of appreciation, for the recreation purpose, in respect to the forestry. Analysing the resolved *pay-off* matrices imposing always a lower cost, in respect to that maximum hypothesised, it is noted that the numerous RPs are reduced, and in the case of the fire control function the route choice shifts from forest roads to harvesting ones.

The application of the *predetermined convex combinations* (*cfr.* Bernetti, 1994) has allowed us to use a series of *compromise programming* models defined by a different combination of weights w_i chosen in relation to hypothetical planner objectives that the park administration could propose (*cfr.* Tab. 5.2).

In this way we have identified the six different management alternatives characterised by:-

- Pure economic alternative (A1): it is hypothesised that the study object area is destined only to the productive function and the project hypothesis verifies, according to the cost constraints, which are the ideal RP combinations;

- Pure recreation alternative (A2): it is hypothesised that the study object area is destined only to the recreation function through the choice of a RP that maximises such an objective;
- Pure fire control alternative (A3): it is hypothesised that accessibility has to respond to the needs of protection of the study object area in face of the risk of fire;
- Multifunctional alternative prevalently in defence of the hydrogeology (A4): it is hypothesised that the study object area has to provide a multifunctional role with particular attention in respect to the problem of water regulation (one can think particularly in areas with hydrogelogical problems);
- Pure multifunctional alternative (A5): it is hypothesised that the study object area has to provide a multifunctional role attributing the same weight to the different objective functions;

Multifunctional alternative with prevalently recreation and prevention of fire values (A6): it is hypothesised that the forest complex has to satisfy in an equal manner the recreation and fire control objectives.

Functions	A1	A2	A3	A4	A5	A6
Economic object.	1	0	0	0,167	0,25	0
Hydrogeological defence object.	0	0	0	0,500	0,25	0
Recreation object.	0	1	0	0,167	0,25	0,5
Fire control object	0	0	1	0,167	0,25	0,5

Tab. 5.2 Vector weights for different management alternatives

The *compromise programming* model solutions, has allowed us to define a matrix of the management alternatives for each of the different levels of finance available from the management body in respect to the costs of route construction.

The approach followed in the resolution of the multiattribute model, chosen from the best management alternatives, makes reference to the ranking method, also known as ideal distance point method. The resolutions proposed derive from analysis of the matrixes of the project alternatives relating to two hypothesises: absence of expenditure constraints and constraints corresponding to a maximum admissible expenditure for the construction of the RPs equal to 150 million lire.

The resolution of the multiattribute model, passes through the construction of a distance matrix between the management alternatives identified and the objective taken into consideration. The metric adopted to determine the management alternative that represents the “the most satisfactory compromise” is that L_∞. That, for the reasons expressed in paragraph 3, is less distorted in the non compensatory case.

In the case of absence of expenditure constraints "the most satisfactory compromise" is given by the pure multifunctional alternative that foresees the realisation of four RPs of which one comprised by a forest road and the other by logging roads (*cfr*. Tab. 5.3, 5.4, 5.5). The area served by the four RPs indicated from the economic alternative is equal to 37% to that obtainable with the realisation of all the RPs, and extends for a length equal to 46% of the realisable maximum. The woodlands that prevail in about 170 hectares transected by this forest route are composed of coppice in conversion (34%), sweet chestnut (21%), mixed woodlands (17%) and the remaining part composed of bare land (6%).

Tab. 5.3 Pay-off matrix

	Management Alternatives					
constraints corresponding equal to1000 milion of lira	A1	A2	A3	A4	A5	A6
Economic object.	331	226	- 65	151	185	115
Hydrog. defence object.	156	208	223	53	81	207
Recreation object.	8	8	7	3	5	7
Fire control object	91	152	171	94	106	164
Cost	170	154	819	49	164	476

Tab. 5.4 Ideal distances matrix

	Management Alternatives						
constraints corresponding equal to1000 milion of lira	A1	A2	A3	A4	A5	A6	
Economic object.	0,000	0,264	1,000	0,454	0,369	0,544	
Hydrog. defence object.	0,699	0,932	1,000	0,236	0,365	0,928	
Recreation object.	0,028	0,000	0,164	0,559	**0,379**	0,045	
Fire control object	0,465	0,112	0,000	0,452	0,377	0,042	
L infinitive	0,699	0,932	1,000	0,559	0,379	0,928	**0,379**
L1	**1,192**	1,308	2,164	1,701	1,490	1,560	**1,192**

