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A RULE-BASED SDSS FOR INTEGRATED FOREST HARVESTING PLANNING

(SVILUPPO DI UN MODELLO PER LA PIANIFICAZIONE
INTEGRATA DEI SISTEMI DI UTILIZZAZIONE)

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Tirare tronchi è dannatamente difficile.
È come condurre l’esistenza prevedendone il futuro
ed è quindi un’arte non da tutti.
Occorre essere addestrati a soffrire fin da piccoli.
La pianta, mentre scivola dietro al tuo passo,
è viva e bene intenzionata,
ma non può evitare tutti gli ostacoli del percorso,
e quando non scorre più, bisogna trascinarla.
A volte tutto va bene e il tronco fila veloce
e senza intoppi, ma più spesso si impunta,
si pianta col naso nel terreno, si ferma, si blocca di colpo
segandoti la volontà nello strappo della frenata.

MAURO CORONA – I *tira-taie*

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RIASSUNTO

Secondo quanto riportano i dati del recente inventario forestale, le foreste italiane crescono annualmente dell'uno percento che corrisponde a circa 100000 ettari. Una delle cause è il generale abbandono della montagna e delle attività di agricoltura montana che lasciano spazi aperti alla ricolonizzazione del bosco, ma anche il mercato del lavoro in bosco e del legno hanno dato il loro contributo. Da una lato infatti il costo del lavoro è andato crescendo, dall'altro il valore del legno, in piedi e all'imposto, è calato a livelli tali da rendere non conveniente il taglio e l'esbosco del legname. Parallelamente il bosco ha acquisito valore in relazione ad altre funzioni quali la conservazione della biodiversità, la protezione dal rischio idrogeologico, le attività turistico-ricreative e non ultima quella dell'accumulo del carbonio. Anche la certificazione forestale ha interferito con il mercato del legno, in parte positivamente rilasciando un marchio di qualità e di gestione sostenibili ai prodotti locali, dall'altro ha imposto regole che limitano la determinazione della ripresa a meno di quello che è l'incremento annuo. Ciò porta inevitabilmente a un aumento costante della provvigione dei nostri boschi e influisce sui costi di utilizzazione poiché la produttività delle operazioni rimane sempre piuttosto bassa. Anche l'introduzione di una meccanizzazione avanzata sembra essere possibile solo in presenza di determinate condizioni. Tuttavia l'industria del legno, soprattutto del mobile, e il nuovo interesse verso l'utilizzo delle biomasse forestali a scopi energetici sono in continua crescita. A trarne vantaggio è stato l'import del legname proveniente dall'est Europa dove la manodopera ha costi più bassi e dove la selvicoltura consente ancora di effettuare tagli a raso.

A livello di pianificazione, alcune regioni hanno introdotto nuove norme per la redazione dei piani di assestamento, ma è ancora difficile trovare indicazioni precise riguardo alle caratteristiche di accessibilità e percorribilità delle particelle nonché delle motivazioni che spingono l'assestatore a consigliare un sistema di utilizzazione piuttosto che un altro. Una scelta errata (se aggiunta a una martellata del lotto mal eseguita) non solo può far lievitare i costi e scoraggiare l'impresa forestale ad eseguire interventi simili in una data area, ma può anche essere causa di danni inevitabili al suolo e al popolamento e, nel caso più estremo, indurre a non eseguire il taglio pregiudicando e annullando l'utilità della pianificazione.

Il modello per la pianificazione integrata dei sistemi di utilizzazione (FOpP model) mira a fornire valide alternative al pianificatore nella scelta dei sistemi di utilizzazione, supportate anche dall'analisi economica degli interventi e dall'effetto che possono avere sul valore del legname. L'interpretazione dei risultati del modello può inoltre essere utile nella valutazione del grado di infrastrutture viarie, evidenziando aree carenti o aiutando il politico a valutare progetti e a indirizzare eventuali contributi finalizzati alla loro costruzione.

Le fasi di abbattimento vengono generalmente effettuate a mano con l'utilizzo della motosega, l'harvester è presente nell'area di studio, ma spesso viene utilizzato solo come processore perché i diametri delle piante superano i limiti tecnici delle testate abbattitrici.

Quello che influenza maggiormente i costi di allestimento dei lotti di legname è dunque l'operazione di esbosco. Ci sono molte sfumature, molte marche e tecnologie diverse utilizzate dalle imprese forestali, ma per semplificare si è deciso di selezionare cinque tipologie nelle quali possono rientrare tutti i sistemi. Tra i sistemi *off-road* è stato scelto il trattore con verricello, il *forwarder* e il *cable-forwarder*. Quest'ultimo, seppure arrivato in commercio da pochi anni, potrà soppiantare il forwarder perché è adatto a lavorare anche su pendenze elevate, tipiche delle foreste alpine italiane. I sistemi di esbosco su fune sono stati raggruppati in due categorie, le gru a cavo mobili e le gru a stazione motrice semifissa su argano. Di ognuno dei cinque sistemi si sono monitorate le produttività attraverso l'analisi dei tempi di lavoro raccolti in diversi cantieri in bosco e si è tentato di ricavare delle formule che mettessero in relazione la distanza di esbosco da strada con la produttività. Sulla base di questi dati sono stati calcolati i costi unitari. Per ogni sistema si sono definiti i limiti tecnici per poter operare: nel caso dei sistemi *off-road* si sono presi in considerazione l'accidentalità del terreno, la pendenza, la distanza da strada e la portanza del suolo, per i sistemi su fune è sufficiente considerare la distanza da strada e la pendenza minima di funzionamento della linea (che opera solitamente a gravità). L'insieme dei parametri costituisce le regole sulle quali si basa il modello.

Molto importante per rendere un modello utilizzabile è cercare di limitare il numero di informazioni richieste all'utente. Il reperimento e la preparazione dei dati richiede spesso grande dispendio di tempo. Per questo motivo il FOpP model è stato costruito basandosi sui dati che sono generalmente disponibili o reperibili presso gli enti regionali (webGIS) o nei piani di assestamento. Si sta inoltre sempre più diffondendo l'utilizzo di database e files già pronti per l'utilizzo con strumenti GIS. Cinque informazioni sono necessarie per far girare il modello: il Modello Digitale del Terreno (DEM), la classificazione dei suoli, i dati medi di precipitazione annui, la rete delle strade forestali e i dati dei piani di assestamento.

Questi shape-files devono essere inseriti in un Geodatabase per poter essere gestiti in modo più veloce e sicuro nella prevenzione di errori di calcolo. Il funzionamento del modello si basa sull'utilizzo degli strumenti (*tools*) di Geoprocessing di ArcMap (ESRI) ed è stato generato con ModelBuilder, interfaccia operativa grafica che consente di creare nuovi strumenti in ArcGIS (*Toolboxes*), di poterli condividere con altri ricercatori e di poterli esportare o integrare attraverso linguaggi di programmazione molto diffusi. La creazione di una maschera di dialogo, supportata da un testo informativo a tergo, consente all'utente di modificare i parametri adattando il modello alle proprie necessità.

Successivamente alla sua creazione il modello è stato sottoposto a una validazione eseguita in due modi diversi. È stata effettuata una intervista ad alcune imprese forestali per recuperare informazioni relative alla localizzazione e alle attrezzature utilizzate in cantieri di utilizzazione effettuati in passato. Inoltre, sottoponendo una mappa ai responsabili di una ditta che utilizza il *forwarder*, si sono individuate delle aree dove secondo loro potrebbe lavorare. Questi risultati cono stati confrontati con i risultati del modello per valutare quanto sia vicino alla realtà. Un altro metodo di validazione ha confrontato le mappe del

FOpP model con quelle prodotte da un modello molto simile sviluppato in Slovenia. Basati entrambi su parametri molto simili, hanno rivelato notevoli differenze per quanto riguarda l'utilizzo del trattore e delle gru a cavo. In particolare, il FOpP model si è rivelato più preciso nell'individuazione delle aree non raggiungibili dai sistemi di utilizzazione.

Sono state eseguite anche alcune prove per saggiare la sensibilità del modello. Si è testato come variano i risultati al variare dei parametri che definiscono i limiti tecnici delle attrezzature. Si è analizzato in particolare come variano i costi di esbosco e la percentuale di area coperta da ogni sistema di utilizzazione al variare della distanza massima di esbosco di *forwarder* e gru a cavo mobile. Si è testata anche la possibilità di effettuare il calcolo selezionando solo alcune attrezzature e si è verificato come questo influisce sulle aree non raggiungibili.

Le mappe ottenute dalle elaborazioni del modello sono facilmente interpretabili e leggibili, riportano delle utili legende che permettono di identificare in quale area ogni sistema può intervenire. Ad un primo risultato che analizza la fattibilità degli interventi di utilizzazione segue una sorta di analisi economica. Si ottengono infatti delle mappe che riportano il costo delle operazioni di esbosco sia per cella (della mappa in *raster*) sia per metro cubo di legname. È così possibile effettuare delle utili statistiche per ogni particella assestamentale e prevedere l'economicità degli interventi sulla base delle prescrizione previste dal piano di assestamento o economico. Una interessante applicazione riguarda le strade forestali: facendo fluire il legname a strada è possibile stimare quanti metri cubi verranno esboscati su ogni specifico tratto di strada e prevedere così quale sarà il traffico di automezzi che la percorrerà. Sulla base del transito previsto, che determina inevitabilmente l'erosione del fondo stradale, è possibile redigere una sorta di piano delle manutenzioni delle infrastrutture. L'analisi consente inoltre di evidenziare quali aree boscate non sono raggiungibili. Nell'ipotesi di analisi di un nuovo progetto, aggiungendo la strada allo shape iniziale e facendo girare nuovamente il modello, è dunque possibile verificare come questo influisce sulla scelta del metodo di esbosco e sul valore del legno.

In seguito a una pianificazione generale d'area è comunque auspicabile uno studio più particolareggiato che vada ad analizzare intervento per intervento tutte le questioni inerenti al cantiere, dalla logistica alla sicurezza dei lavoratori, dai costi fissi a quelli variabili e a quelli aggiuntivi dovuti ai tempi morti o di trasferimento degli operatori.

Vengono alla fine illustrate alcune migliorie che si potrebbero apportare al modello, alcune raccomandazioni e alcuni esempi di applicazione della pianificazione.

Le migliorie riguardano la possibilità di includere nel modello l'analisi dell'idrologia dei versanti (torrenti o zone paludose) che agisce da barriera all'avanzamento dei mezzi fuoristrada, nonché l'introduzione di un parametro legato alla stagione. Il regime pluviometrico è infatti variabile nell'arco dell'anno a seconda delle regioni climatiche: questo influisce sulla saturazione del suolo, ma in modo differente a seconda del periodo. Se gli interventi in bosco avvengono durante l'estate sarà più probabile che la portanza del terreno sia elevata e consenta la circolazione dei mezzi al pieno delle loro capacità tecniche.

Le raccomandazioni riguardano la qualità dei dati. Sarebbe auspicabile poter utilizzare un modello digitale molto più preciso con dimensione delle celle pari o inferiori ai cinque metri. Questo è oggi possibile grazie a strumenti quali il laser scanner (Lidar) e all'aumento delle capacità di elaborazione dei personal computer. Altre informazioni, in particolare la presenza di ostacoli, la ripresa e la classificazione delle strade, andrebbero richieste dai servizi di controllo e supervisione (regione e servizi forestali) al momento della stesura dei piani di assestamento. Inoltre la loro pubblicazione in formato GIS renderebbe più semplice il loro utilizzo e l'aggiornamento continuo e puntuale dei dati.

Concludendo, si riportano due esempi di pianificazione, la prima riguarda la valutazione a livello di regione Veneto del numero di *harvester* che potrebbero potenzialmente lavorare in modo economico e competitivo. La seconda invece è l'applicazione del modello su larga scala (1400 km^2) al fine di valutare costi, carenze e potenzialità della filiera-legno in un'area compresa tra Italia e Slovenia.

ABSTRACT

The forestry sector in Italy had some problems in the last years: the general abandonment of mountains caused the uncontrolled growth of forests and some problems on their management for preventing hazards like wildfires, the increase of forest work salaries and the decrease of wood value, the concurrence of eastside European countries, the forest certification which protected more the ecological function of forests than their economical value, the increment of social and natural functions of forests as the carbon sinks. All this factors influenced the way of planning cuttings inside forests to the point that sometimes, due to technical difficulties or low wood value and amount, they are not economical and they are not done. But now, the increasing interest of the use of wood for heating or building purposes may increase again the demand and the value of this material.

The Forest Operations Planning model helps the forester making decisions about which skidding system is the most viable according to stand assessmental data and geography. The model may also highlight areas which have low forest roads density. The skidding operations have high influence on the total cutting costs so the model considers only the skidding operation, the user will add unit costs for felling operations according to the system used (usually chainsaw or harvester). Five systems are here considered: the tractor with winch or skidder, the forwarder, the cable forwarder and two aerial systems, the mobile tower and the sledge yarder cable cranes.

The model was built on a GIS environment with the ArcGis ModelBuilder. It is practically a tool which can be shared with other researchers and modified according to any needs.

The input files required to run the model are five: the Digital Terrain Model, the soil classification or stability, the average yearly amount of rain, the forest road network and the assessmental forest stand data.

The model was validated comparing results with real working sites done inside the study area or comparing results with other models on different study area. The model evaluation was done checking the influence of parameter variation on output results.

The model outputs are several grid maps showing the feasible working area of each system, the technical and optimized distribution of systems with costs (evaluated cell-by-cell and per cubic meter). The statistic tools allow to make stand reports and deep analysis.

Comparing model outputs it is possible to evaluate the accessibility of forest and plan the building of new roads to improve the infrastructure and reduce the skidding costs.

At the end, two practical examples are reported and some discussion are done about the input data quality and a more site-specific planning.

1. INTRODUCTION

The term “integrated” has become common when speaking of natural and environmental disciplines. Even on a more technical and engineering work, such the model presented inside this dissertation, aim to consider a wide spectrum of sciences: ecology, hydrology, sylviculture, technology and infrastructural planning. Results of an integrated planning have to consider all of them trying to optimize the efficiency and needs or, better, reduce negative impacts.

1.1. FORESTS AND FORESTRY: STATE-OF-THE-ART

Italy occupies a long peninsula stretching from the Alps into the Mediterranean Sea. Forests are mostly located in the Alps and in the mountainous Appennin “backbone”.

According to the National Forest Inventory carried out in 1985-86, the forest area was 8.6 million hectares; while according with the National Institute of Statistics, that publishes annual data, the forest land extension is 6.8 million hectares (COLPI *et al.* 1999). INFC (2007) estimated more than 10 million hectares of Italian forest area with an increase of 20% in 20 years. INFC considers areas with minimal forest cover of 10% and minimal surface of 0.5 ha. Of such area, 6.86 million hectares are high stands, coppice, shrubs and Mediterranean macchia forest, while the remaining part is represented by small woodlots (rocky, riparian forests or shrubby vegetation).

Most of the productive high forests (mainly coniferous) are in the North-Eastern regions while coppices predominate in the centre of the country. Three fourths of the removals of conifer roundwood (about 1.2 Mm^3, table 1.1.2.b) come from North-Eastern regions (DELLAGIACOMA 2005). The only relevant examples of forest plantations are the poplar stands in the northern plain areas of the river Po valley (PETTENELLA *et al.* 2004). Poplar cover the 37% of sawn hardwood (DELLAGIACOMA 2005).

Conifers are dominant in high forest, both for extension (56.3%) and timber volume (63.1%). The most important species is Norway Spruce (*Picea abies* Karst). Also mountain Pines (*Pinus sylvestris* L., *Pinus nigra* Arnold, *Pinus laricio* Poiret) and European larch (*Larix decidua* Mill.) are widespread. Most coniferous forests are located in the Alps (montane e subalpine Spruce, Fir, Larch forests), but some important ones can be found also in Southern Apennines (*Pinus laricio* Poiret). Broadleaved high forests are mostly beech woods (*Fagus sylvatica* L.), but also oak woods (especially *Quercus cerris* L.). In hill zone are widespread Chestnut (*Castanea sativa* Miller) coppices, or coppice of Hornbeam (*Carpinus betulus* L.), Hophornbeam (*Ostrya carpinifolia* Scopoli) and Oaks (*Quercus* spp.) often in mixed compositions. In mountain zone coppice woods are mostly composed by beech both on the Alps and on the Apennines (COLPI *et al.* 1999).

The national growing stock of high forests is about 405 millions of m^3 (about 211 $m^3\ ha^{-1}$), with a total annual increment of approximately 30 million m^3 of timber per year (on average, 7.9 m^3 ha^{-1} yr^{-1}) , but it is harvested only one third of it (PETTENELLA *et al.*, 2004). Currently in high forest, the annual yield rarely exceeds 50% of the annual growth. Harvesting is on average 35% of the current increment. This led to a general increasing of the growing stock in the last decades (COLPI *et al.* 1999). Main causes of low utilisation are lack of infrastructures, difficulties of access, strict regime of protection for protected areas and insufficient economic value of wood (PETTENELLA *et al.*, 2004).

1.1.1 Defining study area

The study area considers Veneto, Friuli Venezia Giulia regions and Trento province in North-eastern Italy (Figure 1.1.1.a).

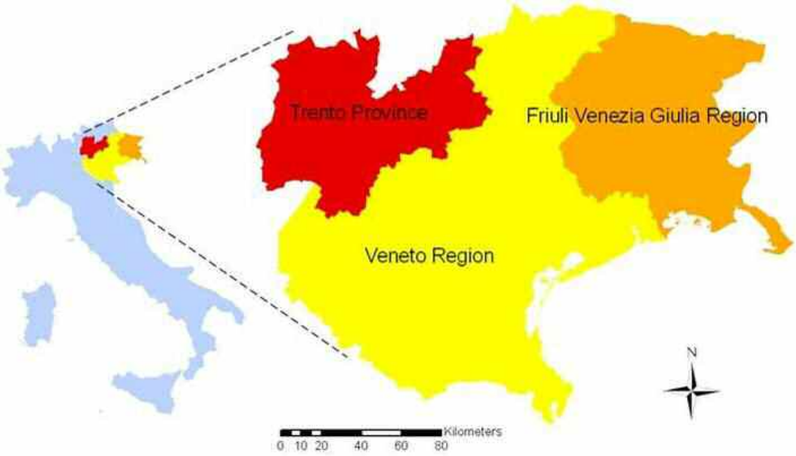


Figure 1.1.1.a: the study area in the north-eastern part of Italy

Forest is mainly located on mountainous area so forest operations are mainly carried out on steep terrain, and this affects the operational method, the machinery equipment, the road network requirement, the length of the working period and the availability of manpower (CAVALLI 2004). The economic feasibility of logging operation in mountainous area is influenced by small private ownership structure, the difficult terrain conditions (steepness and roughness), small harvested volumes driven by sylvicultural requirements (STAMPFER and KANZIAN 2006) and transportation cost and distance (SPINELLI *et al.* 2007).

In this area sawmills are generally small and, especially on mountainous area, they are oriented to process coniferous timber. Sawmill byproducts supply concerns partly the local market and partly it leans on abroad market (Germany, Austria and Eastern countries) (CICCARESE *et al.* 2004).

The use of wood as renewable energy source for heating in the years 2003-2006 was promoted with European structural funds, rural development plans, energy projects, regional and provincial funds. The majority of boilers and heating districts require wood chip. This material comes mostly from sawmills but a good planning of forest operations and cutting systems could improve the use of forest biomass reducing costs and increasing quality (EMER *et al.* 2007).

1.1.2. Forest management

In Italy, 60% of the forest land is owned by private person and the other share is for public property. Public owned forest is possessed by local municipalities. According to General Census of Agriculture (ISTAT 2000), the average size of private forest properties is 7.51 ha. Private owned woodlands are usually very scattered and rarely keep a forest management plan. This is a big problem for an active management of forest resources (EMER 2005). Inside the research area, about 90% of the forests are situated in mountain areas, 7.5% in the hills and only 2.6% in the plains (table 1.1.2.a). According to forest management plans, forest are fast growing to a rhythm of 5.7 m^3/ha.year in high forests and 6.2 m3/ha.year in coppice forests (GPA 2005).

Table 1.1.2.a: forest area and location in North-eastern Italy (CAVALLI 2004)

	Characteristic		Bolzano province	Trento province	Veneto region	Friuli-Venezia Giulia region	N-E Italy
A	Forest area	ha	308844	323005	271885	184156	**1087890**
B	Provincial or regional total area	ha	740043	620687	1836400	784600	**3981730**
	A/B	%	41.7	52.0	14.8	23.5	**27.3**
	Forest location						
C	Mountain	ha	308844	323005	211603	135285	**978737**
D	Hill	ha	0	0	45752	35348	**81100**
E	Plain	ha	0	0	14530	13523	**28053**
	C/A	%	100	100	77.8	73.5	**90.0**
	D/A	%	0	0	16.8	19.2	**7.5**
	E/A	%	0	0	5.3	7.3	**2.6**

Soil and water conservation is the main goal and constraint of forest management. Actually forestry practices are carefully controlled and restricted by specific rules, aiming a sustainable planning and management of forest land. In high forest clear cutting is forbidden and forest operations are leading to natural regeneration, such as selection method and shelterwood method (group-, strip- and edge-cuttings), are strongly encouraged. With this kind of treatment, the forest has shift to uneven-aged or irregular. In beech high forest is typical to treat with uniform method. The opening of gaps or stripes by clearcutting is allowed only in stand composed by light-demanding species, in order to meet the ecological requirements of these species and guarantee the stand natural regeneration. Coppice is widespread, especially with private owners. The most common method is clearcut, but for many species the law prescribes to leave some standards to favour seed production and sprouts regeneration in old stumps. The selection method is applied in many beech coppices, a lot of which are public proprieties (COLPI *et al.* 1999).

Forests are a puzzle of small different typologies, almost 70 forest types have been defined. Each of them is characterized by different degrees of biodiversity, connected to the share of tree species, the forest structure, their regional spreading, the presence of protected animals and flowers, and many other parameters (DEL FAVERO 2001 and 2004). Based on the

Corine Land Cover (APAT 2005), forested area is divided in coniferous (39.3%), hardwoods (46.6%) and mixed forests (14.1%). Ash-hornbeam and oak-hophornbeam are the most spread forest types on the foot of the mountain and hilly areas. On mountains, beech forests and spruce forests in alpine areas are most common. Other rare types like Mediterranean macchia, oak forests on plain areas and *Pinus mugus*, even if they are small, they increase biodiversity. In Veneto region, 45% of forested area are included inside protected area according to the European rules of Natura 2000. Cuttings and re-planting operations to improve forest health have been performed both inside protected areas and in SIC/ZPS areas for a total of about 5000 ha (PSR 2007).

As a priority for the right management of forests and to preserve peculiarities of each forest type, **forest management plans** are a fundamental instrument. According to “Forest regional laws” (as for example the L.R. 52/78 in Veneto), all public forests must be managed in conformity with forest assessmental plans, approved by regional or provincial forest services. In Veneto and in Friuli-Venezia Giulia region the share of forest property is similar, within 50 and 60% for public properties (64% of forests in Veneto are assessed). In Trento province public properties are bigger reaching more than 70%, but inhabitants have local rights to use wood coming from public coppice (mostly beech coppice forests) for house heating purposes. As an average, 1/10 of the yearly Italian yield comes from these three regions (table 1.1.2.b). Even private properties can be assessed by particular environmental and management plans (“piani di riassetto”), but they are not common until now.

Table 1.1.2.b: comparing coppice and high forest area and production (Cavalli 2004)

	Characteristic		Bolzano province	Trento province	Veneto region	Friuli-Venezia Giulia region	N-E Italy
	Coppice forest	ha	17633	68968	125084	62923	**274608**
	High forest	ha	291211	254037	146757	121193	**813198**
A	Spruce and fir high forest	ha	55798	31195	20809	10405	**118207**
B	Italian spruce and fir high forest	ha	163419	163419	163419	163419	**163419**
	A/B	%	34.1	19.1	12.7	6.4	**72.3**
	Annual cuttings						
	Coppice	m^3	26488	17980	134705	58836	**238009**
	High forest	m^3	597947	204410	123902	135293	**1061552**
	Sum	m^3	624435	222390	258607	194129	**1299561**

An important aim of Italian forestry is to foster natural diversity and evolution in forests: mixed forests are promoted and the spontaneous re-colonization of broadleaved species in coniferous plantation is today strongly encouraged (Colpi *et al.* 1999).

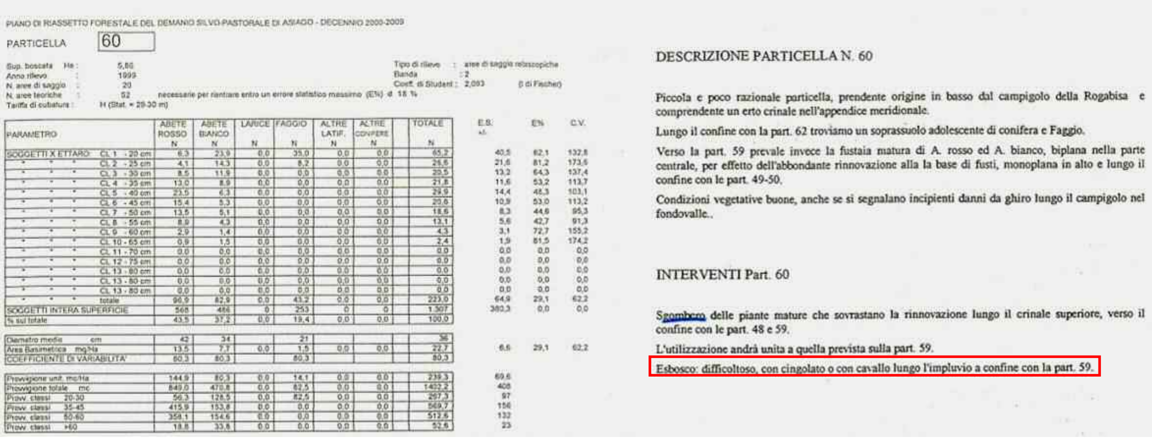
Many land owners have also obtained the PEFC certification for a sustainable management of forest respecting the international standards. Specific indicators have been included to maintain and improve natural habitats and to evaluate environmental damages which could derive from forest operations. The basic principles of the sustainable sylviculture are respected but this lead to plan cuttings that are always below the estimated growing index.

This make difficult the use of high mechanized utilization systems: many planned cuttings have low yield, or they are on difficult terrains, or there is no infrastructure (forest roads) so neither forest enterprises nor sawmills are interested in buying that wood (HIPPOLITI 2004).
If forest planning will consider not only the ecological and environmental point of view but even the social and economical (what is called here **integrated planning**) Italian forestry could raise and be competitive on the European market.
Forest management should be adapted to the needs of society, promoting equity within and between generations. Sustainable management is when wood is harvested until a limit which correspond to the natural re-growth, so that next generations will use that resource as we did. Even DEL FAVERO (2004) pointed out that a change is needed on several fields: cultural and ethics, scientific and technological, political and juridical, besides social and economical.

1.1.2.1. Focusing problems

Nowadays, in some regions (for example Lombardia) or provinces (as Trento), new forest management plans have been testing but still preserving the historical meaning (CALVO *et al*. 1998; CALVO 2004; CALVO *et al*. 2004; WOLYNSKY 2005). One of the main problems is that sylviculture and forest mechanization have usually opposite needs: the sylviculture take care of the ecological aspects and aims to reduce cuttings according to new functions and utilities assigned to forests(CIANCIO and NOCENTINI 1996; DEL FAVERO 2004); on the other side, work and machine investment costs increased so that small cuttings are not sustainable (HIPPOLITI 2006) because high mechanization requires high productivities.
Forester who makes planning should consider and reconcile both needs, but this is difficult and in the past was neglected so that:

- inside forest management plans there are only few information (figure 1.1.2.1.a) about the optimal cutting and skidding method to be applied when cutting a stand (CIELO *et al.* 2004). Some Regions have introduced standard information as for example the terrain roughness, the presence of roads or skidding trails, the slope or other specific information that are now easily managed by Geographic Information Systems or gathered using new technologies as LIDAR (LUBELLO and CAVALLI 2006).
  The way in which forester defines skidding systems is not clear: why he suggests that system? Will it be feasible and economically viable? Building an objective model which will answer these question would be a good solution. Even more, if the cutting operations will be technically and economically feasible, forester will be sure that his planning will be successful. A good knowledge of forest mechanization systems may also help the planner in designing new forest roads and assessing the road network.



PIANO DI RIASSETTO FORESTALE DEL DEMANIO SILVO-PASTORALE DI ASIAGO - DECENNIO 2000-2009

PARTICELLA 60

Sup. boscata Ha : 5,86
Anno rilievo : 1999
N. aree di saggio : 20
N. aree teoriche : 52 necessarie per rientrare entro un errore statistico massimo (E%) di 18 %
Tariffa di cubatura : H (Stat. = 29-30 m)

Tipo di rilievo : aree di saggio relascopiche
Banda : 2
Coeff. di Student : 2,093 (t di Fischer)

PARAMETRO		ABETE ROSSO N	ABETE BIANCO N	LARICE N	FAGGIO N	ALTRE LATIF. N	ALTRE CONIFERE N		TOTALE N	E.S. +/-	E%	C.V.
SOGGETTI X ETTARO	CL 1 - 20 cm	6,3	23,9	0,0	35,0	0,0	0,0		65,2	40,5	62,1	132,8
" " "	CL 2 - 25 cm	4,1	14,3	0,0	8,2	0,0	0,0		26,6	21,6	81,2	173,6
" " "	CL 3 - 30 cm	8,5	11,9	0,0	0,0	0,0	0,0		20,5	13,2	64,3	137,4
" " "	CL 4 - 35 cm	13,0	8,9	0,0	0,0	0,0	0,0		21,8	11,6	53,2	113,7
" " "	CL 5 - 40 cm	23,5	6,3	0,0	0,0	0,0	0,0		29,9	14,4	48,3	103,1
" " "	CL 6 - 45 cm	15,4	5,3	0,0	0,0	0,0	0,0		20,6	10,9	53,0	113,2
" " "	CL 7 - 50 cm	13,5	5,1	0,0	0,0	0,0	0,0		18,6	8,3	44,6	95,3
" " "	CL 8 - 55 cm	8,9	4,3	0,0	0,0	0,0	0,0		13,1	5,6	42,7	91,3
" " "	CL 9 - 60 cm	2,9	1,4	0,0	0,0	0,0	0,0		4,3	3,1	72,7	155,2
" " "	CL 10 - 65 cm	0,9	1,5	0,0	0,0	0,0	0,0		2,4	1,9	81,5	174,2
" " "	CL 11 - 70 cm	0,0	0,0	0,0	0,0	0,0	0,0		0,0	0,0	0,0	0,0
" " "	CL 12 - 75 cm	0,0	0,0	0,0	0,0	0,0	0,0		0,0	0,0	0,0	0,0
" " "	CL 13 - 80 cm	0,0	0,0	0,0	0,0	0,0	0,0		0,0	0,0	0,0	0,0
" " "	CL 13 - 80 cm	0,0	0,0	0,0	0,0	0,0	0,0		0,0	0,0	0,0	0,0
" " "	CL 13 - 80 cm	0,0	0,0	0,0	0,0	0,0	0,0		0,0	0,0	0,0	0,0
" " "	totale	96,9	82,9	0,0	43,2	0,0	0,0		223,0	64,9	29,1	62,2
SOGGETTI INTERA SUPERFICIE		568	486	0	253	0	0		1 307	380,3	0,0	0,0
% sul totale		43,5	37,2	0,0	19,4	0,0	0,0		100,0			
Diametro medio cm		42	34		21				36			
Area Basimetrica mq/Ha		13,5	7,7	0,0	1,5	0,0	0,0		22,7	6,6	29,1	62,2
COEFFICIENTE DI VARIABILITA'		80,3	80,3		80,3				80,3			
Provvigione unit. mc/Ha		144,9	80,3	0,0	14,1	0,0	0,0		239,3	69,6		
Provvigione totale mc		849,0	470,8	0,0	82,5	0,0	0,0		1402,2	408		
Provv. classi 20-30		56,3	128,5	0,0	82,5	0,0	0,0		267,3	97		
Provv. classi 35-45		415,9	153,8	0,0	0,0	0,0	0,0		569,7	156		
Provv. classi 50-60		359,1	154,6	0,0	0,0	0,0	0,0		512,6	132		
Provv. classi >60		18,8	33,8	0,0	0,0	0,0	0,0		52,6	23		

DESCRIZIONE PARTICELLA N. 60

Piccola e poco razionale particella, prendente origine in basso dal campigolo della Rogabisa e comprendente un erto crinale nell'appendice meridionale.

Lungo il confine con la part. 62 troviamo un soprassuolo adolescente di conifera e Faggio.

Verso la part. 59 prevale invece la fustaia matura di A. rosso ed A. bianco, biplana nella parte centrale, per effetto dell'abbondante rinnovazione alla la base di fusti, monoplana in alto e lungo il confine con le part. 49-50.

Condizioni vegetative buone, anche se si segnalano incipienti danni da ghiro lungo il campigolo nel fondovalle..

INTERVENTI Part. 60

Sgombero delle piante mature che sovrastano la rinnovazione lungo il crinale superiore, verso il confine con le part. 48 e 59.

L'utilizzazione andrà unita a quella prevista sulla part. 59.

Esbosco: difficoltoso, con cingolato o con cavallo lungo l'impluvio a confine con la part. 59.

Figure 1.1.2.1.a: a page from the current Asiago forest assessmental plan. The only information is that on the red rectangle saying that skidding will be difficult and hopefully performed with a tracked tractor or horses.

- o the yield is often too low to guarantee economically forest operations. This happen when using cable cranes or harvesters and forwarders because the installation, translocation and maintenance costs are usually higher than traditional systems. Those new technologies make low damages to the soil and to remaining trees (CECUTTI 2001, MARCHI and PIEGAI 2001, CAVALLI 2005) but they require high cutting quantities. If the planner has no consciousness of this problem, operations will not be done and his work will be useless.

Recently (in the Friuli-Venezia Giulia) the forester advises which system is optimal and the owner or the forest manager makes a project of the cutting operations so that there should be a *continuum*, a dialog between planning, management and utilizations, as today is not (DEL FAVERO *et al.* 2000).

1.1.3. Forest economy

1.1.3.1. Wood market

In Italy, the two components of the forestry sector (forest activities and wood working industries) are separated entities acting rather independently. The lack of integration between the two sectors is due to different policies and patterns of development. Forest activities seem more oriented towards the production of non-market public services than to an increase in the internal supply of wood products. The wood industry is strictly oriented towards production and competition in the international market by giving as much added value as possible to the raw material imported (COLPI *et al.* 1999). In Italy, the bulk of industrial activities is based on import of rough and semi-finished products (15.5 Mm^3: FAO, 2007), while internal supply is able only to cover small niches of the market.

Table 1.1.3.a: Main indicators of the wood-based industry structure (ISTAT 1997)

	farms	employ.	turnover	import		export		balance
	n.	n.	1 M	1 M €	1000 t	1 M €	1000 t	1 M €
a. wood in the rough, chips and residual	10830	37034	7070	7019	5041	2939	71	-4080
b. semi-finished products	44873	149469	155552	20224	5105	7571	654	-12653
sawnwood	4081	17943	24392	12917	3812	785	72	-12132
panels	369	12999	48785	5196	1020	4622	438	-573
building material	38520	103672	69928	1653	124	1684	51	31
packaging	1903	14855	12447	460	150	480	93	21
c. wood furniture	31807	162107	116719	4586	155	68926	1572	64340
Total (a+b+c)	**87510**	**348610**	**279341**	**31829**	**10300**	**79436**	**2297**	**47607**

Wood industry is a flowering sector employing 350000 workers (table 1.1.3.a), but the dimension of enterprises is low with an average of 4 employees. Nevertheless the Italian style is famous around the world and the furniture export is at the highest level (table 1.1.3.b).

Table 1.1.3.b: import-export balance in Veneto region (CamCom 2006a) and Udine province in F-VG (CamCom 2007a)

	VENETO region (2005)		Udine province – FVG (2006)	
	Import (€)	Export (€)	Import(€)	Export (€)
sawn or planed wood	398.239.541	77.762.832	108.654.769	n.d.
veneer panels	177.217.125	39.799.606	16.394.205	56.512.781
carpentry	60.196.795	49.040.651	13.799.786	n.d.
wood packing	15.552.122	9.917.337	n.d.	n.d.
other wood products	54.397.652	38.692.822	66.465.594	n.d.
sum	705.603.235	215.213.248	205.314.354	56.512.781
furniture	166.629.430	1.783.849.641	75.062.378	698.314.406

In the North-eastern regions there are some industrial districts that are concentrated as spots on some places or provinces and they are very specialized in the production of specific issue, as for example the chair-district, the furniture-district or the kitchen-district. This is clear reading table 1.1.3.c where Treviso is the Veneto province with vocation to that production activity (comparing its import and export there is 900 M€ of added value!)

Table 1.1.3.c: comparing sawn wood import and furniture export in Veneto provinces.

Veneto provinces (2005)	Import (€) sawn or planed wood	Export (€) furniture
Treviso	117.210.806	1.010.466.974
Vicenza	95.557.288	312.972.746
Padova	67.279.836	223.149.733
Verona	35.617.784	118.134.932
Venezia	54.032.266	93.787.390
Rovigo	10.234.477	12.899.455
Belluno	18.307.084	12.438.411
sum	398.239.541	1.783.849.641

The annual cutting volume is about 10 Mm^3 with a share of 60% for firewood and 40% of logs (figure 1.1.3.a). Within logs poplar cover 37% (DELLAGIACOMA 2005), but it comes mostly from agricultural lands sited in the plain area along the Po river. Poplar is used in panels and paper production. Broadleaves include oaks and chestnut, coming from the Appennins in the centre Italy, and beech that is requested for the production of furniture, for example chairs. 35% of logs production are conifers, of which 21% is spruce (figure 1.1.3.b).

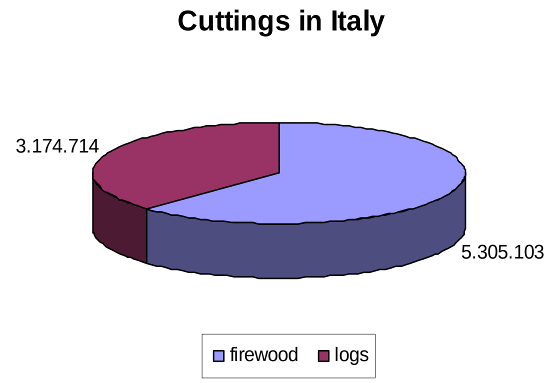


Figure 1.1.3.a: annual cuttings (m^3) in Italy

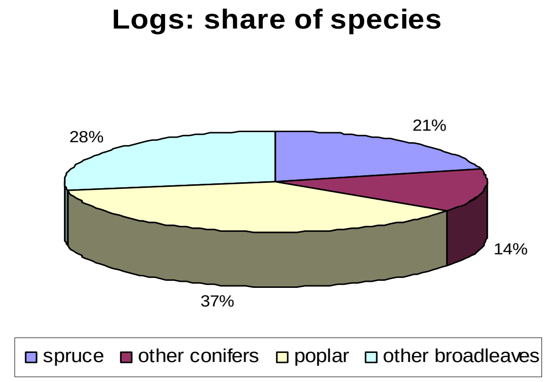


Figure 1.1.3.b: logs share of species

Prices at road side depend on the length, diameter and quality of logs (table 1.1.3.d). Even inside the same Region prices of the same assortment may vary during the year (figure 1.1.3.c) or may be influenced by the provenience (figure 1.1.3.d).

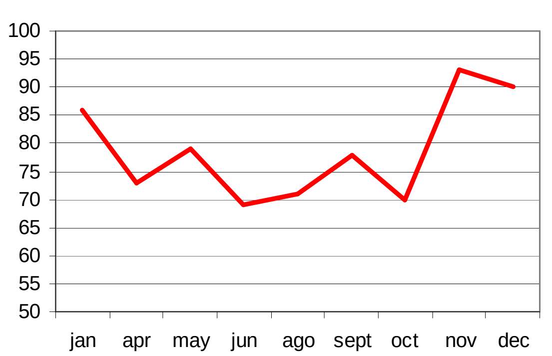


Figure 1.1.3.c: saw logs prices (€) in Trento province during 2005 (CAMCOM 2006b)

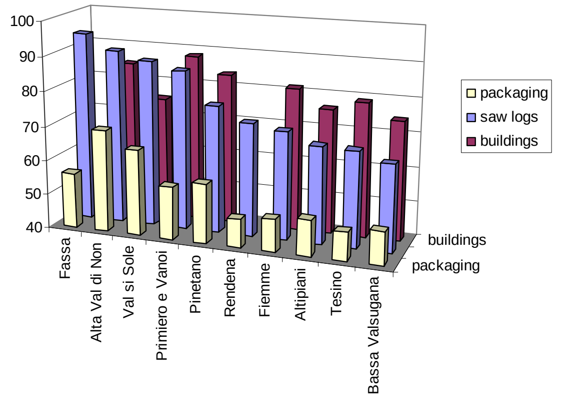


Figure 1.1.3.d: wood prices in different local areas of Trento province (CAMCOM 2006b)

In 2005, after a long period of constant decrease of prices, high quality assortments had an increase of +5% (saw logs and packaging) and +16% for normal assortment (4 m). As in figure 1.1.3.c, prices are quite stable during spring and summer but in autumn they raise rapidly with situations of real fight to buy wood at public auctions (CAMCOM 2006b). This is possibly due to a lack of wood in the European market or to a natural growth of prices which in the last years were constantly decreasing. The situation gave an optimistic view for the future of forestry.

Table 1.1.3.d: comparing wood prices at road side (Lucchini 2006; Lubello *et al.* 2007; CamCom 2007b)

Species			FRIULI-V G	VENETO	TRENTO
	quality	Description	value (€/m3)		
SPRUCE	A	buildings	110	120	111
	B+	sawing	94	98	92
	B	sawing	86	85	85
	C+		64		73
	C	packaging (4 m)	54	68	66
	C	packaging > 4 m			77
	C	lenght 5-7 m	75	75	74
	D	lenght 5-7 m	85		84
	D	sawing	58	60	66
	D	packaging	53		63
	D	poles (10 to 30 cm)	44	45	62
	D	rose wood	32		
	D	for chipping	26		
FIR	B+	> 4-6 m	65		
	B	4 m	55		
LARCH	A		132	150	143
	B+		104		91
	B		93		76
	C+		64		68
	C	> 4 m	60		
	C	packaging	55		
	D	rose wood	32		
	D	for chipping	28		
BEECH	A	2,5 - 4 m	96		
	A-		69		
	B+		92		
	B	Diam. > 35 cm	76		
	B	Diam. < 35 cm	66		
	B	red heart > 35 cm	66		
	B	red heart < 35 cm	61		
	B	packaging	59		
FIREWOOD		2-4 m, Diam > 10 cm	60	60	65

The variation of prices makes planning very difficult: forest management plans have usually a duration of ten years but **who know ten years in advance what will be prices and trends of the wood market?** If prices will get lower, enterprises will need higher yield to cover fixed and variable costs (Lubello and Del Favero 2007), so probably the estimated yield will not be enough and nobody will cut it. If prices will get higher, also standing prices will slowly follow and the gain for enterprises will be lower, with the problem that in the meantime they would have spent money for buying new technologies and they will be more exposed to economical risks.

1.1.3.2. Regional politics

Even if forests are growing in area and stock, wood products contribute by 0.5% on the average regional gross production (PLV) and 0.6% on the agricultural added value (AV). These values decrease in particular after 1997 due to the reduction of wood standing prices ("prezzo di macchiatico")(figure 1.1.3.e and 1.1.3.f). Economists confirm the trend even for the future because markets opened to Eastern Europe, where man work and prices in general are lower, and due to an increase of selling wood after 1990 and 1999 storms (PSR 2007).

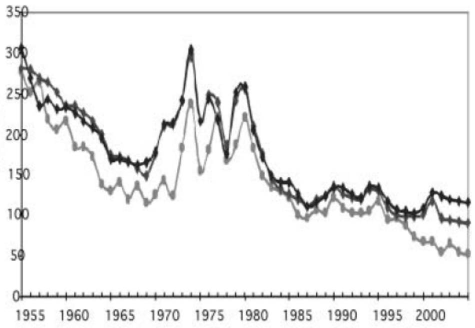


Figure 1.1.3.e: prices trend in Veneto region: in light gray the average coniferous 1st quality standing prices; in gray larch price at road side and in dark spruce price at road side (RIGONI 2006)

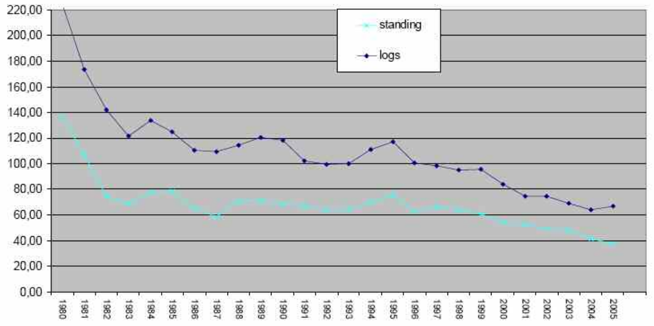


Figure 1.1.3.f: average standing and log prices in Trentino, updated in present value.

Same situation for sawmill by-products, eve if market is more stable. Coniferous board prices are increasing with an average of 7%. Non wood forest products market gives help to local economies: in the last years in Asiago highland, incomings from selling rights for searching mushrooms are 4 times more than those deriving from selling wood!

The reduction of wood standing prices makes part of a common scenario of **general abandonment of mountains** with the consequence in reduction of active forest management and uncontrolled forests growth.

In the meantime even costs of man work decreased, together with profits coming from forest utilizations. Profits reached 29204 € per occupied in 2003 and were saved by the increasing of work productivity (ISTAT 2003a). Introducing higher levels of mechanization (as harvesters) could lead to higher daily productivities ever more than 80 m^3/man.day.

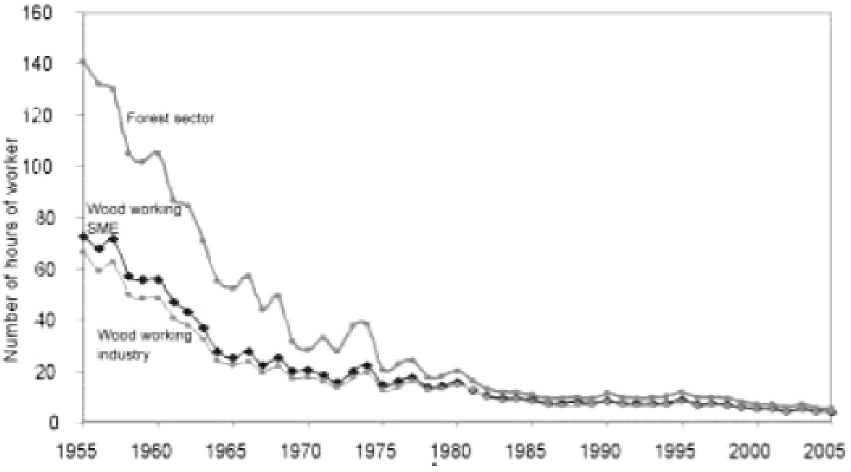


Figure 1.1.3.g: number of working hours in forest that can be covered by selling 1 m^3 of wood (standing tree value) (CIOTTI 2005).

Properties are so scattered and fragmented that, if there is any sort of association, cuttings are too small to fulfill the market demand. During the period 2000-2006,in Veneto, regional funds were provided to promote the creation of forest associations, but, even if the number is quite good (9 associations composed by 270 partners of which 254 are private), the average forested area is 300 ha.

Both forest enterprises and sawmills show a structural weakness. In Veneto region there are 416 forest enterprises with as average 1.7 workers of which 81.8 are seasonal (totally about 1700 workers per year). 313 enterprises have a “working license” which certifies their work and their professional qualification. Sawmills cut only few thousand cubic meters per year and they are family managed so they are not competitive for the European market. In fact 75% of the 14706 wood industries (inside the region prefer the import from abroad of raw material and boards than from regional sawmills. This is probably due to an un-constant production and quality of local products and to the absence of other services like wood drying and steaming.

In Trentino there are 80 forest enterprises, but only few of them cover the market mostly entirely (actually 19 enterprises are able to cut 63.7% of the annual production, table 1.1.3.e).

Table 1.1.3.e: forest enterprises activity in Trento province (CAMCOM 2006b)

Cutting dimension	Number of enterprises	% on the total number	Auctions number	Bought wood	% on total bought wood
more than 2000 m^3	2	2.4	55	9.282	17.5
1500 – 2000 m^3	6	7.2	73	10.994	20.7
1000 – 1500 m^3	11	13.3	99	13.557	25.5
500 – 1000 m^3	14	16.9	73	9.833	18.5
less than 500 m^3	50	60.2	100	9.448	17.8
total	83	100.0	400	53.114	100.0

Forestry in North-eastern Italy has some opportunities and weaknesses that could be resumed in table 1.1.3.f.

Table 1.1.3.f: Swot analysis of forestry sector, ordered by importance (PSR 2007)

Strength	**Weakness**
High potential developing wood-energy chain	Bad structural conditions of forest enterprises
Environmental and social services	Abandonment of active forest management
Increasing wood stock and production	Small and scattered forest properties
Very high quality timber from vocated areas	No dialog between local wood production and industries
Historical sylvicultural tradition	Problems of integration and poor tendency in promoting associations
General good forest health	Few management in private forests
	Old wood selling procedures (auctions) brake forest work continuity

Trying to solve forestry problems is a future issue for politicians because they should seize the opportunities that sector offers and overcome limitations deriving by the European and international market. Some strategies could be:

a. promote wood stocks value as a natural capital for example providing money for cuttings in steep terrains were standing prices make not economically feasible forest operations.
b. promote specific products as wood biomass for heating or industrial (mdf-panels) purposes, coming both from forest and from sawmill by-products (PETTENELLA *et al.* 2004). This is possible providing money for new equipments or promoting the installation of heating districts or private small-medium boilers. In Trento province, specific energy offices were established.
c. promote high quality wood or assortments for specific use (as wood for historical buildings) or promote forest certification standards both in wood-chain and in sustainable forest management (SECCO and BRUNORI 2005).
d. promote new technologies to increase productivity, modify working site and transport logistics, introduce new management forms (large management planning, road-network planning, new kind of contracts, etc…). During period 2000-2006 all three regions provided funds for buying new machines up to 40% of purchasing price (figure 1.1.3.g.), in Trento up to 50% only if the enterprise was less than one year old or if the new machine was one the firsts (according to the new technology) inside the area.

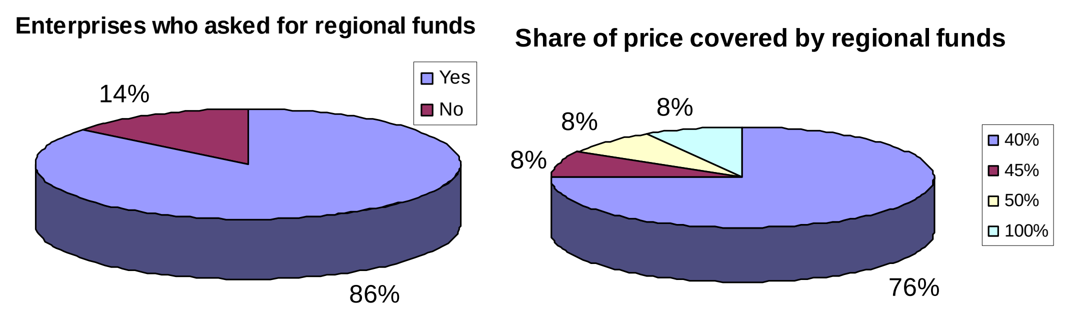


Figure 1.1.3.g: share of enterprises asking for regional funds in Veneto and share of buying price provided with funds

e. improve "commercial dialog" between wood industry and local sawmills introducing new technologies, layouts and services (sawn products, steaming, products on demand)
f. give a value to environmental and ecological, social and tourist public services provided by sustainable management of forests, shrubs and meadows (PETTENELLA 2007; PETTENELLA and CICCARESE 2007).

1.1.4. Forest work

In the North-eastern part of Italy it is estimated that there are 350 forest enterprises, with one thousand stable people working. Other workers belonging to Public Administrations (Servizio Foreste in Provincia Autonoma di Trento, Servizi Forestali Regionali e Veneto Agricoltura in Veneto Region, Servizio per la Selvicoltura e Antincendio Boschivo in Friuli-Venezia Giulia Region) make also sylvicultural cuttings or other environmental activities mostly connected to wildfires hazard.