Tab. 5.5 Route project combinations in relation to management alternatives

	constraints corresponding equal to1000 milion of lira	Route combination for each management alternatives					
Route Project actived	A1	1	-	1	-	-	1
	A2	-	-	1	-	1	-
	A3	-	-	1	-	-	-
	A4	-	-	1	-	-	1
	A5	-	-	1	-	-	1
	A6	-	-	-	-	-	-
	A7	-	-	1	-	-	-
	A8	-	-	1	-	-	-
	A9	-	-	1	-	-	1
	A10	-	1	-	-	-	-
	A11	1	1	-	-	-	1
	A12	1	1	-	-	-	1
	A13	-	1	-	-	-	-
	A14	1	1	-	-	-	-
	A15	-	1	1	1	1	1
	A16	1	1	-	1	1	1
	A17	1	1	-	-	1	1
	A18	1	1	-	-	-	-
	TOTAL	**7**	**9**	**9**	**2**	**4**	**9**

Also in the case of limited resources destined to increase accessibility (cost constraints less than 150 million lire), the alternative pre-chosen by the model is the pure multifunctional (*cfr*. Tab. 5.6, 5.7, 5.8). In this case there are always four RPs activated but all relating to logging roads. The area served by the route realised from this alternative is reduced to 35% and extends for a length equal to 44% of the total. In this case the types of woodlands identified on the 200 hectares served by the route are composed of coppice in conversion (19%), sweet chestnut (18%), mixed woodlands (15%), and conifer high forest (5%); in this case 34% of the area is composed of bare ground and 9% of pasture land.

Tab. 5.6 Pay-off matrix

	Management Alternatives					
constraints corresponding equal to150 milion of lira	A1	A2	A3	A4	A5	A6
Economic object.	310	265	265	151	205	265
Hydrog. defence object.	122	181	181	53	69	181
Recreation object.	6	8	8	3	5	8
Fire control object	66	152	152	94	103	152
costo	128	144	144	49	73	144

Tab. 5.7+BU26 Ideal distances matrix

	Management Alternatives						
constraints corresponding equal to150 milion of lira	A1	A2	A3	A4	A5	A6	
Economic object.	0,000	0,144	0,144	0,512	0,337	0,144	
Hydrog. defence object.	0,677	1,000	1,000	0,291	0,382	1,000	
Recreation object.	0,202	0,000	0,000	0,557	**0,386**	0,000	
Fire control object	0,569	0,000	0,000	0,385	0,323	0,000	
L infinitive	0,677	1,000	1,000	0,557	0,386	1,000	**0,386**
L1	1,447	1,144	1,144	**1,745**	1,429	1,144	**1,144**

Tab. 5.8 Route project combinations in relation to management alternatives

	constraints corresponding equal to150 milion of lira	Route combination for each management alternatives					
Route Project actived	A1	1	-	-	-	-	-
	A2	-	-	-	-	-	-
	A3	-	-	-	-	-	-
	A4	-	-	-	-	-	-
	A5	-	-	-	-	-	-
	A6	-	-	-	-	-	-
	A7	-	-	-	-	-	-
	A8	-	-	-	-	-	-
	A9	-	-	-	-	-	-
	A10	-	1	1	-	-	1
	A11	1	1	1	-	1	1
	A12	1	1	1	-	1	1
	A13	-	-	-	-	-	-
	A14	-	1	1	-	-	1
	A15	-	1	1	1	1	1
	A16	1	1	1	1	1	1
	A17	1	1	1	-	-	1
	A18	1	1	1	-	-	1
	TOTAL	**6**	**8**	**8**	**2**	**4**	**8**

The coincidence in the choice of the pure multifunctional alternatives both in absence of constraints that if present, derive from the fact that the adoption of a L_∞ metric privileges those alternatives that allow to equalise the ideal distance of the different objective functions (*cfr*. Tab. 5.4 and 5.7). It is evident in our case that this condition is satisfied, despite the expenditure constraint, from the alternative management (pure multifunctional alternative A5) that attributes equal weights to the different functions, respecting thus the non compensatory hypothesis between the objectives. Resolving the model with L_1 metric, that is hypothesing a complete compensation between the objectives and in the absence of expense constraints, the pre-chosen alternative is the pure economic (A1) that foresees the realisation of seven RPs of which one is composed by a forest road. The presence of expenditure constraints, always resolving with L_1 metric, places the pure recreation alternative (A2), pure fire control (A3) and the multifunctional alternative with prevalently recreation and prevention of fires (A6) on the same level, in how much it obliges the choice of only logging roads that, in respect to the recreation objective represent the best RP for the purpose of maximisation of the same, while for the fire control function, also if the forest road represents a better solution, the high number of logging roads realisable with the expense limits defined, compensate the lower efficiency of this construction solution.

BIBLIOGRAPHY

AA.VV., (1980) Piano di assestamento delle foreste Casentinesi 1980-89, S.C.A.F., Ponte a Poppi – Arezzo.

BERNETTI I., (1992) L'analisi multicriteriale nella pianificazione delle risorse forestali: una applicazione alla gestione di una azienda forestale pubblica. Tesi di dottorato di ricerca in: Economia e Pianificazione Forestale, Università degli Studi di Firenze.

BERNETTI I., (1994) L'impiego dei modelli di analisi multicriteriale nella pianificazione forestale, ISAFA, Firenze

BERNETTI I., MAETZKE F., TORRINI L. (1993) L'analisi multicriteriale nella pianificazione forestale: Applicazioni ad un caso pratico. Atti del II seminario UNIF di Pianificazione Forestale.

BORSELLI L., (1995) Parametri pedologici ed idrologici come variabili fuzzy per la modellistica a livello di bacino.

BOVIO G., CAMIA A. (1990) Analisi della predisposizione dei boschi piemontesi ad essere percorsi dal fuoco. Cellulosa e Carta, anno XLI n. 3.

BOVIO G., CAMIA A. (1991) Modelli previsionali di efficacia nella protezione antincendi boschivi. Cellulosa e Carta, anno XLII n. 2.

CALABRI G., (1984) La prevenzione degli incendi boschivi. I problemi e le tecniche della difesa. Edagricole, Bologna, p. 184.

CANTER L. W., HILL L., (1976) Handbook of variables for Environmental Impact Assessment, Ann Arbor Science Publishers, Ann Arbor, Michigan.

CANTIANI M., BERNETTI G., (1962) Tavole alsometriche delle abetine della toscana, Ann. Acc. Italiana Scienze Forestali XI: 293-332.

CASINI L., (1998) Metodologie decisionali pubbliche in campo agricolo e forestale. Atti Convegno Associazione Analisti Ambientali su "Valutazione di impatto ambientale".

CIANCIO O., NOCENTINI S., (1995) Il bosco e l'uomo: l'evoluzione del pensiero forestale dall'umanesimo moderno alla cultura della complessità. La selvicoltura sistemica e la selvicoltura su basi naturali. In Il bosco e l'uomo a cura di O. Ciancio Acc. It. Sc. For.

FAGARAZZI C., (1996) Proposte di gestione della zona di protezione del parco Nazionale delle Foreste casentinesi, del M. Falterona e di Campigna, tesi di laurea in Assestamento Forestale, Università degli Studi di Firenze.

HIPPOLITI G., (1990) Le utilizzazioni forestali. CUSL, Firenze.

KRAWIEC B., BERNETTI I., CASINI L., ROMANO D., (1990) Le tecniche multiobiettivo nella pianificazione dell'azienda forestale: aspetti metodologici e applicativi. Dipartimento Economico Estimativo Agrario e Forestale, Firenze.

LAZARSFELD P.F., (1969) Evidence and influence in social research. In: BOUNDON R., LAZARSFELD P.F., L'analisi empirica delle scienze sociali, vol.1, Dai concetti agli indici empirici, Il Mulino, Bologna.

MARINELLI A., MARINELLI M., (1986) La valutazione degli investimenti in reti viarie forestali. Cellulosa e carta, n.5.

PETTINÀ R., (1992) Un prototipo di sistema esperto per la determinazione della potenzialità turistico ricreativa nella pianificazione forestale. Tesi di dottorato. Firenze.

ROMANO D., (1989) La valutazione di massima di un investimento in reti viarie forestali. Annali Accademia Italiana di Scienze Forestali.

ROMERO C., REHMAN T., (1989) Multiple criteria analysis for agricultural decision. Elsevier, Amsterdam.

ZELENY M., (1982) Multiple Criteria Decision Making and Expert System. Kluwer Accademic Publisher, Boston.

ZIMMERMANN H. J., (1987) Fuzzy sets, Decision Making and Expert System. Kluwer Accademic Publisher, Boston.