Forest enterprises are typically independents and belonging to the handcrafters category. Less frequent are societies or associations: one example is the Co.Ge.For founded in 1990 by 13 enterprises and now counting 55 partners of which take part forest enterprises (which are cutting logs, firewood, selling and importing wood) and sawmills. This collaboration lead to open the area of interest and the market possibilities just by sharing machines or working together (AZZALINI 2004; PETTENELLA *et al.* 2004). As shown in figure 1.1.4.a, enterprises are very often working together, but they do not want to make associations, maybe for problems of leading and decision making. Including private forest owners, in the past years 9 forest associations were created in Veneto region. They count 270 members (254 are privates), but the average managed forest area is limited to 300 ha (PSR 2007).

As an average, the share between employers and workers is 1 to 2.5, and the number of workers vary from 3 to 5 (figure 1.1.4.b). Many part-time workers (50% on the total) are recruited when needed; 50% of them comes from new regions included in the European Union or from the Eastern countries (figure 1.1.4.c). In Veneto, Friuli and Trento, Romanian forest workers are very common because it is assumed they are tougher in forest operations and it is easier to talk with because of the common Romance language origin (AZZALINI 2004).

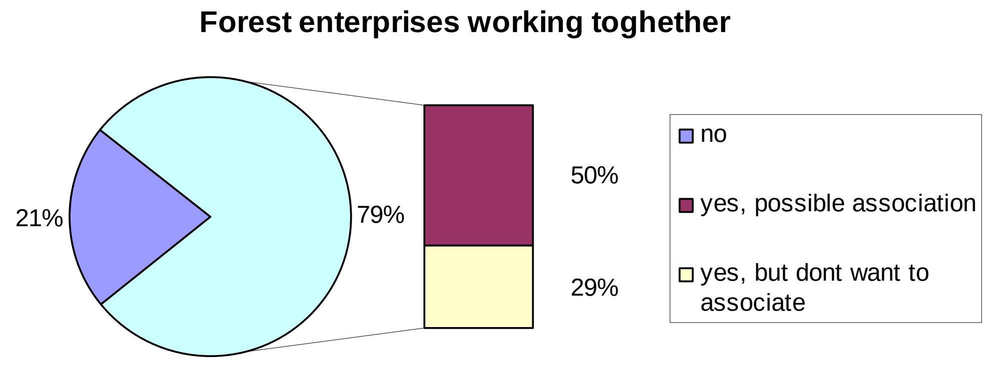


Figure 1.1.4.a: the possibility for forest enterprises of working together

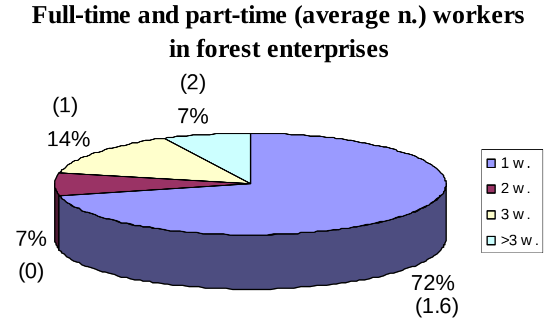


Figure 1.1.4.a: share of part-time and full-time workers

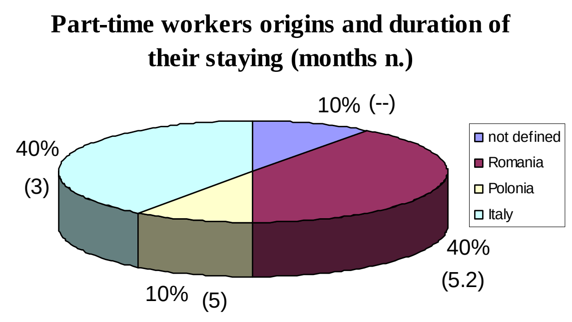


Figure 1.1.4.b: part-time workers nationalities and duration of work

(data on the graphs have been gathered during a research comparing forest enterprises working in Veneto and Trentino regions (LUBELLO *et al.* 2007))

Though the cost of work increased more than the wood value, the minimum level of salaries is on line with National agreements (table 1.1.4.a). It is common indeed to be paid by daily production instead of working hours.

Table 1.1.4.a: National minimum net salaries for workers and forest enterprises gross costs (in parenthesis) (UNCEM 2006; CARBONE 2007, modified)

grade	Employees €/month	worker level	Workers (full-time) €/month	Workers (part-time) €/hour
6°	1524,16	-	-	-
5°	1327,37	super specialized	1278.14 (2525.19)	1379.45 (2424.49)
	-	team chief	1358.99 (2683.36)	-
4°	1221,24	specialized	1211.09 (2370.38)	1306.76 (2277.07)
	-	team chief	1286.96 (2518.81)	-
3°	1147,41	super qualified	1167.06 (2268.68)	1258.84 (2179.87)
2°	1082,19	qualified	1142.53 (2212.12)	1232.29 (2126.01)
1°	1000,60	normal	1065.50 (2034.25)	1147.82 (1954.69)

To be recruited, foreign workers go directly to the employer or workers still assumed are asked searching for others by their employer. It is also common that the employer goes abroad searching for workers. Before starting an enterprise, people usually work in other enterprises or in sawmill to learn and train themselves. Employees usually learn through instructions of older colleagues directly on the ground; only few of them follow learning courses (figure 1.1.4.c). Practical teaching courses are organized in North-eastern regions by the Forest Service (in Trento, addressed periodically both to workers and technicians at different levels), by sort of forest schools (the Cesfam in Paluzza, Friuli-Venezia Giulia) or directly by the region as in Veneto.

In Trento province the number of courses increase each year (table 1.1.4.b) and it is strictly connected to a license that all forest entrepreneur must have. More than 60% of forest employers go to fairs or take participation to technical demonstration days organized by the university or the region (figure 1.1.4.d).

Table 1.1.4.b: number of technical courses attended in Trento province (Pozzo 2007)

Year	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	**TOT**
Courses	2	3	7	5	9	10	9	10	12	12	13	17	23	**132**
Participants	8	11	35	45	90	84	56	65	81	68	79	120	154	**896**

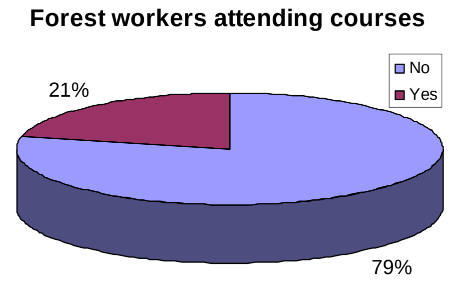


Figure 1.1.4.c: share of forest workers participating to learning courses

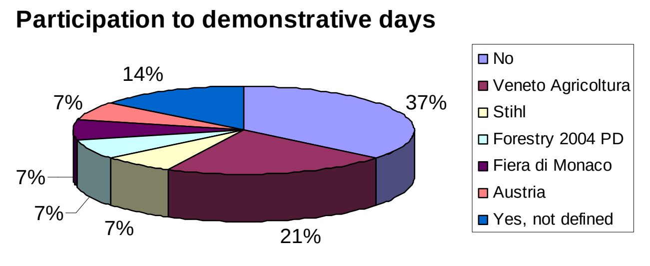


Figure 1.1.4.d: Participation to demonstration days and typologies

Taking care of workers safety is variable depending on the employer sensibility. Forest machines are certified with most recent European rules and in most enterprises there is a document evaluating risks and preventing accidents. Sometimes this document is written in foreign languages to be comprehensible by all workers.

1.1.4.1 Known problems

Speaking with entrepreneurs, one of the biggest problem is the finding of qualified workforce. More and more they recruit foreigners; young Italians do not like working on forest because it is usually part-time and earnings are not proportioned to hard working place conditions.

An other difficulty is to gain enough money to pay back investments for buying new machines. Everybody considers as a necessity the introduction of new machinery and technology to improve processes and productivities and everybody knows that there are specific regional funds. The problem is that retrieving those investments will take more time than the expected economic machines life, ever more if considering their limited use. The complexity of planning forest activities may lead enterprises to leave regional funds unused.

An other weak of the system is not only the quantity, but the quality of road network. Some old roads were built excavating on the up-hill side and moving the terrain on the slope, but trailers and loads increase a lot so that road pavement is to light to support the weight. A construction problem is due to the width (sometimes they are too narrow), the slope (too steep) and switch-backs radius that were studied for trucks loading 4 m log. Today sawmills usually ask for longer (8 or 12 m) logs, but it is not possible to transport them.

About 60% of forest enterprises think that road network is not adequate (figure 1.1.4.1.a), but who gave negative answer is entering deeper inside the forest (figure 1.1.4.1.b). This depend on the owned machines, actually a winch on tractor needs more roads than cable cranes.

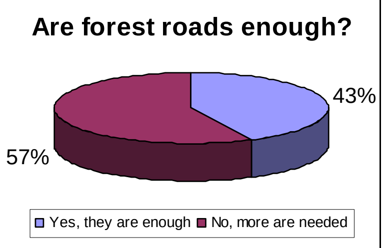


Figure 1.1.4.1.a: about 60% of entrepreneurs think road network is not adequate

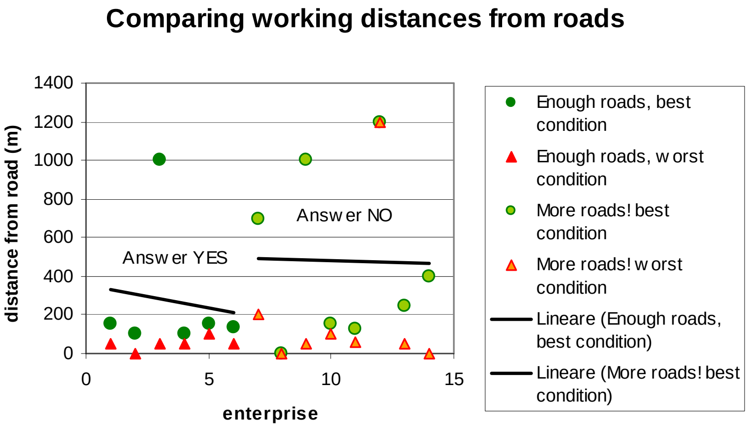


Figure 1.1.4.1.b: maximum distance reached by working sites. Who works near road (maybe with tractor and winch) think that network is adequate

The access in coppice forests is more difficult than in standing forests. Municipalities, which usually own coppices, are not interested in improving road network because of the low value of those forests, so they are abandoned and firewood is bought from the Eastern Europe. By law, coppice forests may be cut only in winter time, so enterprises can work all the year (standing forests are cut in spring and summer time). Nevertheless there are some that are specialized in logs production and others in firewood production (figure 1.1.4.1.c). Firewood may be sold as big pieces of 2 m length, or cut in chops and stored on 1 ton pallets: prices actually vary from and average of 90 to 130 euros/ton (figure 1.1.4.1.d). Someone is also selling 2 m firewood at road side (60 euros/ton).

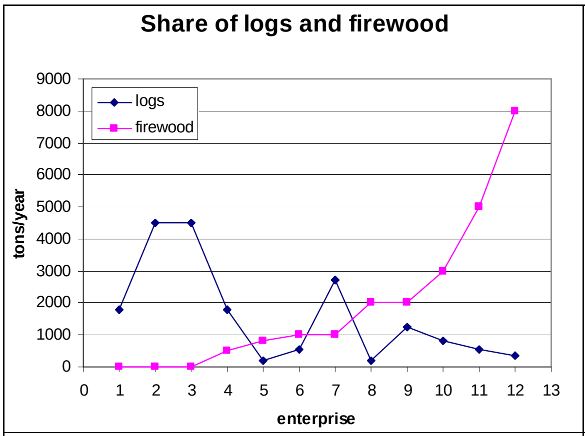


Figure 1.1.4.1.c: enterprises are specialized in cutting firewood or logs. Some do both.

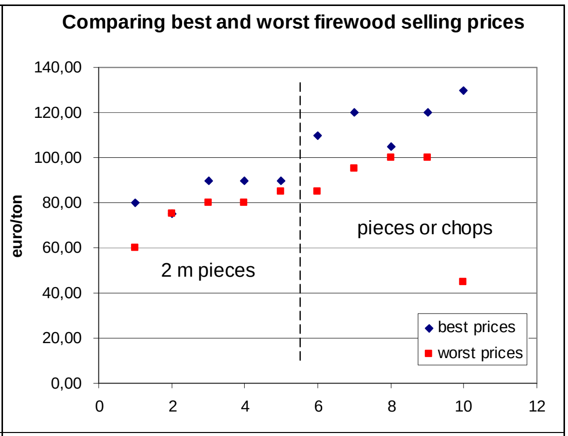


Figure 1.1.4.1.d: firewood prices depend on the piece size. Chops require more work so price is higher

The last problem is the complicate and bureaucratic system of auctions (figure 1.1.4.1.e) and the time consuming system of measuring and verifying logs before selling them. The market is more dynamic and cannot wait time for local products. If they don't come *just in time*, sawmills will search for wood abroad and for better offers, for example spruce from Austria may come in few days in all assortments they need.

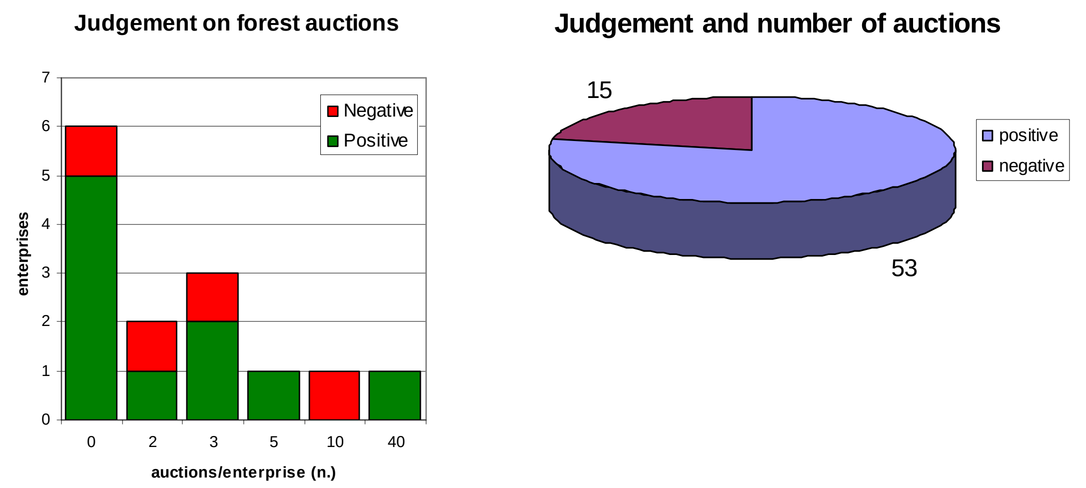


Figure 1.1.4.1.e: judgement on forest auctions efficiency

1.1.4.2 Irregular work

In some cases, work in forest enterprises could be undeclared, workers are often relatives and without training and professional education. Also low technological level lead to high harvesting costs and make domestic timber not competitive (AA.VV., 2004).

Cutting operations in coppice forests usually require lower qualification than in standing forests (HIPPOLITI and PIEGAI 2000) so, especially on private properties, may be done by people with no skill and inadequate tools, workers bad paid for high working rhythms and on an irregular position according to law. Only on public properties it is required that the employer signs a paper in which declares the respect of national rules on working matter, but there is any office that verifies the truth (PETTENELLA and SECCO 2004).

The hidden work, with no respect of safety rules, create a situation of modified market where "good" enterprises will loose. In fact workers will be less paid, but none insurance will cover them with hard consequences on society if something would happen (illness or accidents).

The Italian statistic research office measured the number of regular workers in relation to all working units (theoretical number) and made some indexes (ISTAT 2003b). Data consider the whole sector of Agriculture, Hunting and Forestry, showing that while the occupation decreased, the number of irregular workers increased of about 10% (figure 1.1.4.2.a). The rate of irregulars vary from region to region and from north to south of Italy, from a maximum of 50% in Calabria to a minimum of 18.6% in Toscana (table 1.1.4.2.a).

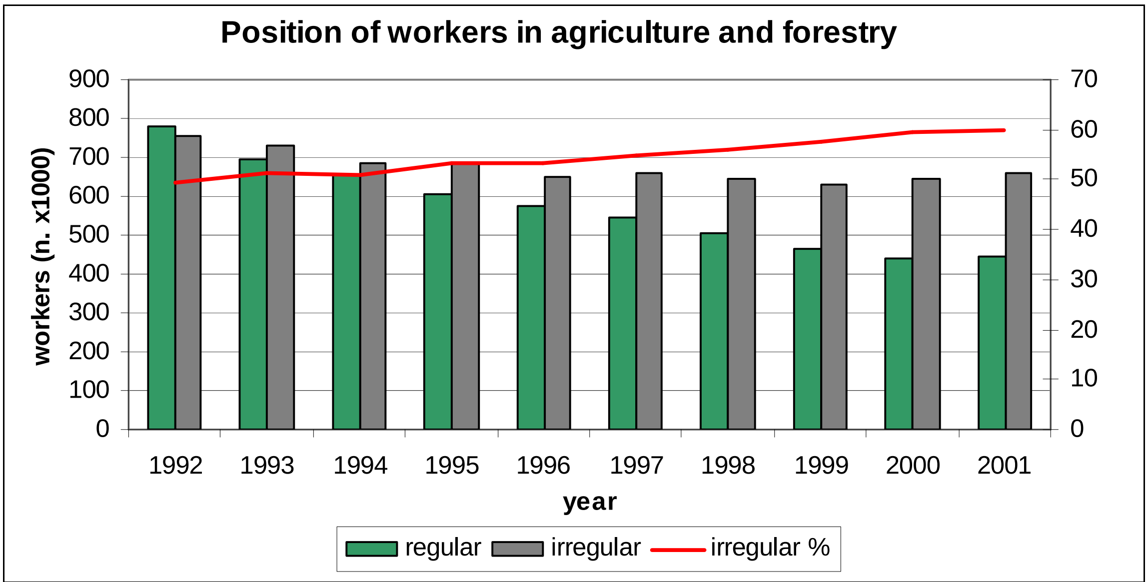


Figure 1.1.4.2.a: the work in agriculture, hunting and forestry (ISTAT 2003b)

Table 1.1.4.2.a: Working units, irregular workers and irregular rates in agriculture by area in Italy (year 2001).

	Working units n. (x1000)	Irregulars n. (x1000)	rate %	Irregulars on the national economy %
North-west	213,2	44,7	21,0	5,7
North-east	292,8	75,6	25,8	12,7
Middle	177,4	48,9	27,6	6,6
South	672,0	278,7	41,5	18,3
Italy	**1355,4**	**447,9**	**33,0**	**12,3**

1.1.5. Forest mechanization

In the North-eastern part of Italy, forest operations are influenced by specific conditions of Alpine forests, particularly steep slope terrains.

Felling, delimbing and bucking are done at felling site while skidding operations may be performed through off-road machines (80%) or cable systems (20%). This is also known as Short Wood System (SWS) or Cut-to-Length (CTL) system. Felling and delimbing operations are used to be done with chainsaw, while skidding depends on the steep slope and the presence of adequate road infrastructures. Off-road machines are mostly represented by 4WD (80-85%) or trucked (15-20%) tractors with winch. Winches may be fixed (40%) or not (60%) and new models are equipped with remote control. Cable systems are divided in fixed (sledge yarders) and mobile (tower on tractor or trailer) in a proportion of 1:1 or 3:2 which varies in relation to the working site conditions and the distances that will be reached (CAVALLI 2004).

In the last years, other working systems have been developed: one is felling and partial delimbing at felling site, then skidding and finishing processing at road side (this is usually called Full Tree combined with Cut-to-Length, FT-CTL); the other is the Full Tree system (FT) where trees are cut and skidded to road side where they are processed. These systems require the use of an excavator mounted or a carried processor that makes all delimbing and bucking operations. It is estimated that 12 processors are working on the study area (figure 1.1.5.a), five are carried on a tractor, six are excavator mounted (both wheeled and trucked) and one is on a truck coupled with a tower (figure 1.1.5.b) of a mobile cable crane (the so called Gebirgsharvester). The number of those systems is growing rapidly and probably it will continue because workers are glad of it and processing at road side will be more usual where the size of roads and the dimension of piling sites will allow it.

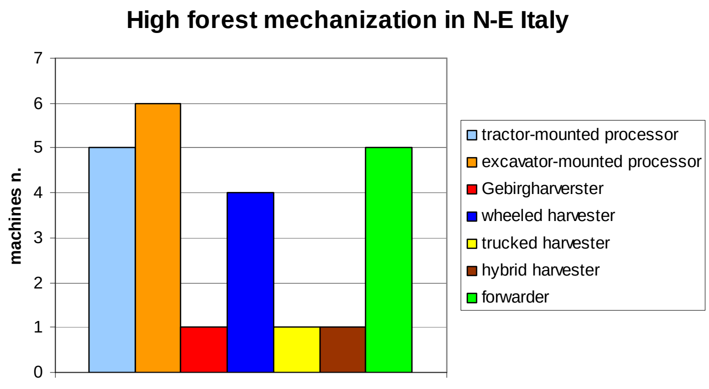


Figure 1.1.5.a: number of machines working (ZUCCOLI BERGOMI 2006)

Figure 1.1.5.b: gebirgharvester

Although motor manual felling is the most common felling method, both in the coniferous and the broadleaved forests, in Italy there are also few contractors working with harvester and forwarders: SPINELLI (2004) relates that in Italy there are totally 44 harvesters, including in that number also excavators with an harvester head and processors. According to CAVALLI (2004), in the North-eastern Italy there are 6 harvesters and 4 forwarders working. Harvester are wheeled (4 of them), trucked and hybrid (wheels and legs). These machines are economically competitive when working with high yields and small-medium sized logs. Wheeled harvester may work on steep slope terrains up to 40% while the trucked one, which the cabin has an auto-leveling system, up to 60% and the hybrid one reaches 100% and more (CAVALLI and ZUCCOLI BERGOMI 2006).

Thinnings in coniferous high forest are done only when there is some European or governmental fund for forestry improvement. Actually thinnings are uneconomical operations because the manpower is too costly so some entrepreneurs use processors mounted on the tractor to process trees at roadside (CAVALLI and ZUCCOLI BERGOMI 2005). Thinnings with harvester are very rare (EMER 2005) even if recent studies confirm that it is cheaper than the traditional method (8 €/m^3 against 25 €/m^3 using chainsaw)(SPINELLI and STAMPFER 2002; CAVALLI and ZUCCOLI BERGOMI 2006).

Two of the four forwarders are working together with harvesters. The interest on them is fast growing because of their high productivities and the possibility of introduce them even on systems partially hard mechanised where they are used instead of tractor and trailer.

1.1.6. Forest roads

Roads are a vital component of civilization. They provide access for people to study, enjoy, and, commune with forested wildlands, to extract an array of resources from natural and modified ecosystems. Roads have well-documented, short- and long-term effects on the environment that have become highly controversial, because of the value society now places on unroaded wildlands and because of wilderness conflicts with resource extraction.

When planning roads should be identifies links among processes and effects that suggest both potential compatible uses and potential problems and risks. The debate on their positive and negative aspects is wide and concerns not only Italy (BALOCCO 1994; LAURENT *et al.* 1996; MARCHI and SPINELLI 1999; BENGSTON and FAN 1999; BORTOLI 2001). Roads issues and road science usually cannot be effectively separated from the specific ecologic, economic, social, and public lands management contexts in which roads exist or are proposed (GUCINSKI *et al.* 2001).

Across a forest or river basin, the access needs, economic dependencies, landscape sensitivities, downstream beneficial uses of water, and so on can be reasonably well defined, but these relations tend to differ greatly from place to place. An effective synthesis of road issues draws local experts together to thoroughly evaluate road and access benefits, problems and risks, and to inform managers about what roads may be needed, for how long, for what purposes, and at what benefits and costs to the agency and society (POZZATI 1979; HIPPOLITI *et al.* 1997; CIELO and GOTTERO 2004).

Road effects and uses may be somewhat arbitrarily divided into beneficial and detrimental.

The largest group of **beneficial** variables relates to access (TUFTS *et al.* 1988; HIPPOLITI 1988, 1989 and 2003; KELLOG *et al.* 1996a and 1996b; LANFORD and STOKES 1996; GREULICH 1997, WIEST 1998). Access-related benefits may be identified as harvest of timber and special forest products, grazing, mining, recreation, fire control (CALVANI *et al.* 1999; BOVIO 2001), land management, research and monitoring, access to private inholdings, restoration (CHIRICI *et al.* 2003), local community critical needs, subsistence, and the cultural value of the roads themselves. Nonaccess-related benefits include edge habitat, fire breaks, absence of economic alternatives for land management, and jobs associated with building and maintaining the roads.

Undesirable consequences include adverse effects on hydrology and geomorphic features (such as debris slides and sedimentation)(WEMPLE *et al.* 1996; FURNISS *et al.* 1997; GUBIANI 2004), habitat fragmentation (REED *et al.* 1996; FORMAN *et al.* 1997), predation, road kill, invasion by exotic species, dispersal of pathogens, degraded water quality (GRAYSON *et al.* 1993) and chemical contamination, degraded aquatic habitat (ALEXANDER and HANSEN 1986; CORN and BURY 1989; WELSH 1990), use conflicts, destructive human actions (for example, trash dumping, illegal hunting, fires), lost solitude, depressed local economies, loss of soil productivity, and decline in biodiversity (HEYWOOD and WATSON 1995; FORMAN and HERSPERGER 1996).

1.1.6.1. Roads classification

When speaking of forest roads it is necessary to understand that there is not only one classification, but it depends on the property of the road, on the areas it cross and serve, on the access regulation (with or without permission).

From a juridical point of view, roads are divided in **public** and **private** roads. The main National rules are:

- L. n. 2248 20/3/1865 on “public works”
- Decreto luogotenenziale n. 1446 1/9/1918 on “constitution of public *Consortia* for building and road maintenance”
- L. n. 126 12/2/1958 on “classification and maintenance of roads”
- D. Lgs. N. 285 30/4/1992 modified by L. 214 1/8/2003: the new “road codex”

Public roads have public interest and access. If the property is also public (State, Region, Province or Municipality) they are included in the so called “Demanio stradale”, if they are privates they are called “strade vicinali” (proximity roads). In this case the Municipality has the right of use and it has competence on the police patrol. The roads included in the “Demanio stradale” are classified, that means they are recorded in public databases (LA ROCCA 1996). Database of proximity roads is not compulsory.

The new Road Codex classifies roads by a technical and functional criterion:

A – highways
B – principal rural roads
C – secondary rural roads (almost two sides)
D – urban roads (high speed)
E – urban district roads
F – local roads, rural or urban not included before
Fb – hike and bike roads

Roads included in letters B, C and F, links cities and towns each others and are also called National-, Regional-, Provincial- or Municipality-roads. The maintenance of proximity roads (if private but with public access) is partially paid by the municipality (from 20% to 50%).

Private roads may be divided in:
farm roads when they are inside a farm and they are used only for internal activities
proximity roads that are owned by people living near the road and who contributed with money for their building. Owners may be associated in *Consortia*
municipality roads owned by the town. They are usually closed to access but they can be subjected to civic rights as forests are.

When talking of a rural-forest road network it means a group of rural roads driven by motor vehicles and **used as main purpose** to manage rural areas, pastures or forests. If they are used mostly with forest purposes or they lie inside forest, they are called forest roads. Similarly, if they are used only for agriculture they are called rural roads or pasture roads when used as access in reaching mountain pastures (figure 1.1.6.1.a).

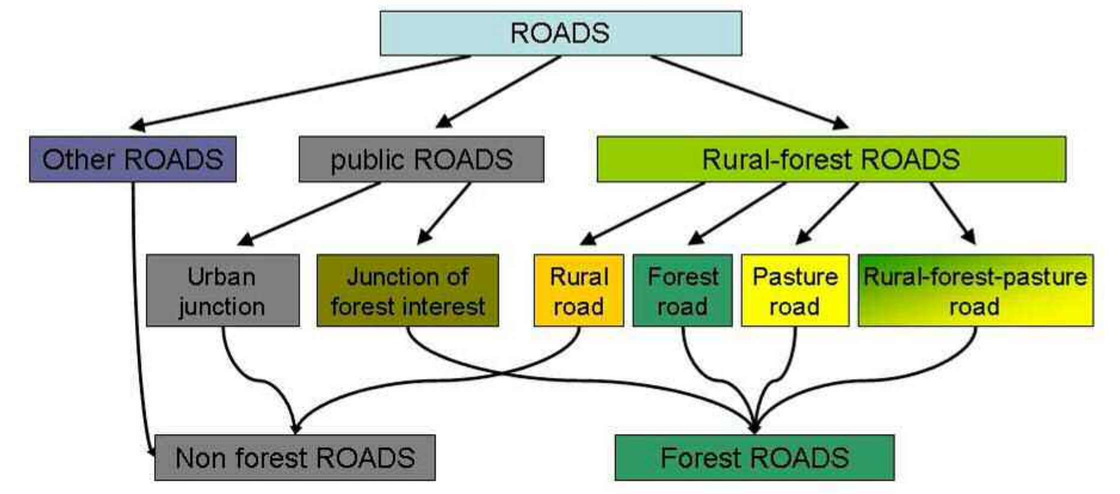


Figure 1.1.6.1.a: classification schema on road function basis (IPLA 2001; Cielo *et al.* 2003)

Forest roads may have other **functions** than the main one providing access, for example they are also classified as:
tourist-roads when they cross protected areas or protection forests

wildland fires protection roads when they are built to provide access of fire-fighting teams or of water tanks or to cut the continuity of wood (fire breaks)

wood transport and storing (piling sites)

Considering the **building structure**, roads may be essentially divided in three types: **truck roads, tractor roads** and **skidtrails**. They can be also divided in native-soil surface or aggregate surface. Native-soil surfacing can be used when harvest operations are conducted during the dry season. However, road operations in the wet season require aggregate surfacing (crushed rock) to increase the strength of the forest road surface to support vehicle traffic (AKAY and SESSION 2004). The general classification in tractor and truck roads concerns the width of the road section and other geometrical parameters (table 1.1.6.1.a)

Table 1.1.6.1.a: forest road classification on geometrical parameters (IPLA 2001)

Attribute	**Principal Truck roads**	**Truck roads**	**Tractor roads**	**Skid trails**
Roadbed width (Road width + base course)* (m)	5	4	3	3
Road width in a straight line (m)	3,5	3	2,5	2,5 (2,2)
Minimum curve radius (m)	9	6	5	5 (4)
Optimal slope (%)	3 - 8			
Maximum average slope (%)	10	15	15	15
Maximum slope on short sections** (%)	15	20	25	25
Maximum surface runoff (%)	10	15	15	15
Type of vehicle able to drive through	Truck and trailers Semitrailers Trucks Vehicles 2WD Vehicles 4WD Tractors	Trucks Vehicles 2WD Vehicles 4WD Tractors	Vehicles 2WD Vehicles 4WD Tractors	Vehicles 4WD Tractors

* 1 m should be added to roads if they have a ditch on the uphill side or a fill-slope on the down-hill.

** A short section is less than 50 m. If there are many steep slope sections on the road, they should not be more than 20% on the total length.

As an example, the Trentino Regional rule n. 12/2006 classifies forest roads into two categories:

A – forest roads with access purposes: only forest workers or forest enterprises are allowed to enter. Skidtrails are included in this category.

B – all roads with mixed function (rural-, pasture- and forest roads). Only private owners or inhabitants who have civil rights can drive through. Other people need a special permission that can be obtained by asking the owner or the manager of the road (municipality or *consortium*)

The Regional database include a third category, the L that are junction roads (figure 1.1.6.1.b) with forest interest (see also figure 1.1.6.1.a).

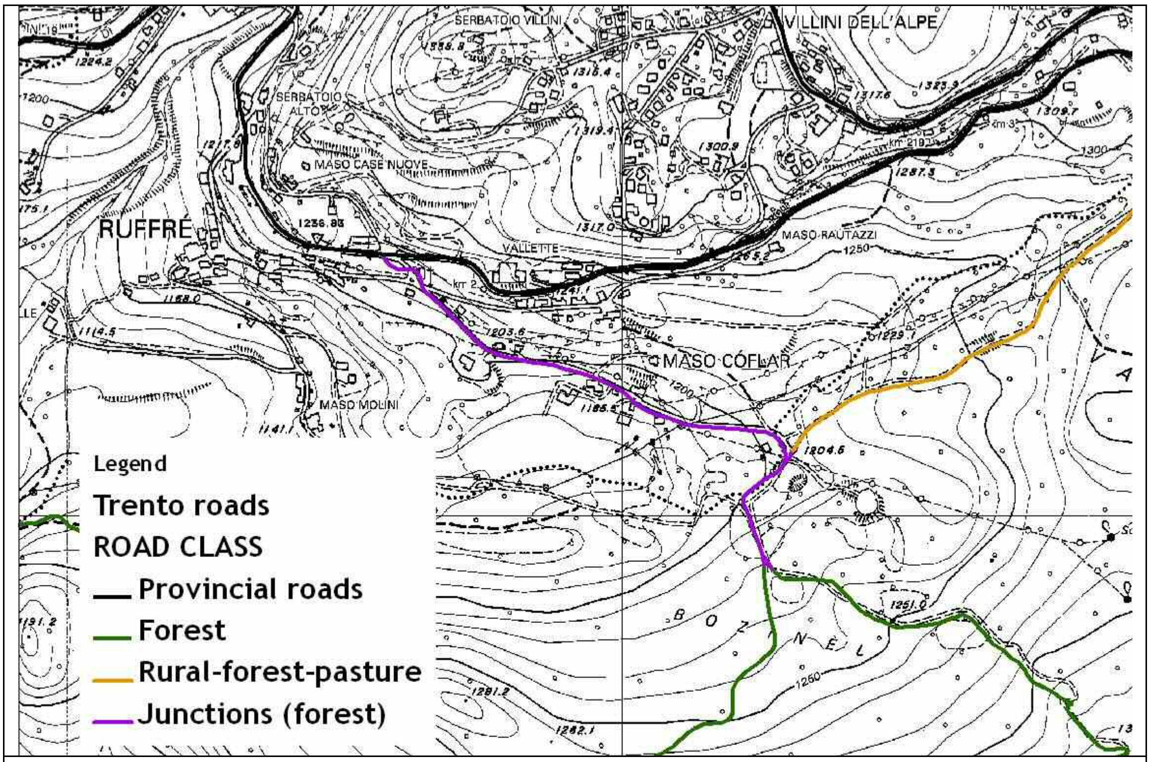


Figure 1.1.6.1.b: an example from the Trento road shapefile.

1.1.6.2. Roads, sylviculture and forest mechanization

The traffic needs are connected to the typology, frequency, economics and level of mechanization used in forest or rural management: the environment conditions and the intensity of forest cuttings have high influence on the needs of accessibility. Forests with high fertility and young trees or coppice forests require a good accessibility because cutting will be frequent (every 10-15 years). High standing forests with low yields or sited in high mountain may require lower road density, while protection forests may also be un-reachable.

The position and the space between roads is to be defined in relation to the technical limits and the maximum skidding distance of systems used in forest operations. When small cuttings are planned (10-20 m^3/ha) and only walking people will enter the forest, roads may be more distant. When skidding operations are done with machines, it should be considered that there is an optimal working distance (Picman *et al.* 2001): if it is overcome, working become first more difficult and expensive than technically un-feasible (Hippoliti and Piegai 2000; Cielo *et al.* 2003). For example, tractors can work form 50 to 200 m far from road, instead of cable systems that are economical till to 1000 m if logs are big. Before planning or building a new road network it is important to know the range of using different machines considering the slope, logs and making approximations to simplify the choice.

On **flat terrain** (slope < 25%) tractors and skidders can work even outside roads or skidtrails without any problem of traction and stability. They were the most productive and cheap system before the introduction of the forwarder. When skidding uphill from far distances, tractors may require a limitation on heavy logs (not more than 200 m). Firewood or small logs may be logged on trailer or inside specific mounted nests. The use of winch is common when skidding heavy logs. Off-road movement could be limited on prescribed skidtrails if there are soft terrains or wet areas. On these gentle slopes only terrain roughness may obstruct the machines movement.

On **gentle slopes** (from 26 to 50%) building new roads is easy and off-road systems are more common than cable systems. For the problem of traction, skidders may work only on downhill direction and over 35% of slope only trucked machines do it. Tractor with winch can reach not more than 50-100 meters (figure 1.1.6.2.a), but cable systems have higher productivity on far distances and can carry heavier logs. When terrain roughness is high, tractors movement is not possible but can be used high-density polyethylene slides (firewood or small logs).

On **steep slopes** (more than 50%) and on young forests, skidding downhill is only possible within 100 m. Skidding uphill with mobile cable cranes may be economically feasible until 300-400 m (figure 1.1.6.2.b). When working inside high standing forests the sledge yarder system allow to skid logs up to 1000 m, but it is important that the yield will be proportional to the length of the line to maintain low costs.

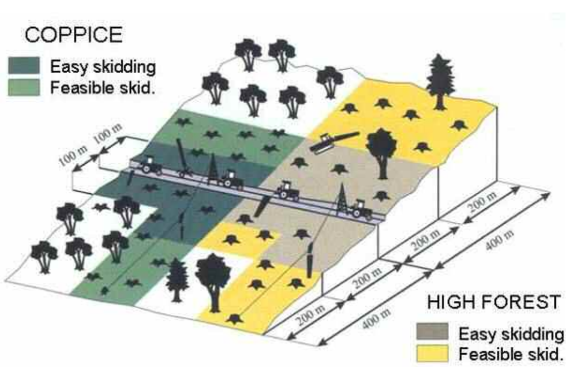
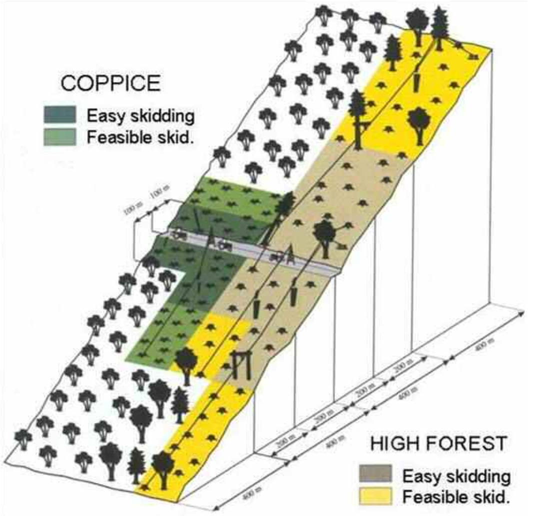
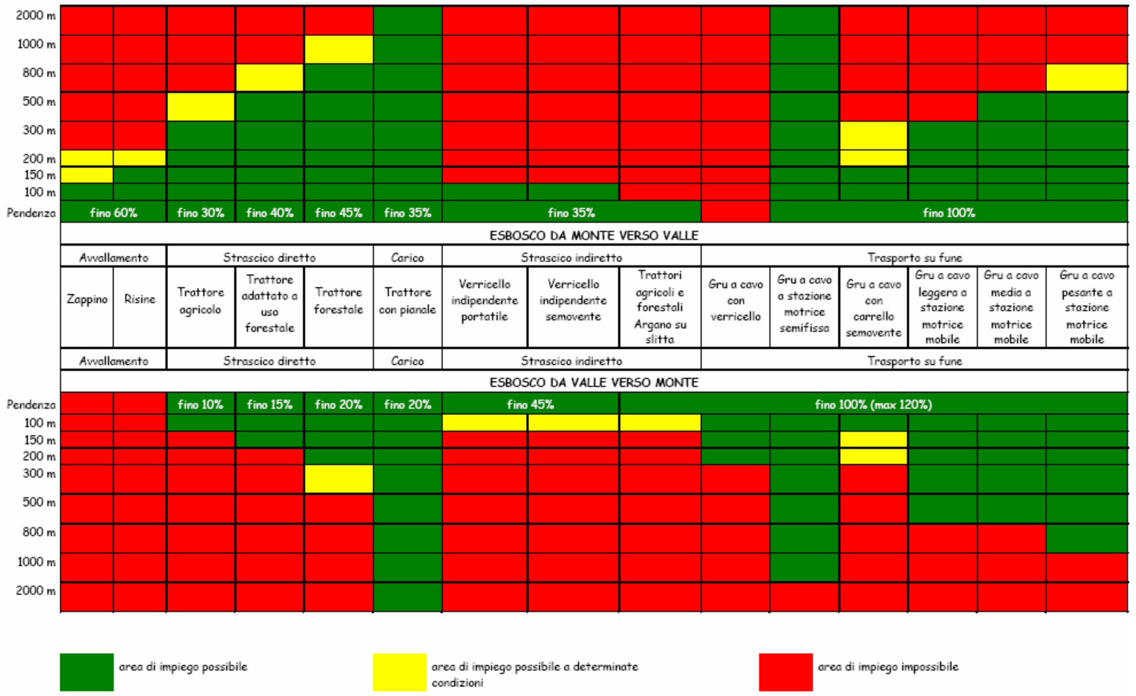
	

Figure 1.1.6.2.a: forest systems used on gentle slope terrains	Figure 1.1.6.2.b: forest systems used on steep terrains



2000 m	🟥	🟥	🟥	🟥	🟥	🟩	🟥	🟥	🟥	🟥	🟩	🟥	🟥	🟥	🟥
1000 m	🟥	🟥	🟥	🟥	🟨	🟩	🟥	🟥	🟥	🟥	🟩	🟥	🟥	🟥	🟥
800 m	🟥	🟥	🟥	🟨	🟩	🟩	🟥	🟥	🟥	🟥	🟩	🟥	🟥	🟥	🟨
500 m	🟥	🟥	🟨	🟩	🟩	🟩	🟥	🟥	🟥	🟥	🟩	🟥	🟥	🟩	🟩
300 m	🟥	🟥	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟥	🟩	🟨	🟩	🟩	🟩
200 m	🟨	🟨	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟥	🟩	🟨	🟩	🟩	🟩
150 m	🟨	🟩	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟥	🟩	🟩	🟩	🟩	🟩
100 m	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟥	🟩	🟩	🟩	🟩	🟩
Pendenza	fino 60%		fino 30%	fino 40%	fino 45%	fino 35%	fino 35%			🟥	fino 100%				
	ESBOSCO DA MONTE VERSO VALLE														
	Avvallamento		Strascico diretto			Carico	Strascico indiretto			Trasporto su fune					
	Zappino	Risine	Trattore agricolo	Trattore adattato a uso forestale	Trattore forestale	Trattore con pianale	Verricello indipendente portatile	Verricello indipendente semovente	Trattori agricoli e forestali Argano su slitta	Gru a cavo con verricello	Gru a cavo a stazione motrice semifissa	Gru a cavo con carrello semovente	Gru a cavo leggera a stazione motrice mobile	Gru a cavo media a stazione motrice mobile	Gru a cavo pesante a stazione motrice mobile
	Avvallamento		Strascico diretto			Carico	Strascico indiretto			Trasporto su fune					
	ESBOSCO DA VALLE VERSO MONTE														
Pendenza	🟥	🟥	fino 10%	fino 15%	fino 20%	fino 20%	fino 45%		fino 100% (max 120%)						
100 m	🟥	🟥	🟩	🟩	🟩	🟩	🟨	🟨	🟨	🟩	🟩	🟩	🟩	🟩	🟩
150 m	🟥	🟥	🟥	🟩	🟩	🟩	🟥	🟥	🟥	🟩	🟩	🟨	🟩	🟩	🟩
200 m	🟥	🟥	🟥	🟥	🟩	🟩	🟥	🟥	🟥	🟩	🟩	🟨	🟩	🟩	🟩
300 m	🟥	🟥	🟥	🟥	🟨	🟩	🟥	🟥	🟥	🟥	🟩	🟥	🟩	🟩	🟩
500 m	🟥	🟥	🟥	🟥	🟥	🟩	🟥	🟥	🟥	🟥	🟩	🟥	🟩	🟩	🟩
800 m	🟥	🟥	🟥	🟥	🟥	🟩	🟥	🟥	🟥	🟥	🟩	🟥	🟥	🟥	🟩
1000 m	🟥	🟥	🟥	🟥	🟥	🟩	🟥	🟥	🟥	🟥	🟩	🟥	🟥	🟥	🟥
2000 m	🟥	🟥	🟥	🟥	🟥	🟩	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥

🟩 area di impiego possibile

🟨 area di impiego possibile a determinate condizioni

🟥 area di impiego impossibile

Figure 1.1.6.2.c: a simple table resuming the maximum distance from road for different systems.

Actually the forest road geometrical parameters (maximum slope, width, curve radius) are inadequate to the new technologies. More or less every 15-20 years, new building parameters should be defined. As happened in the past, new plantation have been done after the second world war, but they built small path thinking that mules or horses would have been used in future operations; plantations needed long time to be ready for cuttings and now these tracks are too narrow even for the smallest tractor, so they are inadequate even before to be used. Roads built on late Seventies have a 2.2 m width that depend on the width that had the front excavator blade. Roads of that size could not be drive by heavy trucks, nowadays indispensable for civil, hydraulic engineering, and wood transportation. The width was sized to machines and techniques of that times, building bigger roads would have cost too much. Today excavators have at least a width of 3 m.

Figure 1.1.6.2.d: a trucked excavator opening a new road on a gentle slope forest

Figure 1.1.6.2.e: gravel distribution on road bed

Figure 1.1.6.2.f: pavement crushing and compacting (Bortoli 2001)

Analyzing the technology development it is possible to observe that machines become bigger (width size, net weight and gross allowable load), increase their ability to move even on steep terrains and increase their stability thanks to auto-levelling systems. It is estimated for the next future that 50-55% of terrain will be reachable by off-road systems (maybe more if considering high level mechanization as the harvester-forwarder chain) so needs of forest access will change (Cielo *et al.* 2003): forest roads will require higher bearing capacity (new building techniques introduce the use of geo-textiles), wide sizes and more space for piling wood or install cable systems. With the increasing technology, the distance between road could be wider and so their density lower.

The **road density** is an index that express the length of roads in relation to the area (m/ha). This parameter can be used the access service given by roads on big sized areas: for example it can be calculated for a valley, a region or a State. The road network varies also depending on the yield of forests. In the most productive alpine forests, the optimal value varies from 25 to 35 m of forest road per hectare (Colpi *et al.*, 1999). Inside productive forests lying on gentle soils the value may increase up to 50 m/ha. On plain areas, tractors are able to move off-road or on temporary skidtrails, so the value decrease to 10-15 m/ha.

In the Piemonte region, the rural-forest road index is between 5 and 20 m/ha. At the beginning of the Nineties, forestry roads in Trento province where about 27 m/ha (PAT 1991), while in Austria (in 1987) there were 40 m/ha iside productive high forests and 7 m/ha inside protection forests (Trezsniowski 1990). In Veneto and Friuli-Venezia Giulia region the average value is near 14 m/ha (Cavalli 2004). This numbers are not representative for the access of a single stand and the distribution of roads is not rational if connected to forest. The difference depend on the geography: Trento has all forests lying on mountain, steep terrains, while in Veneto and Friuli forests grow also on hills so the index is lower because the access is easier. However the road network is less dense than the optimal values required in such typical forest areas (Bortoli 2001).

1.1.6.3. National and Regional laws

The rules connected to planning and building rural and forest roads is quite intricate. Some rules on buildings or civil engineering sometimes have instructions or describe particular procedures concerning forest roads. Rules may be grouped logically, starting from the choice of building site, the planning and the building operations:

- rules on the soil use, planning and environment protection
- building and technical characteristics
- rules on public works
- rules on safety inside working sites

About regional administrative and legislative competences (soil and environment use, urban, environmental goods, etc…) sometimes there are important differences even if regional rules follow national principles (POSTIGLIONE and TROIANI 2001).

Next follow the list of valid rules:

National rules:

General rules:

L. 1150/1942, urban law
D.P.R. 164/1956, rules on working safety during excavation and building foundation
D. Lgs. 626/1994, actuation of CEE rules on safety and wellness of workers
D. Lgs. 242/1996, more about 626/94
D. Lgs. 494/1996, actuation of 92/57/CEE on safety and wellness in temporary and mobile working sites
D. Lgs. 528/1999, more about 494/96
L. 10/1977, soil classification and building rules
L. 109/1994 (L. Merloni), law on public works
D.M. 145/2000, general contract specifications
D.P.R. 380/2001, Unique Text on civil buildings
L. 166/2002, transport and infrastructures
D. Lgs. 227/2001, innovation and guidelines for forestry sector

Classification of roads:

L. 2248/1865, law on public works. Attached F: public roads classification and laws
D. luogotenenziale 1446/1918, managing and building roads by group of users (Consortium)
L. 126/1958, public road classification and maintenance; substituted by
D. Lgs. 285/1992, road rules
L. 214/2003, conversion in law of “decreto” 27jun03: the Road Codex

Environmental laws:

R.D. 1497/1939, natural beauties protection
L. 394/1991, law on protected areas
D.P.R. 357/1997, protected areas
D. Lgs. 490/1999, Unique Text on cultural and environmental goods
“Direttiva Habitat” and Natura 2000 net, protected sites as in DGR 4489/2003 and 44910/2003 based on DPR 35711/1997
“Direttiva Uccelli” (birds), L. 157/1992 updated with L. 221/2002

Technical laws:

D.M. LL.PP. 11 mar. 1988, technical rules on terrains, rocks and slopes for designing, executing and testing support walls and buildings foundation works
D.M. LL.PP. 4 may 1990, technical rules for designing, building and testing bridges
Circ. Min. LL.PP. 34233/1991, technical codes for bridge building
D.M. LL.PP. 9 jan. 1996, technical rules for designing, building and testing concrete and steel structures
D.M. LL. PP. 5 nov. 2001, technical and geometrical rules for road building

Regional rules:

Veneto region:

L.R. 52/1978, forest regional law
L.R.: forest management police rules ("Prescrizioni di massima di polizia forestale")
L.R. 14/1992, rural-forest roads rules
L.R. 5/2000, article n. 9
"Deliberazione" 152/2005, att. n. 4

Trento province:

L.P. 30/1977, fire-fighting
L.P. 48/1978, forestry sector and resource growth
L.P. 11/2007, government of forests and mountains, rivers and protected areas

Friuli-Venezia Giulia region:

L.R. 91/1981, classification and maintenance of public roads
L.R. 6/1982, building and maintaining forest roads
L.R. 34/1984, rules for designing forest roads
L.R. 22/1985, roads regional plan
L.R. 15/1991, motor vehicle access rules for roads in protected areas
L.R. 20/2000 (art. 1) and D.P.R. 32/2003, forestry rules for soils with hydrological problems
L.R. 14/2002 (art. 51 and rules)
Environmental rules for changing the use of soils
L.R. 9/2007, rules on forest resources

When building a new road or when extra maintenance is needed, authorization should be asked as prescribed by laws on the hydrogeological and environmental bond, or, if the work is held by privates, the grant construction is necessary. The ordinary maintenance does not require any permission.

1.1.6.4. Planning and building projects

Trentino

The Forest Service in Trento province has to make a plan to prevent forest wildfires (figure 1.1.6.4.a). Inside the plan forests are classified according to their burning risk. All the management and building of infrastructures, both for preventing and for the active fight, are in charge of the Province. So, even all roads that are planned inside high risk areas or which have the forest fires function are built with public money. The project of all the other function roads may be done by private foresters consultant, but they have to be approved by the forest service.

The project usually must have a general map (scale 1:50000) that shows how the road is located on the environment and if it has some limitations due to other urban or territorial planning. Then there are a more detailed plan with the road track (1:1000) and a longitudinal profile that shows the average slope and sections of excavation or filling. More detailed transversal sections with the evaluation of ground or rock cubic meters to be excavated are drawn in a 1:200 scale (figure 1.1.6.4.b).

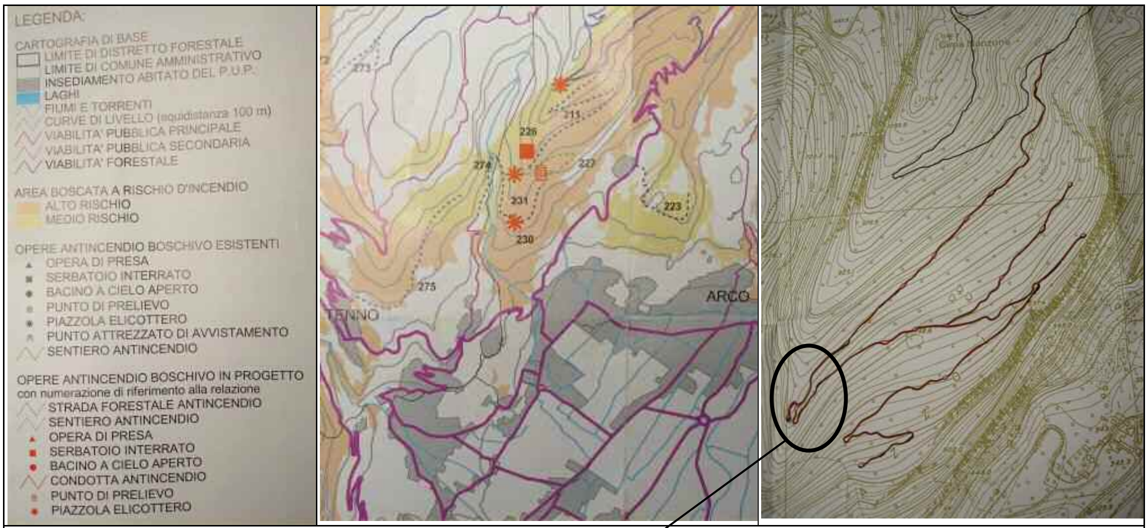


Figure 1.1.6.4.a: the forest wildfire prevention plan and a project of a new road

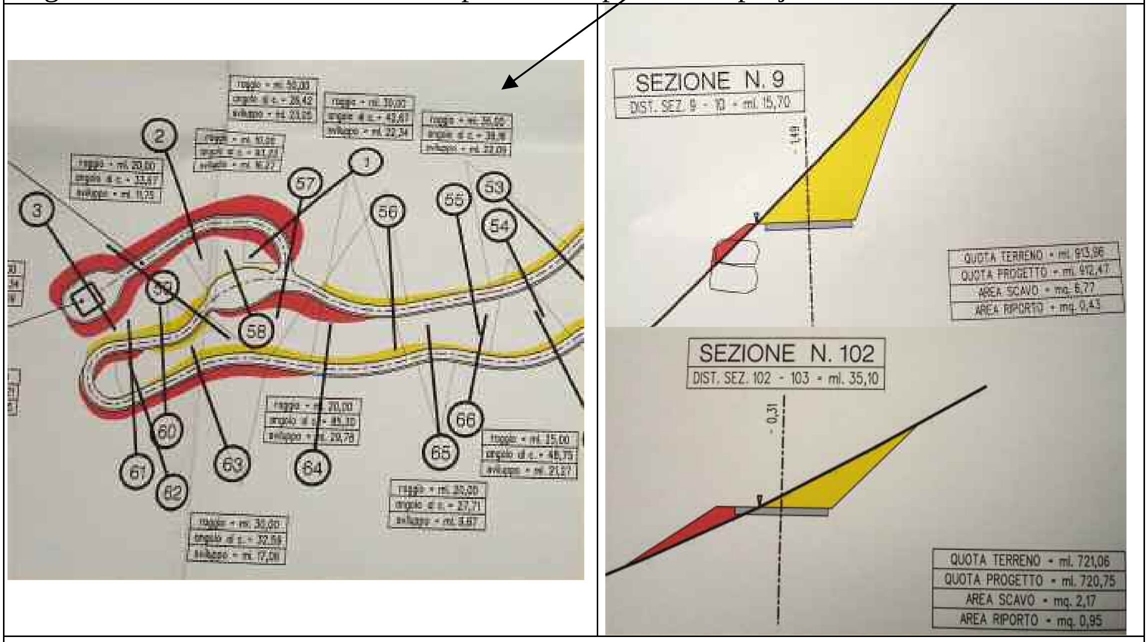


Figure 1.1.6.4.b: the detailed project of road track and profiles

Veneto region

In Veneto region all the roads are projected by professional foresters except in some cases when the road is inside a regional or national park (figure 1.1.6.4.c). In that case, the road is planned by regional forest services. Before building it is usually necessary to ask for a grant construction the municipality and also ask for an authorization to regional forest services and the park council if it is inside a protected area. If the length is more than 10 km or the road lies on a SIC area, it is also requested to write an environment impact evaluation (VIncA) that will be judged by a regional commission. The most important thing when building a road inside a protected area is also to make a work well integrated to the environment using preferably material found on the place (figure 1.1.6.4.d). The project should include all maps and evaluation of volumes as in Trento province (figure 1.1.6.4.e).

COMUNE DI: VARI PROVINCIA DI: PADOVA
UFFICIO COMPETENTE: REALIZZAZIONE: Servizio Forestale di Padova
CONCESSIONE EDILIZIA N° D.G.R. 385 DEL 30 AGOSTO 2005
PROPRIETA':
COMMITTENTE: Progetto 31/05 A.I.B.
LAVORI DI: PREVENZIONE INCENDI BOSCHIVI
IMPORTO COMPLESSIVO DEI LAVORI: 30.000 Euro
DATA INIZIO LAVORI: 12.04.2006 DATA CONTRATTUALE DI ULTIMAZIONE DEI LAVORI: 31.12.2005
PROGETTISTA: SCHERGNA dr.ssa Emanuela
DIRETTORE DEL CANTIERE: SCHERGNA dr.ssa Emanuela
ASSISTENTE DEL DIRETTORE DI CANTIERE:
COORDINATORE PER L'ESECUZIONE DEI LAVORI:
CAPO CANTIERE:
CALCOLATORE STATICO:
CALCOLATORE OPERE C.A.:
COLLAUDATORE IN CORSO D'OPERA:
RESPONSABILE DELLA SICUREZZA: CANTIERE 626/94
IMPRESA ESECUTRICE: ISCR. A.N.C.: ISCR. C.C.I.A.A.:
IMPRESE SUBAPPALTATRICI: ISCR. A.N.C.: ISCR. C.C.I.A.A.:
ISCR. A.N.C.: ISCR. C.C.I.A.A.:
IMPIANTO ELETTRICO PROGETTISTA: IMPRESA INSTALLATRICE:
IMPIANTO RADIO TELEVISIVO PROGETTISTA: IMPRESA INSTALLATRICE:
IMPIANTO ELETTRONICO PROGETTISTA: IMPRESA INSTALLATRICE:
IMPIANTO IDRAULICO PROGETTISTA: IMPRESA INSTALLATRICE:
IMPIANTO TRASPORTO E UTILIZZO METANO PROGETTISTA: IMPRESA INSTALLATRICE:
IMPIANTO RISCALDAMENTO PROGETTISTA: IMPRESA INSTALLATRICE:
NUMERI UTILI: VIGILI DEL FUOCO 115 - PRONTO SOCCORSO 118
ULTERIORI INFORMAZIONI SULL'OPERA POSSONO ESSERE ASSUNTE PRESSO L'UFFICIO COMPETENTE

Figure 1.1.6.4.c: the working site of a road built inside "Parco Colli Euganei" (Padova) with wildfire prevention purpose

Figure 1.1.6.4.d: the same road two years after construction. Spontaneous vegetation has well re-colonized road hedges.

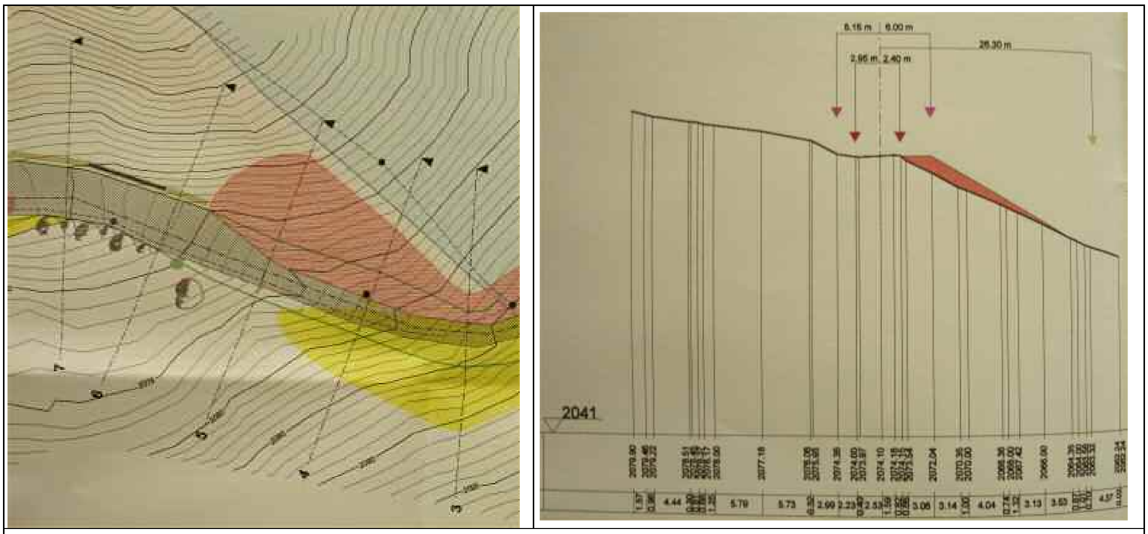


Figure 1.1.6.4.e: project and quoted profile n. 5 (MARTELLO 2005)

Friuli-Venezia Giulia region

In Friuli-Venezia Giulia it's similar to the Veneto situation, but there are some foresters more trained in planning roads and using more powerful instruments. For example they use a laser to measure distances and angles and data are stored on a small portable computer (figure 1.1.6.4.f). At home the data are downloaded on a pc and through a specific software it is possible to draw the terrain profile and choose which is the best location for building the road. Automatically also the general plan is drawn and longitudinal and transversal profiles with the estimation of ground volumes (figure 1.1.6.4.g). This is a very powerful instrument because it is possible to optimize the volumes reducing environmental impacts and costs. It is also possible to insert walls and drainage systems to prevent the movement of sediments.

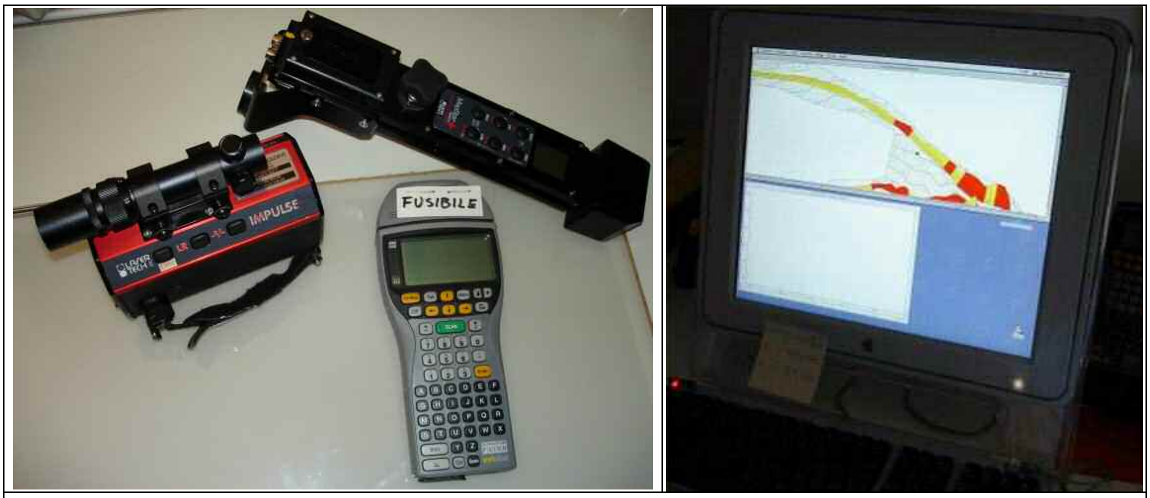


Figure 1.1.6.4.f: the instruments (laser and palm) used during survey and the planning phase as it appear on the computer screen

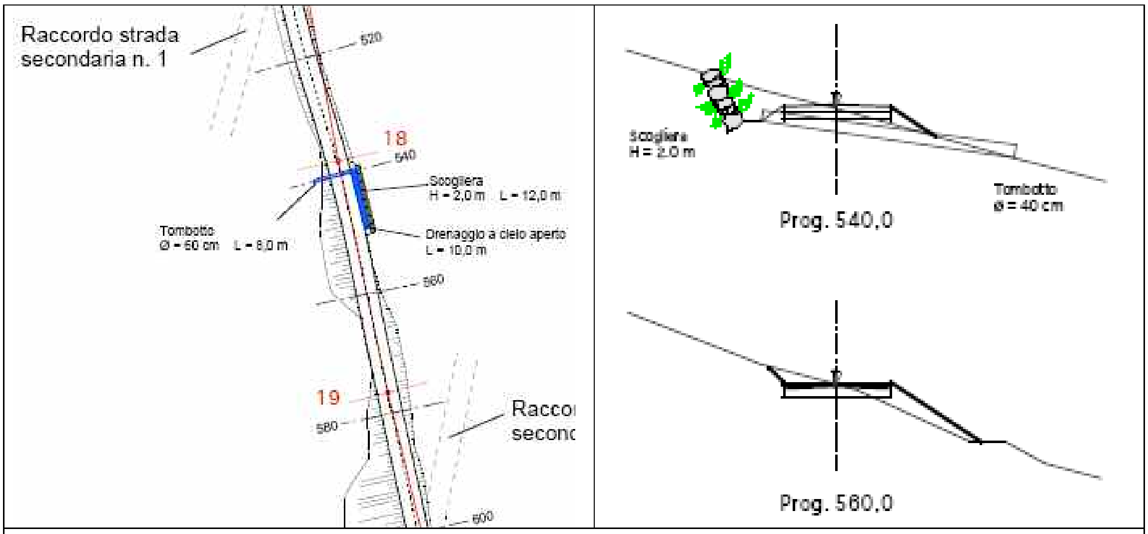


Figure 1.1.6.4.g: section of a project with corresponding profiles (SOLARI 2005)

The project of a new road has to follow a quite intricate procedure before to be approved (figure 1.1.6.4.h). All authorization are usually obtained in a time that varies from 3 to 5 months depending on the size of the work (if more than 10 km or it is inside protected areas it require VIA or VIncA). Usually professional consultants earn money in proportion with the total cost: this is about 10% divided in 6% for survey and project and 4% to lead building operations.

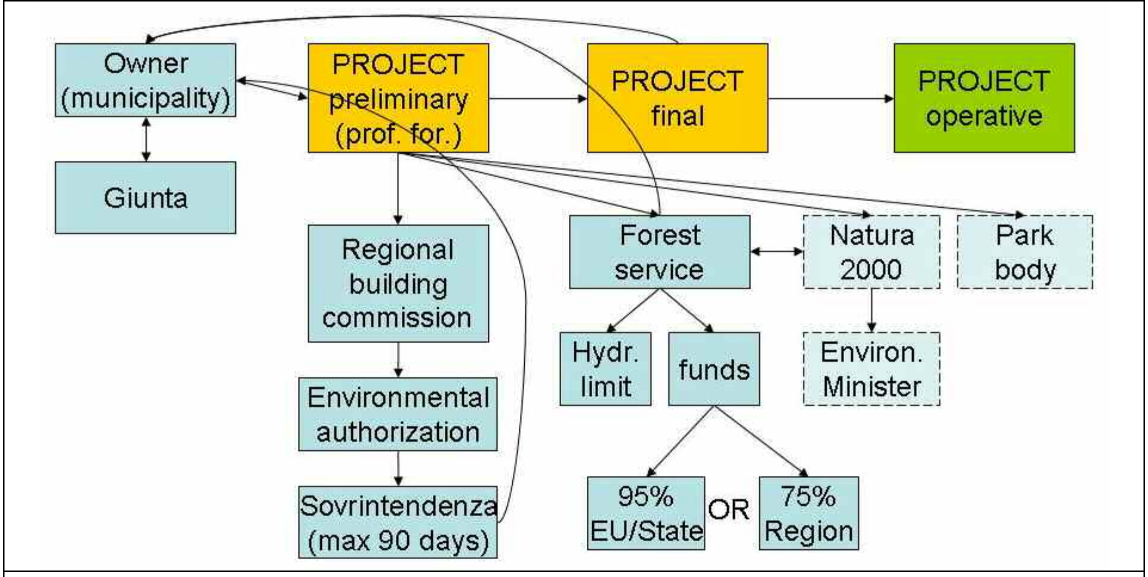
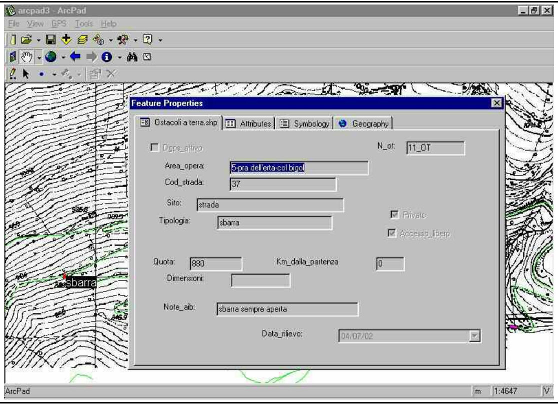


Figure 1.1.6.4.h: the approval procedure in FVG region

1.1.6.5. Road management with GPS-GIS systems

Often the management of a road network is easiest with the use of GIS softwares integrated with Global Position Systems to verify track or to up-load new information.

PELLIZZARI (2002) made a study about the application of a system combining GPS and GIS technologies for surveying the infrastructures and the obstacles of roads to produce a thematic cartography supporting the firefighting operations. The study provided the creation of a data dictionary and the digitalization of surveying tables/schedules about infrastructures and obstacles (as pull-in areas, point of reverse, water supplies, helipads or obstacles on the ground and in-flight). The real time GPS tracking has been experimented to capturing new geometries, combined with a real time filling in a data entry form (figure 1.1.6.5.a) with the most interesting parameters for firefighting features. Working in real time was a great advantage because entry data did not need any particular post processing review. The result of such an application is a database which can be managed on a GIS platform for producing thematic maps (figure 1.1.6.5.b). These maps are useful for preventing wildfires risk, planning infrastructures, identify the weak points or for a better active fight coordination.



☐ Dgps_attivo

N_ot: 11_OT

Area_opera: 5-pra dell'erta-col bigol

Cod_strada: 37

Sito: strada

Tipologia: sbarra

☑ Privato

☑ Accesso_libero

Quota: 880

Km_dalla_partenza 0

Dimensioni:

Note_aib: sbarra sempre aperta

Data_rilievo: 04/07/02

Figure 1.1.6.5.a: the insert data screen after GPS feature recording

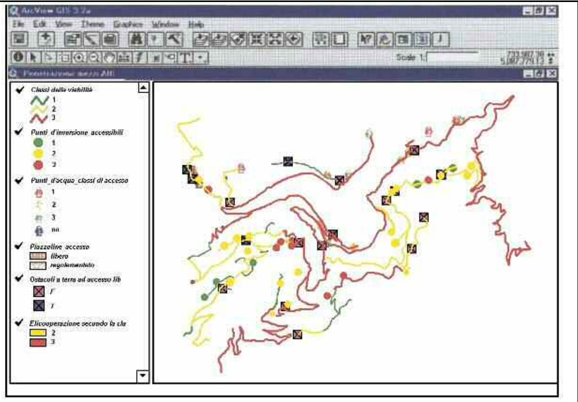


Figure 1.1.6.5.b: access map for different class firefighting vehicles

The use of GPS is powerful when there is a big area that need a management plan, as the case of a mountain community. Inside a project the Dept. TeSAF had with ”Feltrina” Mountain Community (CM), the shape of new built forest roads was checked using GPS mounted on a car in a tracking option (recording 1 point every 5 or 10 seconds). Due to a low quality positioning, data were post-processed with the use of a second fixed GPS antenna. More over, they were checked overlying georeferenced aerial photographs and linked to the existing public road network. Such a work has to aims: the first one is to check the forest road access function and identify which areas need new roads (or viewed on the other side of the mountain community technician, to have an objective map or indexes to judge and accept/refuse new building projects); the second aim is to have inside a database all information they need to manage the road net. During the survey, many data were collected, the average slope, average width, switchback curve radius, the road pavement type, the presence of longitudinal or transversal works and their need of maintenance. Many photographs were also taken for each described point and linked (figure 1.1.6.5.c and 1.1.6.5.d) to the geographical database. The CM has so the possibility to plan the maintenance and estimate the yearly costs (due also by the Veneto regional law n. 19/1992 and n. 39/1999: maintain access on public roads).

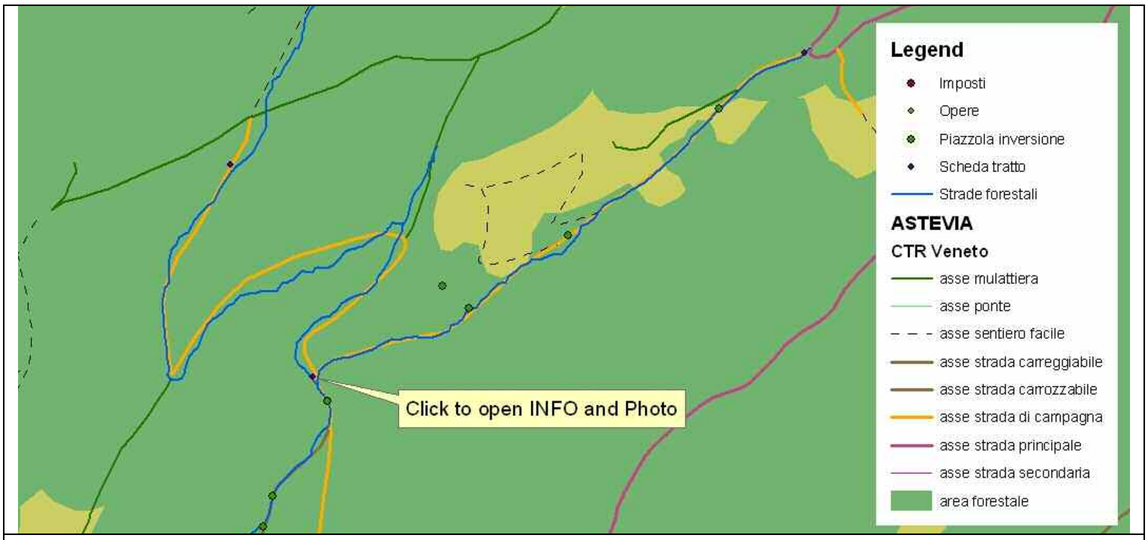
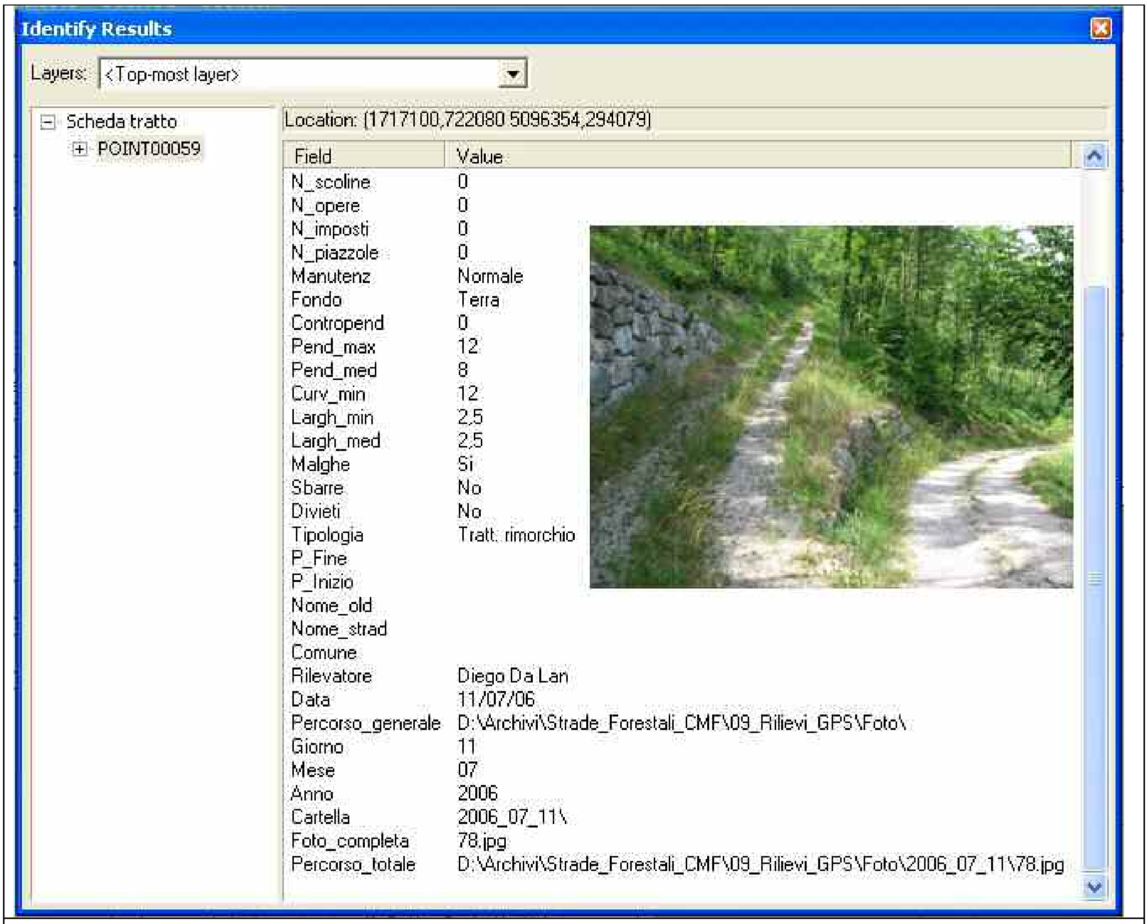


Figure 1.1.6.5.c: Forest roads tracked with GPS (in blue)



Location: (1717100,722080 5096354,294079)

Field	Value
N_scoline	0
N_opere	0
N_imposti	0
N_piazzole	0
Manutenz	Normale
Fondo	Terra
Contropend	0
Pend_max	12
Pend_med	8
Curv_min	12
Largh_min	2,5
Largh_med	2,5
Malghe	Si
Sbarre	No
Divieti	No
Tipologia	Tratt. rimorchio
P_Fine	
P_Inizio	
Nome_old	
Nome_strad	
Comune	
Rilevatore	Diego Da Lan
Data	11/07/06
Percorso_generale	D:\Archivi\Strade_Forestali_CMF\09_Rilievi_GPS\Foto\
Giorno	11
Mese	07
Anno	2006
Cartella	2006_07_11\
Foto_completa	78.jpg
Percorso_totale	D:\Archivi\Strade_Forestali_CMF\09_Rilievi_GPS\Foto\2006_07_11\78.jpg

Figure 1.1.6.5.d: the database and photo related to each forestry road

1.2. THE IMPORTANCE OF PLANNING

Wood chain is a multifaceted process involving people and machines under influences of several environmental, ecological, social and economical factors. Through each step of the chain, wood increases its value. Cutting, skidding and hauling operations could be very expensive because of hard forest operation environment and not-efficient working system. Consequently timber value could be depreciated up to the point that wood is not cut because it is not convenient. Logging and transporting optimization are becoming, thus, ever more a key factor to be improved. For this reason, studies and analyses on wood chain, mainly based on modeling and planning tool have been in the past developed and toady are still increasing due to the introduction of powerful software as Geographical Information Systems.

First interest and applications on modeling and planning by developing Decision Support System (DSS) were primarily related to military needs and to estimate trafficability of soil for off-road vehicles (AA.VV. 1961; ANDERSON 1985; BONASSO 1989). These approaches were then transferred to many sectors of agriculture and forestry (SAMSET 1975; ROWAN 1977; MELLGREN 1980; LÖFFLER 1984).

Accessibility maps and analysis on planning forest operation have been developed preventing damages to wetland soils and ecosystems (WRONSKI 1989; AA.VV. 2002; EICHRODT 2003; CAVALLI 2005; MURPHY *et al.* 2006). In steep Alpine areas, where forest management aims at different forest functions, modeling represents a complex analysis considering also not productive forest function (HEINIMANN 1999; DEL FAVERO 2000): density and size of remaining standing trees (clear cuttings are forbidden), for example, have an high influence on skidding operations. Moreover, planning models have to consider not only environmental and stand factors but also can be developed to support prevention of soil compaction damages (ZIESAK 2003). Also many works have considered the optimization of different skidding systems in relation to different machine size, as for cable cranes and forest operation conditions (HEINIMANN 1986 and 1994; LÜTHY 1998; KRČ 1999, CHUNG *et al.* 2001). Further interests could be oriented to develop models and support systems in order to prevent also forest workers injuries and consequently increasing safety of forest operations (GANDASECA *et al.* 2001).

In the contemporary sense, consideration must be given to the importance of the forest as a source of non-wood forest products and environmental services, as well as its role in the conservation of biological diversity and cultural values. Timber harvesting operations must therefore be planned in such a way as to accommodate, and where possible enhance these multifunctional characteristics of the forests (BALDINI and POLLINI 1998).

Thinnings operations are designed to remove some of the trees in order to enable the remainder to thrive, which is an essential sylvicultural operation. During first thinning operations, it is necessary to open up access routes (trails) within the forest for use by harvesting and extraction machines. As the trails are the only routes for the machines to operate, they can become badly damaged due to repeated trafficking. The "trails" layout typically consists of short "side trails" (along which the timber is gathered) leading into "main trails" which act as the principal routes out to the stacking point. As the main trails are the most highly trafficked, most damage (e.g. deep rutting in excess of 0.3 m in some cases, soil compaction and tree root damage) may occur along these routes. The main traffic source through the forest is the forwarders, as they have to make repeated journeys to and from in order to collect the logs. In contrast, the harvester fells the trees as it progresses slowly along the trails and generally has no requirement for repeated trafficking of the trails. In a clear felling operation, machinery movement is less restricted, hence, forwarders can reduce the number of passes along the same routes in order to minimise rutting and soil damage. Soil damage can also be minimised by effective use of brash i.e. stem and branches with diameter below the minimum set for utilisation (AA.VV. 2002).

Depending on the soil types some soil structural change is an inevitable consequence of mechanised timber harvesting operations. Such damage is of particular importance if it impacts negatively on the environment (e.g. acceleration of reduced infiltration and surface water run off into watercourses). Mechanised timber harvesting operation should be planned and executed in such a manner as to avoid such potential environmental impact. Some sites are more "sensitive" to environmental damage than others. For example, wet peat soils on sloping ground can pose considerable difficulties for environmentally efficient harvesting operations (NUGENT *et al.* 2002).

The environmental impacts of mechanised harvesting operations depend on several factors such as site type, matching the machinery to the site, machinery operation, layout of the trails so as to minimise trafficking by the forwarders. The time of year during which the operations are carried out may also be important (HINZE 1990). For example, harvesting on certain peat soils may be feasible only during the summer when the soil is relatively dry or during the winter in cold climates (such as Finland) when the surface soil is frozen.

A key factor in determining the environmental impact of mechanised timber harvesting is the potential risk of run off water entering local streams, rivers or lakes. For example, traffic damage in trails (such as severe rutting) only poses a significant environmental risk if it channels surface run off water into a watercourse. Some rutting or soil scuffing is inevitable when dealing with mechanised harvesting operations on sensitive sites, but **judicious selection and operation** of the machinery system **can minimise the potential site damage**. However, given that this risk exists, the overriding principle must be one of containment of water flows so as to minimise the risk of run off into watercourses. While it is important that damage along the trails is minimised, this must be combined with planning the rack layout to include riparian buffer zones, which minimise the risk of direct run off into watercourses (WRONSKI and HUMPHREYS 1994). Rehabilitation operations after the harvesting and extraction that includes levelling of deep ruts and establishing surface vegetation may be necessary also. Soil erosion can pose significant environmental risk when mechanised timber harvesting is carried out on sloping sites, particularly in dry climates (e.g. Mediterranean countries). Severe scuffing exacerbates the effect, hence the selection and operation of the mechanisation system is important in containing the risk. Scuffing has the effect of loosening the surface layer, hence predisposes it to erosion from wind or rain.

The sensitivity of a forest site encompasses a broad range of issues such as aesthetics and social functions, inherent archaeological features, economics, and potential environmental degradation such as the pollution of watercourses. One principal aim of planning is how to minimise the impact that mechanised harvesting operations can have on the environment. With this consideration, the following definition of a sensitive site may be adopted (NUGENT *et al*. 2002):

"*A sensitive forest site is where alterations to normal mechanised harvesting practices are required in order to avoid adverse effects on the ecological, economic and social functions of the forest*"

In this context, the sites at risk of degradation as a result of timber harvesting and extraction include: areas with gley soils, particularly on sloping terrain, and where there is insufficient brush to minimise surface disturbance; poorly drained shallow peat soils (less than 1 m deep) often with inferior tree crop with limited amounts of brash; deeper peat (greater that 1 m), usually with good drainage networks which present very difficult harvesting conditions; low organic matter soils on steep slopes in areas prone to drought and sudden spells of high rainfall (as occur in Mediterranean areas). The percentage of total forested area in Europe that is classified as sensitive ranges from 5% to 25%, depending on country. For example, 50% of forested area in Italy is on steep terrains (more than 40%) and protected areas as SIC or ZPS cover in Nort-eastern Italy more than 50% of the productive forests.

Ground skidding comprises a significant proportion of harvesting operations in southern European countries. Planning eco-efficient and cost-effective timber harvesting systems for sensitive sites should:

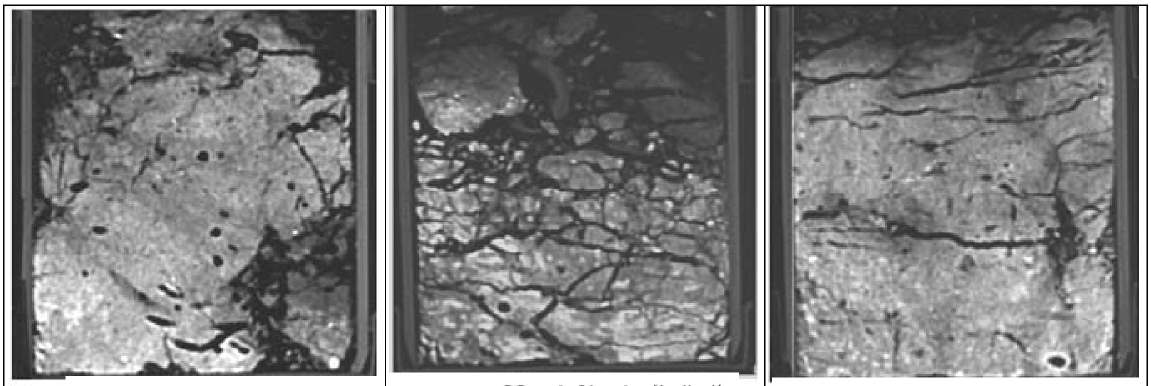
1) **minimise** or eliminate the associated **soil disturbance** (*viz.* terrain surface rutting, soil compaction, layer inversion, erosion) that ordinarily may be incurred by harvesting and extraction operations
2) **minimise** the **damage to residual tree** crop and seedlings, in thinning operations and natural regenerating stands, respectively
3) **minimise** or eliminate the **damage to natural watercourses**, and artificial drainage and soil protection structures within or adjacent to the harvested areas
4) **optimise the productivity** of the extraction operation, i.e. deliver the trees/logs to landings at economic rates and with minimal loss of volume and/or quality, and
5) **ensure the safety** of the extraction crews and other personnel involved in the related harvesting processes, by ensuring that only skilled operators are engaged for planning and execution of the harvesting and extraction works.

Within the first three points there are five main categories of site damage and secondary environmental degradation that can occur due to the operation of timber harvesting machinery. These can be divided in categories as follows:

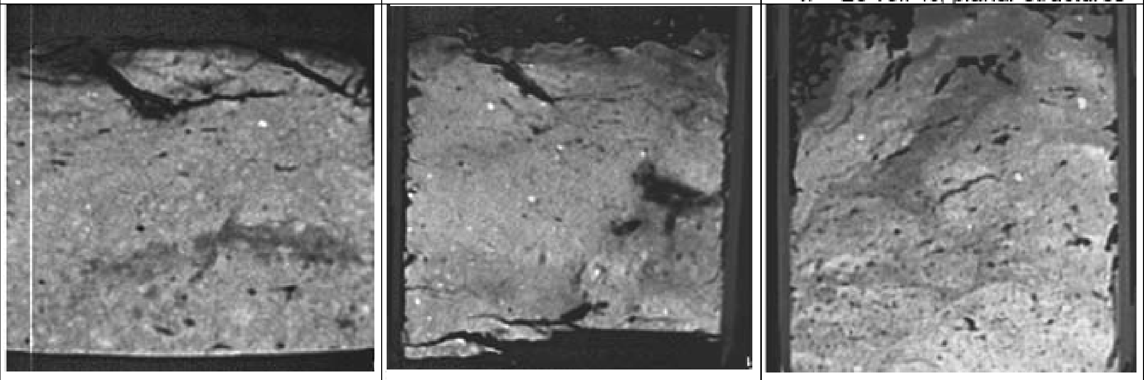
1. *Rutting:* repeated passes of heavy machinery along the same route lead to the development of ruts. Rutting is a phenomenon closely associated with soft soils, such as wet peats or gleys. On most of these soils the rutting effect is incremental with each machine pass, but is most pronounced in the first 1 to 2 passes. In extreme cases, such as where inappropriate machinery systems are used, the soil structure can become so damaged that it turns into a liquid slurry (so called “slurrying”)(figure 1.2.a).

	
Figure 1.2.a: rutting after 10 passes of a wheeled forwarder (with 8 t load) along a main extraction trail comprising a shallow gley soil overlying solid foundation	Figure 1.2.b: Forwarder (with 8 t load) operating on a waterlogged site with a shallow (<700 mm depth) solid foundation. The machine caused severe rutting as it sank right down to the underlying solid stratum. This is also a risky situation for working people.

2. *Soil compaction:* the development of ruts (as outlined above) is in effect an outward manifestation of soil compaction (figure 1.2.c). The soil beneath the ruts becomes compacted, with the zone of maximum compaction extending to a depth equal to approximately half the rut width (viz. the zone typically extends down to ca. 300 mm). This compaction will reduce the water infiltration capability of the soil hence making the rut an excellent channel for surface water flow. It is therefore very important that the network of ruts, resulting from forest machinery operations are remediated and do not channel water into watercourses.



reference | w = 20 vol.-%, plastic limit | w = 26 vol.-%, planar structures



w = 32 vol.-%, compaction | w = 40 vol.-%, liquid limit | w = 43 vol.-%, intense puddling

Figure 1.2.c: typical moisture related soil structural alterations after traffic. Up to moisture contents of w = 26% total pore volume and coarse pores show little effects only, while moisture contents around liquid limit lead to a complete loss of soil structural diversity (=soil damage)(MATTHIES *et al.* 2006).

3. *Surface disturbance:* Forestry machines rely on slip between the wheels (or tracks) and the soil (figure 1.2.d) in order to generated the required drawbar pull. The magnitude of this slip depends on several factors such as soil condition, vehicle weight, tyre (or track) type, inflation pressure, drawbar pull requirement and several other soil and vehicle parameters. Damage due to slip includes smearing of the soil surface, mixing (and dislodgment) of components of the upper soil layer (top 50 mm or so), root damage and, in extreme cases, a breakdown in the structure of the top layer of soil leading to “slurrying” in wet soils. Loosening of the soil surface can lead to significant erosion problems in dry climates, such as in certain Mediterranean sites after rainfall.

Figure 1.2.d: on the left a cable-forwarder corridor with 40% steep slope. On the right, without the help of the winch, the wheels slip and are cause of surface damages (Zuccoli Bergomi 2006; Cavalli *et al.* 2006)

4. *Residual stand damage:* Traffic induced stand damage can be important in thinning operations. The process of soil compaction, outlined above, leads to compaction of roots, particularly those in the maximum compaction zone (viz. down to ca. 300 mm). Such compaction when associated with rutting may make the trees beside the tracks more prone to tipping over in heavy winds. In addition, roots may become exposed (figure 1.2.e) as a result of a tearing action by the wheels (or tracks), and this can reduce subsequent tree growth and allow entry of pathogenic fungi (Isomäki and Kallio 1974). The extent of such root damage depends on the degree of rutting and the severity of the machine's action (Čermák *et al.* 2006). The use of metal cleats (track shoes) to enhance machine flotation exacerbates the effect. As rut depths can extend to 500 mm on poorly maintained main extraction routes, this implies that root damage may not be confined to surface roots and can have a significant negative impact on the residual trees. Rummer and Klepac (2002) studied the difference on residual tree damage when harvesting with manual felling or mechanized (harvester) system. They found a relationship between the distance from the extraction trail and the incidence of scarring (figure 1.2.f). Fifty percent of the damaged trees were located from 1.5 to 3 m from trail center (table 1.2.a). Since the harvester had to process and pile trees along the skid corridor, more trees were damaged than during manual operations. Only 5% were located mid-reach (3 – 4 m), with the remaining 45% located 4 – 7 m from trail centre. This likely reflects the difficulty of handling trees at the extreme limits of the boom reach. Limbeck-Lilienau (2003) found that the cut-to-length wheeled harvester-forwarder system causes the lowest number of damages to remaining trees if compared to trucked harvester-forwarder, harvester-sledge yarder and chainsaw-cable yarder systems. During thinnings, steep terrain and cutting intensities may be the reason for higher damage level.
5. *Soil erosion and accumulation of sediment in streams:* Input of soil to the watercourses (increased suspended solids and sedimentation on the stream bed) is potentially the most

significant change in the environment surrounding the forests. Erosion can be particularly severe in hot dry climates with occasional short periods of very high rainfall. Harvesting can increase soil input to watercourses especially in mountainous areas by a variety of processes, including:

- surface erosion from landings and skid trails;
- slope failure caused by the removal of vegetation;
- physical damage to the stream banks, such as slippage and bank collapse, and;
- increased surface run off as a result of clear fell operations

The environmental impact of the above processes will depend on the proximity of the harvest site to watercourses, the expanse of the disturbed areas, site-sensitivity, topography, weather conditions and the intensity of the harvesting operation.

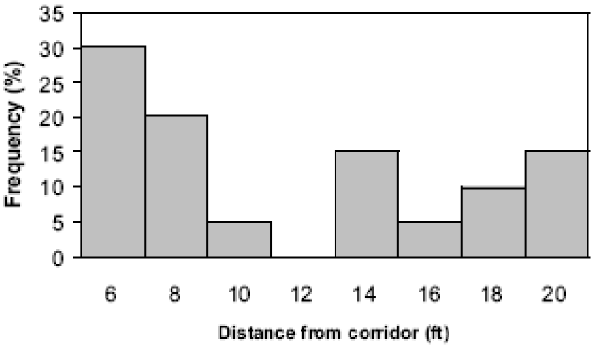


Figure 1.2.f: frequency of damaged trees from skidtrail center in the harvester plots

Figure 1.2.e: illustration of damage inflicted by machine traffic on an exposed root

Table 1.2.a: residual tree damage comparing manual and mechanized felling

Variable	Manual felling	Harvester
Damage tree/acre	20	170
Trees/acre with cambium exposed	20	160
Trees/acre with wood damage	0	10
Mean scar size (in^2)	1.24	12.34
Mean scar/tree	2	2.5
Mean height above ground (ft)	9.1	3.5
Mean distance from trail (ft)	-	11.7

Optimize the productivity

Foresters should consider the technology when planning yield and cuttings inside a forest stand. If enterprises will not have the right machines or there are not enough forest roads to enter the forest or the value of wood get lower and operations will not be economically viable, cuttings will not be done. And if this will happened, the work of the forester and the ecological value of cuttings will loose all their significance (LUBELLO *et al.* 2007). Even more forests will be abandoned and the cultural and social value of the environmental management will be lost.

Thinnings or selective cuttings should also be planned in a way that makes them economically feasible, reducing at the minimum fixed costs and providing the enterprises of also some good assortments. But the work of forester should not be deleted by the man who have to sign the trees which must be cut and which not. He should have read prescription as reported on the forest management plan and he should also know which utilization systems will be used. With this knowledge he should adapt the yield amount to the site conditions: as an example, signed trees would not be far from road more than 150 m on gentle terrains if tractor with winch is used. Otherwise skidding operations will cause very high level of standing trees damage.

The problem is when a wrong cut effects an economical loss. The use of cable systems, for example, should be carefully planned. The table 1.2.b shows the results of two different extraction site where the average diameters where the same, and so also the cut volume, but having mounted and dismounted three corridors (that where not planned) instead of one caused higher operation costs and a lower selling price which gave a 13780 € total loss (13 e/m^3 less than expected). Moreover the yield of the second working site was 700 m^3 with a low rate per hectare (as usual in thinnings operations), but installing the three lines needed to clear the corridor and 300 m^3 more where cut (43% more) with a big ecological impact on the site because it changed the normality of the population (number and diameter of trees).

Table 1.2.b: the effect of wrong cable crane planning operations (Grigolato and Lubello, 2006)

	Working site 1	Working site 2
Cable corridors	**1**	**3**
Cutting type	Final cutting (clear cutting)	Selection cutting
Planned yield	1000 m^3	700 m^3
Unit yield	75 m^3/ha	13.7 m^3/ha
Average diameter	34 cm	34 cm
Cut wood	1070 m^3	1060 m^3
Clearing corridors	70 m^3	360 m^3
Cable crane index	1.74 m^3/m of cable	0.57 m^3/m of cable
Prices		
Road side	98 €/m^3	86 €/m^3
Harvest-skidding	42 €/m^3	37 (planned) 50 (real) €/m^3
Standing tree	56 €/m^3	49 (planned) 36 (real) €/m^3
Total selling	59920 €	~~51940~~ 38160 €

Inside high forests with high value logs it should be planned to use high mechanized systems as forwarders or cable systems on steep terrains to give to the wood a little more value. Sawmills pay from 2 to 3 €/m^3 more clear logs (Sambugaro 2006), in fact dirty logs dragged on the ground may pick up some small stones that could break the saw-teeth.

Ensure the safety

A good planning may help regions or provinces in organizing training and learning courses for operators on the basis of enterprises need and new technology. A workers illness is mad for him, but has also some not negligible social costs. New machines follow European rules and provide safer working site (thinking for example of a worker sitting inside a harvester cabin: he is far from cutting tools, he do not breath chainsaw smoke, he is protected from falling branches, etc…), but working rhythms and new posture of the body introduce new illness more common to video-terminal workers (e.g. musculoskeletal disorders) (AXELSSON and PONTÉN 1990; SYNWOLDT and GELLERSTEDT 2003). One of the riskiest things in forest is walking (table 1.2.c and 1.2.d), meaning falling, so a good forest road infrastructure and a good site specific planning should improve workers safety.

Table 1.2.c: forest workers accidents in 2001 in Trento province (PAT 2002)

Forest workers	236
<10 days stop accident	15
Up to 20	6
Up to 40	3
>40 days	7
Total	31 (13.4%)

Table 1.2.d: where the accident took place and which part of the body hit (PAT 2002)

	shoulder	eye	face	arm	breast	hand	leg	knee	back	others	total
n.	3	2	4	2	1	5	3	6	3	2	31
%	10	6	13	6	3	**16**	10	**20**	10	6	100

	ground	falling rock	stem	branches	splinter	chainsaw	axe	other tools	insects	total
n.	7	1	2	11	1	1	3	1	4	31
%	**23**	3	6	**36**	3	3	10	3	13	100

1.3. MODELLING

1.3.1. Forest resource management

Forest resource management is the art and science of making decisions with regard to the organization, use and conservation of forests and related resources (BUONGIORNO and GILLESS 2003). Forests may be actively managed for timber, water, wildlife, recreation, or a combination of their functions (COSTANZA *et al.* 1996). Management also includes the "hands-off" alternative: letting nature take its course, which may be the best thing to do in some cases. Forest resource managers must make decisions affecting both the very long-term future of the forest and day-to-day activities (WILLIAMS 1992). The decisions may deal with very complex forest systems or with simple parts. The geographic area of concern may be an entire country, a region, a single stand of trees, or an industrial facility. Some of the forest resource management problems which can be considered include:

- scheduling harvesting and reforestation in even-aged forests to best meet production and/or ecological objectives
- determining what trees to harvest in uneven-aged forests and when to harvest them to optimize timber production, revenues, or ecological diversity
- planning the production activities in forest stands and in forest industries to meet goals concerning revenues, employment and pollution control
- designing efficient road networks to provide access to recreation or timber production projects
- managing complex projects in efficient and timely ways, given fixed budgets and other constraints
- recognizing the uncertainty of biological and economic outcomes and dealing with this uncertainty in the best possible way
- ranking alternative investment projects in such a way that those selected maximize the contribution to private or public welfare
- forecasting the demand, supply, and price of forest products

1.3.2. The nature of models

In tackling problems of this sort and making related decisions, forest managers use models. *Models* are abstract representations of the real world that are useful for purposes of thinking, forecasting and decision making.

Models may be very informal, mostly intuitive, and supported by experience and information that is not put together in any systematic manner. Nevertheless, in the process of thinking about a problem, pondering alternatives, and reaching a decision, one undoubtedly uses a model, that is, a very abstract representation of what the real-life problem is. Most decisions are made with this kind of informal model. The results may be very good, especially for a smart, experienced manager, but the process is unique to each individual and it is difficult to learn.

Forest managers have long used more concrete models. Some are physically very similar to what they represent. For example, a forest hydrologist may use a sand-and-water model of a watershed that differs from the real watershed only with respect to scale and details. Water or a liquid of higher density is made to flow through the model at varying rates to simulate seasonal variation in precipitation and flooding. The resulting erosion is observed, and various systems of dams and levees can be tested using this model.

A forest map is an example of a more abstract model. There is very little physical correspondence between the map and the forest it represents. Nevertheless, maps are essential in many forestry activities. Few management decisions are made without referring to them to define the location and the extent of activities such as harvesting, reforestation, campground development, and road building.

Mathematical models have little visual analogy between the real world and the model. Reality is captured by symbolic variables and by formal algebraic relations between them. Despite or because of their abstraction, mathematical models are very powerful. These models are not new in forestry. For example, tabular and mathematical functions have long been used to express biometric relationships between a stand volume per unit area, its age, and site quality. Forest economists long ago developed formulas to calculate the value of land as function of its expected production, forest product prices (both timber and non-timber), management costs, and interest rates (BRACK and MARSHALL 1996). These investment models are fundamental to forest resource decision making. In general, mathematical models can tackle problems with a very large number of variables and relationships. This makes them well suited to complex, real-life managerial situations.

1.3.3. Systems models

Forest resource management problems involve many different variables. Some are biological, like the growth potential of a particular species of trees on a particular soil. Others are economic, like the price of timber and the cost of labor. Still others are social, like the environmental laws that may regulate for whom and for what a particular forest must be managed. Often, these variables are interrelated. Changes in one of them may influence the others.

All these variables and relationships that tie them together constitute a *system*. Because of the complexity of the real forest resource systems, foreseeing the consequences of a particular decision is not an easy task. For example, to increase the diversity of the trees in a forest, we may think of changing the method, timing, or intensity of harvesting (REED 1986; HEMM *et al.* 2006). But what exactly is the relation between harvest, or lack thereof, and diversity? How much does the frequency and the intensity of the harvest matter? What is the effect on the long-term health of the forest of taking some trees and leaving others? What is the effect of changing the harvesting pattern on the timber income from the forest? How much will it cost, if anything, to increase forest diversity?

System models are meant to help answer such questions. They are tools that managers can use to predict the consequences of their actions. In a sense, a model is a device to bring the real world to the laboratory or to the office. As HELLRIGL (2005) stated: the dream for foresters is to have the forest inside their computer. Managers can, and do carry out experiments with models that would be impossible in reality. For example, they can try several management alternatives on a model of their forest and observe the consequences of each alternative for many future decades (WOOD and DEWHURST 1998; HINRICHS 2006), a thing that is impossible to do with a real forest. It is this ability to experiment and predict, to ponder different choices, that makes forest systems modeling such an exciting endeavor.

Some of the first systems models and the methods to solve them were developed during the Second World War, to assist in military operations (U.S. ARMY, 1961). This led to a body of knowledge known as *operations research* or *management science* (BUONGIORNO and GILLESS 2003, HEINIMANN 2007). After the war, operations research methods began to be applied successfully in industry, agriculture and government. The first applications of operations research to forest management problems date from the early 1960s. Their number has been growing rapidly since then. The Society of American Foresters has had for many years an active Operations Research Working Group. A similar group exists within the International Union of Forest Research Organizations (IUFRO Division3).

Several modern systems models in forest resource management combine the methods of operations research and those of economics. Economics remains an essential part of forest resource management: even when the objectives of management are purely ecological, such as in designing a conservation program, economics are needed to compare the costs, if not the benefits, of alternative approaches.

1.3.4. The role of computers

Although systems models are formulated via mathematics, mathematics alone cannot make them work. The reason is that only very simple mathematical models have exact analytical solutions. For example, a simplistic model of the growth of a deer population in a forest would state that the growth proceeds at a rate proportional to the number of animals. That relation can be expressed as a simple equation, a solution of that equation would give the population size as a function of time. In fact, the growth of the population is also a function of the amount of food available in the forest, which itself changes at a rate that depends on the way the forest is managed, and so on. To model these relationships properly one needs a system of equations for which there is no exact solution, only approximate ones.

This example is typical of systems models. By their very nature, they do not have exact analytical solutions. They must be solved by numerical methods, that is to say, essentially by trial and error. But algorithms can decrease the number of trials considerably. Algorithms are methods of calculation that ensure that, starting from a rough approximation, a good solution is approached within a reasonable number of steps.

Algorithms have long been used in approximating solutions of equations. But the power of algorithms has been increased immensely by computers. The advent of computers has caused a scientific revolution similar to the discovery of differential and integral calculus. Problems that a mere 50 years ago could not even be considered are now routinely solved in a few seconds on a personal computer. Computers can now easily determine the best solution to problems with several thousand variables and as many constraints on the values of these variables. The search for optimality, that is, seeking not just a solution but the *best* solution among a possibly infinite number of solutions, is a recurring theme in operations research.

1.3.5. Good models

The availability of powerful and cheap computers is not without dangers. In forestry, as in other fields, it has often led to the development of many awkward, expensive, and cumbersome models. A good roadmap does not need confusing topographical detail. Similarly, the best forest system models are usually the simplest ones that reflect the key elements of the question to be answered. Too many times, models have been sought that could "do everything". It is usually better to precisely define the problem to be solved and to limit a model strictly to that problem. In this respect, one can recognize three elements in model development: **problem definition**, **model building** and **model implementation**. There is a tight dependency between them. A well-defined problem is half solved, and the solution of a well-defined problem is likely to be readily understood and implemented. To be any good, models must ultimately help managers make decisions. Thus, it is unfortunate that managers do not usually build models themselves.

A recent development that is helping to bridge the gap between forest resource managers and model builders is the popularity of computer spreadsheets. Most managers are now using spreadsheets routinely for a variety of purposes. Modern spreadsheets have sophisticated built-in functions, including optimizers that avoid the need for specialized computer programming. A spreadsheet is an ideal medium for managers to develop simple, small, purpose-oriented models on their own (BUONGIORNO and GILLESS 2003). A full implementation of simple models may require specialized software or programming, but the approach itself ceases to be a "black box" with little managerial input or understanding (JOHNSEN *et al.* 2000).

Good modeling is not a way of computing, but rather a way of thinking. More than finding a particular solution, good models should help forest resource managers reason through a problem in a logical manner. Thus, although the quality of data underlying the model is important, it is not critical. Much useful understanding of a problem can be acquired by building a model with very rough data. All important decisions must often be made quickly. Good models do not need the perfect data set to materialize. Instead, they help make the best decision possible in a timely fashion with whatever data are available.

1.3.6. DSS and S-DSS models

1.3.6.1. Decision Support Systems origins

The concept of Decision Support System (DSS) is based on the seminal work by Simon and associates in 1950s and 1960s (SIMON 1960). During the years 1960s, researchers began systematically studying the use of computerized quantitative models to assist in decision making and planning (RAYMOND 1966; TURBAN 1967; URBAN 1967). FERGUSON and JONES (1969) reported the first experimental study using a computer aided decision system. They investigated a production scheduling application running on an IBM 7094. In retrospect, a major historical turning point was SCOTT MORTON's (1967) dissertation field research at Harvard University. Scott Morton's study involved building, implementing and then testing an interactive, model-driven management decision system. The concept of decision support systems was first articulated by Scott Morton in February 1964 in a basement office in Sherman Hall, Harvard Business School (POWER 2007). During 1966, SCOTT MORTON (1971) studied how computers and analytical models could help managers make a recurring key business planning decision. He conducted an experiment in which managers actually used a Management Decision System (MDS). Marketing and production managers used an MDS to coordinate production planning for laundry equipment.

The pioneering work of George DANTZIG and WOLFE (1960), Douglas ENGELBART (1962) and Jay Forrester likely influenced the feasibility of building computerized decision support systems. In 1952, Dantzig became a research mathematician at the Rand Corporation, where he began implementing linear programming on its experimental computers. In the mid-1960s, ENGELBART (1962) and colleagues developed the first hypermedia-groupware system called NLS (oNLine System). NLS facilitated the creation of digital libraries and the storage and retrieval of electronic documents using hypertext. NLS also provided for on-screen video teleconferencing and was a forerunner to group decision support systems. Forrester was involved in building the SAGE (Semi-Automatic Ground Environment) air defense system for North America completed in 1962 (EVERETT *et al.* 1963). SAGE is probably the first computerized data-driven DSS. Also, Professor Forrester started the System Dynamics Group at the Massachusetts Institute of Technology Sloan School. His work on corporate modeling led to programming DYNAMO, a general simulation compiler.

Keen and Stabell claim the concept of decision support systems evolved from "the theoretical studies of organizational decision making done at the Carnegie Institute of Technology during the late 1950s and early '60s and the technical work on interactive computer systems, mainly carried out at the Massachusetts Institute of Technology in the 1960s. (KEEN and SCOTT MORTON 1978)". SIMON's books (1947, 1960) and articles provide a context for understanding and supporting decision making.

In 1960, J.C.R. LICKLIDER published his ideas about the future role of multiaccess interactive computing in a paper titled “Man-Computer Symbiosis.” He saw man-computer interaction as enhancing both the quality and efficiency of human problem solving and his paper provided a guide for decades of computer research to follow. Licklider was the architect of Project MAC at MIT that furthered the study of interactive computing. By April 1964, the development of the IBM System 360 and other more powerful mainframe systems made it practical and cost-effective to develop Management Information Systems (MIS) for large companies (DAVIS 1974). These early MIS focused on providing managers with structured, periodic reports and the information was primarily from accounting and transaction processing systems, but the systems did not provide interactive support to assist managers in decision making.

Around 1970 business journals started to publish articles on management decision systems, strategic planning systems and decision support systems (SPRAGUE and WATSON 1979). DSS evolved as a field of research, development, and practice during the 1970s and 80s (SPRAGUE and WATSON 1996); the SDSS concept has evolved in parallel with DSS (DENSHAM and GOODCHILD 1989). The first use of the term decision support system was in GORRY and SCOTT-MORTON’s (1971) Sloan Management Review article. They argued that Management Information Systems primarily focused on structured decisions and suggested that the supporting information systems for semi-structured and unstructured decisions should be termed “Decision Support Systems”.

GERRITY (1971) focused on Decision Support Systems design issues in his article titled "The Design of Man-Machine Decision Systems: An Application to Portfolio Management". His system was designed to support investment managers in their daily administration of a clients' stock portfolio. John D.C. Little, also at Massachusetts Institute of Technology, was studying DSS for marketing. LITTLE and LODISH (1969) reported research on MEDIAC, a media planning support system. Also, LITTLE (1970) identified criteria for designing models and systems to support management decision-making. His four criteria included: robustness, ease of control, simplicity, and completeness of relevant detail. All four criteria remain relevant in evaluating modern Decision Support Systems. By 1975, Little was expanding the frontiers of computer-supported modeling. His DSS called Brandaid (LITTLE 1975) was designed to support product, promotion, pricing and advertising decisions.

In 1974, Gordon DAVIS, a Professor at the University of Minnesota, published his influential text on Management Information Systems. He defined a Management Information System as "an integrated, man/machine system for providing information to support the operations, management, and decision-making functions in an organization". Davis's Chapter 12 was titled "Information System Support for Decision Making" and Chapter 13 was titled "Information System Support for Planning and Control". Davis’s framework incorporated computerized decision support systems into the emerging field of management information systems.

In 1995, KLEIN and METHLIE noted that "a study of the origin of DSS has still to be written. It seems that the first DSS papers were published by PhD students or professors in business schools, who had access to the first time-sharing computer system: Project MAC at the Sloan School, the Dartmouth Time Sharing Systems at the Tuck School. In France, HEC was the first French business school to have a time-sharing system (installed in 1967), and the first DSS papers were published by professors of the School in 1970".

1.3.6.2. Definitions

Definitions of decision support systems range from: "interactive computer based systems that decision makers utilize data and models to solve unstructured problems" (GORRY and MORTON, 1971) to "Any system that makes some contribution to decision making" (SPRAGUE and WATSON, 1986). MALCZEWSKI (1997) states that SDSS is an interactive, computer-based system designed to support a user or group of users in achieving a higher effectiveness of decision making while solving a semi-structured spatial decision problem.

A decision is a choice between alternatives. The *alternatives* may represent different options of action based on different hypotheses among which a choice is desirable based on some criteria. *A criterion* is some basis for a decision that can be measured and evaluated. It is the evidence upon which a decision is based. Criteria can be of two kinds: constraints, that exclude any kind of action and factors that act in favour of a specific decision. A decision is based on a set of rules by which criteria are combined to arrive at particular decision (SPRAGUE 1980; SPRAGUE and CARLSON 1982). Decision rules are structured in the context of a specific objective, for example, to determine which area is suitable for a given activity. To meet a specific objective it is frequently the case that several criteria will need to be evaluated (Multi-Criteria Evaluation).

The decision support field is the "development of approaches for applying information systems technology to increase the effectiveness of decision makers in situations where the computer can support and enhance human judgement in the performance of tasks that have elements which cannot be specified in advance" (SOL 1983).

Decision support systems must provide integration of information and feedback loops to support investigation in the quest for scientific discovery. The intangible factors in the decision making process may be accounted for through information supplied and choices made by a decision-maker who operates the SDSS interactively or through an analyst (LEVINE and POMEROL 2005).

The above suggest that spatial decision support systems may be developed as general-purpose tools for decision-making (GOODCHILD and DENSHAM 1990). The spatial decision support systems have been extensively and adequately covered in the literature (GOODCHILD and DENSHAM 1990; CRAIG and DAVID 1991; DENSHAM 1991; MOON 1992; NCGIA 1992). According to DENSHAM (1991) and GEOFFRION (1983), Decision Support Systems has six characteristics:

− Explicit design to solve problems;

− Powerful and easy-to-handle user interface;
− Ability to flexibly combine analytical models with data;
− Ability to explore the space analysis solution by building alternatives;
− Capability of supporting a variety of decision-making styles; and
− Allowing interactive and recursive problem solving.

The distinguishing capabilities and functions of spatial Decision Support Systems are to:

− Provide mechanisms for the input of spatial data
− Allow representation of the spatial relations and structures
− Include the analytical techniques of spatial and geographical analysis
− Provide output in a variety of spatial forms, including maps

Notwithstanding, in the specialised literature (HOLSAPPLE and WHINSTON 1996) DSS is mainly viewed as a mathematical technique or a set of techniques for decision making by optimising something under some specific constraints, we consider SDSS in its broad meaning as an information system that can be used to support decisions at spatial level. By SDSS we mean the integration of all the methods and tools that can be useful to build up a decision support system for spatially related problems. The system needs the following components: GIS, Data analysis and Image processing, modelling and Expert systems, Simulation and Optimisation, Multi-Criteria Decision Analysis and a suitable User Interface (FEDRA and FEOLI 1998)

The ultimate objective of a computer based spatial decision support system **for integrated ecosystem management** is, or should be, to improve planning and decision making processes by **providing useful and scientifically sound information to the actors involved in these processes, including public officials, planners and scientists, and the general public**.

SDSS components:

A Geographic Information System (GIS) is designed as a computer tool to efficiently capture, store, update, manipulate, analyse, and display all forms of geographically referenced information (e.g., ESRI). A GIS typically links data from different sets, using geo-referencing, for example, spatial coordinates, as a common key between the data set.

Data Analysis and Image processing: the maps obtained by GIS may be seen not only as cartographic representations of a classification of the landscape at the end of an analytical process, but mainly as data sources for the landscape spatial pattern analysis through the many different indices of the landscape structure such as shape, fragmentation, fractal, diversity, etc. (EBDON 1977; TURNER 1989; MILNE 1991; GARDNER and O'NEILL 1991; FABBRI 1991; BAKER and YUNMING 1992; CULLINAM and THOMAS 1992; GUSTAFSON and PARKER 1992; OLSEN *et al.* 1993). Many GIS have internal data analysis and image processing systems that can calculate different pattern indices. Some GIS such as IDRISI, ILWIS, GRASS (see MALCZEWSKI (1999) for a comparison between different GIS) have the possibility to treat remote sensing data (Image processing) coming from LANDSAT, SPOT, NOAA, etc. however there aren't GIS including data analytical and statistical techniques that are able to classify specific Operational Geographic Units (OGU) according CROVELLO (1981). The classification may be obtained by applying the clustering algorithms (ORLÓCI 1978; LEGENDRE and LEGENDRE 1983; GOODALL and FEOLI 1988) or other multivariate techniques. FEOLI and ZUCCARELLO (1996) treat this aspect. GIS can manage different OGUs to obtain maps.

Modelling and expert systems: in GIS, the basic concept is one of location, of spatial distribution and relationship; basic elements are spatial objects. In environmental modelling, by contrast, the basic concept is one of state, expressed in terms of numbers, mass, or energy, of interaction and dynamics; the basic elements may be biological, chemical, and environmental media such as air, water or soil.

In a Multi-Criteria Evaluation (MCE), an attempt is made to combine a set of criteria to achieve a single composite basis for a decision according to a specific objective (EASTMAN *et al.* 1995). Decisions about the allocation of land typically involve the evaluation of multiple criteria according to several, often conflicting-objectives (EASTMAN *et al.* 1995). Making-decisions about the allocation of land is one of the most fundamental activities of resource development (UNESCO 1993). With the development of GIS, we now have the opportunity, for a more explicitly reasoned process of land-use evaluation (TUČEK 1994).

The advantage of MCE is that it provides a flexible way of dealing with qualitative multi-dimensional environmental effects of decisions (MUNDA 1995).

Although a variety of techniques exist for the development of weights for the criteria, one of the most promising would appear to be that of PAIRWISE comparisons developed by SAATY (1980) in the context of a decision making process known as the Analytical Hierarchy Process (AHP). In the PAIRWISE comparison method the decision-maker is asked to give the relative importance to the criteria by comparing them two by two.

Multi-Objective Evaluation (MOE): while many decisions we make are prompted by a single objective, it also happens that we need to make decisions that satisfy several objectives. A Multi-Objective problem is encountered whenever we have two candidate sets (i.e., sets of entries) that share members. These objectives may be complementary or conflicting in nature (CARVER 1991). In case of complementary objectives, multi-objective decisions can often be solved through a hierarchical extension of the multi-criteria evaluation process. For example, we might assign a weight to each of the objectives and use these along with the suitability maps (see figure 1.3.6.2) developed for each to combine them into a single suitability map indicating the degree to which areas meet all of the objectives considered (VOOGD 1983; KRČ 2006).

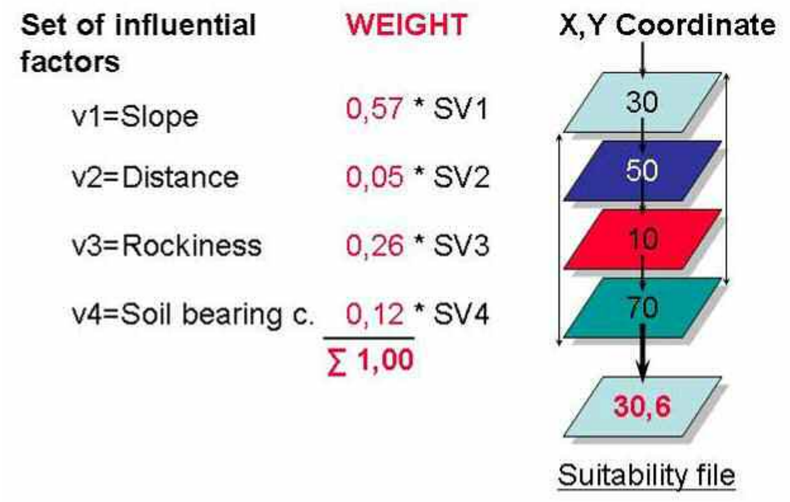


Figure 1.3.6.2: Example on how suitability files are derived by KRČ (2006) in his model selecting the most suitable skidding mean. It is based on a weighted linear combination of factors and a square reciprocal matrix of pairwise comparison between the criteria.

However, with conflicting objectives the procedure is more involved. With conflicting objectives, it is sometimes possible to rank order to objectives and reach a prioritised solution (ROSENTHAL 1985). In these cases, the needs of higher ranked objectives are satisfied before those of lower ranked objectives are dealt with. However, this is often not possible, and the most common solution to conflicting objectives is the development of a compromise solution. Undoubtedly the most commonly employed techniques for resolving conflicting objectives are those involving optimisation of a choice function such as mathematical programming (FEIERING 1986) or goal programming (Ignizio 1985). In both, the concern is to develop an allocation of the land that maximises or minimises an objective function subject to a series of constraints.

1.3.6.3. Principles of SDSS

The DDM paradigm: the technology for a DSS must consist of three sets of capabilities in the areas of ***dialog***, ***data***, and ***modeling*** (the DDM paradigm) (SPRAGUE and WATSON, 1996). A well-design SDSS should have balance among the three capabilities.
The components of SDSS are three:

- the ***Data Base Management System*** (DBMS) which contains the functions to manage the ***geographic data base***;
- the ***Model Base Management System*** (MBMS) which contains the functions to manage the ***model base***;
- the ***Dialog Generation and Management System*** (DGMS) which manages the interface between the user and the rest of the system.

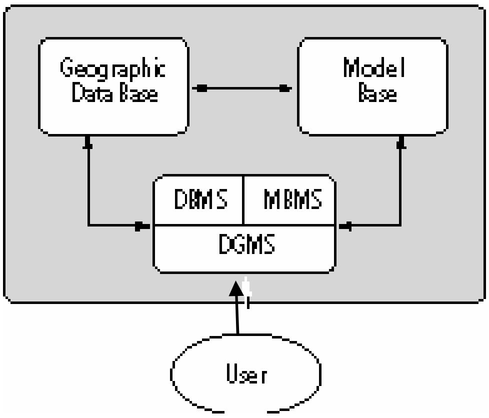


Figure 1.3.6.3: the components of SDSS

There are different technologies for developing SDSS (CROSSLAND *et al.* 1995; MALCZEWSKI 1997):

- ***DSS tools*** facilitate the development of either a DSS generator or a specific DSS; examples include:
  - procedural programming languages and code libraries (e.g., Arc Macro Language (AML) scripting tool of ARC/INFO, Avenue - ArcView GIS software's built-in object-oriented scripting language, TransCAD - Caliper Script macro language, MapInfo - MapBasic);
  - visual programming language (e.g. STELLA II, Cantata and Khoros);
  - inter-application communication software (e.g. dynamic data exchange (DDE), object linking (OLE), open database connectivity (ODBC));
  - simulation languages and software (e.g. SIMULINK, SIMULA);
  - application programming interfaces (API) (e.g. the IBM's geoManager API, Java Advanced Imaging API, TransCAD's API);
  - applets (e.g. GISApplet, Microsoft Visual J++),
  - visual interfaces, graphics and color subroutines (e.g. graphical user interfaces - GUI).

Table 1.3.6.3: the functions of SDSS

Components	Functions
DATA BASE AND MANAGEMENT	• ***Types of data*** o locational (e.g. coordinates) o topological (e.g. points, lines, polygons and relationships between them) o attributes (e.g. geology, elevation, transportation network) • ***Logical Data Views*** o relational DBMS o hierarchical DBMS o network DBMS o object-oriented DBMS • ***Management of Internal and External Databases*** o acquisition / manipulation o storage / directory o retrieval / queries / integration
MODEL BASE AND MANAGEMENT	• ***Analysis*** o goal seeking o optimization o simulation o what-if • ***Statistics and forecasting*** o exploratory spatial data analysis o confirmatory spatial data analysis o time series o geo-statistics • ***Modeling decision maker's preference*** o value structure o hierarchical structure of goals, evaluation criteria, objectives and attributes o pairwise comparison o multi-attribute value/utility o consensus modeling • ***Modeling uncertainty*** o data uncertainty o decision rule uncertainty o sensitivity analysis o error propagation analysis
DIALOG MANAGEMENT	• ***User friendliness*** o consistent, natural language comments o help and error messages o novice and expert mode • ***Variety of dialog styles*** o command lines o pull-down menus o dialogue boxes o graphical user interfaces • ***Graphical and tabular display*** o visualization in the decision space (high-resolution cartographic displays) o visualization in the decision outcome space (e.g. two and three-dimensional scatter plots and graphs, tabular rapports)

- ***DSS generator*** is a package of related hardware and software which provides a set of capabilities to quickly and easily build a specific SDSS; examples include:
  - GISystems (e.g. ARC/INFO, ArcView, ARCNetwork, Spatial Analyst, MapObjects LT, GRASS, IDRISI, MapInfo, TransCAD);
  - database packages (e.g. dBase, Access, Paradox);
  - decision analysis and optimization software (e.g. LINDO, EXPERT CHOICE, LOGICAL DECISION);
  - statistical and geo-statistical software (e.g. S-PLUS, SPSS, SAS);
  - simulation (e.g. Spatial Modelling Environment);
- ***Specific DSS*** are systems devoted to the analysis of a particular set of decision problems; the systems which actually support the decision makers in tackling semi-structured problems; examples include:
  - Active Response Geographic Information System;
  - IDRISI Decision Support;
  - GeoMed;
  - Spatial Group Choice;
  - winR+GIS Spatial Decision Support.

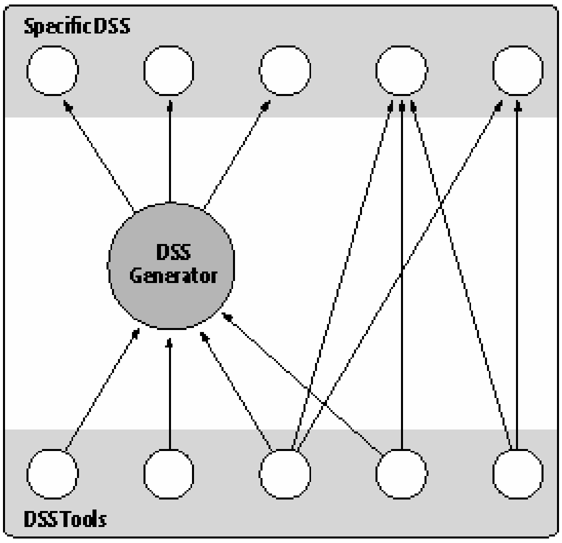


Figure 1.3.6.3.2: Three levels of DSS technology (Sprague and Watson, 1996)

2. AIM

Planning forest harvesting systems is a complex undertaking. Many factors must be considered: the physical characteristics of the terrain, the forest stand, the climate, the forest management and sylvicultural plans, the product, labor, logging equipment and the method of measuring production (FAO 1977). All the factors have been studied according to the typical mountainous alpine Italian forest and considered while building a Spatial Decision Support Model (SDSS) for planning forest operations. The model was conceived as a GIS tool, working on GIS ArcMap software, and user friendly as much as possible to be shared with other researchers. Consequently to its building phase, a validation and a sensitivity analysis were carried on to verify results. The model, called Forest Operations Planning (FOpP), would be useful not only at the assessment stage, but also when analyzing the road network and its influence on logging costs (for example when evaluating a new forest road project).

3. METHODS

3.1. TERRAIN EVALUATION AND GRADEABILITY

Systematic terrain classification for forestry was originally started after World War II in the Nordic countries, particularly in Norway (AA.VV. 1961; ANDERSON 1985; BONASSO 1989). During the last two decades numerous proposal for characterization and classification of forest land have been submitted. In several countries (Norway, Sweden, United Kingdom, Northern Italy) terrain classification has already been in use for scientific and practical purposes for years (LÖFFLER 1984). For more than a decade FAO, the Joint Committee and IUFRO have been attempting to unify or make comparable at least the various approaches, so far, however, without success. After preparatory work by ROWAN (1977) the Joint Committee started another attempt in 1978. In accordance with IUFRO a group of experts, composed of members from Canada, the United Kingdom, the Federal Republic of Germany, Finland, Yugoslavia, Norway, the Soviet Union, Sweden and the United States of America, was formed and commissioned to elaborate a proposal for a terrain classification system for forestry. The report (LÖFFLER 1984) is the results of several consultations and written contributions.

3.1.1 Terrain classification for forestry – definition and purposes

The technical possibilities are limited and the cost of forest operations are influenced by the accessibility of forest land. Due to this relation the kind and intensity of the management and treatment of forests also depend upon accessibility. In this context forest operations include all operational field activities necessary to establish or re-establish, to tend, to protect, to open up and to harvest forests. As pointed out by SAMSET (1971 and 1975) accessibility is a function of:

- the transport conditions or infrastructure on the one hand, and of
- the terrain conditions between the transport lines on the other hand.

Transport conditions or infrastructure means the connection of a forest area with the public transport network as well as the internal opening up of a forest area by means of transport lines, mainly by roads. Terrain classification (for forestry) is understood as the characterization and grouping of forest land according to the accessibility or, in other words, according to the degree of difficulty and to the possibilities and limitations of forest operations. In some cases terrain classification is seen in a narrower sense and restricted merely to the characterization of the terrain conditions, i.e. without considering the infrastructural situation.

For numerous purposes terrain classification is a necessary or at least a useful instrument in the science and practice of forestry. Following the example of a similar list of the British Forestry Commission (ANONYMOUS 1975), three groups of application with different requirements as to the size of the areas to be characterized and to the minuteness of detail of description and classification can be distinguished:

- **Long-term management planning**, referring to areas of medium (management unit, forest enterprise) or large size (region, province, country) taking only the permanent and "average" or "normal" terrain conditions into consideration and with low to medium requirements with regard to the accuracy and detail of terrain description.
- **Medium-term** operational planning, referring mainly to areas of medium size and with medium requirements as to accuracy and intensity of terrain characterization.
- **Short-term operational planning**, working site assessment and follow-up, dealing with the planning and control of activities to be carried out in the near future or already executed, related to small areas (individual and identifiable working sites), with medium to high requirements as to accuracy and detail (figure 3.1.4.c and 3.1.4.d) and with the necessity to consider the up-to-date terrain conditions.

The importance of a uniform or at least comparable terrain description and classification for exchange of knowledge and experience on an international level may be pointed out in particular. Information on performance and cost of equipment and operational activities cannot be interpreted and transformed to other situations unless the conditions on which they have been obtained are mentioned (BEKKER 1969; BERG 1992). So far many valuable data cannot be utilized elsewhere, since information on the terrain and infrastructural conditions are missing or not comparable.

Types of terrain classification systems

The scientific findings and practical experience indicate clearly that one has to distinguish between:

- a descriptive or primary terrain classification system, and
- functional or secondary terrain classification systems.

A descriptive or primary terrain classification system describes and classifies forest land according to the terrain features influencing the degree of difficulty of forest operations. Functional or secondary terrain classification systems describe and classify forest land with regard to the possibilities and limitations of operational methods and technical equipment.

A functional terrain classification refers always to a defined operation or equipment. Typical and commonly used functional terrain classification systems are for example the grouping of forest land according to the trafficability for off-road vehicles like tractors and skidders, or according to the workability of the soil and the applicability of soil preparation and planting equipment respectively. For functional classification systems the very different regional and local conditions and needs have to be considered. Besides, with the development of technical equipment and working methods functional systems become out of date, and new techniques require the adjustment and modification of functional classification. A descriptive terrain classification system must provide the possibility to characterize and classify the terrain with different intensity and consequently with varying degrees of generalization. In order to guarantee this flexibility, it is recommended that two classification levels should be envisaged (IUFRO 1967; SAMSET 1971):

- a macro description of terrain or regional terrain classification or classification on the reconnaissance or upper level, and
- a micro description of terrain or local terrain classification or terrain classification on the lower level,

each of them to be applied separately or combined and each of them to be worked out with varying degrees of intensity.

Terrain parameters are properties of the terrain which determine the degree of difficulty and the possibility and limits of forest operations and are used for characterization and classification of the terrain. In relation to temporal variability the terrain parameters can be differentiated as follows:

- permanent or invariable features
- features subject to seasonal variations (affected by weather conditions)
- features subject to medium- to long-term changes (decay of stumps and logging residues, construction of new roads)

It depends upon the purpose of the classification, which state of the variable features has to be considered. As a rule for medium- to long-term planning purposes the “average” or “normal” state of features subject to seasonal variations should be taken as a basis. “Average” or “normal” conditions mean: normal moisture conditions in summer and frost- or snow-free ground. In the case of short-term operational planning, working site assessment and follow-up the variable features must be considered, if at all, in the state at the time the operation will be carried out. An entire picture of the operational conditions in an area (accessibility) requires, in addition, information on the infrastructural situation.

The underlined terrain parameters in table 3.1.1.a have been considered as factors influencing the choice of the skidding system inside the model. All others may be also included but they are sometimes redundant or their importance is less then the difficulty to find data about. On the next pages, terrain parameters used inside the model will be deeply explained.

3.1.2 Terrain parameters

Macro description and Classification of terrain

Climatic conditions

The factor climate is to be described by the following obligatory features:

climatic zone, distinguishing arctic, sub-arctic, temperate, sub-tropical and tropical

climatic type (maritime or continental)

For more detailed characterization optional features may be used: mean annual precipitation, mean annual temperature, number of days per year with frost and snow cover. These data are usually given by regional environmental agencies (e.g. ARPAV) for free or paying a small fee. If possible it would be better to use specific data of meteo-station near the place of planning.

Table 3.1.1.a: terrain parameters on macro and micro classification level. The underlined factors are included in the model functioning.

Upper classification level		**Micro classification level**	
Terrain parameters		Terrain parameters	Variability
Macrotopography		*Ground conditions*	
-cumulated slope class frequency -macrotopography class		-soil strength class (according to texture and drainage conditions and possibly to bulk density)	Seasonal variations
Climatic conditions		-soil depth	Invariable (permanent)
-climatic zone -climatic type		-strenghtening factors (roots, ets…)	Medium-term changes
-mean annual rainfall		-frost	Seasonal variations
-mean annual temperature -number of days per year with frost -number of days per year with snow cover		*Ground roughness* -ground roughness class (according to size and height of permanent obstacles)	Invariable (permanent)
Geology		-temporary obstacles (logging residues, stumps)	Medium-term changes
-parent material -mode of formation		*Slope conditions*	
Ground conditions		-slope gradient (inclination) class	Invariable (permanent)
-prevailing (textural) soil class		-shape or type of slope -length of slope	Invariable (permanent)
-prevailing drainage conditions		*Infrastructure*	
Infrastructure		-off-road transportation distance class	Medium- to long-term changes
-forest infrastructure (density of truck roads inside forest) -public infrastructure		*Snow conditions*	Seasonal variations

Geology and ground conditions

For reasons of operational oriented terrain classification information about the geological situation (parent or genetic material and mode of formation of the soil material) is valuable, but of less importance, however, as compared to the factors macro-topography, climate and ground conditions. If the geological situation is described this should be done according to the following rules:

-as to the parent (genetic) material the customary terms might be used

-as to the mode of formation of the soil material the following terminology, proposed by Canadian Resource Analysis Branch (GOLOB 1978; TSAY 1979; MELLGREN 1980b), can be applied:

A Anthropogenic
C Colluvial
E Eolian
F Fluvial
I Ice
L Lacustrine
O Organic
R Bedrock
S Saprolite
V Volcanic
W Marine
U Undifferentiated

Within the scope of macro description the terrain factor “prevailing soil class” is to be typified by one of the following four soil classes:

1 coarse-textured soils	(gravel and coarse sand, sand, loamy sand)
2 medium-textured soils	(sandy loam, fine sandy loam, very fine sandy loam, silt loam, loam, clay loam, silty clay loam)
3 fine-textured soils	(silt, sandy clay, silty clay, clay)
4 organic soils	(content of organics more than 30%)

In the case where other classes than the predominant one occur on a noticeable percentage of the area (more than 10%), this should be noted.

Micro description and Classification of terrain

The classification on the lower (or micro) level is intended to serve the following purposes:

- to characterize smaller areas which as a rule are delineated on the map and in the field respectively and consequently are identifiable,
- to give a statistical breakdown on the terrain conditions (terrain classes) of large areas, based on the classification of sample plots using the rules of micro classification.

While terrain classification on the upper or reconnaissance level in formal and taxonomic respect (macro description) is a more verbal description, it is recommended, in principle, to use terrain condition classes at the level of micro classification (LÖFFLER 1984).

Soil strength class

First of all, trafficability of soils, which is the capacity of the ground to support vehicular off-road movement or the interaction of vehicle and soil, and the workability of soils, which means the interaction of soil working tools and the soil, should be recorded. Finally, a classification of ground conditions should provide information concerning the main behavior of soils from the civil engineering point of view (construction of forest roads) and the sensitivity of soils to compaction and erosion as far as influenced by and depending upon soil conditions. These soil or ground properties are first of all a function of soil strength and consequently soil strength should be used as main criterion for the characterization and classification of ground conditions within the scope of a descriptive terrain classification system. However, to classify forest soils according to soil strength causes considerable difficulties:

- even amongst the experts diverging opinions exist as to which method should be used to measure soil strength and how it should be expressed numerically (CBR-value, cone index, modulus of elasticity as received by the plate bearing test, parametric methods like bevameter, etc…)

- until now little was known about the strength of forest soils

Agreement has been reached at least to the point where soil strength, as it is understood in that connection, is correlated with the following physical properties of a soil:

- soil type (soil texture)
- soil moisture content and soil drainage conditions respectively
- soil dry density (bulk density)
- soil depth (depth of unconsolidated material)
- strengthening factors like stoniness, roots and slash cover

With the present knowledge and experience, ground condition may be classified with 5 classes:

- very strong
- strong
- medium
- weak
- very weak.

According to the (prevailing) texture of the surface layer (30 cm) and to the drainage conditions a soil is classified in one of the aforementioned classes:

a) Gravelly	(gravels, loamy gravels, gravelly sands)
b) Sandy	(sands, loamy sands)
c) Coarse loamy	(sandy loams and loams with less than 18% clay)
d) Fine loamy	(silt loams and loams with more than 18% clay loams, clay loams)
e) Clayey	(sandy clays, silty clays, clays)
f) Organic	(muck and peat)

The soil drainage classes refer to the frequency and duration of periods when the soil is free of saturation or partial saturation. The classes indicate the combined influence of precipitation, runoff and ponding, soil permeability and internal soil drainage. The classes are used extensively in pedology and soil surveying as a means of characterizing the seasonal soil moisture variations (AA.VV. 1975). The definitions of the drainage classes are as follows:

- *Excessively drained* – water is removed from the soil very rapidly, commonly due to very porous soil or a combination of porous soil and slope and steep slope. Soils are free of gley mottles indicative of wetness, and are seldom saturated
- *Well drained* – water is removed from the soil readily, but not rapidly. Porosity is sufficiently rapid and/or infiltration sufficiently slow to prevent saturation except for a few brief periods following the heaviest rainfalls. Soil is free of gley (gray) mottles.
- *Moderately well drained* – water is removed from the soil somewhat slowly, in most soils of this type because of a slowly permeable layer deep in the soil, a high water table, or additions of water through seepage. Soil has gley mottles deep in the profile, usually between 1.5 and 2.5 m, and is saturated for short periods.
- *Imperfectly drained* – water is removed from the soil slowly enough to keep it saturated for significant periods, but less than half the time in the average year. Gley mottles are present in the upper 1.5 m of the soil.

- *Poorly drained* – water is removed so slowly that the soil remains saturated for a large part of the time. Gley colors are dominant in the upper 1.5 m of the soil.
- *Very poorly drained* – water is removed from the soil so slowly that the water table remains at or near the surface the greater part of the time. Areas of these soils are frequently ponded. Gley colors dominate.

If it is impossible here to go into details of soil physics and soil mechanics. The basic soil strength classification may be used flexibly in the following way:

- the five main strength classes can be further sub-divided by forming sub-classes
- the classification according to the rules of soil strength conditions may be varied
- soil drainage classification should be derived from the descriptive classification

The information necessary to assess the ground conditions can be obtained by ad hoc investigations of soil samples, but here were derived from already existing soil classifications developed for other purposes (soil stability).

<u>Ground roughness</u>

Ground roughness is determined by the size (height) and incidence of obstacles (Samset 1975; Mellgren 1980). The term obstacle refers to:

- depressions that have hard edges and are well defined. Relative to ground level, a depression must be at least 0.2 m. Depressions with an average diameter greater than six times the depth are not included, unless the edges are very sharp.
- Stones, boulders and ground obstructions at least 0.1 m high. The following rules are applied to accumulations of stones and rocks.
- RULE 1: a stone, whose centre is closer to that of an adjacent, larger stone than the height of the larger stone, is not counted

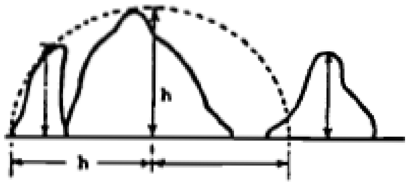


Figure 3.1.2.a: on the left side, the stone in "shadow" of larger stone is not counted; on the right side, the centre of the stone (imaginary centre of gravity) is outside the "shadow" of the larger stone: counted.

- RULE 2: a stone whose centre is closer to the circumference of an adjacent, larger stone than twice its own height, and whose height is less than a quarter of that of the larger stone, is not counted.

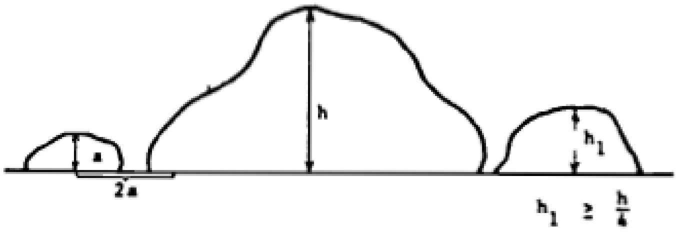
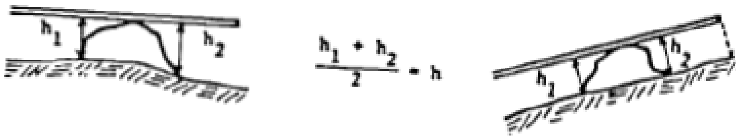


Figure 3.1.2.b: on the left: the center of this smaller stone is closer than twice its height to the circumference of the larger stone, not counted. On the right side, the height of the smaller stone is more than a quarter of that of the larger stone, counted.

The height of an obstacle is determined by taking the mean value of two measurements (Rowan 1977; Löffler 1984):



Stumps and logging residues, which will be degraded in time, are not counted as obstacles in the context of a descriptive terrain classification.
Obstacles are classified as follows:
1) by height:

Height class	H20	H40	H60	H80	H100	H130
Limits (m)	0.1-0.3	0.3-0.5	0.5-0.7	0.7-0.9	0.9-1.1	1.1-1.5

2) by incidence (Terlesk 1983):

	Distance between obstacles (m)	Number of obstacles per ha
Isolated	> 16	< 40
Infrequent	5 to 16	40 – 400
Moderately frequent	1.6 to 5	400 – 4000
Frequent	< 1.6	> 4000

Based on size (height) and incidence of obstacles the ground roughness class of an area may be assessed according to table 3.1.2.a.

Table 3.1.2.a: assessment of ground roughness class. The obstacle density considers the number per hectare and average distance between obstacles.

<table>
<tr><th colspan="4">Height class</th><th rowspan="2">Ground roughness class</th><th rowspan="2"></th></tr>
<tr><th>H20</th><th>H40</th><th>H60</th><th>H80+</th></tr>
<tr><td>Infrequent (40-400/ha; 5-16 m)</td><td colspan="3">Isolated (< 40/ha; > 16 m)</td><td rowspan="2">1</td><td rowspan="2">Smooth</td></tr>
<tr><td rowspan="2">Moderately frequent (400-4000/ha; 1.6-5 m)</td><td colspan="3">No other classes represented</td></tr>
<tr><td>Infrequent (40-400/ha; 5-16 m)</td><td colspan="2">Isolated (< 40/ha; > 16 m)</td><td rowspan="2">2</td><td rowspan="2">Slightly uneven</td></tr>
<tr><td rowspan="2">Frequent (> 4000/ha; < 1.6 m)</td><td colspan="3">No other classes represented</td></tr>
<tr><td>Moderately frequent (400-4000/ha; 1.6-5 m)</td><td>Infrequent (40-400/ha; 5-16 m)</td><td>Isolated (< 40/ha; > 16 m)</td><td>3</td><td>Uneven</td></tr>
<tr><td colspan="3">Moderately frequent (400-4000/ha; 1.6-5 m)</td><td rowspan="2">Infrequent (40-400/ha; 5-16 m)</td><td rowspan="2">4</td><td rowspan="2">Rough</td></tr>
<tr><td colspan="2">Frequent (> 4000/ha; < 1.6 m)</td><td>Infrequent (40-400/ha; 5-16 m)</td></tr>
<tr><td colspan="4">All surfaces with ground roughness more difficult than that of class 4</td><td>5</td><td>Very rough</td></tr>
</table>

Figure 3.1.2.c: example of terrain roughness on the Italian North-eastern alpine study area. On the left side a smooth terrain and on the right a very rough surface.

Inside the model, a simplified version of ground roughness classification (table 3.1.2.b) was used according to Hippoliti and Piegai (2000).

Table 3.1.2.b: ground roughness as considered by the model

Surface occupied (%)	Obstacle dimension (m)	Max distance (m)	Class	
If not defined	If not defined	If not defined	0	-
< 33	< 0.5	> 2.5	1	Smooth
33 - 66	< 0.5	< 2.5	2	Uneven
> 66	> 0.5	< 2.5	3	Rough

Slope conditions

Slope conditions are characterized by:

gradient (inclination) as main and obligatory parameter

shape or type pf slope and length of slope as optional factors

The gradient is given as a percentage or in degrees. It should be measured (assessed) over horizontal distances of approximately 25 m in the direction of the maximum inclination, i.e. perpendicular to contours.

Slope classes may be determined from the gradient values recorded as in table 3.1.2.c.

Table 3.1.2.c: slope gradient classes (Rowan 1977; Löffler 1979)

Slope class	Gradient percent	Gradient degree	Designation
1	0 – 10	0 – 6	Level terrain
2	10 – 20	6 – 11	Gentle terrain
3	20 – 33	11 – 18	Moderate terrain
4	33 – 50	18 – 27	Steep terrain
5	> 50	> 27	Very steep terrain

For smaller areas with more or less uniform relief, specific terms may be used (figure 3.1.2.d) (SAMSET 1971).

In the case of larger areas with irregular relief, for example with a heterogeneous slope pattern, the characterization used in the Norwegian terrain classification (KIELLAND-LUND 1963; CARLSSON *et al.* 1969; SAMSET 1975) can be applied (figure 3.1.2.e).

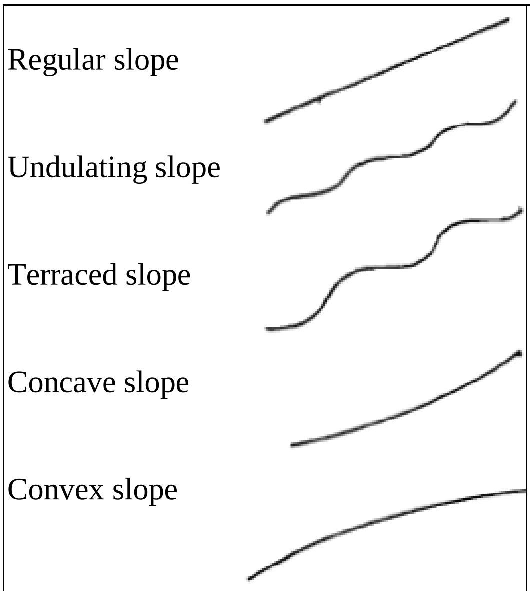


Figure 3.1.2.d: relief description

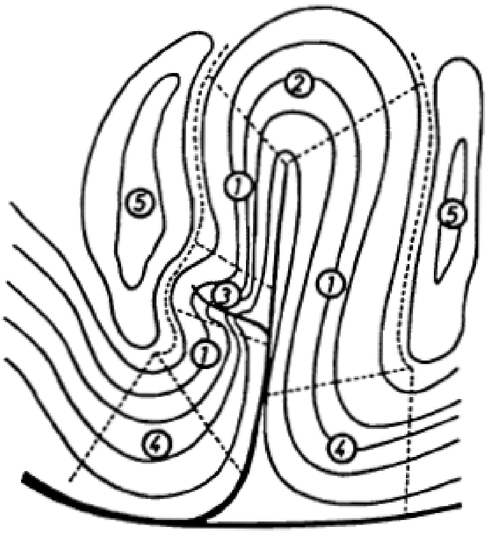


Figure 3.1.2.e: large areas irregular relief description. 1) Uniform hillsides, 2) Basinshaped hillsides, 3) Close valleys, 4) Coneshaped hillsides, 5) Plateaux

The slope length is classified according to:

- the uninterrupted length, i.e. the overall length of a slope from the bottom to the top or to a forest (truck) road, regardless of terraces, ditches, etc…
- the interrupted length, i.e. the most frequent length of regular stretches of slope between terraces, ditches, etc…, occurring within the overall length. This interrupted length is usually regarded as a marginal class.

The length of a slope may be classified according to the following scale

Class 1	25 – 100 m
Class 2	100 – 200 m
Class 3	200 – 300 m
Class 4	300 – 700 m
Class 5	> 700 m

Off-road distance class

On the level of micro classification the infrastructural conditions may be characterized best by the mean off-road transportation (skidding, extraction) distance, which is defined as the average distance between stum-site and the next forest (truck) road or storage place for further transportation. The range of the off-road transportation distance is grouped into classes as follows:

Class 1	< 100 m
Class 2	100 – 250 m
Class 3	250 – 500 m
Class 4	500 – 1000 m
Class 5	> 1000 m

For a very exact description, as on the occasion of scientific studies (machines productivities), it might be recommendable to report the concrete value. The mean (realistic) off-road transportation distance can be achieved in two ways:

- by direct measurement on the topographical map according to the point-grid method suggested by SEGEBADEN *et al.* (1964)
- by an indirect way with the help of road density (RD in m/ha) and road spacing respectively and road network factor (f) appropriate to the area under consideration. The mean off-road transportation distance (TD) is then:

$TD = (f \cdot 250) / RD$ [m]

3.1.3 Gradeability

The complete terrain description and classification of an area (a site, a sample plot, etc..) under operational aspects is represented by the terrain condition or accessibility class. To this, the classes (and additional information) of the single features are combined in the following sequence and importance: ground conditions, ground roughness, slope conditions, infrastructure and snow conditions. As an example, the terrain description on the micro level might be represented by a number sequence (table 3.1.3.a and figure 3.1.3.a):

2.3.3.4 where 2 means strong soil
3 means uneven surface
3 means moderate terrain
4 means off-road transportation (distance between 500 and 1000)

Table 3.1.3.a: functional classification for use of harvesting machinery (terrain limitations). Numbers refer in order to ground condition class, ground roughness class and slope class.

Type of equipment	Off-road movement on slopes un-restricted (parallel contour)	Off-road movement restricted	
		Downhill only	Uphill only
	Worst terrain class on which machine can be expected to operate		
Agricultural tractor	2/3.2.2	3.3.3	2.3.2
Skidder	3.3.3	3.4.4	3.4.3
Forwarder	3.2/3.3	3.3/4.4	3.3/4.3
Crawler tractor	3/4.3.3	4.4.4	4.4.3/4
Cable cranes	5.5.5		

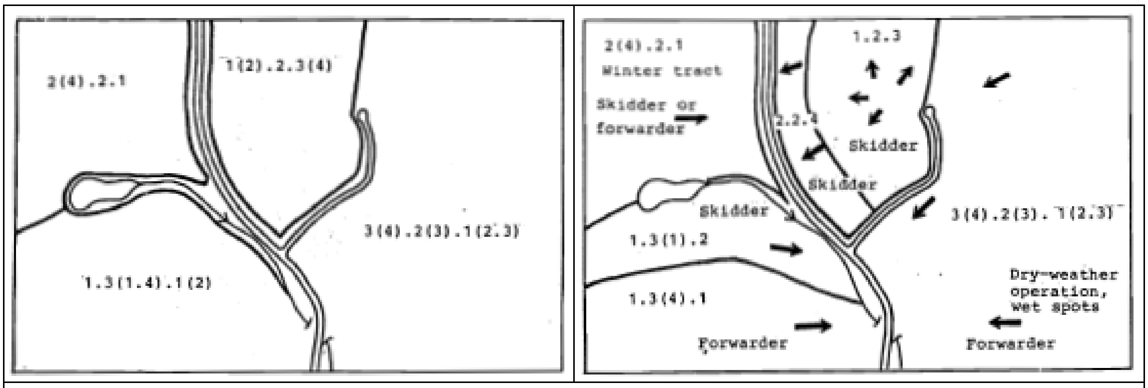


Figure 3.1.3.a: on the left a long-term activity planning, on the right a detailed operational planning. Reference to terrain strength, ground roughness and gradients (LÖFFLER 1984)

To evaluate performance characteristics of off-road vehicles, different criteria were proposed such as drawbar performance, transport productivity and maximum feasible operating speed (WONG 1993). Mobility is a multidimensional concept which considers vehicle performance in relation to terrain stability, obstacle and slope negotiation, water crossing, and ride quality (WONG 1993). To evaluate performance of carriers on slopes, an analysis of relationships between vehicle parameters, slope negotiation, and terrain properties is of primary importance (BONASSO 1989; HEINIMANN 1999). Terramechanics offers three basic approaches to this analysis: (1) empirical, (2) analytical, and (3) numerical (computer aided, see WONG 1994). Analytical and numerical models are based on the plastic equilibrium theory and require a parametric description of the soil's plastic behaviour. In keeping with the work of BEKKER (1956 and 1969) usually five soil parameters must be determined. This limits covering the variability of soil properties in space and time.

Therefore empirical approaches based on characterizing soil properties by the **Cone Index** (CI) are more suitable and were used for the current analysis. Following engineering design equilibrium principles, single wheel and single track conditions may be formulated, respectively, as shown below:

For powered uphill motion,

$$\frac{1}{\gamma_r} \cdot R_{thrust} = \left[F_{slope} + F_{acc} + F_{tow}\right] \cdot \gamma_F \qquad [1]$$

for braked downhill motion,

$$\frac{1}{\gamma_r} \cdot R_{thrust} = \left[F_{slope} - F_{acc} - \left(F_{tow}\right)\right] \cdot \gamma_F \qquad [2]$$

and for powered downhill motion

$$\frac{1}{\gamma_r} \cdot R_{thrust} = \left[-F_{slope} + F_{acc} + F_{tow}\right] \cdot \gamma_F \qquad [3]$$

where R_{thrust} = Thrust resistance of the soil
F_{slope} = Slope action (driving effect of gravity on an inclined plane)
F_{acc} = Acceleration action (a·mass)(a > 0 acceleration, a < 0 deceleration)
F_{tow} = Soil action against moving of a wheel/track (towing)
γ_r = Resistance factor
γ_F = Action factor

Downhill motion requires two equilibrium conditions [1] and [2] considering that the towing action F_{tow} can become greater than the sum of the slope action F_{slope} and the deceleration action F_{acc}.

Gradeability was analyzed to evaluate performance of carrier platforms based on the work of BRIXIUS (1987) for wheeled, and HALEY *et al.* (1979), for tracked vehicles. Figure 3.1.3.b presents the relationships between gradeability, soil properties and wheel/track characteristics.

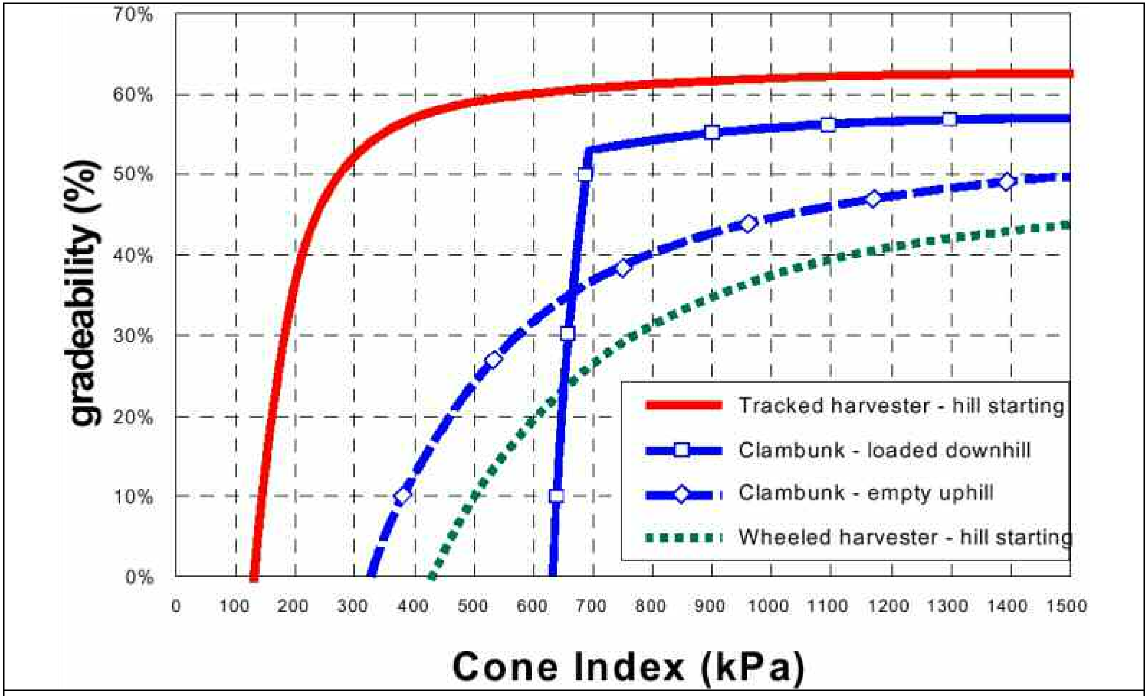


Figure 3.1.3.b: gradeability for tracked and wheeled carriers as a function of soil properties (Cone Index).

The underlying vehicle parameters are typical for the IMPEX "Bengal Tiger„ tracked harvester, the FMG Timberjack 1270B wheeled harvester (600/55-26.5 tires), and the FMG 1710 clambunk skidder (800/40-26.5 tires). The derived gradeability curves agree quite well with figures of WONG (1993). In most textbooks on forest operations, limits of mobility are provided in terms of maximum negotiable slope gradient.

Results in figure 3.1.3.b show that slope gradient alone is not an adequate criterion. Soil bearing capacity must be taken into consideration, especially on soft ground conditions (WRONSKI *et al.* 1989; HEINIMANN 1999, EICHRODT 2003). Wheeled carrier harvesting systems should be applied only to soil with bearing capacities greater than 850 kPa CI (= 4.6% CBR). Wheeled harvesters may operate on slopes up to 35-45%. Wheeled extraction is limited to uphill gradeability of about 45-50%, which agrees with recommendations of LAMBERT and HOWARD (1990). Downhill transport may take place on slopes with grades up to 50%, but is strictly limited to terrain with good bearing capacity. On very soft ground conditions, soil with bearing capacities of 400 kPa CI (= 1.6 % CBR) to 700 kPa CI (= 3.3% CBR) which may be encountered on the northern slopes of the Alps, tracked harvesters should be used, whereas extraction should be done by cable systems or by helicopters. The advantage of tracked versus wheeled carriers is quite clear. However, applicability of the known vehicle configurations is limited to about a 60% slope.

The practice of forestry is more interested in functional terrain classification systems than in descriptive ones (PUTKISTO 1964; HAARLAA and ASSERSTAHL 1972). However, no consensus can be internationally achieved about functional terrain classification systems;

functional terrain classification systems can only be developed under consideration of the local and regional circumstances, and finally that functional terrain classification will generally only be appropriate for shorter periods.

The following examples (§ 3.1.4) merely demonstrate in which way functional terrain classification systems can be derived from a descriptive terrain classification. The step from the descriptive to a functional classification calls for an evaluation of the descriptive terrain classes with regard to the function in question. So for instance the relationships between terrain conditions and technical properties of the machines must be investigated and defined, or those between terrain conditions and the sensitivity to soil movement (Olsen and Wästerlund 1989; Wronski *et al.* 1989; Ziesak 2003). This can be done on the basis of experiences as well as of purposeful experiments and studies.

3.1.4 Matching systems to the area – reference examples

Several authors studied a functional classification of soils and they built their own matrices to match systems to each terrain category. They also draw simple planning maps showing technical working areas for forest utilizations, but at that time they had no powerful softwares like ArcGIS and the work was made by hand and needed a lot of observations. The most interesting examples, very near to the Forest Operations Planning presented here are those of Rowan (1977) in table 3.1.4.a and figure 3.1.4.a, 3.1.4.b, 3.1.4.c and 3.1.4.d, Mellgren (1980) shown on figure 3.1.4.e, Lüthy (1998), figure 3.1.4.f and 3.1.4.g and Spinelli and others (Forest Service 2000; AA. VV. 2002), table 3.1.4.b.

Table 3.1.4.a: probable terrain limits of forest machines. This table is the only one which consider different parameters according to the extraction direction.

Machine type		Worst terrain class on which machine can be expected to operate			Remarks
		Ground conditions	Ground roughness	Slope	
Agricultural tractor (2WD)	Uphill	3	3	2	Uphill extraction may require a reduced load
	Downhill	4	3	3	
Agricultural tractor (4WD)	Uphill	3	4	3	Load probably reduced on uphill extraction
	Downhill	4	4	4	
Forwarders	Uphill	3	4	3	Load probably reduced uphill: band-tracks essential in worst conditions
	Downhill	4	4	4	
Skidders	Uphill	3 (4)	4	2 (3)	Load probably reduced uphill: band-tracks essential in worst conditions
	Downhill	4	4	4	
Crawler tractors	Uphill	4	4	3	
	Downhill	4	4	4	
Cablecranes		5	5	5	

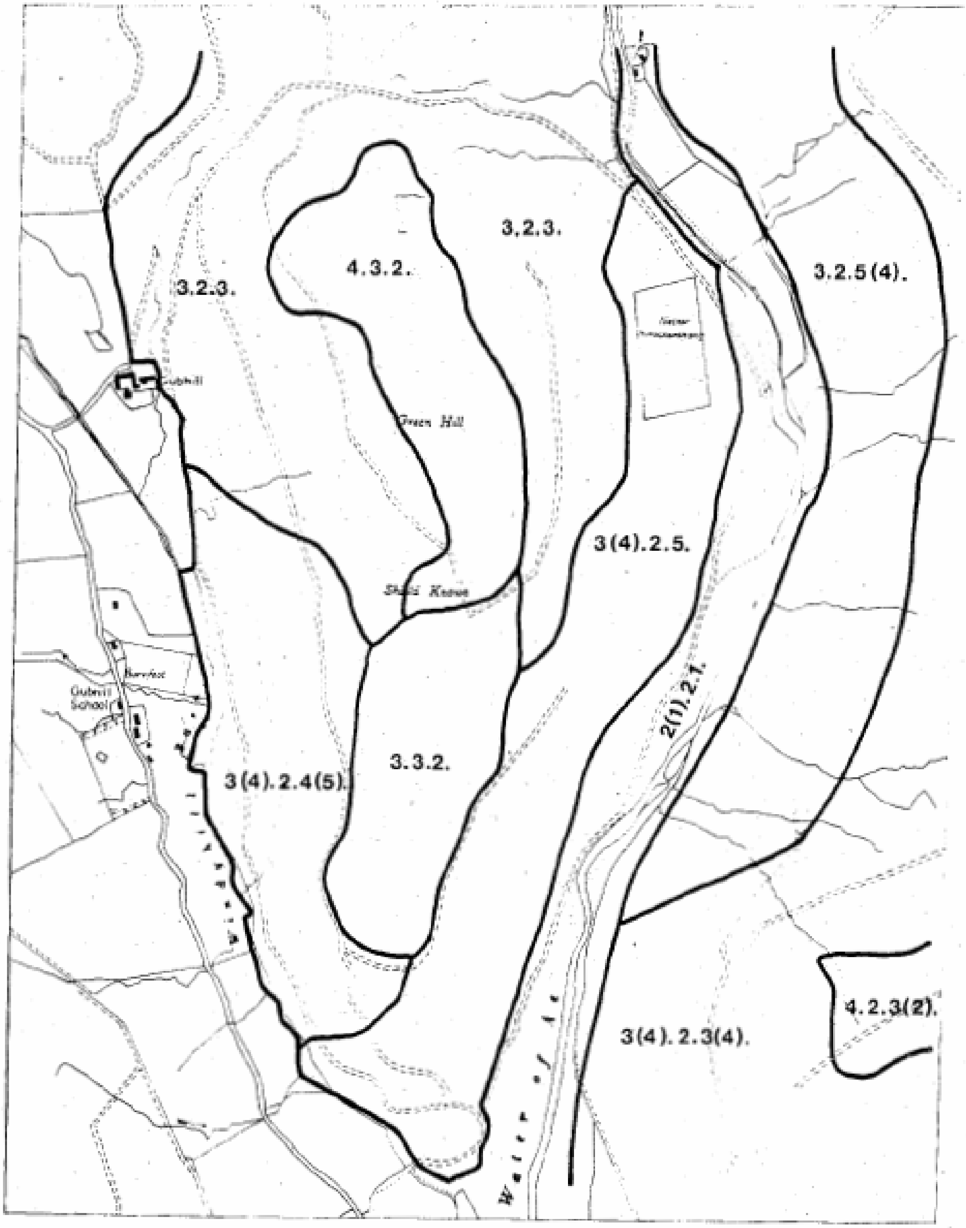


Figure 3.1.4.a: **long-term planning**, descriptive map. This map records terrain data in a fairly “broad-brush” manner, as the object is to provide information on which the choice of possible harvesting systems, and consequent road planning, can be based. So it is not necessary to record every patch of differing ground, as these will have little or no influence on the final result (ROWAN 1977).

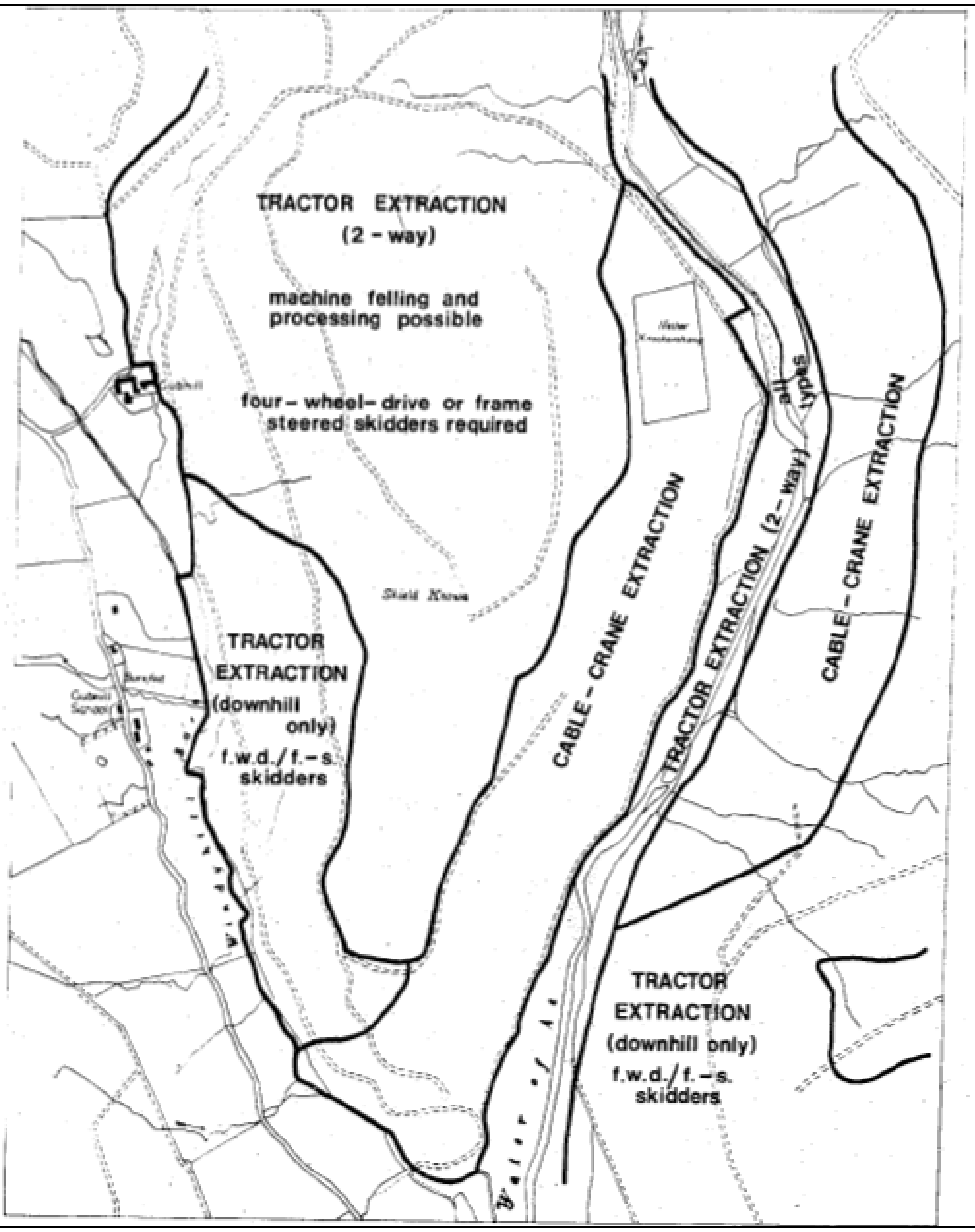


Figure 3.1.4.b: **long-term planning**, functional map. This is an example of the type of operational planning map. It could take the form of an overlay on the descriptive map (figure 3.1.4.a). Information presented on such planning maps could include: the areas which are negotiable by particular machines or machine types; the areas to be harvested by particular harvesting systems.

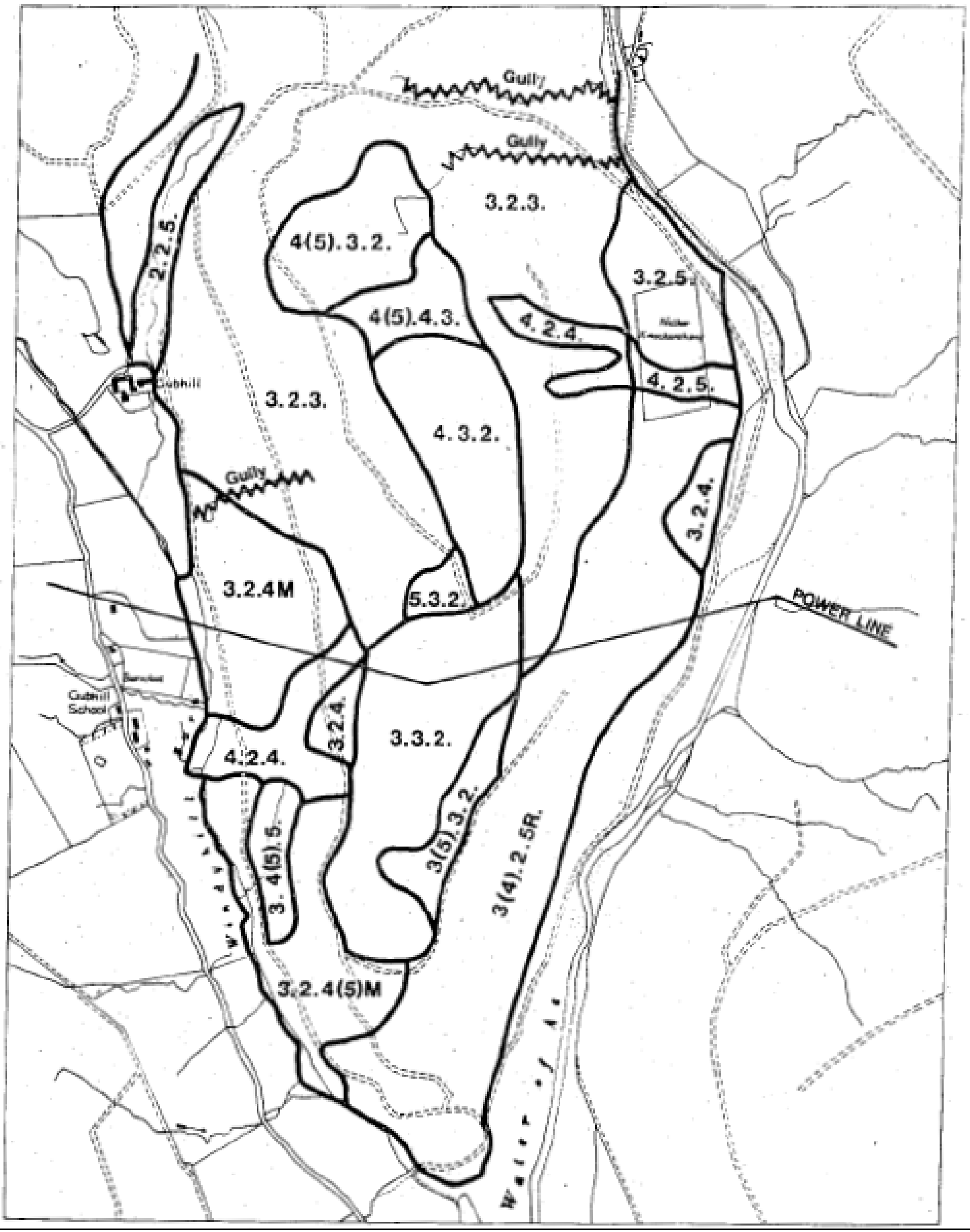


Figure 3.1.4.c: **short-term planning and operational control**: descriptive map. This records detailed terrain data on the sites on which work will be done within the next two years or so. Areas of the forest on which no work is proposed in the near future are not surveyed, and there is no attempt to obtain complete coverage of the forest initially. Information on sites on which work will be done in later years can be collected nearer the time it is required, and so there is a build-up of lasting value

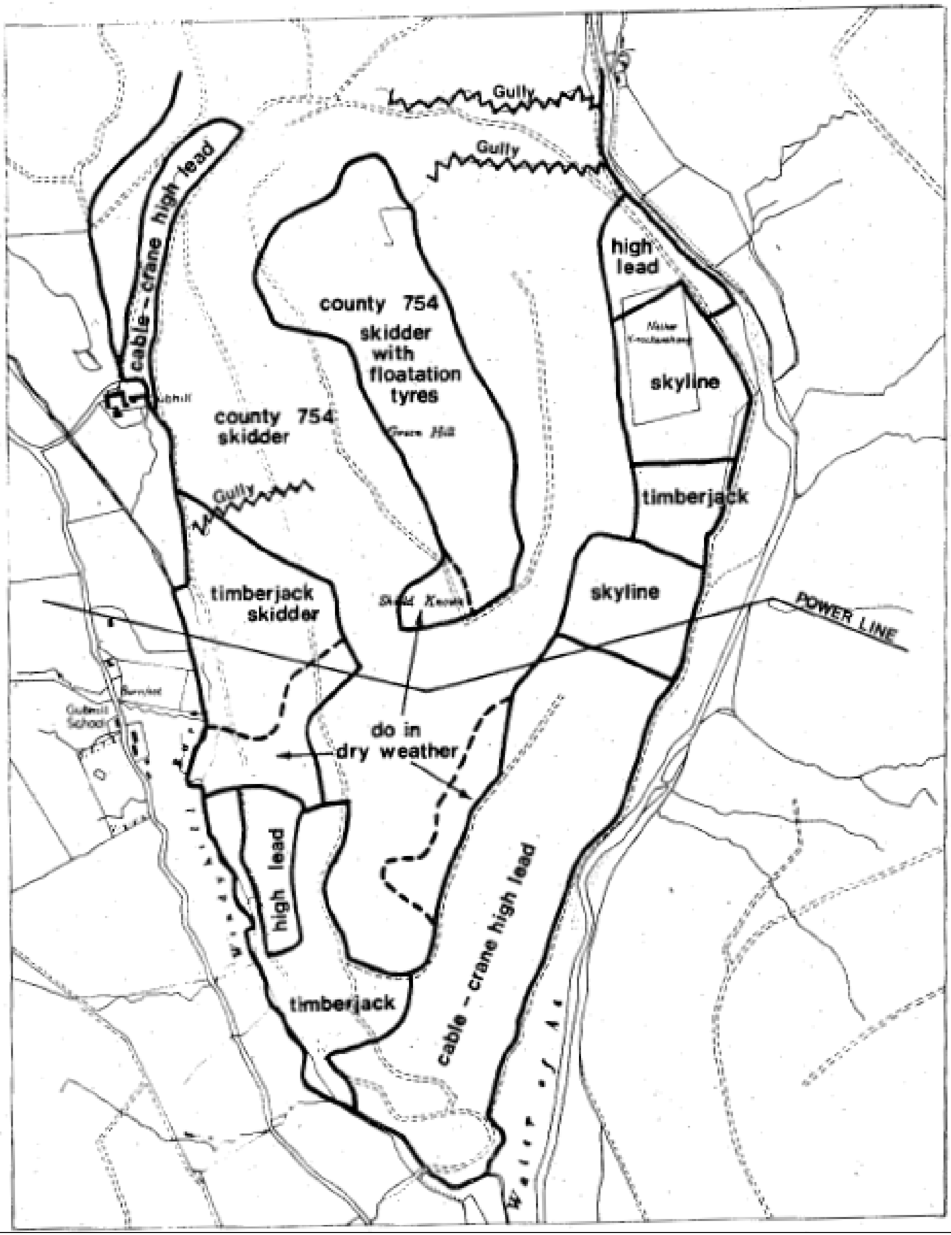


Figure 3.1.4.d: **short-term planning and operational control**: functional map. This type of maps have a limited "life". They can record a range of information, usually relating to current work, such as: defining working areas for specified machines, perhaps at a particular times of the year; planning extraction routes; defining areas where costs or incentive payments can be expected to change according to terrain features, either directly or because the terrain imposes some change in working method.

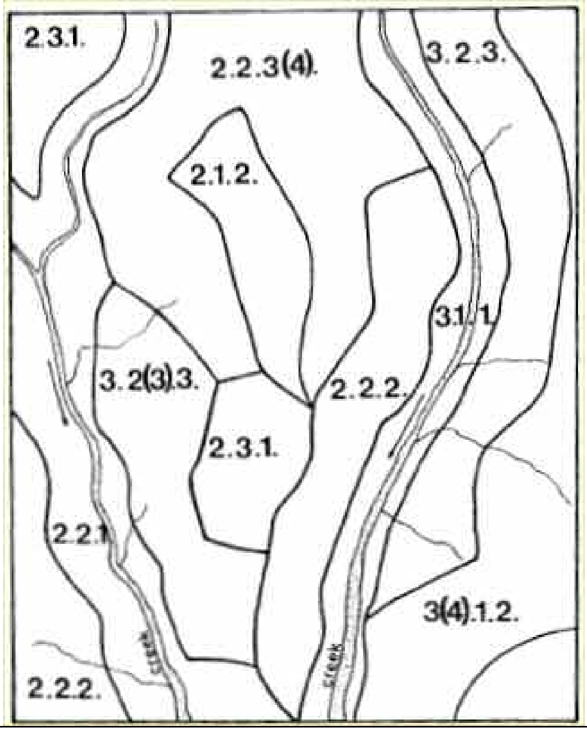


Figure 3.1.4.e: long-term planning map using terrain parameters (MELLGREN 1980).

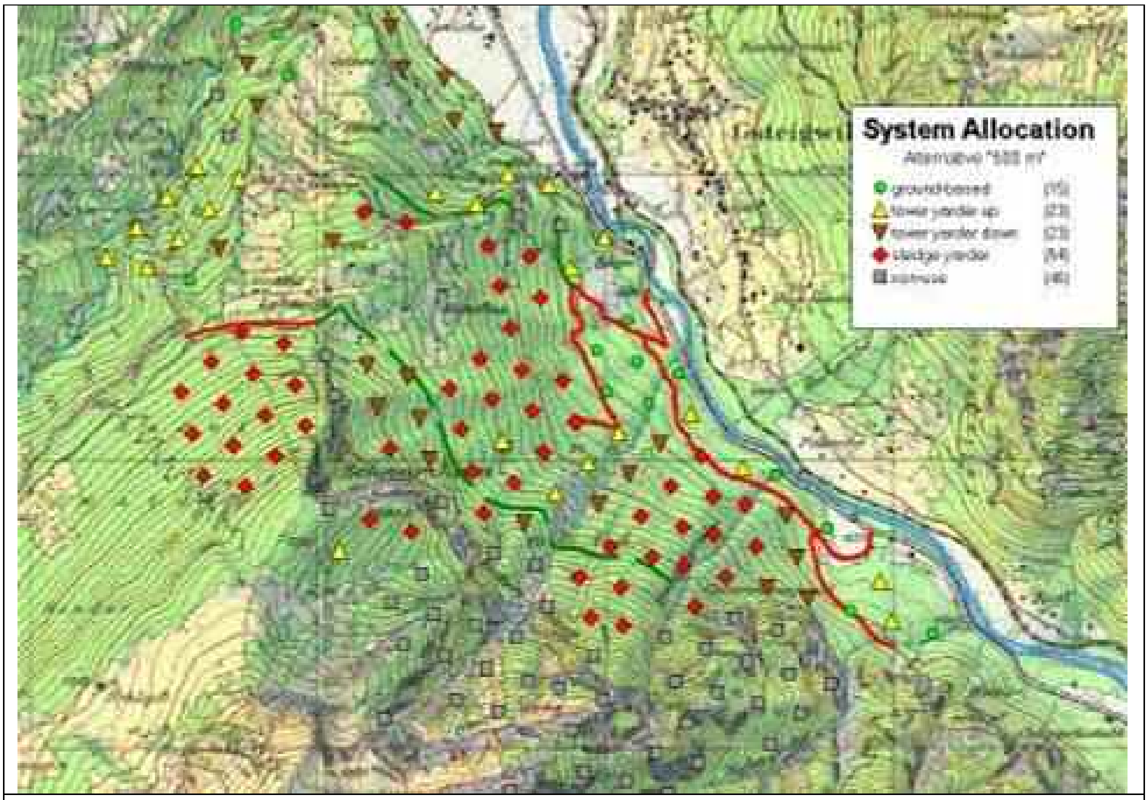


Figure 3.1.4.f: skidding systems map. This is one of the first maps created with the use of a geographical software as ArcInfo (LÜTHY 1998). The evaluation of system allocation is done on a regular grid and not on a continue surface.

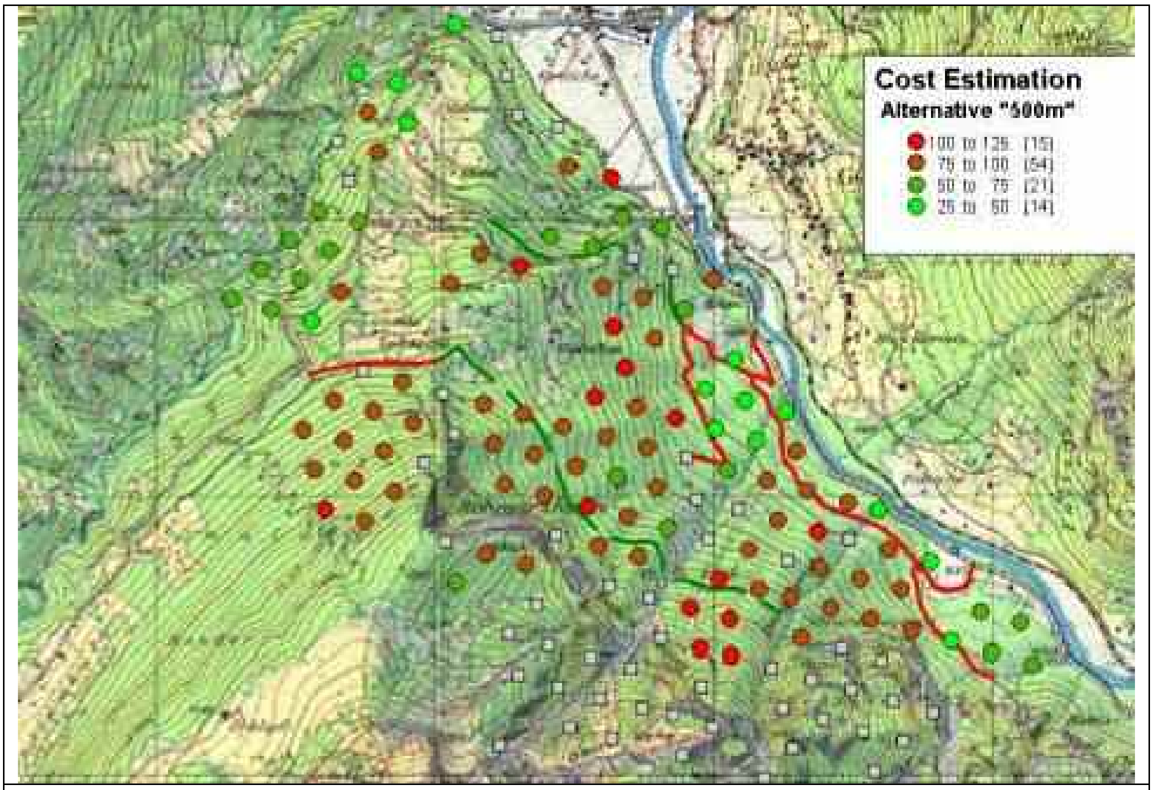
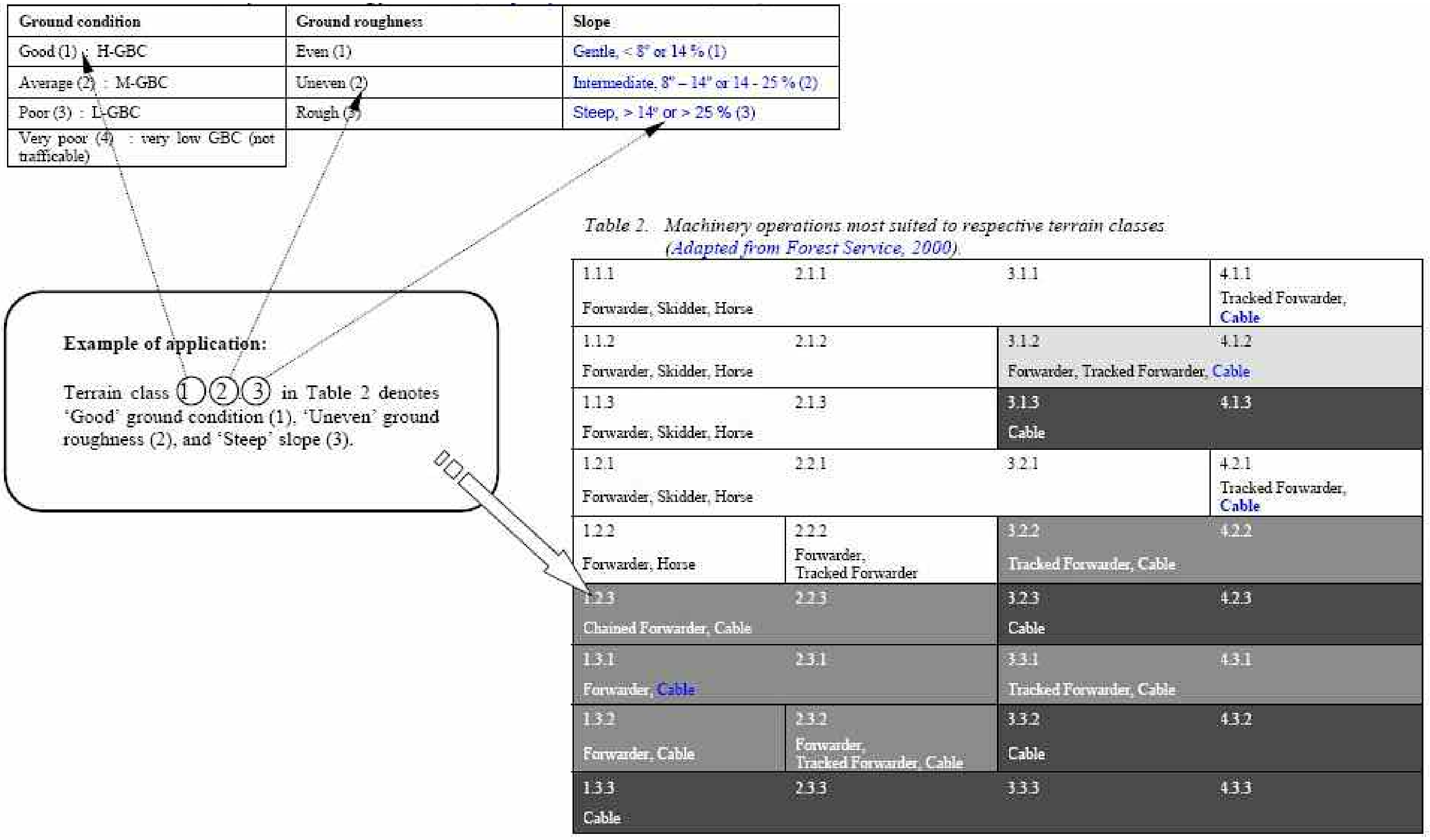


Figure 3.1.4.g: costs map. The evaluation is done point by point starting from results of figure 3.1.4.f. A simple program was built inside an excel sheet and run on the basis of input parameter set by the user (HEINIMANN 1986; LÜTHY 1998).

Table 3.1.4.b: general terrain classification scoring for Ireland (AA.VV. 2002; FOREST SERVICE 2000)



Ground condition	Ground roughness	Slope
Good (1) : H-GBC	Even (1)	Gentle, < 8° or 14 % (1)
Average (2) : M-GBC	Uneven (2)	Intermediate, 8° – 14° or 14 - 25 % (2)
Poor (3) : L-GBC	Rough (3)	Steep, > 14° or > 25 % (3)
Very poor (4) : very low GBC (not trafficable)		

Example of application:

Terrain class ①②③ in Table 2 denotes 'Good' ground condition (1), 'Uneven' ground roughness (2), and 'Steep' slope (3).

Table 2. Machinery operations most suited to respective terrain classes (Adapted from Forest Service, 2000).

1.1.1 Forwarder, Skidder, Horse	2.1.1	3.1.1	4.1.1 Tracked Forwarder, Cable
1.1.2 Forwarder, Skidder, Horse	2.1.2	3.1.2 Forwarder, Tracked Forwarder, Cable	4.1.2
1.1.3 Forwarder, Skidder, Horse	2.1.3	3.1.3 Cable	4.1.3
1.2.1 Forwarder, Skidder, Horse	2.2.1	3.2.1	4.2.1 Tracked Forwarder, Cable
1.2.2 Forwarder, Horse	2.2.2 Forwarder, Tracked Forwarder	3.2.2 Tracked Forwarder, Cable	4.2.2
1.2.3 Chained Forwarder, Cable	2.2.3	3.2.3 Cable	4.2.3
1.3.1 Forwarder, Cable	2.3.1	3.3.1 Tracked Forwarder, Cable	4.3.1
1.3.2 Forwarder, Cable	2.3.2 Forwarder, Tracked Forwarder, Cable	3.3.2 Cable	4.3.2
1.3.3 Cable	2.3.3	3.3.3	4.3.3

3.2. SKIDDING SYSTEMS AND THEIR LIMITS

3.2.1 Defining off-road vehicles and aerial systems

The first dimension of Boyd and Novak's (1977) approach, concept factors, considers machine functions. Ground-based harvesting concepts are based on carriers that are capable of moving over natural terrain. Tree felling and processing depend on the functional abilities of attachment devices and handling features (positioning, reach, lifting force, etc.). Extraction depends on load building, attachment performance, and carrying capacity.

In forest to mill transportation, the most costly portion is often from stump to landing (Silversides 1980). Therefore the system chosen for off-road transport is one of the most critical aspects of a tree harvesting system. Four principal technology paths are available for facilitating off-road transportation: ground vehicles moving on natural terrain, ground vehicles moving on skid roads, carriages moving on cable structures and airships moving in the atmosphere (Heinimann 1999). Figure 3.2.1 shows the factors differentiating these harvesting concepts.

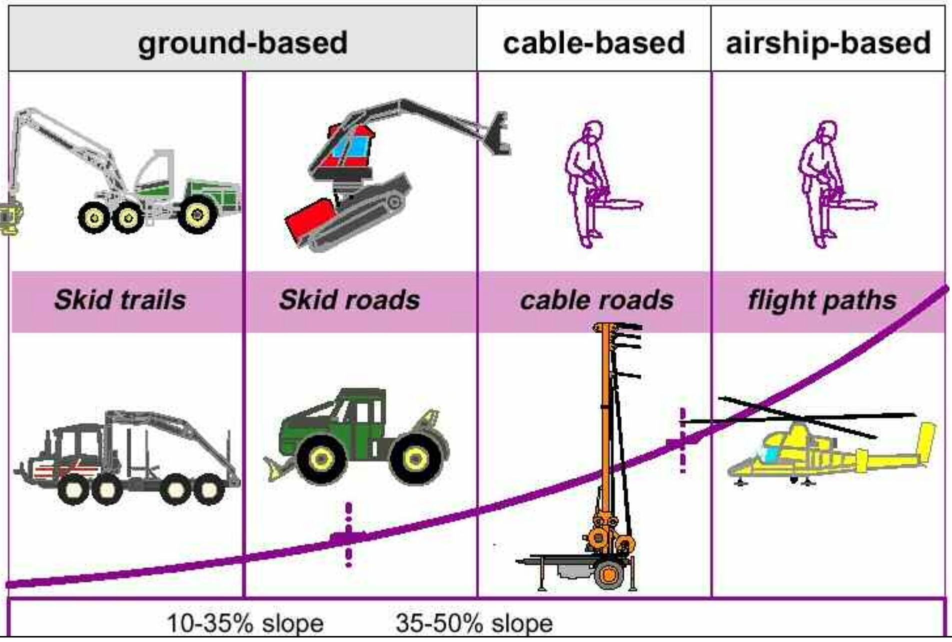


Figure 3.2.1: Differentiation of ground-based harvesting concepts and aerial systems.

As long as harvesting technology is based on ground vehicles, they are classified as *ground-based*. System complexity increases with the effort to ensure off-road locomotion. Ground vehicles may move on a path over natural terrain or, if the terrain conditions become too complex, over geotechnical structures (skid roads). If terrain conditions become too difficult, cable structures enable the transport of partially or full suspended loads over large distances overcoming various terrain obstacles. Airship-based technologies use the atmosphere as media for transport. Although at a high operational cost, helicopters have found a niche in transport for a number of site-specific situations. Cable systems and airships may be applied in all terrain conditions. Their use is limited due to economic inefficiency and to environmental disturbance (e.g. lack of energy efficiency in helicopters). Ground-based technologies are limited because of the restrictions in off-road mobility. Therefore, understanding the factors influencing mobility is absolutely essential. There are no general rules for differentiating the basic concepts of figure 3.2.1. In most textbooks and guidelines, rules of thumb are often based on slope gradient. Recent investigations based on life-cycle cost analysis demonstrated that differentiating ground-based and cable-based concepts is unclear (HEINIMANN 1998) and may be defined only for known harvesting strategy and road building costs.

3.2.2 Off-road systems

Tractor and winch

The tractor with winch system is the most spread inside Italian forest enterprises because tractor is cheap and may be adapted to the forest use with very few adjustments. Agricultural 4WD tractors are usually modified putting protections to wheels valves, increasing front weight and mounting chains (CAVALLI 1997).

The principal factors influencing its operability are the terrain slope and roughness and the infrastructures density. The terrain maximum slope is different according to the skidding direction (uphill or downhill) and if moving with or without loads.

Moving uphill, the maximum slope is about 10-20%, up to 35% if driving unloaded, with a maximum of 40% on very short road tracks. Moving downhill the maximum slope is 30%, up to 60% on well maintained roads and short tracks. Both the uphill and downhill extraction is not possible out of skidtrails and roads if the average slope is more than 20% (HIPPOLITI and PIEGAI 2000).

The terrain roughness should be very low, the ground smooth so the road network is the factor limiting forest accessibility of tractor when average slope is high. Density of temporary roads (skidtrails) in this case is also very important (CIVIDINI 1983; FABIANO 2002).

The extraction distances, within which the productivity of tractor is not badly influenced, have to be distinguished if skidding uphill or downhill. When skidding uphill, the maximum distance is 150 m, the optimal would be 100 m, while skidding downhill the maximum distances are respectively 500 and 300 meters. Tractor with winch is well adapting to many different situations, even on those cuttings with very low yield, but logs must be concentrated inside the forest stand in a way that extraction distances are not higher than the allowed ones.

Logs can be of all dimensions, usually 4 to 6 meters but bigger dimensions would be also better for optimizing the load (PIEGAI 1990). The average load size is between 0.5 to 1.5 m^3, but may be also 2 m^3 for huge machines. Productivities are influenced by many factors as the extraction distance (figure 3.2.2.a), logs dimensions (figure 3.2.2.b), skidding times, technical properties and direction and the characteristics of skidding path. As an example, daily productivities of a tractor with two operators working is 10-20 m^3 inside young forests with small diameters (thinnings), 15-30 m^3 inside forests with average dimensions and 20-40 m^3 on final cuttings (Hippoliti and Piegai 2000; Cavalli and Menegus 2003). Costs are related to working times and productivities and they are also influenced by the extraction distance (figure 3.2.2.c) and the load size (figure 3.2.2.d).

When skidding firewood it seems that there is a optimum size of pieces between 15 and 16 cm diameter (figure 3.2.2.b) because the loading is done by hand: when the size is smaller it takes longer time to fill the firewood nest (Piegai and Quilghini 1993), when chops are bigger they are also heavier and difficult to lift or handle.

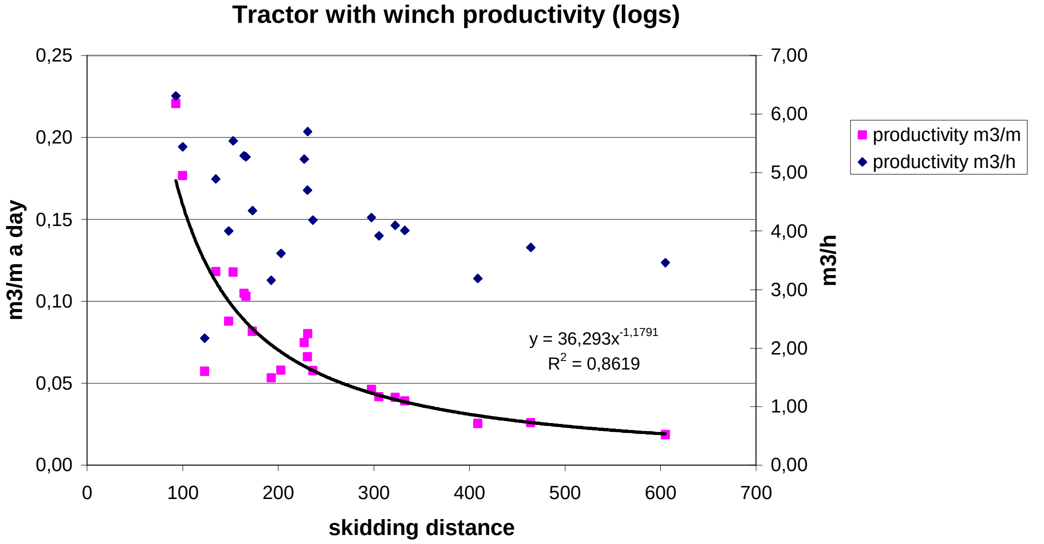


Figure 3.2.2.a: tractor productivity when skidding logs (Dellagiacoma *et al.* 2002, modified)

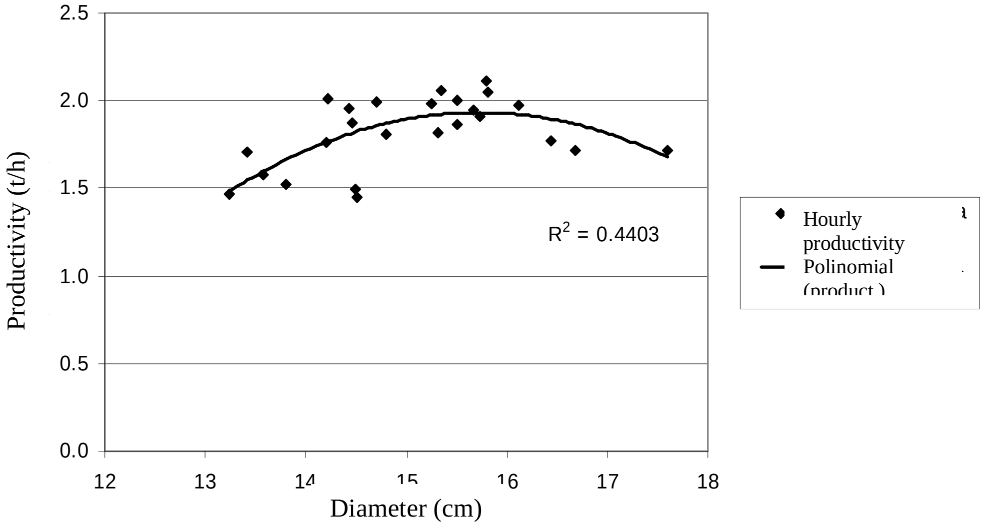


Figure 3.2.2.b: tractor productivity when skidding firewood (Rizzi 2007)

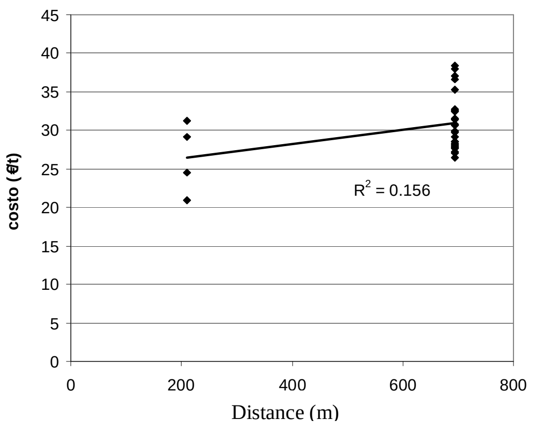


Figure 3.2.2.c: firewood skidding costs and extraction distance.

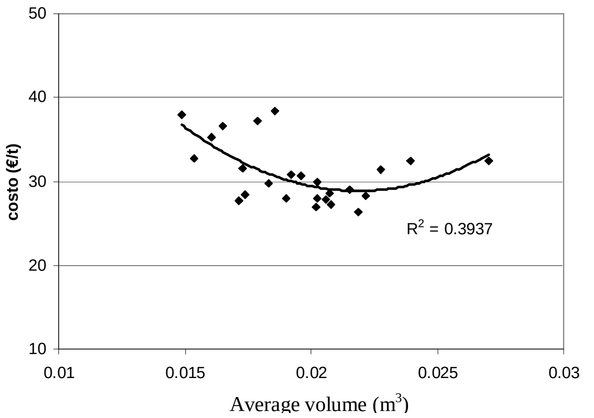


Figure 3.2.2.d: firewood skidding costs according to average chop size.

Forwarder

The forwarder is an articulate tractor composed by two units free to move and steel on the horizontal plan. On the first unit are sited the driving cabin and the engine usually very powerful, up to 170 kW. The second unit is composed by a trailer and an hydraulic boom which commands are sited inside the cabin (BIDINI 2004). This particular configuration allow easier loading and un-loading operations, decreasing the operator stress and increasing his safety. The trailer may be adjustable both in length and width dimensions adapting it to different log lengths and sizes or to stand characteristics like tree density or soil bearing capacity.

Italian forest enterprises are usually small and they have not enough money to buy a forwarder which as new may cost more than 250000 €. Moreover the yearly wood cuttings are not enough to cover fixed costs and depreciation in a short period. The use of this machine would also cause a change in the way of the working scheme and logistic that is quite difficult to realize. Few examples of people buying forwarder in Italy show that this is possible only when the enterprise has a well organized logistic and scheduled work (as Ciech in Trento province), when the machine is bought used from an other country (Sambugaro brothers in Asiago) or when regional funds cover a percentage of the selling price (Dalle Ave brothers in Asiago). The use of forwarder at its highest performance is only possible after attending a specific course and after months of practice (ACKERMAN *et al.* 2002; PURFÜRST and ERLER 2006).

The first forwarders were thought to work on open spaces and flat terrains in the Northern Europe so they did not fit inside Alpine forests because of their size. During the years new adapted smaller machines entered the market and opened to the Italian forest sector. Till now its use is still highly connected to the cuttings and the stand tree density.

As other off-ground machines, the forwarder technical limits depend on the terrain slope, roughness and extraction distance (GARDNER 1966). The uphill extraction is feasible on slopes up to 25-30%, while skidding downhill slopes may reach 40%. This ability is due to the hydraulic transmission which is spread over all traction wheels and which vary continuously (there is no gear) adapting to the terrain conditions. The wheels have a large width and a low tire pressure and they are coupled on a bogie system which limits the soil damages and increases the grip even on muddy conditions (ACKERMAN *et al*. 2002).

The terrain roughness is less influencing the forwarder than the tractor because its frame is higher from ground (more than 60 cm) due to the wheels configuration and hydraulic system. Moreover, the wheels bogies increase its agility over obstacles like rocks and stumps. Forest truck roads are not required, but the road network should be quite dense to allow the machine reaching logs at felling sites inside the forest. The cutting operations should take count of the use of forwarder and trees should be felled and bucked in a favorable direction which make easier the loading phase.

The forwarder trailer may load up to 15 tons and this make convenient also long distance extraction, but not more than 1 km (figure 3.2.2.e) because the productivity decreases and skidding is not yet cheap (GARDNER 1966; ACKERMAN *et al*. 2002). Logs can be of any dimension, but they influence productivity and costs (figure 3.2.2.f and 3.2.2.g). The time for loading and un-loading small logs is higher and the wood volume is less than that of big dimensions, so each trail may increase costs up to 40% than the average (KELLOGG and BETTINGER 1994). Usually trees are bucked at 4, 6 or 8 meters, but longer logs or full trees can be loaded according to the loading space or using some artifice.

The forwarder increased the safety of worker because he is inside a protected cabin, but new problems are introduced, for example the muscle and skeletal diseases or the psychological problems linked to the working stress, due to fast operations, and to a solitary work which brings to social relation problems (ACKERMAN *et al*. 2002). These are well know problems on countries where the use of forwarder is now common and it is more strong where the operators are shifted on a 24 h working day.

References state high productivities, from a minimum of 6 m^3/h up to 47-50 m^3/h and averages of 20 m^3/h, depending by assortments and extraction distances between 500 and 1000 m (PULKKI s.d.; ACKERMAN *et al*. 2002), but first studies in Italy (figure 3.2.2.g) show a variation between 10 and 20 m^3/h. Skidding costs are lower than 10 €/m^3, but they are depending on the log size: in fact skidding big size logs at far distances may be cheaper than skidding small logs near roads (figure 3.2.2.f).

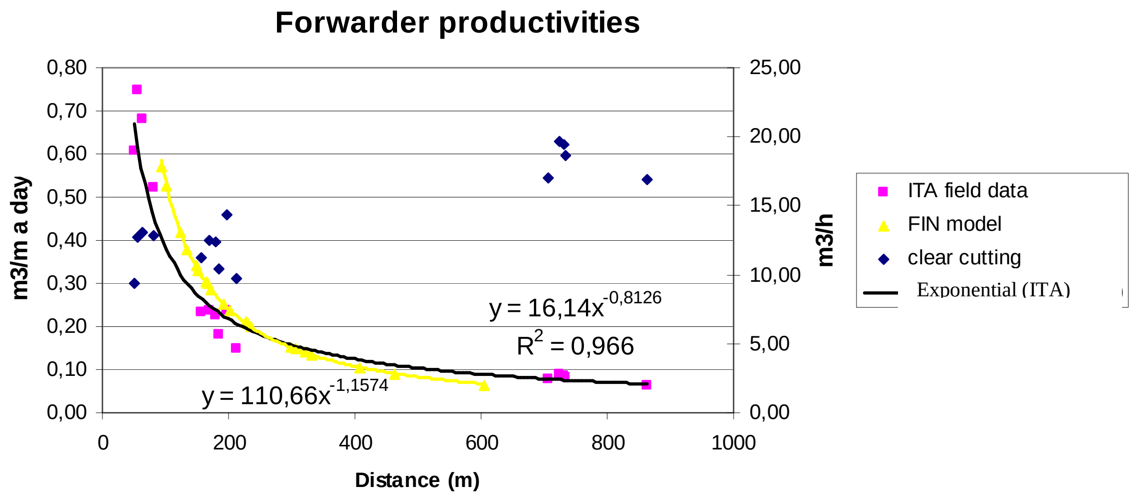


Figure 3.2.2.e: the forwarder productivity function in Italy and compared with a Finnish productivity model (Emer 2005)

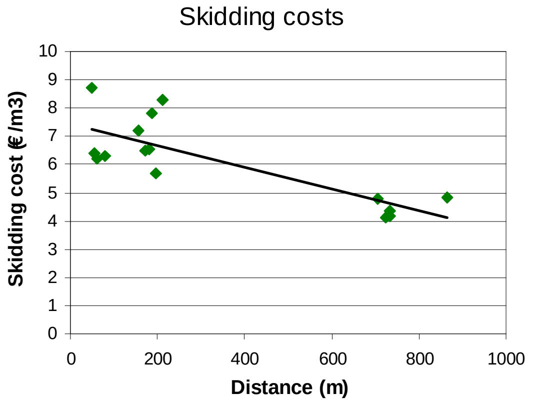


Figure 3.2.2.f: skidding costs may decrease if loading big sized logs

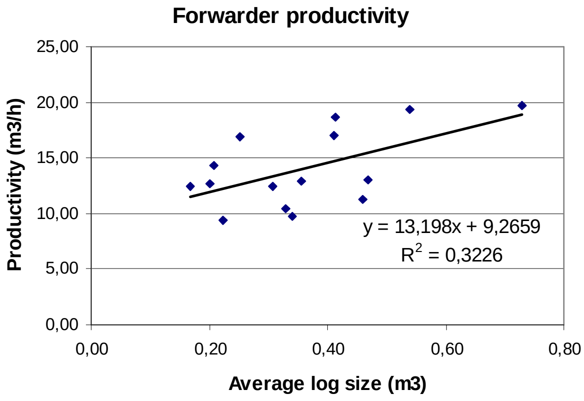


Figure 3.2.2.g: hourly productivity is influenced by the log dimensions

Cable-forwarder

Usually the forwarder begins to work two days after the harvester, drives on the same corridors, loads the logs left on the two sides (likely bunched according to homogenous assortments) and transports the load to the landing site. Due to the recurrent passages at fully loaded conditions on the same tracks, this machine, much more than the harvester, can damage the soil (compaction, rutting); anyway, negative effects are mitigated using logging debris (branches, tree tops) to reinforce the strip roads, which results in a substantial increase in soil bearing capacity (McDonald and Seixas 1997). Most recent forwarders are agile, stable and compact enough to move in the forest without specific corridors, after a motor-manually performed cut.

In Italy forwarders are usually matched with the few harvesters, mostly operating in poplar plantations. The already scarce literature about forwarders (Tufts and Brinker 1993a; Tufts and Brinker 1993b; Kellogg and Bettinger 1994; McNeel and Rutherford 1994) does not concern their application under Alpine conditions: productivities, costs and concrete limits are unknown. Their use in mountainous areas has always been hold up by the maximum negotiable slope gradient, which difficultly can be over 40%. In the Austrian literature examples of cable extraction of harvester-felled thinnings are presented (VISSER and STAMPFER 1998; HEINIMANN *et al.* 1998; STAMPFER and STEINMÜLLER 2004), but this method is not so widespread in every day's practice. Exactly in Austria, considering the need to widen forwarder's range, has recently made its appearance the so-called cable-forwarder. If pilot studies were requiring an external winch to pull up the machine (BOMBOSCH *et al.* 2003), the project has evolved to its actual state, which sees the forwarder able to self-haul up by a winch integrated in the machine; the rolling up speed of the cable is synchronized with the transmission of the vehicle. The winch is mounted behind the head board of the bunk and the cable exits from the back of the machine; once the cable is fixed on an anchor tree or stump, the forwarder can climb up along the corridor created by the harvester, negotiating slopes up to 70% without evident wheel slippage.

Before travelling uphill, the machine needs to have the cable of the winch fixed on an anchor tree or stump at the head of the corridor. The harvester pull the cable up along the first corridor, in order to spare the forwarder operator a very heavy task. The process is easier for the other corridors, because, once completed the haulage, the forwarder can use a forest ride at the head to move to the beginning of the adjacent corridor, ready to descend it loading the logs. Unhooking the cable and setting it up again on a new stump is usually requiring just few minutes. Considering the steep slope, the cable is always kept in tension while moving on the corridor, but once on the forest road the operator is loosening it in order to freely move on the road (perpendicular to the corridors) and unload the logs (CAVALLI *et al.* 2006).

Extraction distance, as evidenced in Figure 3.2.2.h, exerts a stronger influence over the productivity, confirming how a good forest road density is fundamental to carry out forest exploitation in a productive and economical way.

Figure 3.2.2.i reveals how productivity decreases with the increasing slope negotiated by the cable-forwarder. The gap, anyway, is not so noticeable (no more than 2 m^3), hence underlining the validity of the system: the use of the winch minimizes the effect of the slope on the moving of the machine. The average productivity formula is shown.

Travelling speed (both uphill and downhill) remains almost constant, thanks to the uniform pulling force of the winch.

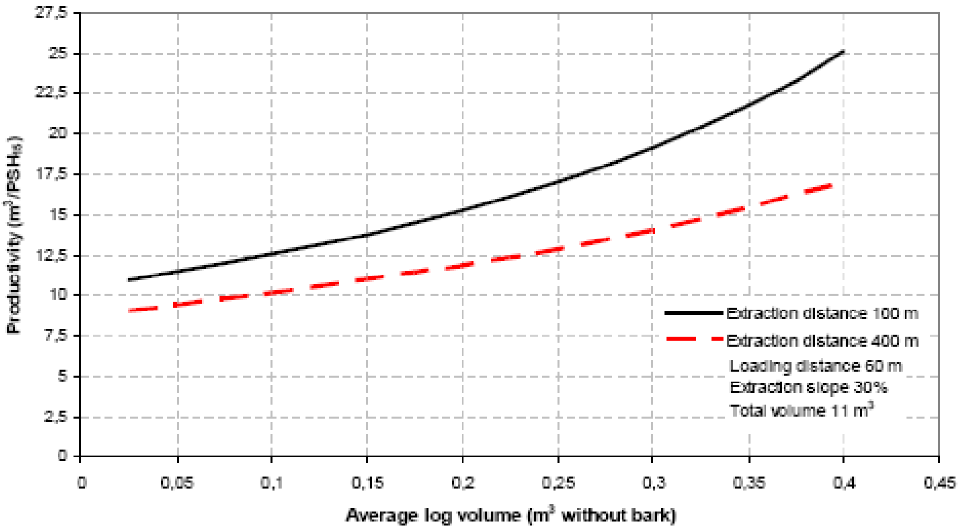


Figure 3.2.2.h: productivity of the cable-forwarder (m^3/PSH_{15}) according to average log volume and extraction distance

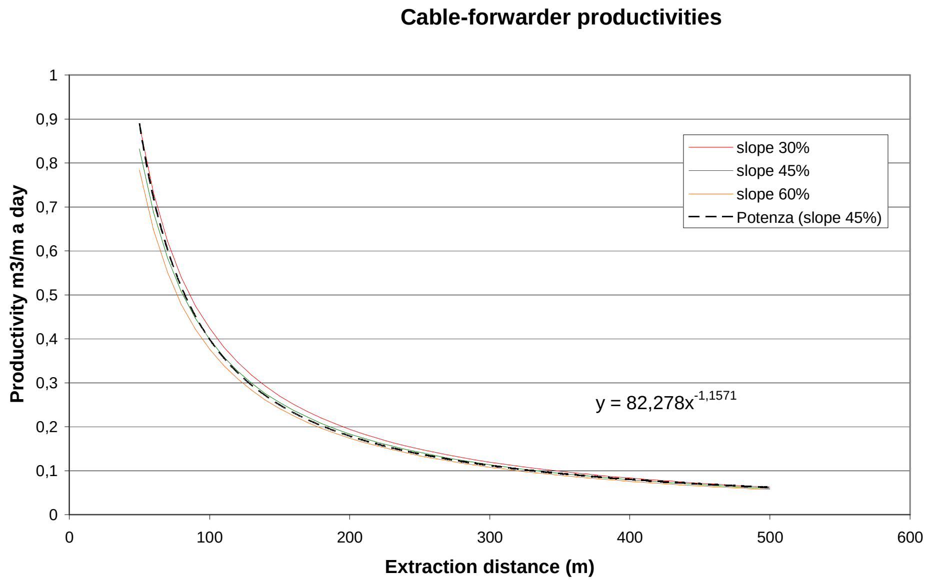


Figure 3.2.2.i: productivity functions according to extraction distance and average corridor slopes. The formula was used inside the model.

The machine hourly cost was estimated in 71.46 €. The extraction cost per cubic meter (€/m^3) derives from the quotient between the machine hourly cost (€/h) and the machine productivity (m^3/h). Figure 3.2.2.j evidences how the extraction cost decreases with the growing productivity.

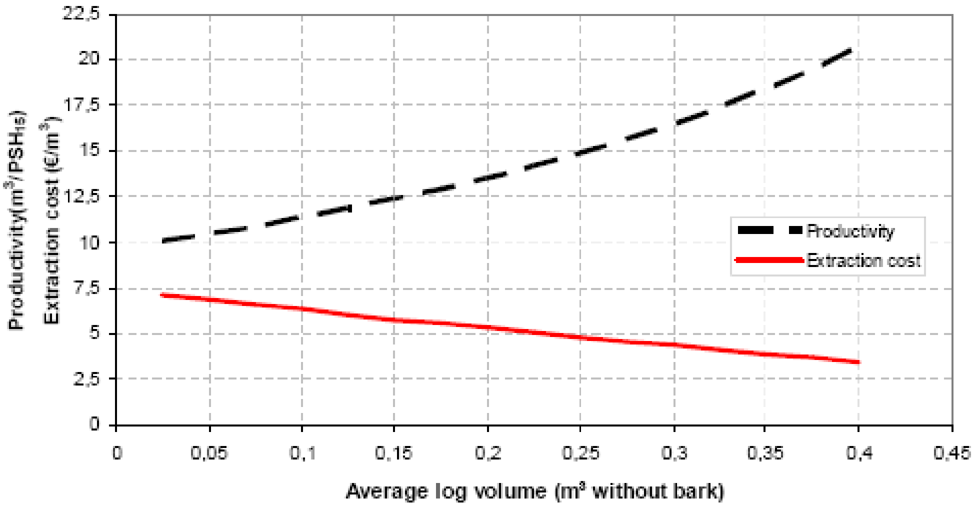


Figure 3.2.2.j: cable-forwarder productivity (m^3/PSH_{15}) and consequent processing cost (€/m^3). Hypothesis: loading distance 60m, extraction distance 270 m, extraction slope 30% and total volume 11.5 m^3.

3.2.3 Cable systems

Mobile cable systems – tower yarder

The mobile cable systems are usually composed by some drums (for the skyline, the main line and guy-lines) mounted on a compact unit and by a tower used as span support. The system may be autonomous if it is provided by an engine and mounted on a wheeled trailer, or it is carried and connected to the tractor pulling force (BORTOLI and SOLARI 1996).

Carriages can be mechanic or semi-automatic. The mobile cable cranes are the simplest, cheapest and rapid to install aerial skidding systems. They usually work with gravity skidding small size logs deriving from thinnings or coppices on short corridors (100-400 m). The lateral skidding never goes farer than 25 m (BORTOLI e SOLARI 1996). To make the system economical, the minimum yield should be at least 0.3-0.5 m^3 per linear meter (HIPPOLITI and PIEGAI 2000). The productivity may reach 5.5 m^3/h, but considering also the mounting and dismounting times it decrease to 3-3.5 m^3/h. Skidding firewood, the productivity is between 2 and 5 tons per hour being influenced by the average size of wood (figure 3.2.3.a). The difference between firewood and logs extraction is more or less 1/3 (comparing tons and cubic meters as equal), but after 200 m this becomes less evident (figure 3.2.3.b). Commonly skylines have a 14-16 mm diameter, with a breaking load under 15 kN (about 1.5 tons). Working with gravity force, the minimum slope should be at least 20%, while the maximum slope is 100% skidding downhill or 120% skidding uphill (BORTOLI and SOLARI 1996; DELLAGIACOMA *et al.* 2002).

The working sites require enough space to set up the tower and piling logs, tractor roads and skidtrails with good pavement are sufficient. The forest road density should be 40 m/ha considering an average skidding distance of 400 m, but it would be better between 60 and 70 m/ha (BORTOLI and SOLARI 1996).

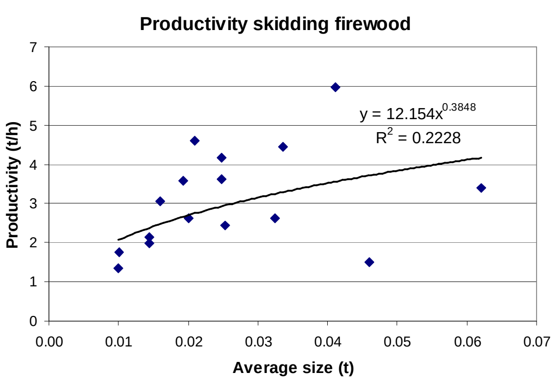


Figure 3.2.3.a: firewood extraction's productivity according to chops size.

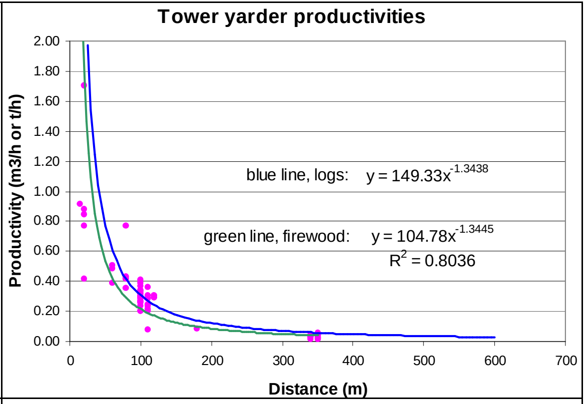


Figure 3.2.3.b: productivity functions. Comparing firewood and logs extraction.

During time studies also lateral skidding distances were measured and it was demonstrated that the lateral distance has a statistical influence on total productivities (figure 3.2.3.c). The corridor width is important when planning cuttings because it influences the number of lines required. The mounting and dismounting times may be less than 2 days for the tower cranes, so it would be better to build one more corridor than skidding with far lateral distances. When skidding farer than 25 meters, the total productivity decrease of 60%, moreover the forces and structure stress is higher and workers safety decrease. Average costs are very low when skidding within 200 m (over 15 €/t, figure 3.2.3.d), but they can increase depending on the logs size and on the site characteristics.

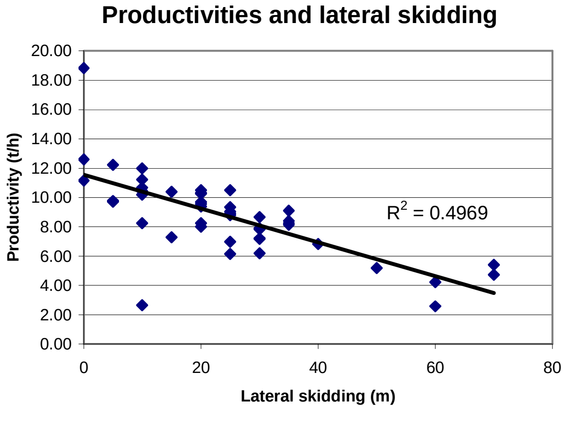


Figure 3.2.3.c: the relation between hourly productivity and lateral skidding distance.

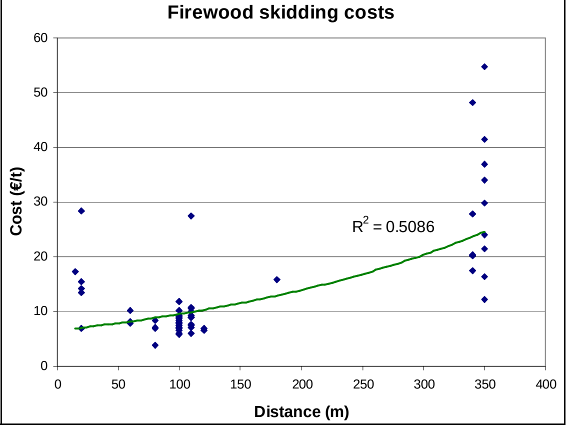


Figure 3.2.3.d: extraction costs.

Sledge yarder cable system

The sledge yarder system is composed by three elements.

The first is the yarder, which is mounted on a sledge, and the main line which is stored inside the drum. The drum is powered by an engine and the movement may be mechanical or hydraulic, as the brakes are. It is fixed usually uphill near the anchor tree and skids logs downhill using the gravity force. The main line can be used to lift the sledge uphill and reach places where there are not forest roads. The skidding direction may also be uphill when the felling site is located above the forest road; the sledge yarder can be fixed both uphill and downhill, so the evaluation of the skidding direction is not important. The minimum slope is 15-20% while the maximum slope is 100% skidding downhill and 120% skidding uphill (CAVALLI and MENEGUS 2003). The use of an additional drum and an endless rope allow to work on "all terrain" conditions, even on flat terrains, but this is quite expensive and it is used only for civil engineering.

The second element is the skyline which it is usually stored on an another big drum. This drum is independent and it is used only to store the skyline, it can be sited on a forest road and can be powered with the tractor force when storing back the cable after its use. The maximum extraction distance depends on the main line length and diameter (the drum volume is fixed) and the maximum allowed load. When skidding light logs, the rope can be thinner and lighter, so the maximum extraction distance may be up to 1500-2000 m. Usually the skyline is a 22-24 mm diameter with minimum break load of 20 kN and tensioned up to 120 kN (about 12 tons) (BORTOLI and SOLARI 1996).

The third element is the carriage. The automatic carriages may load up to 3 tons and are very practical because they can stop everywhere along the line with hydraulic clamps. Other cheaper carriages are the semi-automatic ones which are lighter but they can not work with high spans because the blocks would not be easily moved. These carriages may load not more than 2 tons.

The sledge yarder is a versatile and powerful system, but the long mounting and dismounting times cause first a productivity reduction (if we consider that mounting and dismounting a line of 900 m with two or three supports may take one week), second that cuttings should be intense and well distributed on the area to compensate the low productivity and the high unit costs. These systems are optimal when skidding big size logs bucked into 4 to 8 m size or the full tree. Productivities are about 8-10 m^3/h (figure 3.2.3.e), but they decrease to 3-5 m^3/ha considering the time for setting the line; skidding firewood the productivity is lower, between 2 and 6 tons per hour (figure 3.2.3.f) depending on the site organization and to the firewood assortment (full tree or 2 m tied pieces). To be convenient, the lines should measure more than 200 m, and yield should be at least 0.9-1.8 m^3 per each linear meter (HIPPOLITI and PIEGAI 2000; IENTILE 2003), corresponding to 200-400 m^3 per working site (MARCHI 1997).

Being able to move through the forest using the main line to lift it up, and thank to the length of the ropes, the sledge yarder system does not require high density roads. When skidding at 800 m distances, 20 to 30 m/ha of roads are quite enough; if the extraction distance is even more, road density might decrease to 15-20 m/ha (Bortoli and Solari 1996).

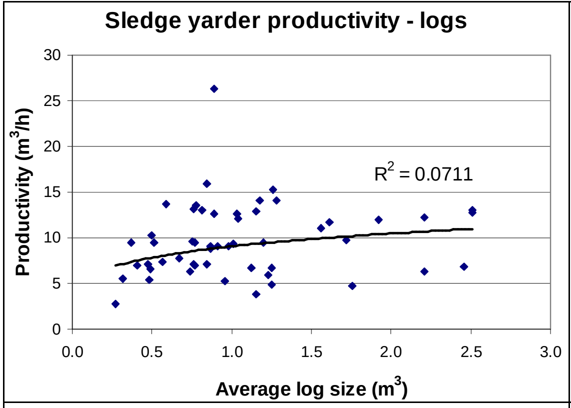


Figure 3.2.3.e: the sledge yarder productivity slowly increase with the average size of skidded logs

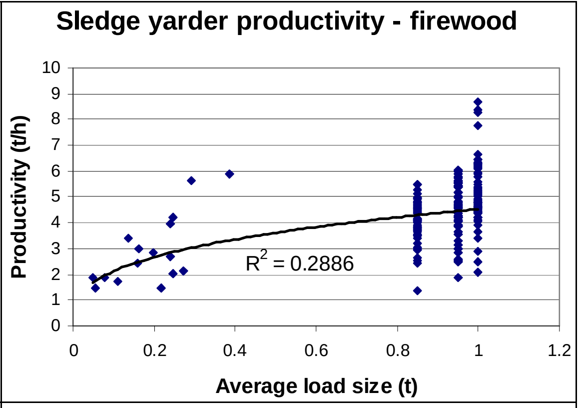


Figure 3.2.3.f: productivity of the system when skidding firewood, data over 0.8 t were 2 m tied pieces.

The system productivities are different when skidding logs and firewood. Figure 3.2.3.g compares 50 carriage trails skidding big sized spruce logs (Rizzi 2007) and 179 trails skidding beech firewood on very steep terrain (Cavalli and Lubello 2006; Rizzi 2007; Zanoni 2007). The productivity is higher when skidding logs because their tying is easier and they have less problems during the lateral skidding operation. The operating cost of the sledge yarder was estimated in 98 €/hour so the productivity influences costs (figure 3.2.3.h) more than the distance. The average costs are quite constant between 10 e/m^3 or 18-28 €/t.

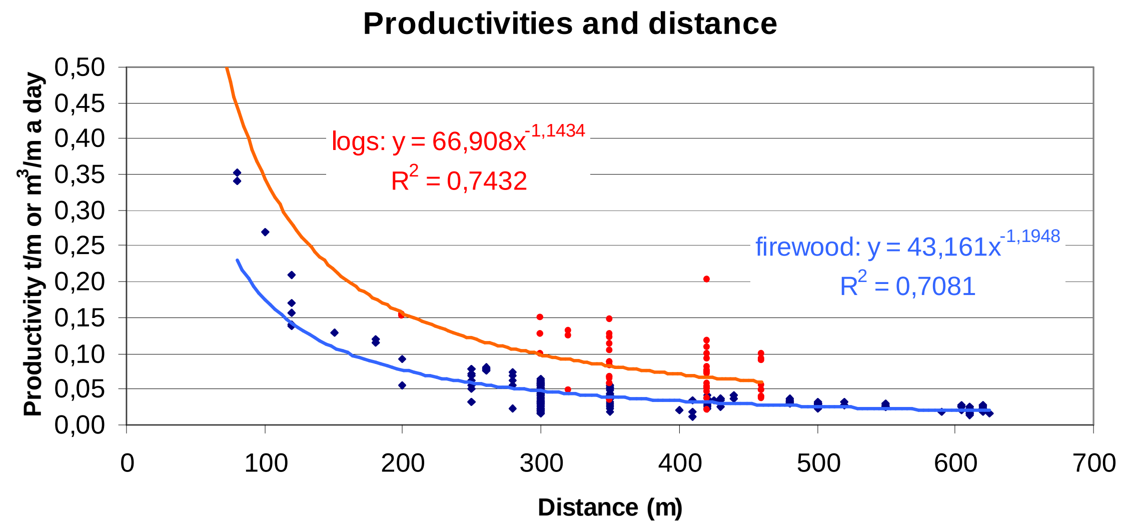


Figure 3.2.3.g: comparing productivities when skidding logs and firewood

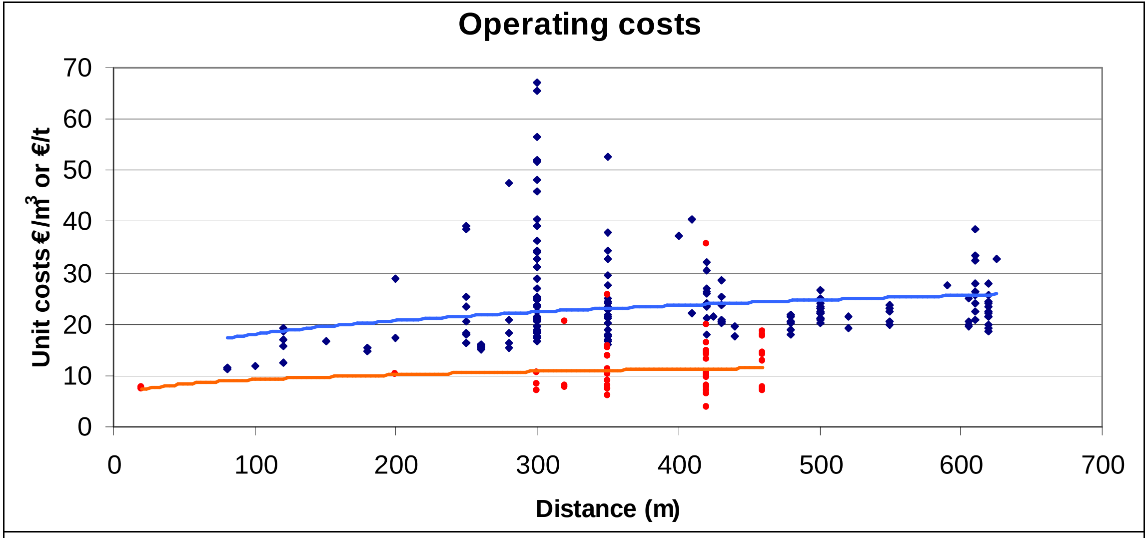


Figure 3.2.3.h: comparing costs when skidding logs (red) and firewood (blue)

3.2.4 Technical parameters input values

All the information of skidding systems were collected from literature and supported by field observations. At the end, they were resumed on table 3.2.4.a to have a clear idea of all variables (technical systems limits, costs and formulae) which would be needed inside the model and to easily compare them.

The graph on figure 3.2.4.a shows the productivity functions of all the considered five systems. The different productivities will be helpful when optimizing the choose of the optimal system because after the general order given by importance, the most productive (and consequently economic) system will be selected by the model.

Table 3.2.4.a: resuming all systems technical limits and functions.

	Skidder	Forwarder	Mobile tower	Sledge yarder	Cable-forwarder
Max slope skidding up-hill (%)	18	32	100	120	63
Max slope skidding down-hill	23	38	100	120	63
Max distance skidding up-hill	150	500	350	900	250
Max dist. skidding down-hill	300	600	350	900	250
Max ground roughness (cl.)	1	2	3	3	2
Average productivity (m^3/h)	4	8	5	4	2
Operating costs (€/h)	35.0	66.2	63.0	98.0	71.5
Formula (y = a(x^b)) a =	36.293	16.14	149.33	56	82.278
b =	-1.1791	-0.8126	-1.3438	-1.1685	-1.1571

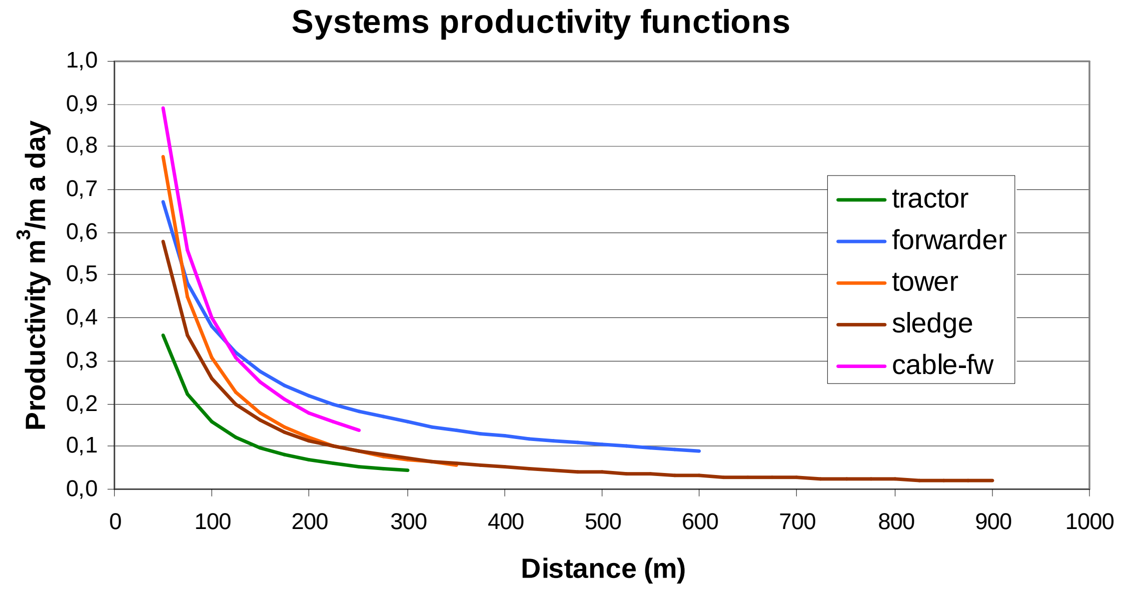


Figure 3.2.4.a: systems productivity functions derived by literature and gathered field data.

3.3. COSTS EVALUATION

Today's logging equipment ranges anywhere from chainsaw to complex multi-functional equipment which can fell, delimb, buck, and haul to the landing. To select specific equipment and use that equipment profitably, loggers should know something of equipment costs and how to determine them.

A "machine rate" is a calculated hourly charge for owning and operating a piece of capital equipment. The classical approach was defined by MATTHEWS (1942) and more recently by MIYATA (1980). Costs are averaged over the ownership life of the asset to estimate a constant hourly charge. The formulae have been used in many forms as a simple method of cost estimation (e.g. BRINKER *et al.* 2002). The machine rate calculations are simple, easy to understand, do not require detailed cost history, and are constant over the life of the machine.

However, a number of authors (RICKARDS and PASSMORE 1977; STENZEL *et al.* 1985; BURGESS and CUBBAGE 1989) note the limitations of the machine rate:

- the treatment of depreciation and interest does not consider the effect on compound interest on capital recovery
- the machine rate does not consider the effect of tax treatment for various cost categories
- costs are assumed constant (average) for all years of ownership.

While the limitations are well-known, the standard machine rate is still widely used for quick estimation of machine costs when actual costs are unknown (FAO 1992).

A more exact approach to estimating machine costs is the discounted cash flow, incorporating additional cost categories such as tax effects. The detailed calculations are particularly important for economic analysis of expensive equipment (helicopters, yarders, harvesters). BUTLER and DYKSTRA (1981) and TUFTS and MILLS (1982) illustrate the application of discounted cash flow analysis to equipment replacement decisions.

While the machine rate method has limitations, it has advantages for specific applications. The machine rate spreadsheet used here (see next tables) uses a modified approach to address some of the stated concerns with earlier formulations such as MIYATA (1980):

- economic life is estimated as longer (PETTENELLA and CUTOLO 1987; EDWARDS 2001; AMMAN 2004)
- capital costs are estimated using an equivalent annual cost calculation (RIGGS 1977; SARTORI and GALLETTO 1992)
- insurance is calculated as a % of average annual investment
- salvage values are estimated based on CUBBAGE *et al.* (1991)
- housing is calculated as the result of the formula: Vm(0.054CSh), where *Vm* is the volume of the equipment, *CSh* is the initial investment or the rent rate for the building and 0.054 is the yearly maintenance cost (% on building value) as depreciation, interests, maintenance and insurances (CROSS 1998; AMMAN 2004)
- potential repair is estimated as a % of depreciation, but charged at a variable rate depending on utilization (SARTORI and GALLETTO 1992; EDWARDS 2001)
- fuel consumption is adapted taking care of information from the owner records (HIPPOLITI *et al.* 1980)
- cost of lubricants is calculated as percentage of total fuel cost (SAMSET 1972; CROSS 1998; EDWARDS 2001; ASAE 2004)

The spreadsheet also displays calculated annual costs to aid comparison with actual cost data. Costs for cable crane systems do not consider the time needed for mounting and dismounting the line: this cost should be added time by time depending on length of the line (BORTOLI and SOLARI 1996) and should be divided by the real skidding time (in days or hour, but this is possible only when the work is finished!).

Table 3.3.a: evaluating tractor/skidder unit costs, fields in grey have to be filled by user.

TRACTOR or SKIDDER					***WINCH***	***TIRES (x4)***
Cost item	**Symbol**	**Formula**	**Value**	**Unit**	**Value**	**Value**
Initial investment	P		29602	€	15000	3000
Salvage value	S	15% P	4440,3	€	3000	
Economic life (years)	n		10	years	10	3,4
Daily scheduled operating time	DSH		8	h	8	8
Operating time (days)	DY		150	days	95	150
Scheduled operating time	SH	DSH*DY	1200	h	760	1200
Average value of yearly investment	AI	(P-S)*(n+1)/2n+S	18279	€/year	9600	1941
Maintenance (rate)	RMr		80	%	60	
Interest rate	R		4	%	4	4
Insurances, taxes and housing	ITGr		6	%		
Fuel consumption	Fc		4	l/h		
Lubricant consumption	Lc		0,11	l/h	0,4	
Fuel cost	Fp		0,9	€/l		
Lubricant cost	Lp		2,4	€/l	2,4	
Fixed costs						
Depreciation	Amm	(P-S)/n	2516	€/year	1200	882
Interests	In	AI*R	731	€/year	384	78
Insurances, taxes and housing	ITG	AI*ITGr	1097	€/year		
Unit fixed costs	OCh	Amm+In+ITG/SH	**3,62**	**€/h**	**2,08**	**0,80**
Daily fixed costs	OCg	Amm+In+ITG/DY	28,96	€/day	16,67	6,40
Yearly fixed costs	OCa	Amm+In+ITG	4344	€/year	1584	960
Operating costs						
Maintenance and repair	RM	(Amm*RMr)/SH	1,7	€/h	0,95	
Fuel	FC	Fc*Fp	3,6	€/h		
Lubricants	LC	Lc*Lp	0,26	€/h	0,96	
Labor cost	WB		14,93	€/h		
Unit operating costs	OpCh	RM+FC+LC+WB	**20,47**	**€/h**	**1,91**	
Daily operating costs	OpCg	(RM+FC+LC+WB)*DSH	163,77	€/day	15,26	
Yearly operating costs	OpCa	(RM+FC+LC+WB)*SH	24566	€/year	1449,6	
Partial sum		OCh+OpCh	**24,09**	**€/h**	**3,99**	**0,80**
Hourly unit cost			**28,88**	**€/h**		
Only machine			13,95	€/h		

Table 3.3.b: evaluating mobile tower yarder (cable crane) unit costs, fields in grey have to be filled by user. In this case the tower is powered by tractor engine so the fuel consumption is null.

MOBILE TOWER				***ACCESSORIES***	***TIRES (x2)***
Cost item	**Symbol**	**Value**	**Unit**	**Value**	**Value**
Initial investment	P	55000	€	15200	400
Salvage value	S	11000	€		
Economic life (years)	n	15	years	10	4
Daily scheduled operating time	DSH	6	h	6	6
Operating time (days)	DY	195	days	195	195
Scheduled operating time	SH	1170	h	1170	1170
Average value of yearly investm	AI	34467	€/year	8360	250
Maintenance (rate)	RMr	60	%		
Interest rate	R	4	%	4	4
Insurances, taxes and housing	ITGr	2	%		
Fuel consumption	Fc	0	l/h		
Lubricant consumption	Lc	0,2	l/h		
Fuel cost	Fp	0,8	€/l		
Lubricant cost	Lp	2,4	€/l		
Fixed costs					
Depreciation	Amm	2933	€/year	1520	100
Interests	In	1379	€/year	334	10
Insurances, taxes and housing	ITG	689	€/year		
Unit fixed costs	OCh	**4,27**	**€/h**	**1,6**	**0,1**
Daily fixed costs	OCg	25,65	€/day	10	1
Yearly fixed costs	OCa	5001	€/year	1854	110
Operating costs					
Maintenance and repair	RM	1,5	€/h		
Fuel	FC	0	€/h		
Lubricants	LC	0,48	€/h		
Labor cost	WB	14,93	€/h		
Unit operating costs	OpCh	**16,91**	**€/h**		
Daily operating costs	OpCg	101,49	€/day		
Yearly operating costs	OpCa	19790	€/year		
Partial sum		**21,19**	**€/h**	**1,6**	**0,1**
Workers		3			
Hourly unit cost		**52,73**	**€/h**		
Only machine		7,94	€/h		

Table 3.3.c: evaluating sledge yarder (fixed cable crane system) unit costs, fields in grey have to be filled by user.

SLEDGE YARDER				*CARRIAGE, ROPES, ACCESSORIES*
Cost item	**Symbol**	**Value**	**Unit**	**Value**
Initial investment	P	75000	€	28000
Salvage value	S	15000	€	
Economic life (years)	n	12	years	10
Daily scheduled operating time	DSH	6	h	6
Operating time (days)	DY	150	days	150
Scheduled operating time	SH	900	h	900
Average value of yearly investment	AI	47500	€/year	15400
Maintenance (rate)	RMr	60	%	
Interest rate	R	4	%	4
Insurances, taxes and housing	ITGr	2	%	
Fuel consumption	Fc	4,1	l/h	
Lubricant consumption	Lc	0,3	l/h	
Fuel cost	Fp	1,1	€/l	
Lubricant cost	Lp	2,4	€/l	
Fixed costs				
Depreciation	Ammort	5000	€/year	2800
Interests	In	1900	€/year	616
Insurances, taxes and housing	ITG	950	€/year	
Unit fixed costs	OCh	**8,72**	**€/h**	**3,8**
Daily fixed costs	OCg	52,33	€/day	23
Yearly fixed costs	OCa	7850	€/year	3416
Operating costs				
Maintenance and repair	RM	3,3	€/h	
Fuel	FC	4,49	€/h	
Lubricants	LC	0,72	€/h	
Labor cost	WB	14,93	€/h	
Unit operating costs	OpCh	**23,48**	**€/h**	
Daily operating costs	OpCg	140,85	€/day	
Yearly operating costs	OpCa	21128	€/year	
Partial sum		**32,20**	**€/h**	**3,8**
Workers		5		
Hourly unit cost		**95,71**	**€/h**	
Only machine		21,06	€/h	

Table 3.3.d: evaluating forwarder unit costs, fields in grey have to be filled by user.

VALMET 860.1				***GRAB CRANAB C***	***TIRES (x8)***	***TRACKS&CHAINS***
Cost item	**Symbol**	**Value**	**Unit**	**Value**	**Value**	**Value**
Initial investment	P	200000	€	4000	15200	8000
Salvage value	S	40000	€			
Economic life (years)	n	8	years	4	4	8
Daily scheduled operating time	DSH	8	h	8	8	8
Operating time (days)	DY	195	days	195	195	150
Scheduled operating time	SH	1560	h	1560	1560	1560
Average value of yearly investment	AI	130000	€/year	2500	9500	4500
Maintenance (rate)	RMr	60	%	60		
Interest rate	R	8	%	8	8	8
Insurances, taxes and housing	ITGr	8	%			
Fuel consumption	Fc	9	l/h			
Lubricant consumption	Lc	0,3	l/h	0,2		
Fuel cost	Fp	0,9	€/l			
Lubricant cost	Lp	2,4	€/l	2,4		
Fixed costs						
Depreciation	Ammort	20000	€/year	1000	3800	1000
Interests	In	10400	€/year	200	760	360
Insurances, taxes and housing	ITG	10400	€/year			
Unit fixed costs	OCh	**26,15**	**€/h**	**0,8**	**2,9**	**0,9**
Daily fixed costs	OCg	209,23	€/day	6	23	9
Yearly fixed costs	OCa	40800	€/year	1200	4560	1360
Operating costs						
Maintenance and repair	RM	7,7	€/h	0,4		
Fuel	FC	8,1	€/h			
Lubricants	LC	0,72	€/h	0,48		
Labor cost	WB	18,08	€/h			
Unit operating costs	OpCh	**34,59**	**€/h**	**0,9**		
Daily operating costs	OpCg	276,74	€/day	6,9		
Yearly operating costs	OpCa	53964	€/year	1348,8		
Partial sum		**60,75**	**€/h**	**1,6**	**2,9**	**0,9**
Hourly unit cost		**66,17**	**€/h**			
Only machine		48,09	€/h			

Table 3.3.e: evaluating cable-forwarder unit costs, fields in grey have to be filled by user. The cable-forwarder is a forwarder with basically two more accessories: the tilt system, that allow the boom working properly and gain pulling force when the machine is on angled position, and a rear winch to help moving up and down on steep terrains.

JOHN DEERE 810D				***GRAB/ACCESSORIES***	***TIRES (x8)***	***TRACKS&CHAINS***
Cost item	**Symbol**	**Value**	**Unit**	**Value**	**Value**	**Value**
Initial investment	P	230000	€	12000	15200	8000
Salvage value	S	46000	€			
Economic life (years)	n	8	years	4	4	8
Daily scheduled operating time	DSH	8	h	8	8	8
Operating time (days)	DY	195	days	195	195	150
Scheduled operating time	SH	1560	h	1560	1560	1560
Av. value of yearly investment	AI	149500	€/year	7500	9500	4500
Maintenance (rate)	RMr	60	%	60		
Interest rate	R	8	%	8	8	8
Insurances, taxes and housing	ITGr	8	%			
Fuel consumption	Fc	9	l/h			
Lubricant consumption	Lc	0,3	l/h	0,1		
Fuel cost	Fp	0,9	€/l			
Lubricant cost	Lp	2,4	€/l	2,4		
Fixed costs						
Depreciation	Ammort	23000	€/year	3000	3800	1000
Interests	In	11960	€/year	600	760	360
Insurances, taxes and housing	ITG	11960	€/year			
Unit fixed costs	OCh	**30,08**	**€/h**	**2,3**	**2,9**	**0,9**
Daily fixed costs	OCg	240,62	€/day	18	23	9
Yearly fixed costs	OCa	46920	€/year	3600	4560	1360
Operating costs						
Maintenance and repair	RM	8,8	€/h	1,2		
Fuel	FC	8,1	€/h			
Lubricants	LC	0,72	€/h	0,24		
Labor cost	WB	18,08	€/h			
Unit operating costs	OpCh	**35,75**	**€/h**	**1,4**		
Daily operating costs	OpCg	285,97	€/day	11,2		
Yearly operating costs	OpCa	55764	€/year	2174,4		
Partial sum		**65,82**	**€/h**	**3,7**	**2,9**	**0,9**
Hourly unit cost		**73,32**	**€/h**			
Only machine		55,24	€/h			

The unit costs calculated in such a way are then filled in the model to evaluate the cheapest system inside different assessed forest stands. The user-interface window allow to change inputs adapting them to specific social, cultural and technical level environment.

3.4. INPUT DATA

To run the model, five input shapefiles are requested: The Digital Elevation Model (DEM), the soil stability and composition, the yearly amount of rain, the road network and forest assessmental plan information.

The model was first developed on a small area inside Veneto Region, on the Asiago highlands because detailed data were already available.

The **Digital Elevation Model** was provided from the regional forest and economy head office (DFEM – Direzione Foreste ed Economia Montana). It is a grid file that covers all the region with a cell size precision of 25 meters. The file is quite heavy, about 250 Mbites, so it has been cut with the *Extract by mask* tool (ESRI 2005) on the study area (figure 3.4.a) to makes faster operations and calculations.

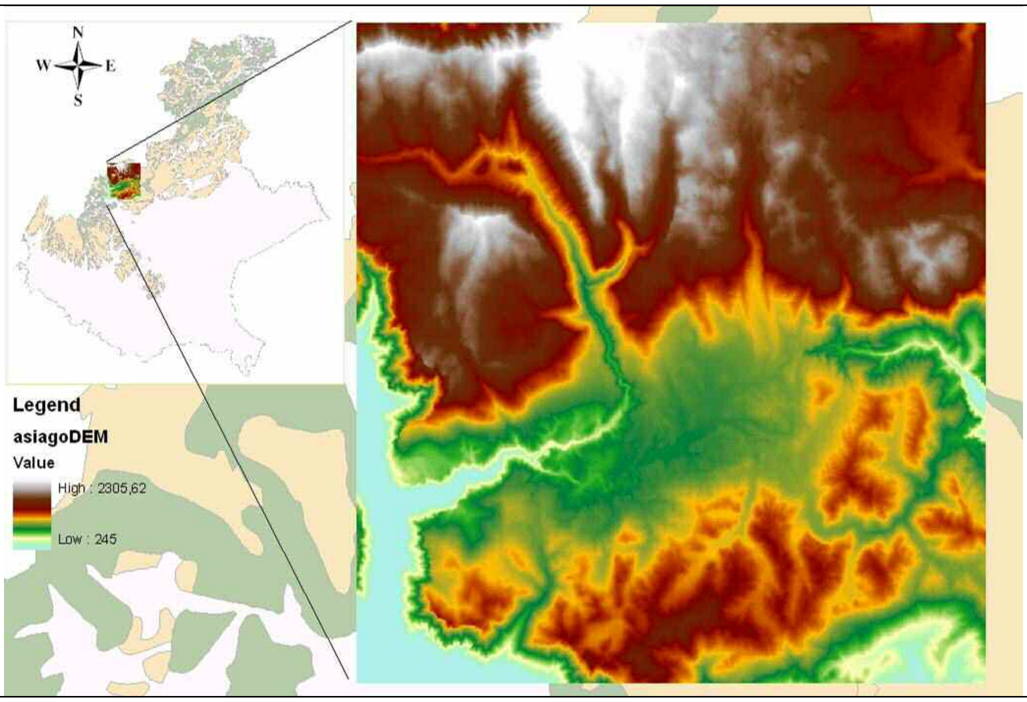


Figure 3.4.a: location of study area and the Digital Elevation Model

The precision is not bad comparing it to Friuli DEM that is of 40 m, but it would have been better to have 10 m as Trentino did. Smaller is the cell size and more precise are operations like converting feature shapefiles, as roads, to raster (see also figure 3.6.2.d). working with integer values would also be preferable.

Soil information was found on a cd-rom containing several Veneto region shapefiles (Del Favero 2001). The file has complete and precise information about the soil formation, permeability of water, susceptibility to erosion and stability. All information were merged and a new field called “B_CATEG” was created (table 3.4.a and 3.4.b). This field is essential when running the model: actually all soils are reclassified into three stability categories (figure 3.4.b) to determine gradeability (see next chapter). Even the string values and field name inside the database should be the same, and in the same position to avoid errors.

Table 3.4.a: database fields of soil shapefile, fields in gray color are compulsory.

Field	Type	Precision
OBJECTID	counter	-
Shape	polygon	-
B_CATEG	string	-
Stability categories	numeric	Short (2 – 0)
Name	string	-
Category	string	-
Permeability	string	-
Susceptibility to erosion	string	-
Stability	string	-

Table 3.4.b: example on how soil categories were reclassified. Note that B_CATEG values must not differ from "scarsa, ridotta, intermedia, buona, elevata" (very low, low, intermediate, good, high)

B_CATEG	Stability categories	Name	category	permeability	susceptibility to erosion	stability
scarsa	10	Gessoso	carbonatico	elevata	elevata	scarsa
ridotta	10	Sciolto	carbonatico	elevata	buona	ridotta
ridotta	10	Argillo-scistoso	silicatico	ridotta	elevata	ridotta
intermedia	20	Flyscioide	carbonatico-terrigeni	ridotta	elevata	buona/ridotta
intermedia	20	Arenaceo	carbonatico-terrigeni	ridotta	buona	buona/ridotta
buona	30	Calcareo	carbonatico	ridotta	scarsa/ridotta	buona
buona	30	Magmatico	silicatico	ridotta	ridotta	buona
elevata	30	Dolomitico	carbonatico	scarsa	scarsa	elevata

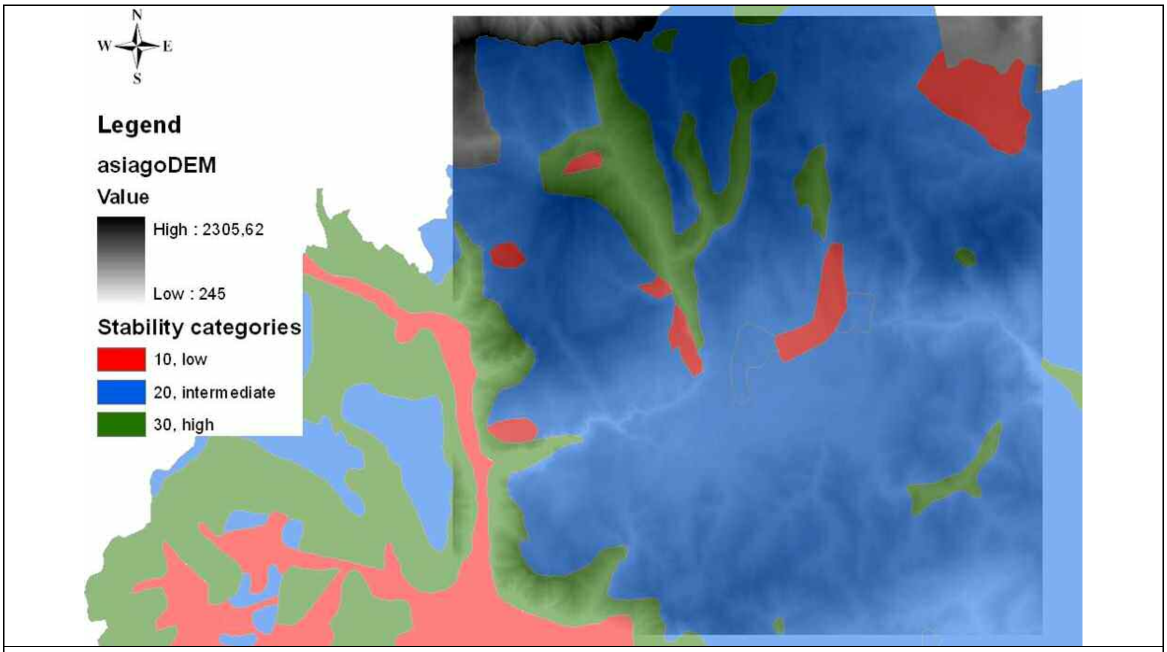


Figure 3.4.b: map of soil stability categories.

The **annual amount of rain** comes from the same cd-rom than soil shapefile (Del Favero 2001). It is a polyline feature and each one has a single value (mm/year). Observing the regional distribution it is evident that it rains heavier on mountains than on the plain (figure 3.4.c). There is only one essential field to run the model that has to be called “A_MM_AA” (table 3.4.c). This kind of data are not easy to be found, sometimes they can be gathered or bought from regional environmental agencies (ARPA), otherwise inside websites there could be find nice images showing rain lines. It is possible to import those images inside ArcMap, *georeferencing* them and creating a new file as needed. Rain values were reclassified into four categories (<700 mm; 700-1500 mm; 1500-2500 mm; >2500 mm) and mixed inside a matrix together with soil categories to evaluate gradeability.

Table 3.4.c: database fields of rain shapefile, fields in gray color are compulsory.

Field	Type	Precision
OBJECTID	counter	-
Shape	polyline	-
A_MM_AA	numeric	Short (2 -0)
Shape_lenght	numeric	Double (8 – 0)

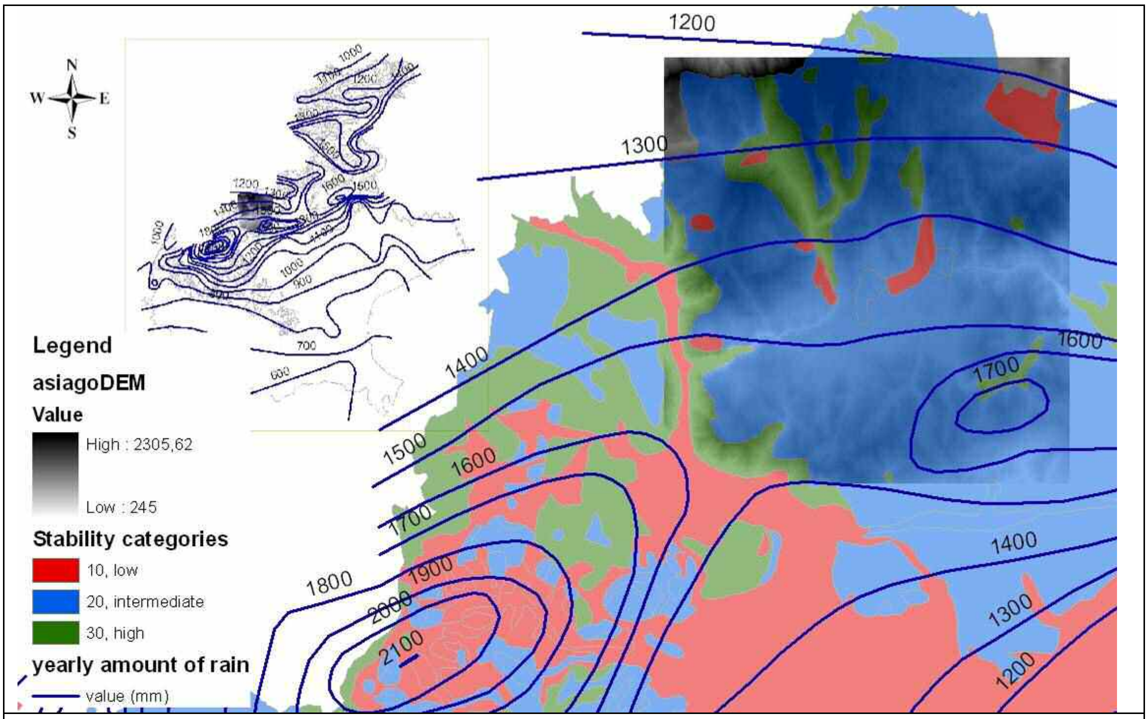


Figure 3.4.c: map of yearly rain amount and Veneto region gradient.

Road network is based on the regional technical maps (“Carta Tecnica Regionale” – CTR). The free download of those maps can be done on the regional website through a well done web-GIS (figure 3.4.d)

Figure 3.4.d: the Veneto web-GIS page (http://cartografico.regione.veneto.it/wpcartograficoveneto/framesetup.asp)

All maps are already in a shapefile format including several data as buildings, objects, rivers, etc… The fact is that working on a big area it is necessary to download a lot of different maps and than *merge* (ESRI 2005) them obtaining one unique file (figure 3.4.e). This is only time consuming, the real problem is that those maps have been done probably by different people at different moments, so it is common to find writing errors, wrong data or information with no coincidence on what should be the same road. All data were deeply checked before the road reclassification according to forest machines accessibility. One new field ("TRANSIT") was added to the file database (table 3.4.d), this field is necessary to run the model together with "NUMERO" which must contain unique values for each road sector. The roads reclassify was carried on according to available information as the road grading (index related to their size and management) and width as reported in table 3.4.e. and on figure 3.4.e.

Table 3.4.d: database fields of roads shapefile, fields in gray color are compulsory.

Field	Type	Precision
OBJECTID	counter	-
Shape	polyline ZM	-
NUMERO	numeric (key-field)	double (8 – 0)
TRANSIT	string	-
DESCRZ	string	-
INDEX	string	-
WIDTH	numeric	float (4 – 0)
Shape_Lenght	numeric	double (8 – 0)

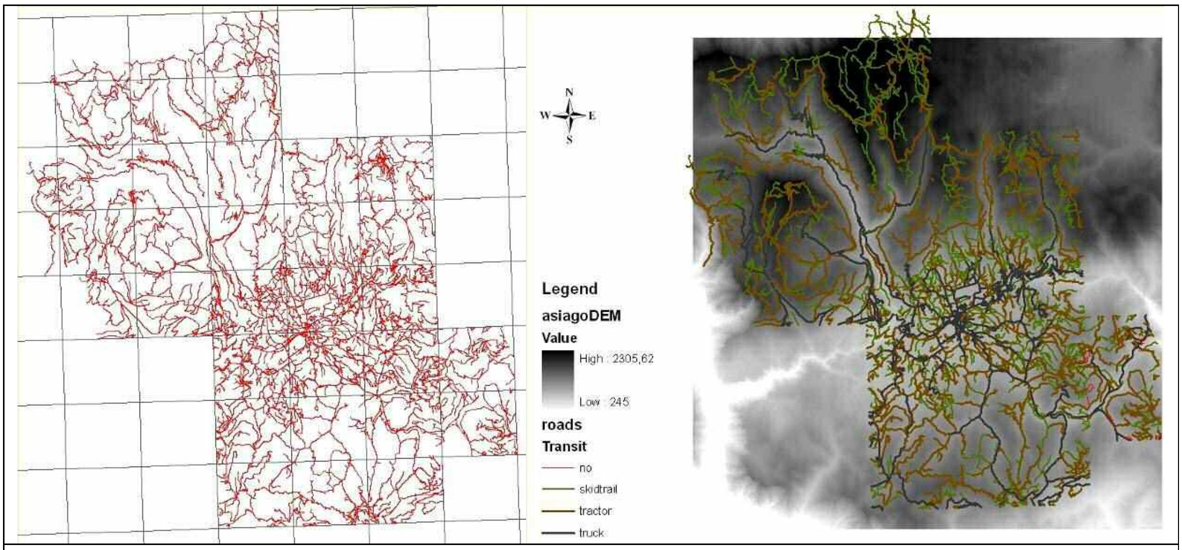


Figure 3.4.e: the study area road network. On the left side rough data and regional grid of technical map are shown. On the right side roads have been classified according to their accessibility (skidtrail, tractor road or truck road).

Table 3.4.e: roads categories and their reclassification.

ROAD Category	Index	Width (m)	TRANSIT
Accesso privato	0	0	NO
Sentiero difficile	0	0	NO
Mulattiera	6	2	Skidtrail
Sentiero facile	6	2	Skidtrail
Ponte	1	3	Tractor
Strada carreggiabile	3	3	Tractor
Strada carrozzabile	3	3	Tractor
Strada di campagna	6	3	Tractor
Strada secondaria	3	5.5	Truck
Strada in costruzione	3	5.5	Truck
Tracciato in galleria	3	5.5	Truck
Sottopasso stradale	3	5.5	Truck
Strada principale	2	7.5	Truck

The regional database of **forest assessmental plans**, called GPA, was provided from the regional forest and economy head office (DFEM – Direzione Foreste ed Economia Montana). It is a polygon shapefile that covers all the regional public properties. The 204 Asiago forest stands were extracted from a total of 136 assessmental plans and 6644 stands. Like the roads file, even here some data were not exact or they were lost, so it has been needed to check the original printed version of the forest plan. In there were found more data about the prescribed yield and the year of cutting. Information about the accessibility and the ground were compared to a field survey with the aim of determine ground roughness values for each stand (figure 3.4.f). All data were updated inside a new dataset (table 3.4.f).

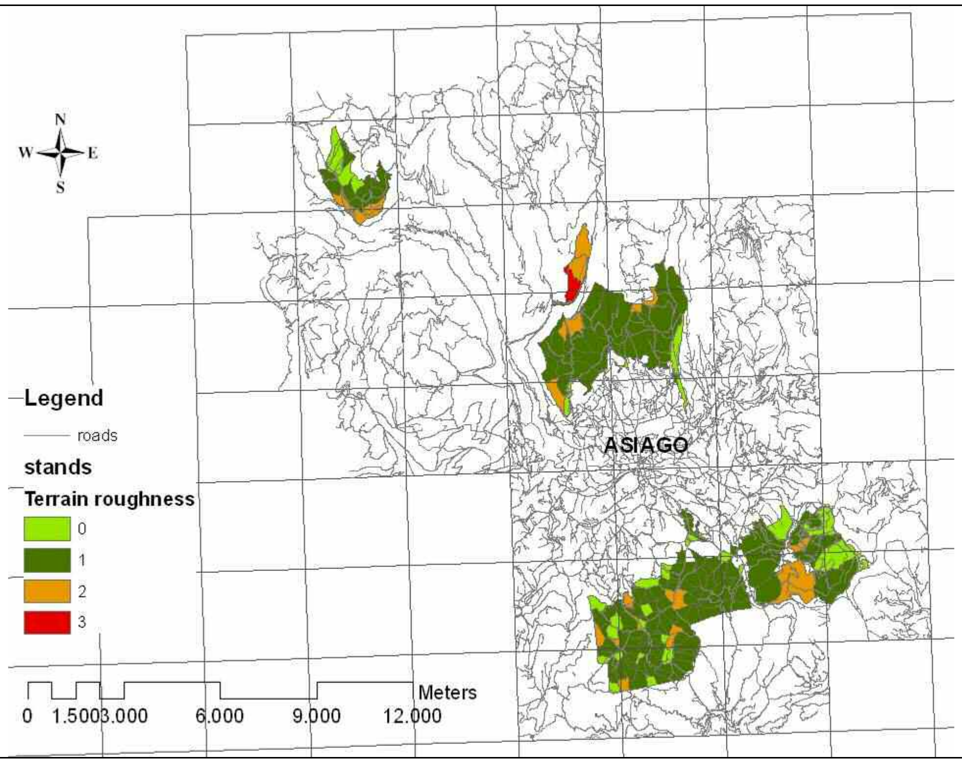


Figure 3.4.f: the Asiago forest properties and stand terrain roughness classes

Table 3.4.f: database fields of stands shapefile, fields in gray color are compulsory.

Field	Type	Precision	Notes
OBJECTID	counter	-	-
Shape	polygon	-	-
C_CODPPA	string	-	-
CUTFCELL	numeric	float (4 – 0)	yield in m3/grid cell (same as DEM)
T_ROUGH	numeric	short (2 – 0)	terrain roughness 0-4
D_SUPTOT	numeric	double (8 – 0)	total stand area
E_SUPBOS	numeric	double (8 – 0)	forested stand area
F_FUNZ	string	-	forest function (protective – productive)
G_GOV	string	-	coppice or high forest
STAT_R	numeric	long (4 – 0)	average height of trees
ETA_R	numeric	long (4 – 0)	average age of trees
DMAXR	numeric	long (4 – 0)	maximum diameter
DMEDR	numeric	long (4 – 0)	average diameter
PHA	numeric	long (4 – 0)	n. of trees per ha
PROV_UN	numeric	double (8 – 0)	stock/ha
INCR_PER	numeric	double (8 – 0)	% yearly increment of forest
M_FUST	numeric	long (4 – 0)	total high forest stock
M_CED_Q	numeric	long (4 – 0)	total coppice stock
YEAR	numeric	long (4 – 0)	year of stand cutting
Shape_Lenght	numeric	double (8 – 0)	-
Shape_Area	numeric	double (8 – 0)	-

3.5. BUILDING THE MODEL

3.5.1. Model basics

The model, called Forest Operations Planning (FOpP) is based on three different informative layers. The first one considers technical and economical data for each mechanical system, for example productivity (m^3/h), costs (€/h) and technical limits (see § 3.2 and 3.3). These elements are entered inside the model as parameters and they strongly influence the choose of the most suitable harvesting system, technically and economically. The second informative layer concern to sylvicultural and assessmental data including stands boundaries, standing stocks and planned yield which are needed to calculate unit costs and to make spatial statistics. The last informative layer is the most important because is the basis to evaluate the forest accessibility. Both geographical, climatic and infrastructural data are included as Digital Elevation Model, terrain roughness, forest road network, geology and hydrology (yearly precipitation, mm/year). Digital data or user data enter the model as inputs (figure 3.5.1.a) through a window panel (kind of interface). Then the model starts elaborating: the elaboration time depend on the grid size because all calculations (more than 150) have a cell-basis depending on the use of *geoprocessing tools* inside *Spatial analyst* (Arcmap, ESRI). The expected time for a 10 km^2 area can be 8 minutes if DEM cell is bigger than 70 m and reach 20 minutes for 25 m cell size. Outputs are directly displayed in Arcmap and can be used for further evaluations or compared with other scenarios.

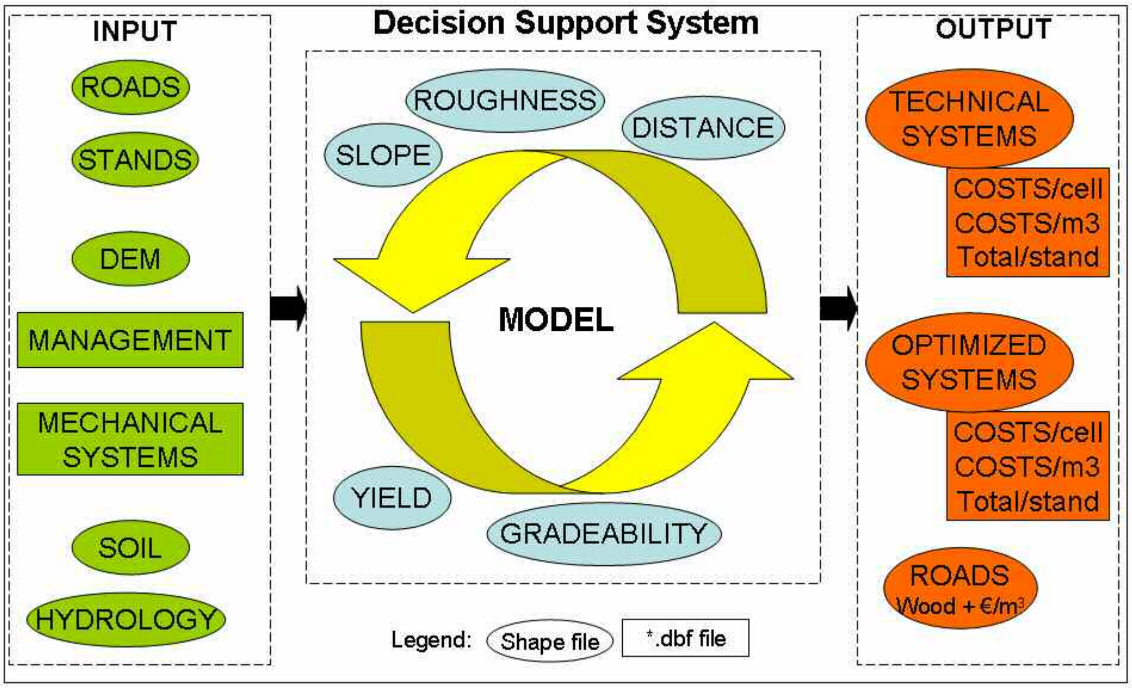


Figure 3.5.1.a: the FOpP (Forest Operations Planning) model functional schema.

The model is built to evaluate harvest systems inside high forests, but can be adapted to be used also in coppice forests. We must distinguish high forest sites from coppice ones because if systems are involved in both forest type they have different productivities and different costs. A solution is to make first evaluations inside high forests and then in coppice forests changing parameters and selecting appropriate system. Actually in coppice forests tractor with winch, high-density polyethylene chutes and simple cable yarding systems are used, instead of high forests where tractor with winch, forwarder, cable-forwarder and cable yarding systems work. Chainsaw and harvester can be used for felling, other processing operations can be performed by processors or debarking machines. Felling operation costs or other management costs can be added inside output **.dbf* files to evaluate total working site costs (LUBELLO *et al.* 2007; KRČ *et al.* 2007).

3.5.2. The Arcmap ModelBuilder

There are many programming languages used for building models, as C+ (STÜCKELBERGER *et al.* 2006), Pascal (LÜTHY 1998), Visual Basic (MEYER *et al.* 2001, HRADETZKY and SCHOPFER 2001, PRETZSCH *et al.* 2002, VÄÄTÄINEN *et al.* 2006) and others (statistical models (GELLRICH *et al.* 2006, GELLRICH *et al.* 2007) or integer variables models (BUONGIORNO and GILLESS 2003)), but they are not easy to learn and often they need powerful computers to be ran. GIS is a good software to handle and manipulate digital/spatial data and it is possible to build complex procedures to solve qualitative or quantitative problems (SHIBA *et al.* 1990, ARONOFF 1993, LAARIBI *et al.* 1993, BILL and FRITSCH 1994). The power is given connecting database to data logical structure like geometries (points, polygons, lines, coordinates), topologies (position and boundaries related to other adjacent objects), data structures (tables and databases) and it is an easy way to manipulate, to build query and make statistics (TOMLINSON 1987, DENSHAM 1991, KEENAN 1995, CHIRICI *et al.* 2003). In ArcGIS 9.1 ESRI introduced a new useful tool called ModelBuilder. When you right click on the *toolbox* and add a new model, the ModelBuilder window (figure 3.5.2.a) opens automatically and provides to you a graphical environment in which you can build models (ESRI, 2005).

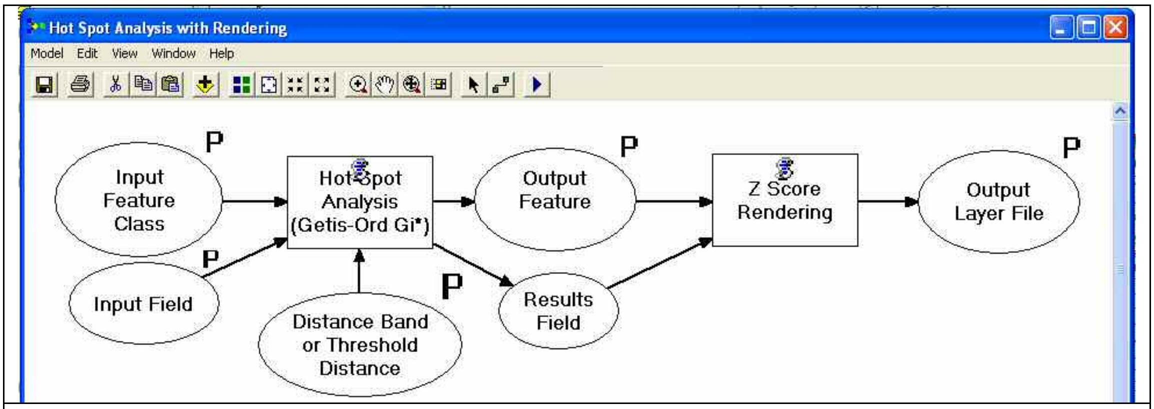


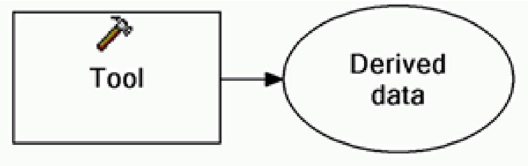
Figure 3.5.2.a: the ModelBuilder window showing a short model.

When you start working with the ModelBuilder window you find that:
- you can build a model by stringing processes together
- you can construct processes by adding tools and setting values for the parameters of each tool
- you can share parameter values between processes
- you can set model parameters inside the ModelBuilder window so that the values for these parameters can be set when the model is run from its dialog box
- you can edit dialog box with custom tips and helps
- you can change the default diagram properties to change the layout of the model or the symbology applied to elements
- you can add text labels to the display window, elements, connector lines or custom scripts
- you can navigate easily in the model using the zoom or pan tools
- you can easily repair an invalid parameter value or tool reference
- you can print your model and generate a report
- you can import existing models created in ArcView GIS 3, and you can export models to scripts or graphics to share it.

In geoprocessing in ArcGIS, a process is made by a tool and its parameter values (ESRI, 2005). One process, or multiple processes connected together, creates a model. Each process in a model is in one of three states:

- not ready to run
- ready to run
- has been run

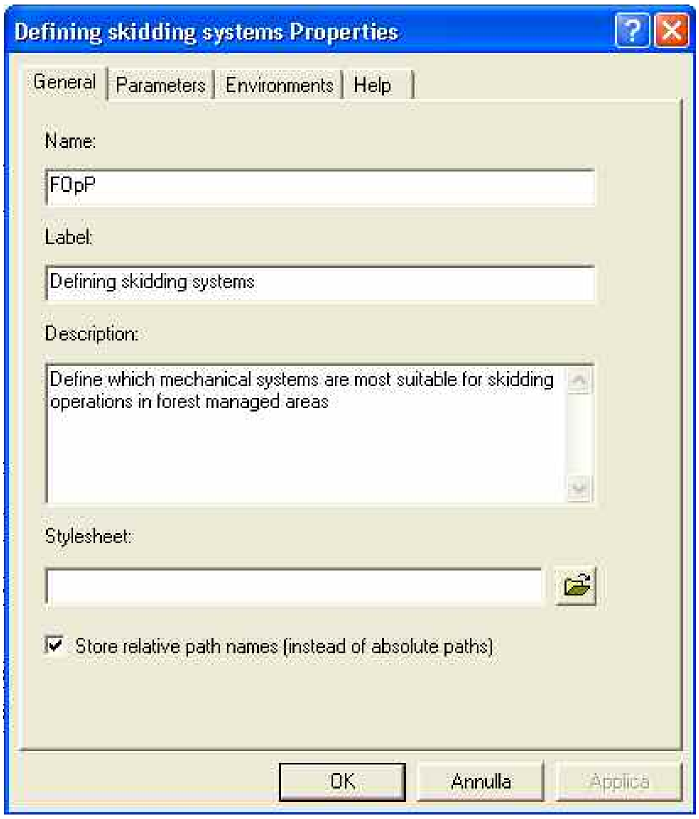
The state of a process depends on the state of its elements. A process is ready to run when each of its elements is ready to run. By default, elements that are not ready to run are symbolized in white. An element is not ready to run if the required parameter value or values for that element have not been set. When you initially drag a tool into a ModelBuilder window, the tool is in a not-ready-to-run state because the required parameter values have not been specified, as the graphic below shows:



Elements that are ready to run are symbolized with colors: input (or project) data elements are blue, tool elements are yellow, and output data (derived data) elements are green. A process is ready to run when all elements have been supplied with the required parameter values.

When a process has run successfully, the tool and derived data elements are displayed with drop shadows, indicating that the process has run and the derived data has been generated. You can also decide the order of tools when running the model by right clicking any tool and setting priorities.

Once the model has been saved, it is useful to give it a name and a short description. This is possible entering the General folder inside the Model properties window. The model here described was called FOpP (Forest Operations Planning)



Name:
FOpP

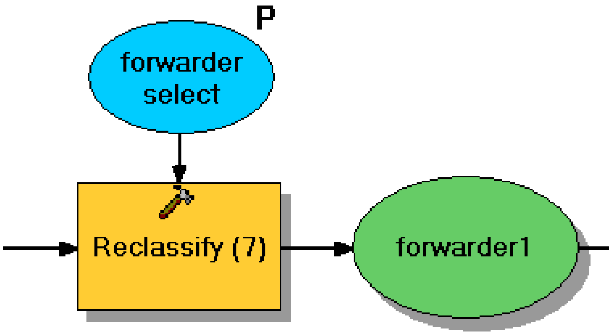
Label:
Defining skidding systems

Description:
Define which mechanical systems are most suitable for skidding operations in forest managed areas

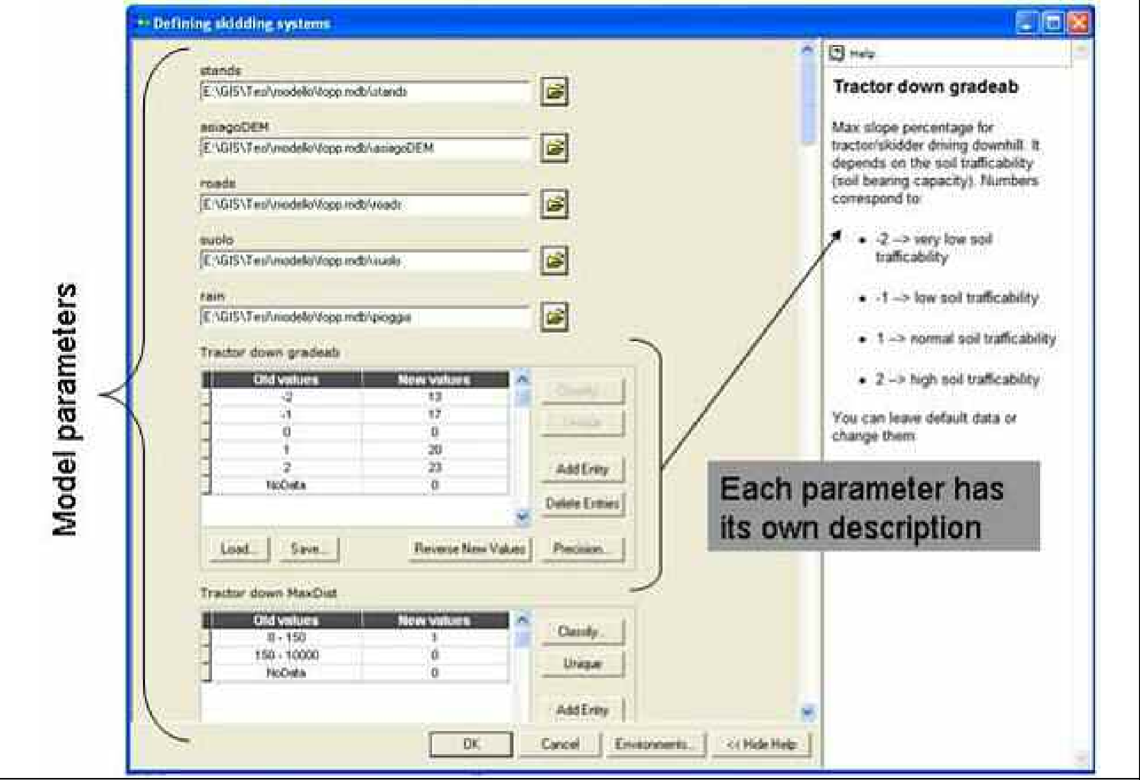
Stylesheet:

☑ Store relative path names (instead of absolute paths)

It is very useful to introduce in the models some parameters that will be managed by future users through the user interface window. From the building model window it is possible to introduce a new variable by right clicking any tool. Variables are shown in light blue and have a “P” if they are set as model parameter. As in the example below, you may ask the user to give a new reclassification method or you could ask to find this information selecting it from a *.txt file.



All your model parameters are shown as a list in the Parameters folder inside the Model properties window (see above). You can order them as you prefer and the same order will be in the user interface. To each parameter you can also insert a comment describing it or a short lines to help the user filling or modifying data to adapt the model to his necessities.



Model parameters

stands: E:\GIS\Tesi\modello\fopp.mdb\stands

asiagoDEM: E:\GIS\Tesi\modello\fopp.mdb\asiagoDEM

roads: E:\GIS\Tesi\modello\fopp.mdb\roads

suolo: E:\GIS\Tesi\modello\fopp.mdb\suolo

rain: E:\GIS\Tesi\modello\fopp.mdb\pioggia

Tractor down gradeab

Old values	New values
-2	13
-1	17
0	0
1	20
2	23
NoData	0

Tractor down MaxDist

Old values	New values
0 - 150	1
150 - 10000	0
NoData	0

Tractor down gradeab

Max slope percentage for tractor/skidder driving downhill. It depends on the soil trafficability (soil bearing capacity). Numbers correspond to:

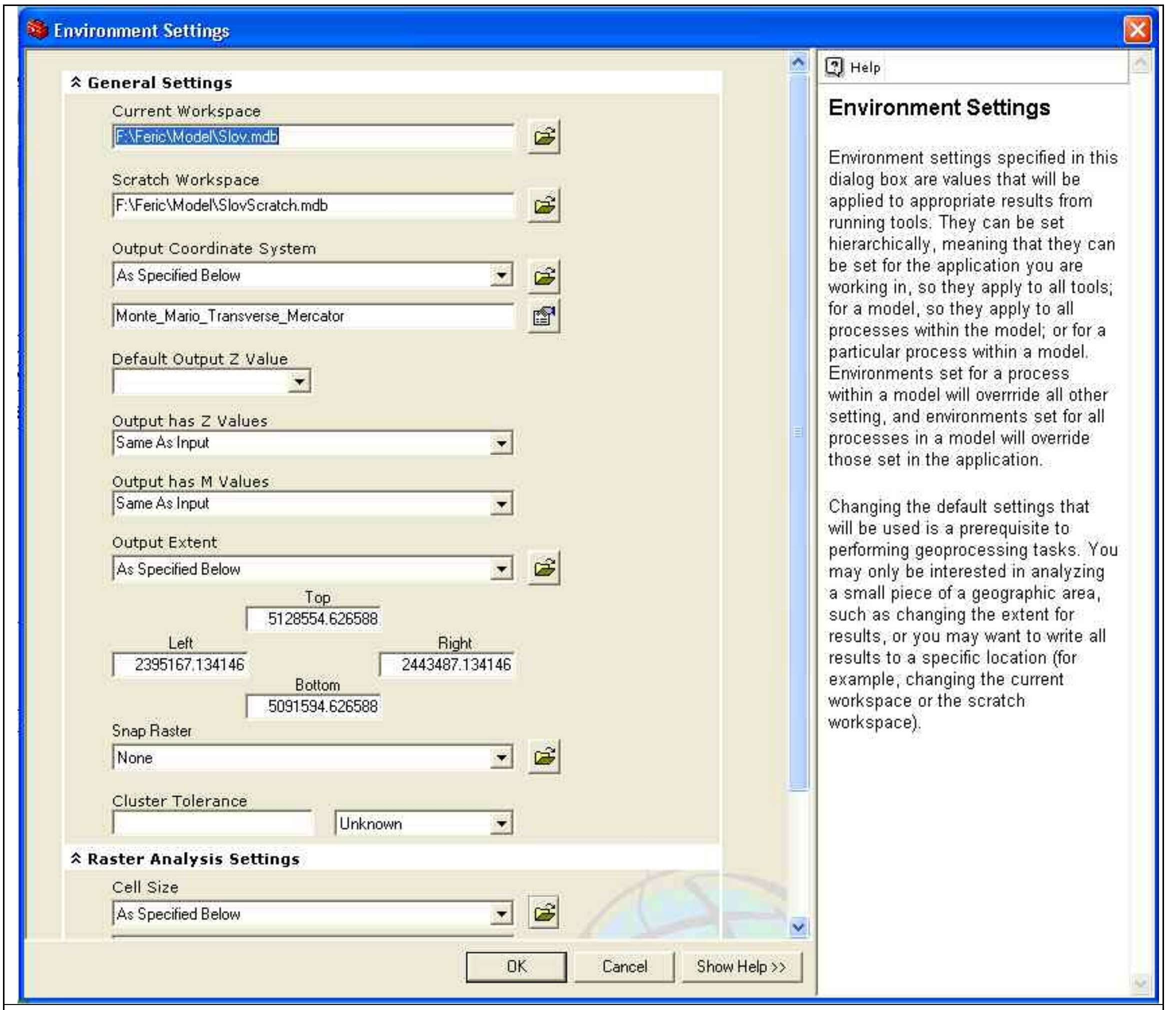
- -2 --> very low soil trafficability
- -1 --> low soil trafficability
- 1 --> normal soil trafficability
- 2 --> high soil trafficability

You can leave default data or change them

Each parameter has its own description

Figure 3.5.2.b: the FOpP – defining skidding systems dialog window

Through the Model Properties window, or if you are a user through the Dialog window, you can enter the Environments settings.



General Settings

Current Workspace: F:\Feric\Model\Slov.mdb

Scratch Workspace: F:\Feric\Model\SlovScratch.mdb

Output Coordinate System: As Specified Below

Monte_Mario_Transverse_Mercator

Default Output Z Value:

Output has Z Values: Same As Input

Output has M Values: Same As Input

Output Extent: As Specified Below

Top: 5128554.626588

Left: 2395167.134146

Right: 2443487.134146

Bottom: 5091594.626588

Snap Raster: None

Cluster Tolerance: Unknown

Raster Analysis Settings

Cell Size: As Specified Below

Environment Settings

Environment settings specified in this dialog box are values that will be applied to appropriate results from running tools. They can be set hierarchically, meaning that they can be set for the application you are working in, so they apply to all tools; for a model, so they apply to all processes within the model; or for a particular process within a model. Environments set for a process within a model will overrride all other setting, and environments set for all processes in a model will override those set in the application.

Changing the default settings that will be used is a prerequisite to performing geoprocessing tasks. You may only be interested in analyzing a small piece of a geographic area, such as changing the extent for results, or you may want to write all results to a specific location (for example, changing the current workspace or the scratch workspace).

Figure 3.5.2.c: the Environments setting window

This is the core of the model, you must set your workspace (input data and output geodatabases) and your geographical coordinate system. If you do not, you could have problems in showing or even in running the model because geoprocessing tools will not work properly. It is suggested to set your input Digital Elevation Model as mask for the Output extent and for the Cell size. This will avoid problems of not exact coincidence between output rasters that could derive by some conversions that the model performs. It is the case of converting polylines or polygons into grid or rasters files (figure 3.5.2.d): you may notice some loosing data near roads or near your study area boundaries.

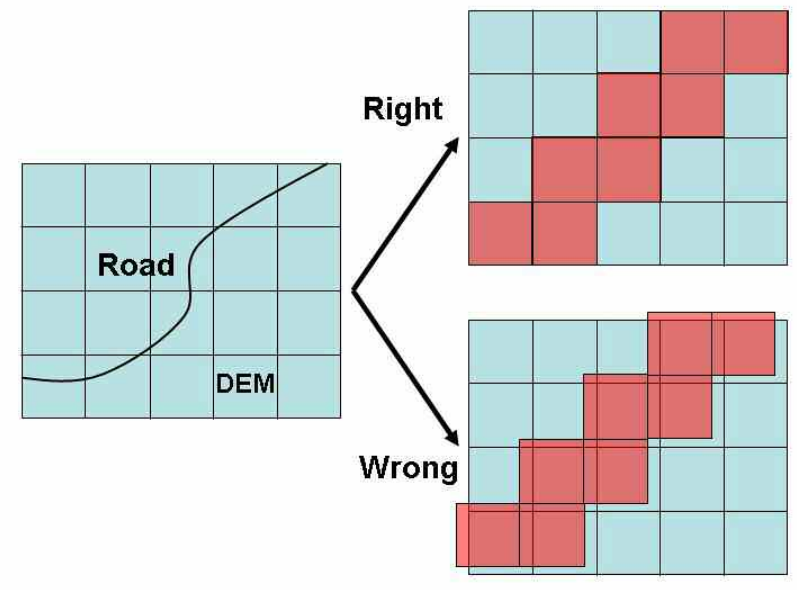


Figure 3.5.2.d: an example of errors that may occur performing shape conversion

3.5.3. Organizing data: geodatabases

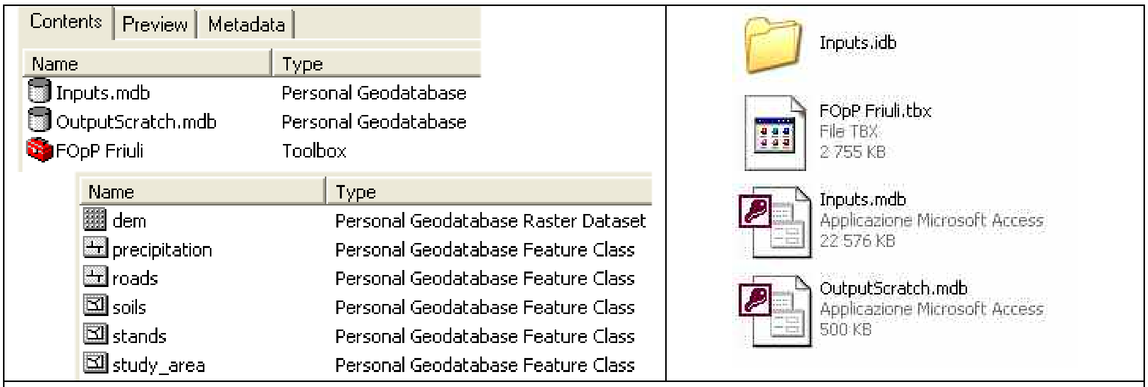
When working with a model, you need to set the location of your files in the “environment settings” window. For this reason two folders are needed, one containing input shapefiles, the other will store all output-files. But when closing ArcMap, all those output-files will be deleted but not those that were defined as “parameters” inside the model. All intermediate calculations and maps will be lost, but you will save a lot of space in your hard-disk. These folders containing geographic files are called geodatabases.

The **geodatabase**, short for geographic database, is the core geographic information model to organize GIS data into thematic layers and spatial representations (ESRI 2005). The geodatabase is a comprehensive series of application logic and tools for accessing and managing GIS data. This application logic is accessible in client applications (ArcGIS Desktop), server configurations (ArcGIS Server), and logic-embedded custom applications (ArcGIS Engine). The geodatabase is a GIS and database management system (DBMS) standards-based physical data store and is implemented on a number of multiuser and personal DBMSs and in XML. The geodatabase was designed as an open simple-geometry storage model.

Some advantages of a geodatabase are:

- Geodatabases can have built-in behavior and are stored completely in a single database.
- Large geodatabase feature classes can be stored seamlessly, not tiled.
- In addition to generic features, such as points, lines, and areas, you can create custom features, such as transformers, pipes, and parcels.

- Custom features can have special behavior to better represent real-world objects. You can use this behavior to support sophisticated modeling of networks, data entry error prevention, custom rendering of features, and custom forms for inspecting or entering attributes of features.
- Each feature is stored as a row in a table. The vector shape of the feature is stored in the table's shape field, with the feature attributes in other fields. Each table stores a feature class.



Name	Type
Inputs.mdb	Personal Geodatabase
OutputScratch.mdb	Personal Geodatabase
FOpP Friuli	Toolbox

Name	Type
dem	Personal Geodatabase Raster Dataset
precipitation	Personal Geodatabase Feature Class
roads	Personal Geodatabase Feature Class
soils	Personal Geodatabase Feature Class
stands	Personal Geodatabase Feature Class
study_area	Personal Geodatabase Feature Class

Inputs.idb

FOpP Friuli.tbx
File TBX
2 755 KB

Inputs.mdb
Applicazione Microsoft Access
22 576 KB

OutputScratch.mdb
Applicazione Microsoft Access
500 KB

Figure 3.5.3.a: the geodatabase and model files as shown inside the ArcCatalog (left) and in the “resources manager” of a personal computer (right)

Two types of geodatabase architectures are available: personal geodatabases and multiuser geodatabases. Personal geodatabases, which are available to all ArcGIS users, use the Microsoft Jet Engine database file structure to persist GIS data in smaller databases. Personal geodatabases are much like file-based workspaces and hold databases up to 2 GB in size. Microsoft Access is used to work with attribute tables in personal geodatabases. Personal geodatabases are ideal for working with smaller datasets for GIS projects and in small workgroups. Personal geodatabases support single user editing, and no versioning support is provided. Multiuser geodatabases require the use of ArcSDE and work with a variety of DBMS storage models (IBM DB2; Informix; Microsoft SQL Server; and Oracle, with or without Oracle Spatial or Locator). Multiuser geodatabases are primarily used in workgroups, departments, and enterprise settings. They take full advantage of their underlying DBMS architectures to support:

- Large, continuous GIS databases.
- Many simultaneous users.
- Long transactions and versioned work flows.

Multiuser geodatabases readily scale to large sizes and numbers of users.

Geodatabase XML represents ESRI's open mechanism for information interchange between geodatabases and other external systems (i.e.: internet). ESRI openly publishes and maintains the complete geodatabase schema and content as an XML specification and provides example implementations to illustrate how you can share data updates between heterogeneous systems. XML interchange of geospatial information to and from the geodatabase is simplified using the geodatabase XML specification. External applications can receive XML data streams, including:

- Exchange of complete lossless datasets.
- Interchange of simple feature sets (much like shapefile interchange).
- Exchange change-only (Delta) record sets using XML streams to pass updates and changes among geodatabases and other external data structures.
- Exchange and sharing of full or partial geodatabase schemas between ArcGIS users.

Geodatabases are relational databases that contain geographic information. Geodatabases contain feature classes and tables. Feature classes can be organized into feature datasets.

Feature classes store geographic features represented as points, lines, polygons, annotation, dimensions, and multipatches and their attributes. All feature classes in a feature dataset share the **same coordinate system**. Tables may contain additional attributes for a feature class or geographic information, such as addresses or x,y,z coordinates.

Many objects in a geodatabase can be related to each other. For example, tables containing customer addresses and billing information are related, just as state and county feature classes are related. To explicitly define the relationships between objects in a geodatabase, you must create a relationship class. Relationships let you use attributes stored in a related object to symbolize, label, or query a feature class (BURROUGH 1986; SMITH *et al.* 1987).

Feature classes in a feature dataset can be organized into a geometric network or a topology. A geometric network combines line and point feature classes to model linear networks - for example, electrical networks - and maintains topological relationships between its feature classes. A topology is a set of relationships that defines how the features in one or more feature classes share geometry - for example, cities must be properly inside states.

Topology in a geodatabase allows you to represent shared geometry between features within a feature class and between different feature classes. You can organize the features in a geodatabase to create planar topologies or geometric networks.

Feature classes can share geometry with other feature classes in a planar topology. For example, you might define a topological relationship between streets, blocks, block groups, and census tracts. The street segments define the boundary of the block they enclose. Groups of blocks can be collected into block groups, and block groups into tracts.

A planar topology is composed of a set of nodes, edges, and faces. When you update the boundary of one feature, the shared boundaries are updated as well.

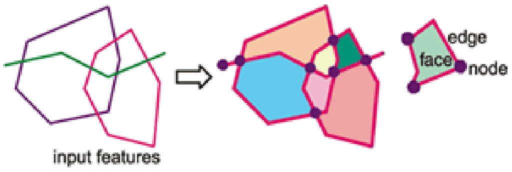


Figure 3.5.3.b: basis of topology

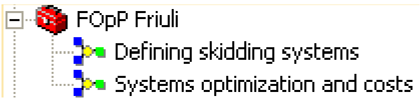
Topologically related edge and junction features within a dataset can be bound into a geometric network. This is useful when the features must be connected to each other with no gaps. For example, you could organize pipes, valves, pumps, and feeders into a water network.

3.5.4. Describing processes of the model

The Forest Operations Planning model is split in two parts to simplify procedures and reduce the running time. The two parts are called:

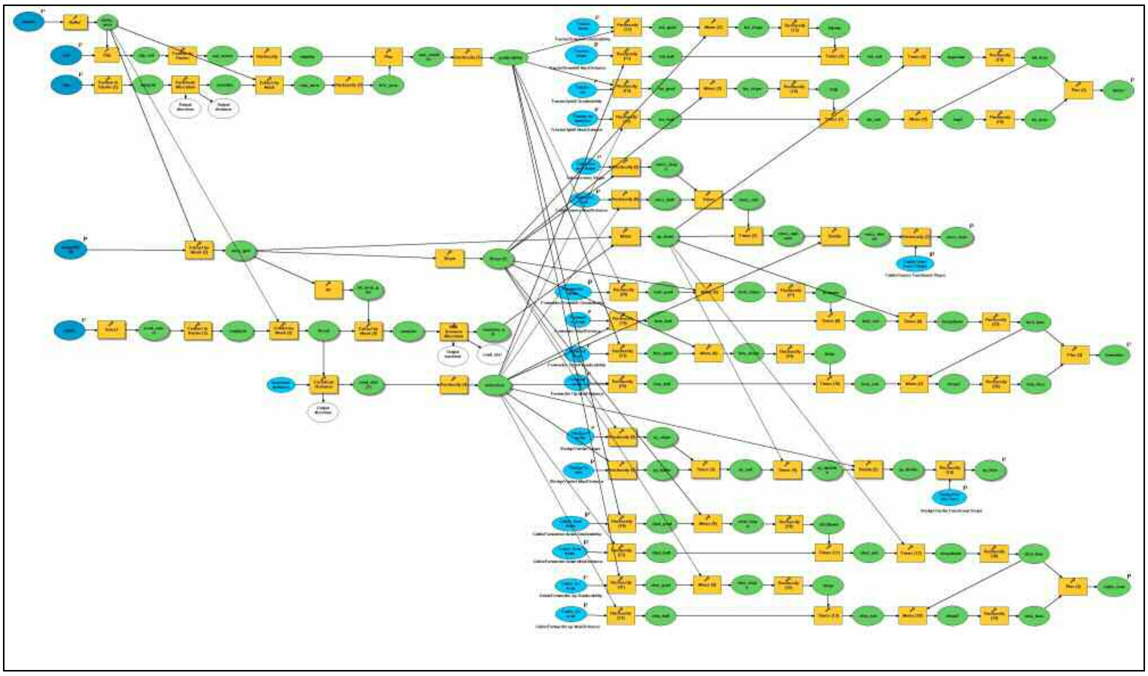
1. Defining skidding systems (which makes a feasibility analysis)
2. Systems optimization and costs (establish technical and economical preferences)

They may be opened trough the ArcMap toolbox by double-clicking the icon. An user interface like that on figure 3.5.2.b will appear and enable the user to set parameters and run the tools.



FOpP Friuli
Defining skidding systems
Systems optimization and costs

The functioning structure of the model is quite intricate (figure 3.5.4.a) and will be next explained step by step with diagrams and examples.



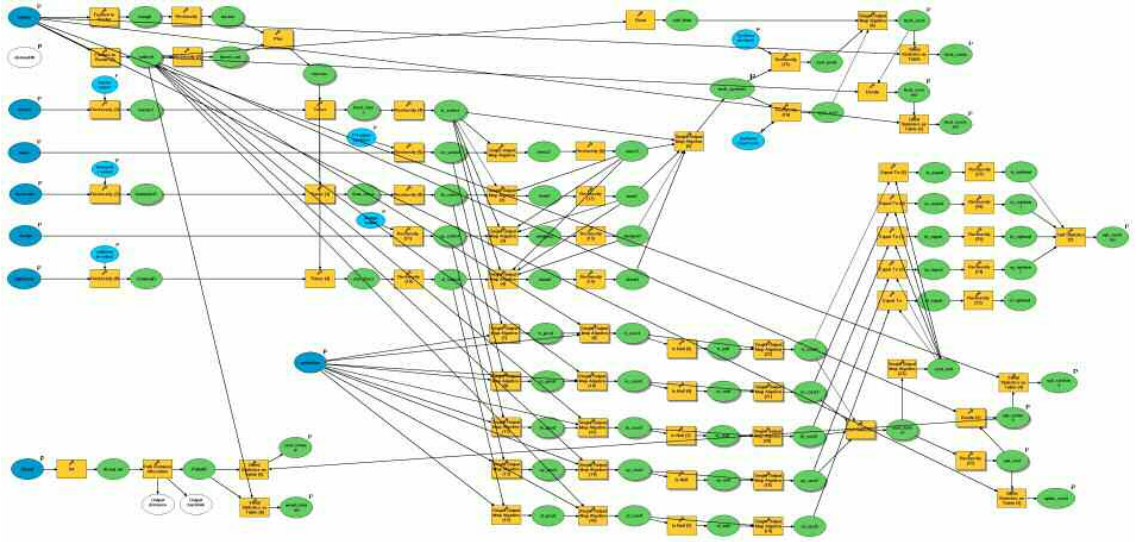


Figure 3.5.4.a: the defining skidding systems and systems optimization and costs tools diagrams. They include more than 150 steps which take from half to one hour running time depending on the size of the planning area.

3.5.4.1 Defining skidding systems

The first step of this tool is determining trafficability classes and gradeability. Starting from geology and precipitation, the model defines a list of soil trafficability classes (AA.VV. 1961; ANDERSON 1985; BONASSO 1989; AA.VV. 2002). On the basis of the soil composition and pH, the geology shapefile is converted into a grid file and consequently reclassified into three stability classes: high, normal and low (values 1-3 - table 3.5.4.1.a). The rain input shapefile is also converted into a grid file and reclassified into four classes according to the average amount of rain (values 10 - 40). Classes are defined considering the Alpine climate.

The two grid files (*stability* and *h2o_year*) are summed (figure 3.5.4.1.a) with algebraic instruments and reclassified into four gradeability classes (table 3.5.4.1.b). These classes are used then to select the maximum slope to which off-road systems can move inside forest (BEKKER 1969; SAMSET 1975; ROWAN 1977; MELLGREN 1980; LÖFFLER 1984). The maximum slope values are set as model parameters, so they can be modified by the user through the model interface. Figure 3.5.4.1.b show an example of the output *gradeability* file.

Table 3.5.4.1.a: Reclassifying soil and rain input files to evaluate gradeability

Soil stability Rain mm/year		HIGH 1		NORMAL 2		LOW 3	
< 700	10	HIGH	(11)	HIGH	(12)	HIGH	(13)
700-1500	20	HIGH	(21)	HIGH	(22)	NORMAL	(23)
1500-2500	30	HIGH	(31)	NORMAL	(32)	LOW	(33)
> 2500	40	NORMAL	(41)	LOW	(42)	VERY LOW	(43)

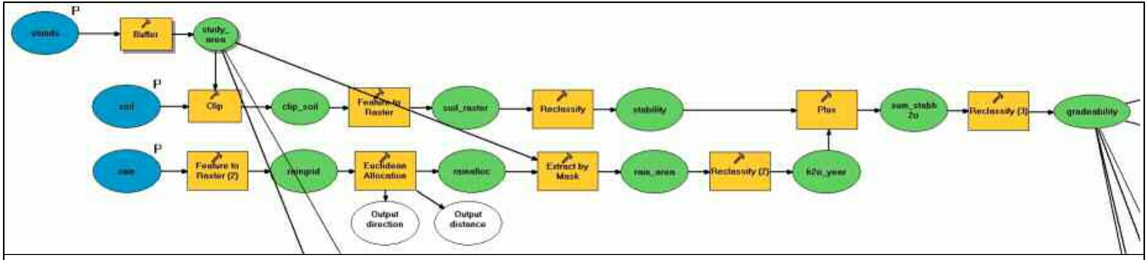


Figure 3.5.4.1.a: lay-out for gradeability calculation starting from stands, soil and rain input shapefiles.

Table 3.5.4.1.b: Maximum slope values according to gradeability classes

Gradeability / Systems		High	Normal	Low	Very Low
Tractor	Uphill	18	15	12	8
	Down	23	20	17	13
Forwarder	Uphill	32	30	27	22
	Down	38	35	32	28
Cable-forw	Uphill	63	60	57	53
	Down	63	60	57	53

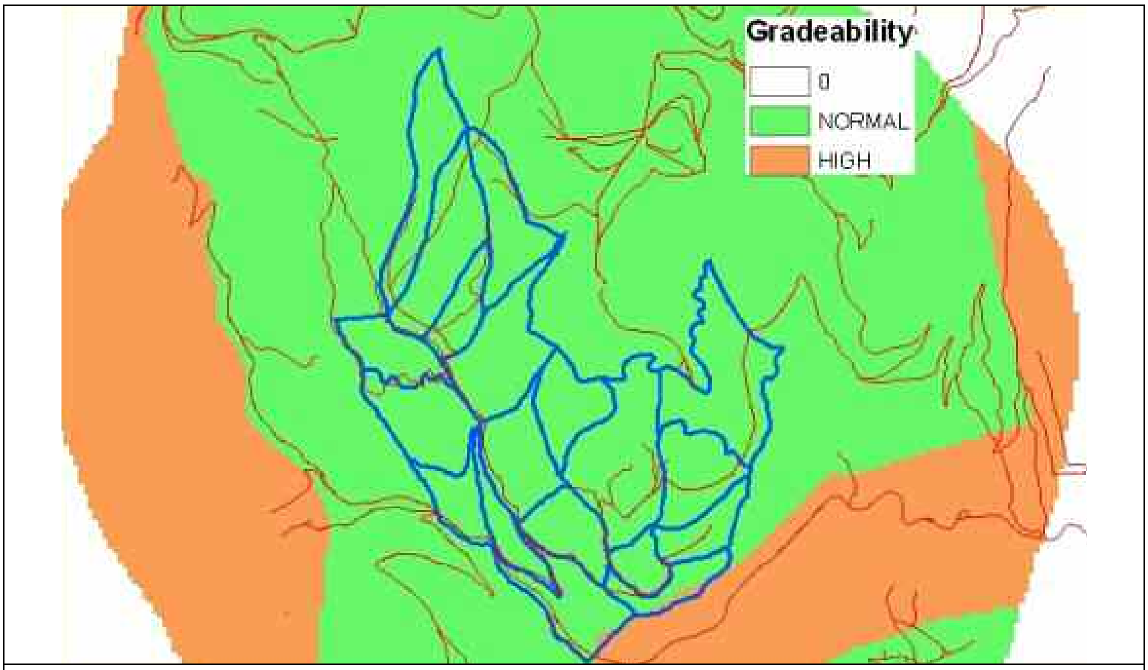


Figure 3.5.4.1.b: a gradeability output map

Consequently, three basic maps are created: the slope, the extraction distance and the uphill or downhill direction (figure 3.5.4.1.c).

The slope is created starting from the Digital Elevation Model using the slope tool inside the Spatial Analyst toolbox. Values are calculated in percentage (figure 3.5.4.1.d)

The extraction distance is generated, starting from the roads shapefile, by the Euclidean distance tool (TUČEK and PACOLA 1999). The maximum distance may be changed by the user, as default it is set up to 1500 m. The map is after reclassified to eliminate a small error, in fact the cells corresponding with the road track have null value and this will cause a wrong choice of systems. A new value (we used 15 m as average) was set to these cells and a continuous surface is obtained (figure 3.5.4.1.e).

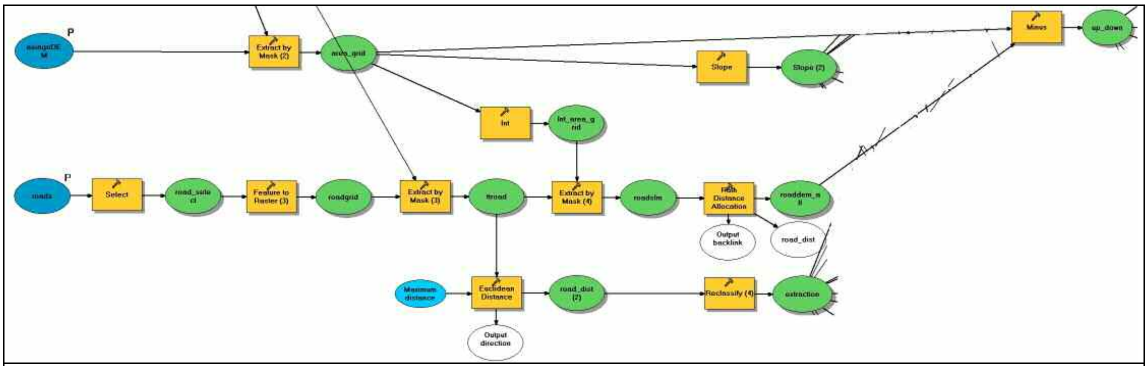


Figure 3.5.4.1.c: FOpP model lay-out of slope, extraction and UpDown maps evaluation

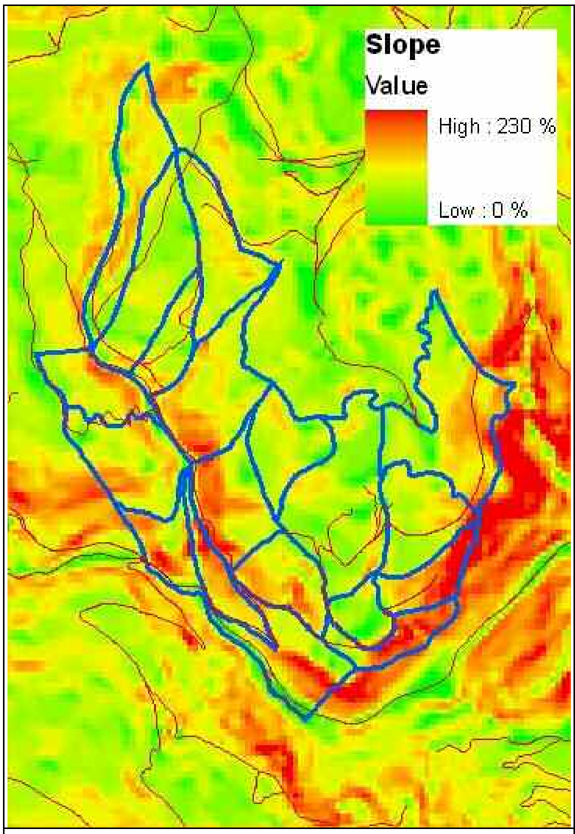


Figure 3.5.4.1.d: the slope map

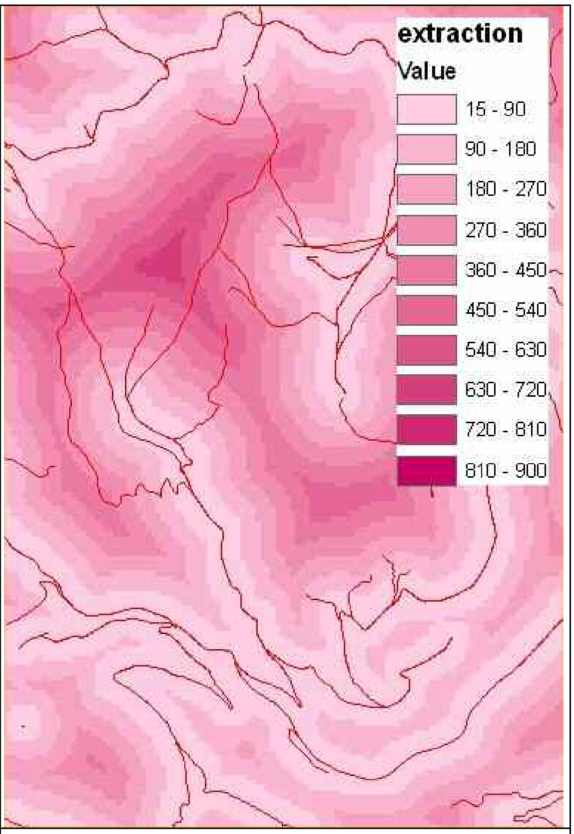


Figure 3.5.4.1.e: the extraction distance map

The evaluation of up and down skidding direction is a little complicate (figure 3.5.4.1.f). Vector roads are converted into a grid file (only truck and tractor roads, skidtrails are not considered) and they are used as a mask to extract values from the DEM (the RoadSlm map is obtained). Using the Path Distance allocation tool the values of each road cell are spread all over the area at an equal distance from other roads (demRoad grid file). Through a simple operation performed with the map calculator) DEM values are subtracted from demRoad values obtaining a map with positive and negative values. The Up-down grid file (figure 3.5.4.1.g) is calculated by a reclassification of values: positive values correspond to the uphill side (downhill skidding direction), negative values to the downhill side (GRIGOLATO 2006).

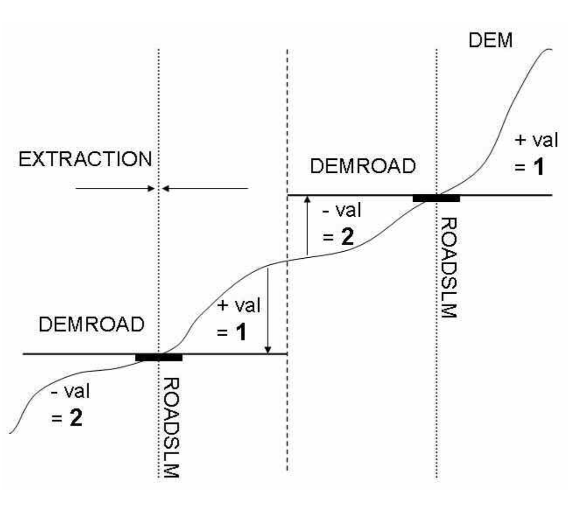


Figure 3.5.4.1.f: showing elements considered generating the up-down grid file

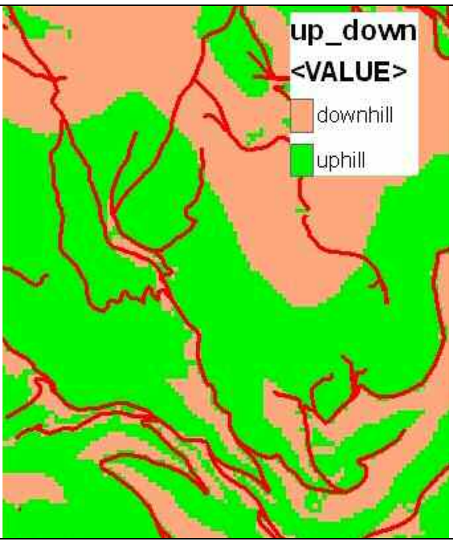


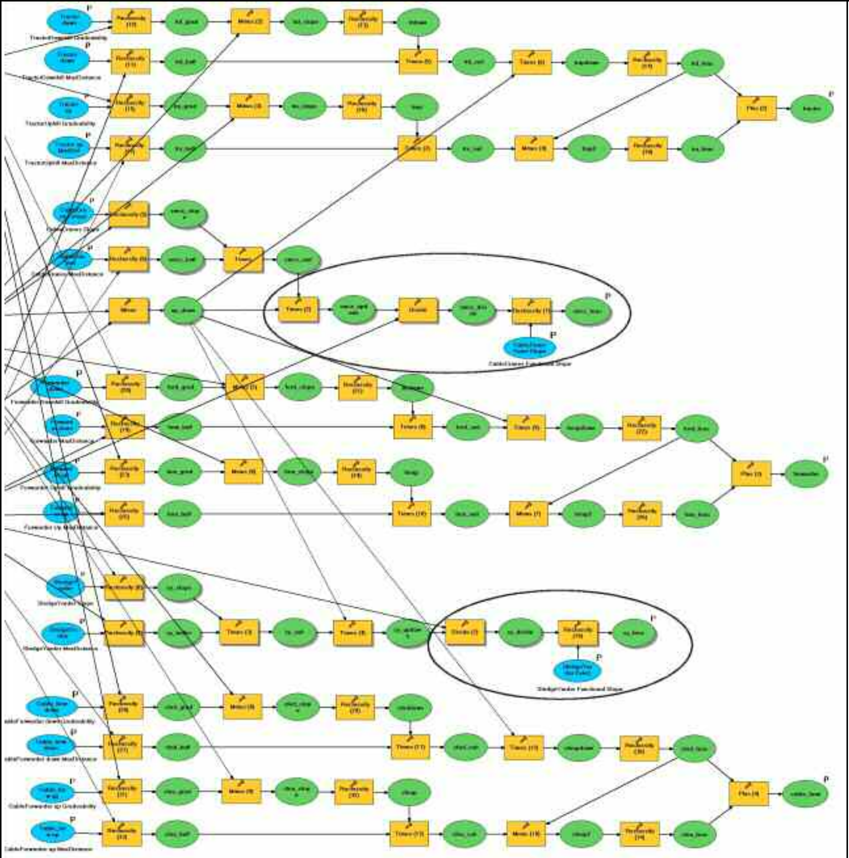
Figure 3.5.4.1.g: the up-down map

The evaluation of feasibility maps is quite similar for the off-road systems and for the cable systems, as it is shown in figure 3.5.4.1.h. The model makes a cell-by-cell evaluation for both skidding directions according to slope and distance technical limits (CIELO *et al.* 2003; HIPPOLITI and PIEGAI 2000) as on table 3.5.4.1.c. These parameters (the blue balloons in figure 3.5.4.1.h) may be adapted to the user needs.

Table 3.5.4.1.c: technical limits used in the ArcMap model. The maximum slope varies according to the gradeability.

Skidding system	Downhill		Uphill	
	max slope	max distance	max slope	max distance
Tractor/skidder	13-23	300	8-18	150
Tower cranes	100	350	100	350
Forwarder	28-38	600	22-32	500
Sledge yarder	120	900	120	900
Cable-forwarder	50-63	150	50-63	150

With the technical limits information, model is able to determine feasible areas for each selected skidding system. Output maps (example on figure 3.5.4.1.i) distinguish the skidding direction (HEINIMANN 1986 and 1994; LÜTHY 1998; KRČ 1999) and for cable systems the model verify (sort of profile slope analysis) that average inclination from each cell to the nearest road is enough to guarantee the gravity functioning (figure 3.5.4.l).



Feasibility analysis

Tractor – TR

Mobile tower yarders – CC

Forwarder – FO

Sledge yarder – SY

Cableforwarder – CF

Figure 3.5.4.1.h: the schema of tool used creating feasibility maps. In blue balloons are model parameters that may be set by the user. Circles underline a sort of profile slope analysis.

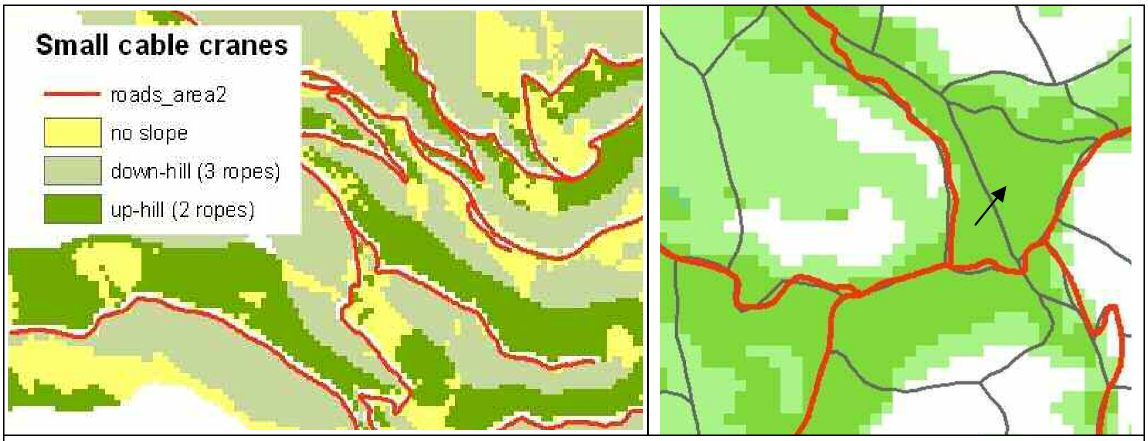


Figure 3.5.4.1.i: example of mobile tower cranes output map (on the left side) and the overlay of tractor and forwarder maps (on the right side). The stand with the arrow is the same one considered on the model validation paragraph (§ 3.6.1)

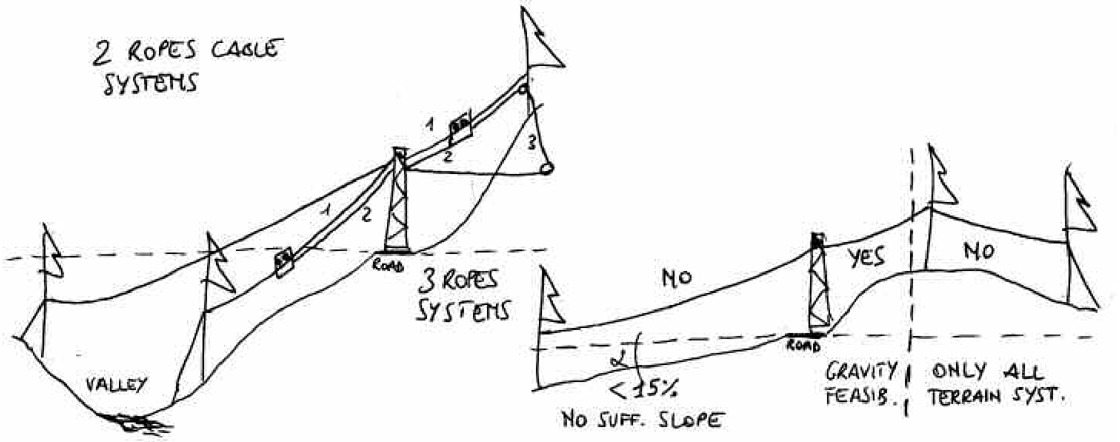


Figure 3.5.4.1.l: mobile cable crane systems (tower yarders) are divided in two types, the 2 ropes cable systems skidding uphill and the 3 ropes cable systems skidding downhill. If the terrain shape and slope are quite flat or irregular, the feasibility map will show "no slope" areas in which only all-terrain systems can work (on the right side)

3.5.4.2 Systems optimization and costs

The second part of the FOpP model makes an overlay of all five systems maps (tractor, forwarder, cable crane, sledge yarder and cable-forwarder) in two different ways, from a technical and an economical point of view.

Both algorithms start from a basic stand classification according to the terrain roughness and to the stand yield (cutting amount). The terrain roughness is one limiting factor for the machine off-road movement, while the yield influence the productivity of systems and their choice. If there are less than 48 m^3/ha it is not convenient to relocate big machines as forwarder, but to use tractor and winch. Systems have so an order of importance: tractor and mobile cable cranes are at same level, then follow the forwarder and sledge yarder and last comes the cable-forwarder. According to the defined classes, the choice will be done on the "importance" basis. Starting from input stand shapefile, terrain roughness is reclassified into four levels (values 10 – 40), while the yield is reclassified into three levels (values 0 – 2). The two maps are summed and stand classes are obtained (figure 3.5.4.2.a). All possible values are shown on table 3.5.4.2.a: to each value is assigned the most feasible system (written in red) and all the other systems which could work on the same parameters combination. When the model makes the map overlay it will select systems in that order.

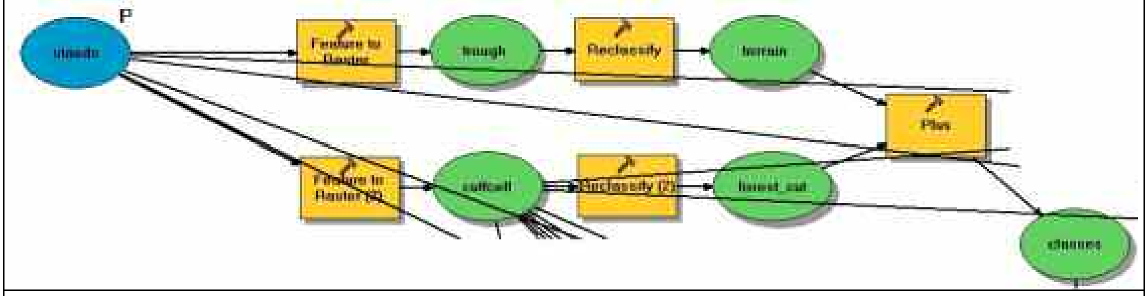


Figure 3.5.4.2.a: determining stand classes for systems selection

Table 3.5.4.2.a: matrix of values defining stand classes and order of systems for their choice.

Yield m^3/cell Roughness	= 0 0	0 - 3 1	> 3 2
Smooth 10	10 **TR** CC / FO / SY / CF	11 **TR** CC / FO / SY / CF	12 **FO** CC / SY /CF
Uneven 20	20 **TR** CC / FO / SY / CF	21 **TR** CC / FO / SY / CF	22 **FO** CC / SY /CF
Rough 30	30 **CC** FO / SY /CF	31 **CC** FO / SY /CF	32 **CC** FO / SY /CF
Very rough 40	40 **CC** SY	41 **CC** SY	42 **CC** SY

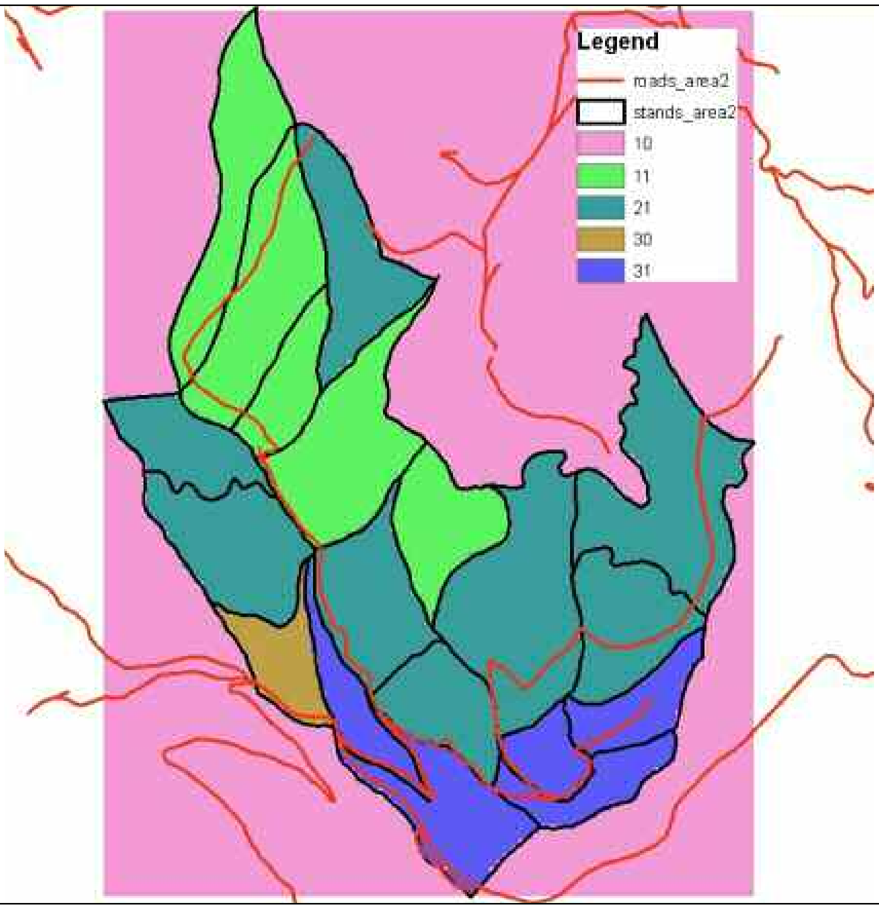


Figure 3.5.4.2.b: example of classes output map.

The technical evaluation algorithm starts from the five systems maps and perform an overlay taking care of classes as defined in table 3.5.4.2.a and figure 3.5.4.2.b (figure

3.5.4.2.c). The procedure looks like complicate, but the used tools are only two, the *reclassify* tool and the single output map algebra. The number of systems and the distinction between uphill and downhill extraction make calculation quite long.

Figure 3.5.4.2.d shows an example of technical system evaluation map, some areas are not reachable due to distance from roads or steep slope.

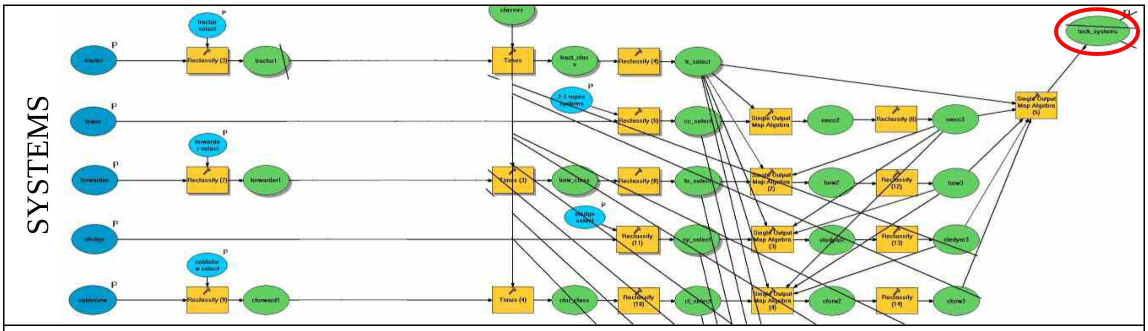


Figure 3.5.4.2.c: lay-out of the FOpP algorithm for technical output map

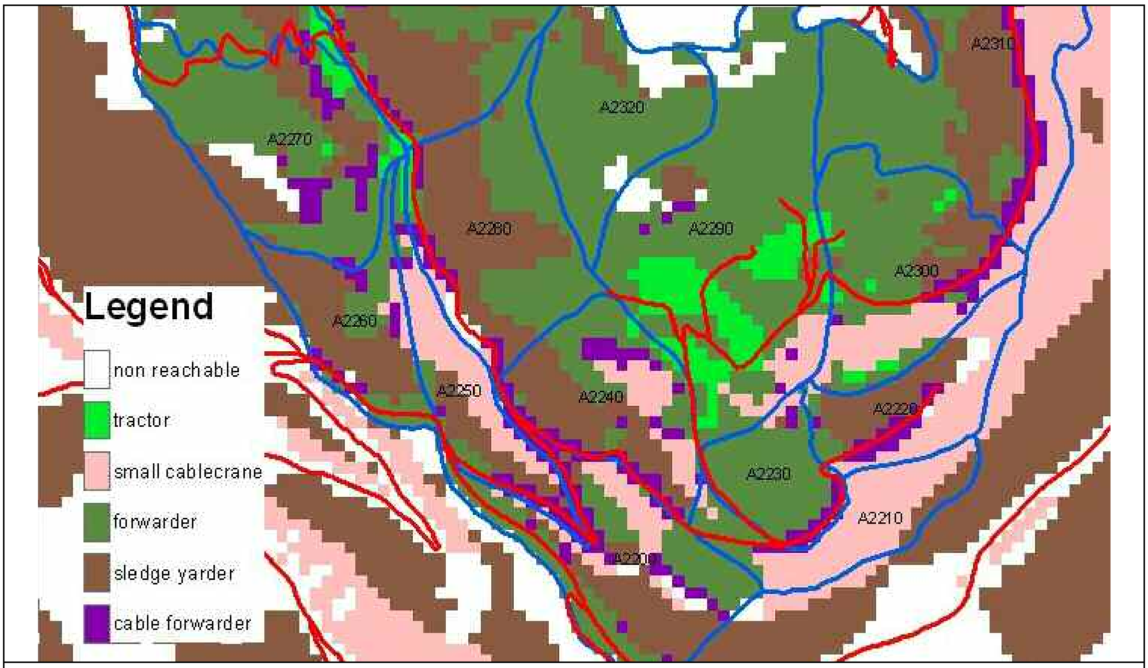


Figure 3.5.4.2.d: example of technical systems output map.

Through the input model window the user can set average costs and productivities of selected systems. With these data the model makes a simple evaluation of costs. The technical map is reclassified and costs are calculated cell-by-cell both per cell and per cubic meter (figure 3.5.4.2.e). Outputs can be see as grid maps (figure 3.5.4.2.f) or resumed in database tables with some statistics on forest stand basis (table 3.5.4.2.b). Minimum, maximum, average and total costs are calculated. Costs are strictly depending on the yield distribution and the choice of systems.

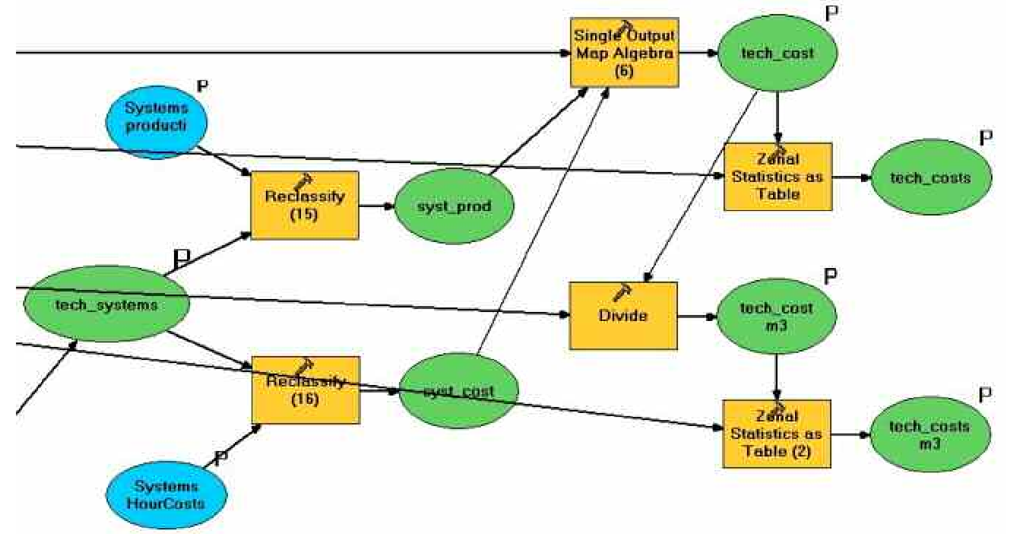


Figure 3.5.4.2.e: lay-out of tools used to make statistics.

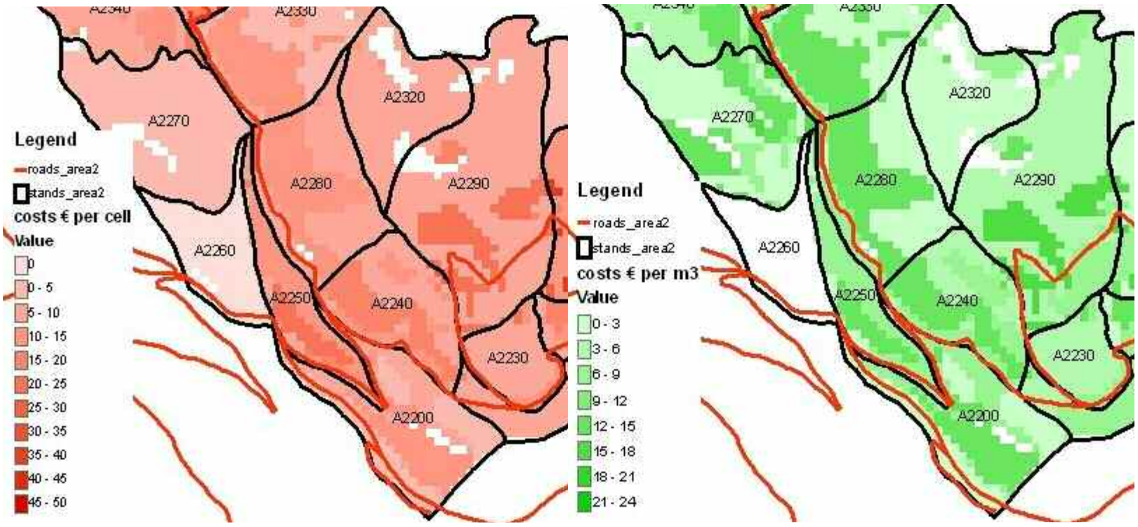


Figure 3.5.4.2.f: cost maps, costs are calculated cell-by-cell (left side) or per cubic meter (right side).

Table 3.5.4.2.b: summary statistics of some stands. Values equal 0 means that there will not be cuttings in the next 10 years. Skidding costs vary from 5.5 €/m^3 where forwarder is mainly used to 8.8 where sledge yarder is necessary to work (stands A223 and A228).

Stand n°	AREA	MIN	MAX	MEAN €/cell	€/m3	SUM €/stand
A2200	163125	4.98	12.25	7.47	7.62	1948.83
A2210	84375	6.24	15.38	8.81	7.17	1189.79
A2220	90000	7.62	18.75	11.88	7.92	1710.54
A2230	65625	9.09	22.38	9.85	5.50	1033.76
A2240	123125	7.51	25.16	12.69	8.57	2499.76
A2250	81875	9.85	24.25	14.94	7.70	1957.13
A2260	90000	0.00	0.00	0.00	0.00	0.00
A2270	178750	1.17	3.91	1.81	7.85	516.35
A2280	167500	6.04	20.23	10.47	8.80	2806.66
A2290	293750	6.30	21.08	9.48	7.65	4457.70

Having different productivities and costs, each system has a unique value per each cell, different from values of the other systems. The optimization tool starts from this assumption and select the cheapest system through a *cell statistic* tool (choose the minimum value between different overlaying grid files). The obtained map (*cost_select*) is compared with systems cost maps to assign to each cell the systems which correspond to (tool *equal to*). The optimal systems map is obtained making a sum of the previous maps (obtained from the comparison of costs selection and systems costs) as shown on figure 3.5.4.2.g. The result map (figure 3.5.4.2.h) is similar to the technical system map, but for example the tractor disappeared because is the less productive systems which means one of the most expensive where the yield is very low.

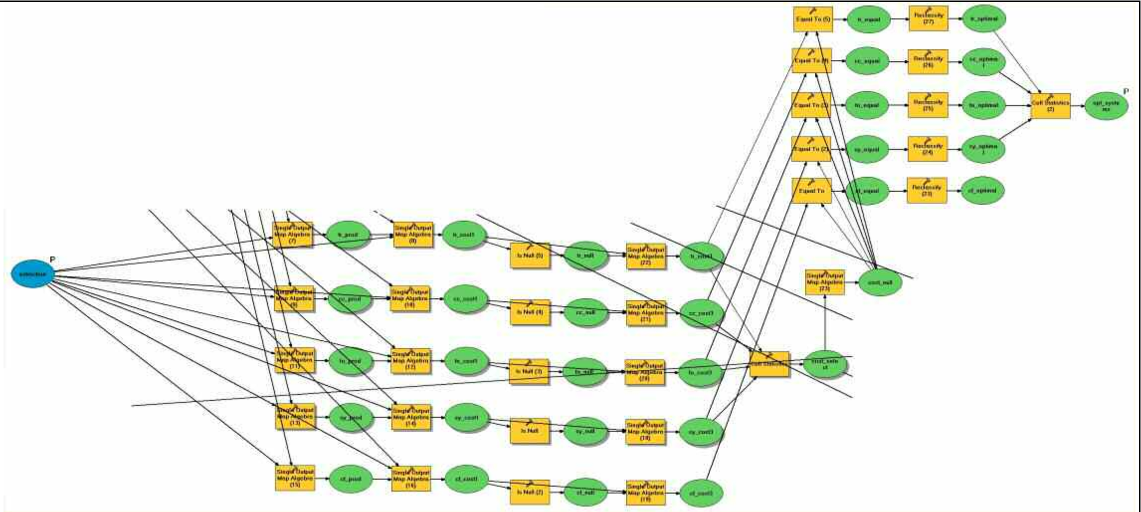


Figure 3.5.4.2.g: lay-out of tools used to make systems and costs optimization.

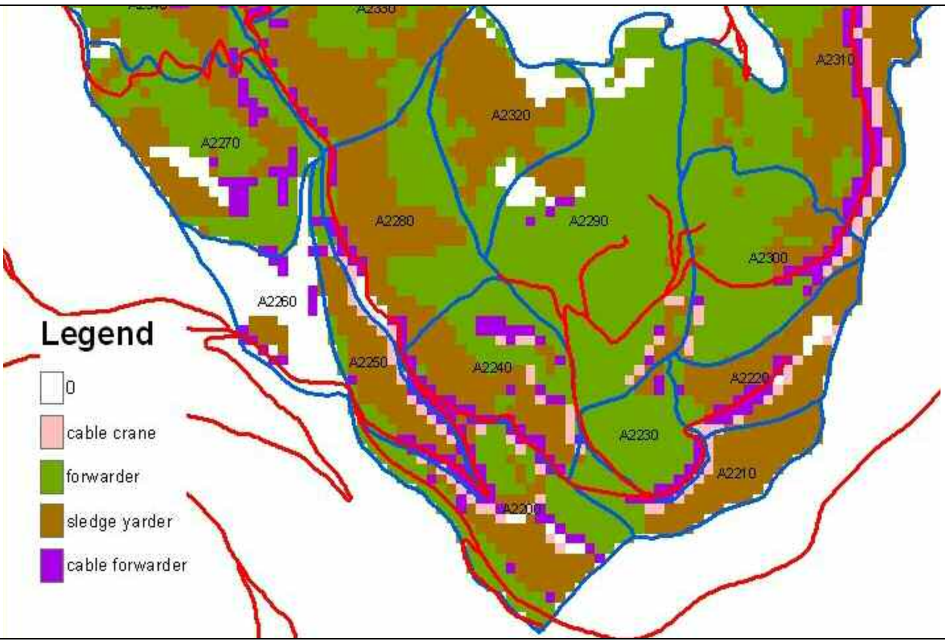


Figure 3.5.4.2.h: example of optimized systems output map.

The optimization method uses the systems productivity functions (figure 3.2.4.a) which were estimated giving correlation to skidding distance from forest road (PIEGAI 1990; FANARI *et al.* 1999; DELLA GIACOMA *et al.* 2002; ZUCCOLI *et al.* 2006). The result gives a decreasing value (in m^3/hour) for each system working far from road (figure 3.5.4.2.i). After this calculation, dividing productivities by yield it is possible to know how much time skidding operations will last and how much they will cost (figure 3.5.4.2.l). This value is suddenly divided by the yield (cell by cell), transformed in €/m^3 and a statistic table is created (table 3.5.4.2.c).

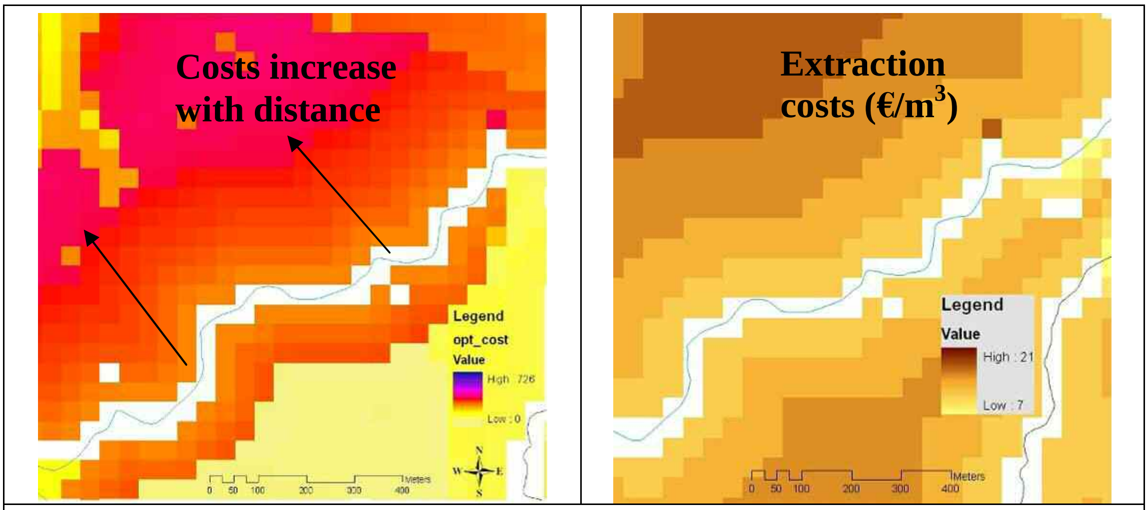


Figure 3.5.4.2.i: on the left side a general cost function map; on the right side a cost output map (€/m^3).

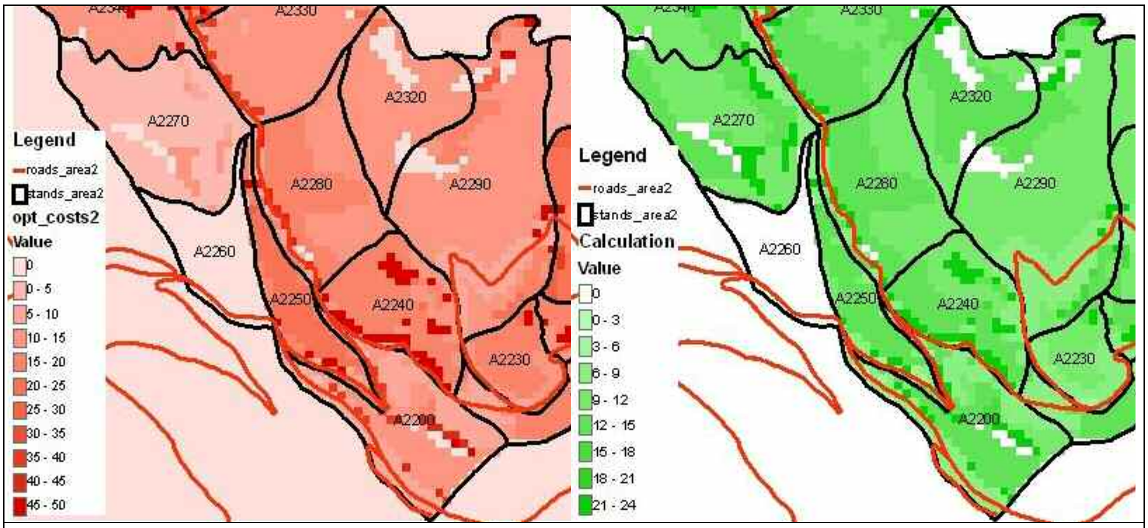


Figure 3.5.4.2.l: optimized costs maps, costs are calculated cell-by-cell (left side) or per cubic meter (right side).

Table 3.5.4.2.c: summary statistics of some stands. Values equal 0 means that there will not be cuttings in the next 10 years. Skidding costs vary from 9.66 €/m^3 where forwarder is mainly used to 16.91 where cable crane systems are necessary (stands A223 and A224).

stand n°	AREA	MIN	MAX	MEAN €/cell	€/m3	SUM €/cell
A2200	167500	0.00	46.29	12.26	12.51	3286.82
A2210	84375	8.80	15.56	14.15	11.50	1910.14
A2220	92500	0.00	67.30	21.37	14.25	3162.76
A2230	65625	7.68	84.54	17.29	9.66	1815.56
A2240	123125	10.59	75.26	25.02	16.91	4929.77
A2250	81875	8.33	75.14	24.29	12.52	3182.14
A2260	91875	0.00	0.00	0.00	0.00	0.00
A2270	187500	0.00	11.96	3.28	14.24	982.62
A2280	168750	0.00	43.65	14.92	12.53	4027.36
A2290	308750	0.00	64.23	13.31	10.74	6576.31

An interesting step of the model was the evaluation of how much wood will be skidded to each forest road section, and to calculate average costs. The schema was implemented inside the model (figure 3.5.4.2.m), but after several tries was eliminated because there were some functional problems. In fact, there were two joins between tables that had to be created running the model, but this caused errors and the evaluation needs to be hand-made. Nevertheless results (figure 3.5.4.2.n) are interesting because they highlight which roads will support more traffic and will need more maintenance.

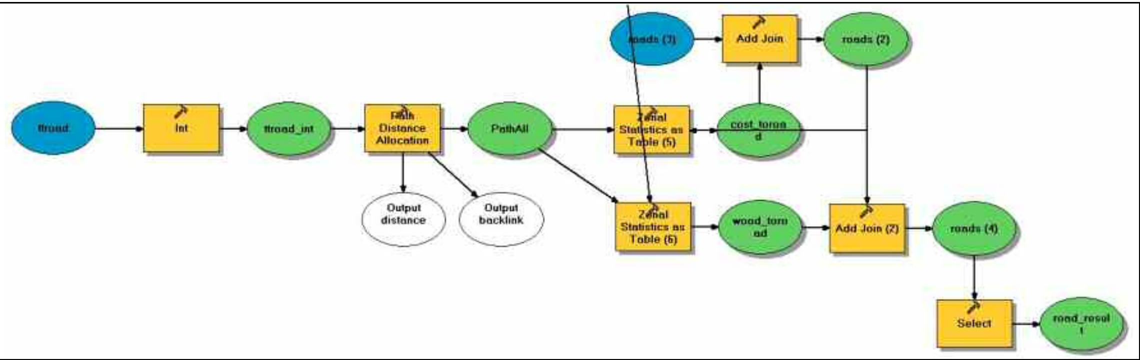


Figure 3.5.4.2.m: lay-out for wood skidding to road analysis.

The FOpP model can be shared with other researchers by exporting and installing it as a simple toolbox in ArcGIS (*.tbx file). This is not the only one way, it can be exported as a txt file or as a program into a specific language (Python) or into a Visual Basic for Applications (VBA) using ArcObjects. There are several helps on-line inside the customer service websites that everybody could modify the model or improve it with own algorithms.

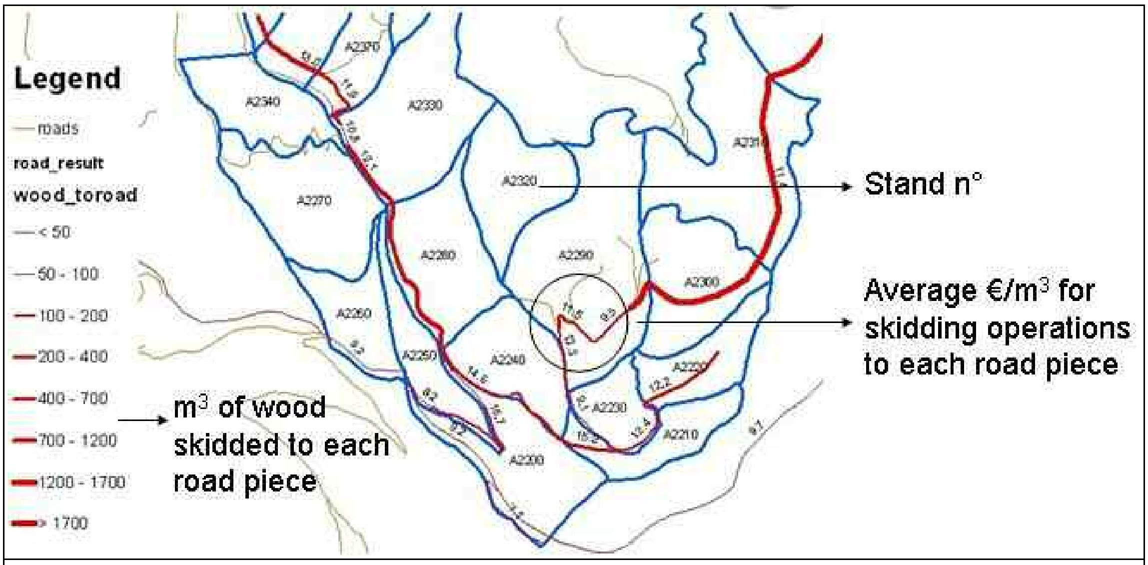


Figure 3.5.4.2.n: road results. Thicker are roads, more wood will flow.

3.6. MODEL VALIDATION

Model verification and validation (V&V) are essential parts of the model development process if models are to be accepted and used to support decision making. In fact, one of the very first questions that a person who is promoting a model is likely to encounter is "has your model been validated?" (MACAL 2005).

Verification is done to ensure that the model is programmed correctly, the algorithms have been implemented properly and the model does not contain errors, oversights, or bugs. Verification ensures indeed that the specification is complete and that mistakes have not been made in implementing the model, thus it does not ensure the model solves an important problem, meets a specified set of model requirements and correctly reflects the workings of a real world process.

The practical verification is a long process and it should take count that:

- no computational model will ever be fully verified, guaranteeing 100% error-free implementation
- a high degree of statistical certainty is all that can be realized for any model as more cases are tested
    - Statistical certainty is increased as important cases are tested
    - In principle, a properly structured testing program increases the level of certainty for a verified model to acceptable levels
    - Exercise model for all possible cases
    - Automated testing process
- model verification proceeds as more tests are performed, errors are identified, and corrections are made to the underlying model, often resulting in retesting requirements to ensure code integrity

- the end result of verification is technically not a verified model, but rather a model that has passed all the verification tests!

Validation ensures that the model meets its intended requirements in terms of the methods employed and the results obtained. The ultimate goal of model validation is to **make the model useful** in the sense that the model addresses the right problem, provides accurate information about the system being modeled, and to makes the model actually used.

3.6.1 Comparing results with real working sites

A good way to test the model is to compare results with some real working sites. To do this it was asked to two private enterprises (SAMBUGARO and DALLE AVE from Gallio and Asiago municipalities) which were the latest operations and which systems were used. To their answers were added also some observations taken during a previous study conducted on cable crane systems on the same area (TOMASINI 1996). Seven working sites were considered, three using tractor and winch, one using forwarder, two using mobile cable cranes and one particular site were sledge yarder was used in parallel with forwarder, both owned by the same enterprise. The working area was georeferenced and used as a *mask* to evaluate FOpP results using the *summary statistic* tools in ArcGIS. Classified cells were summarized per each system and compared to the real used skidding system. FOpP results were so evaluated as percentage of right or wrong estimation (error). It should be pointed out that inside each forest stand FOpP result have to be interpreted by the forester that uses this model and probably he will chose the skidding method by choosing the one with the majority of cells inside that stand.

Figure 3.6.1.a shows FOpP results on tractor with winch working sites. On the left and on the right forest stand the majority of cells would suggest the use of the forwarder, but when the operations were done this machine was not available. Inside these two stands, the forwarder is better than tractor because of quite high values of steep slope and terrain roughness. The stand showed in the center was on a very good terrain condition (gentle and smooth) and cutting amount was not so intense, so the tractor is the best. The competition between tractor and forwarder is quite strong now on the Asiago forests because there are two machines, so the evaluation of the model could be considered quite good. Nevertheless the error is high (only 79 “tractor” cells on 319 total cells of the tree areas), figure 3.6.1.b.

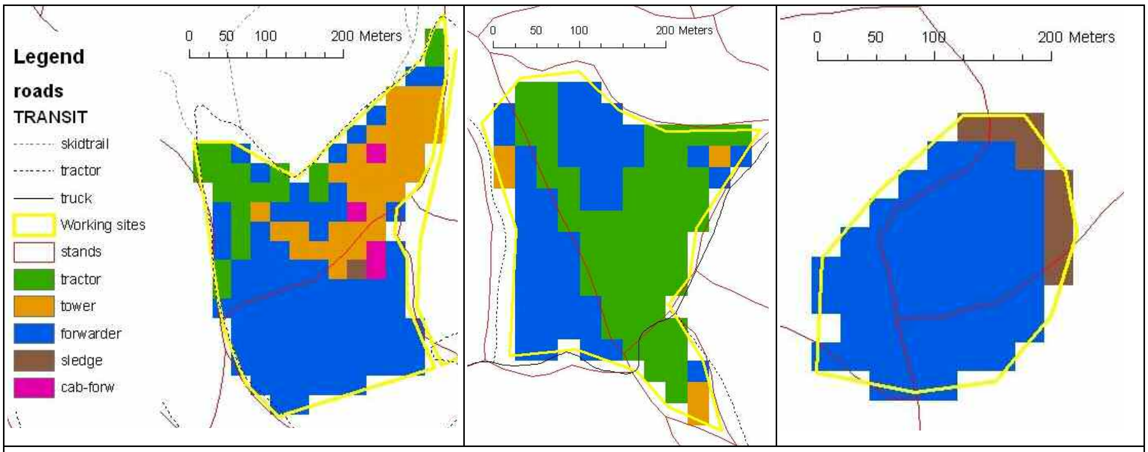


Figure 3.6.1.a: comparing FOpP results on three working sites where skidding operations were performed with tractor and winch.

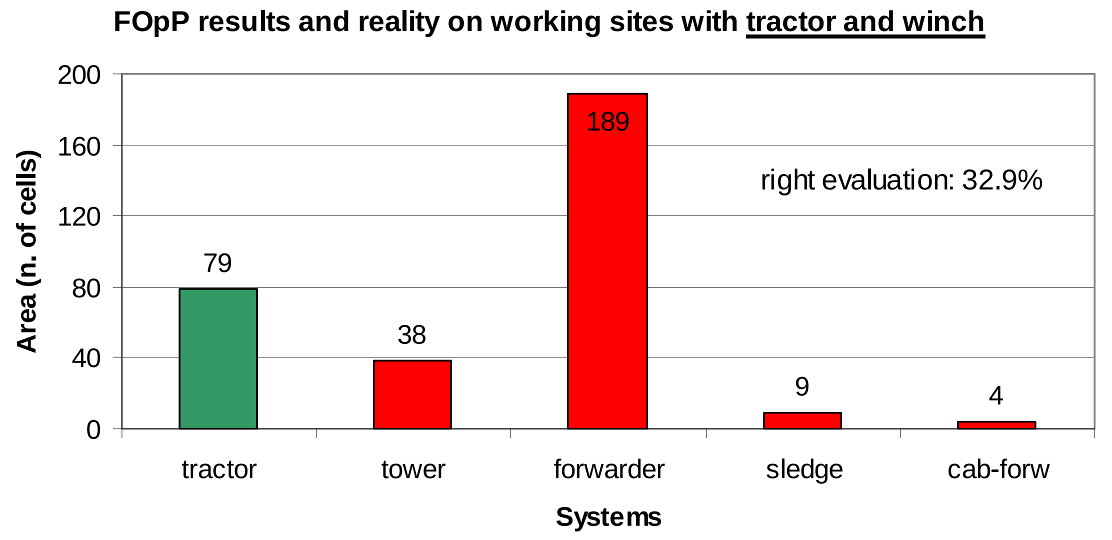


Figure 3.6.1.b: comparing the number of cells where FOpP results suggest the use of the tractor against the other systems.

Inside the study area was found only one site where extraction operations were performed with the forwarder (it was also possible to be present at that time). When the soil is not wet, the machine can easily drive loaded (downhill direction) on steep slopes up to 38%. During the loading phase a skilled operator may be able to reach felled trees even on steeper terrains using tricks with the boom. This is even more easy if the chainsaw operator fells trees toward the right directions knowing the needs of the machine. This means that using a terrain Digital Elevation Model with a 25 m definition, some cells, where the slope is too high and the model suggest for example the use of cable systems, would be also reachable by the forwarder. This is the case of figure 3.6.1.c where almost all cells lying on the stand borders (the browns) would be skidded with forwarder. Green cells will be also easily reached as the violets (but only in this case) because the forwarder in use had a winch with 20 m wire rope (so comparable as a cable-forwarder – figure 3.6.1.c). The estimation of forwarder working areas is quite good: the error is only 19%, but could be less considering valid cells also those with tractor or cable-forwarder (13,6% - figure 3.6.1.d).

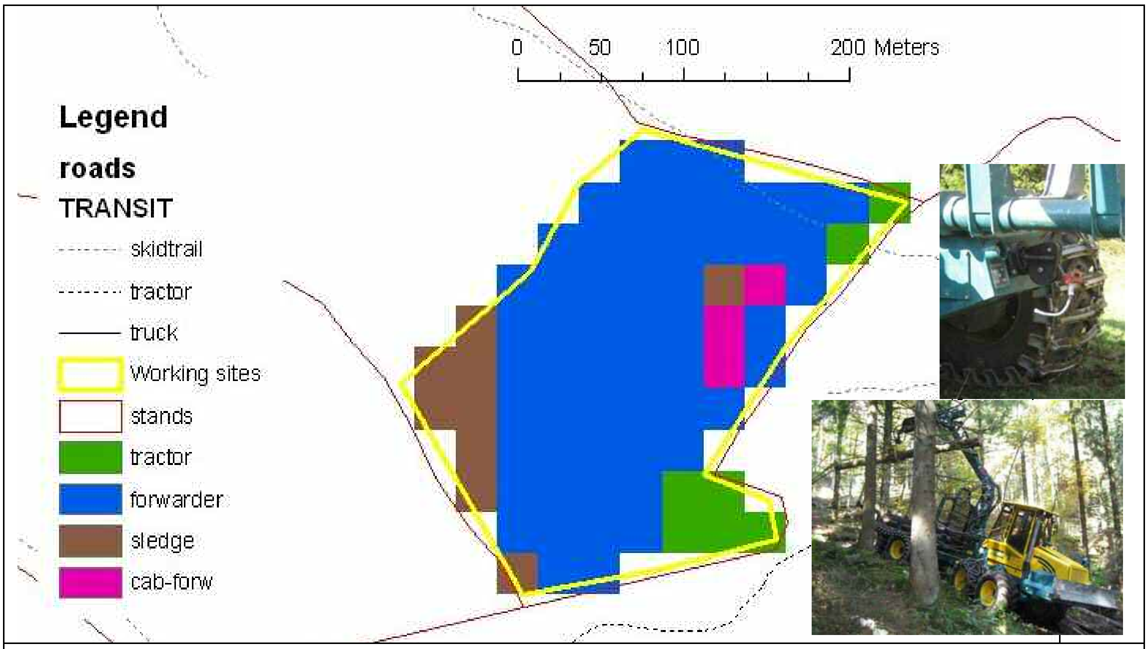


Figure 3.6.1.c: comparing FOpP results on two working sites where skidding operations were performed with forwarder.

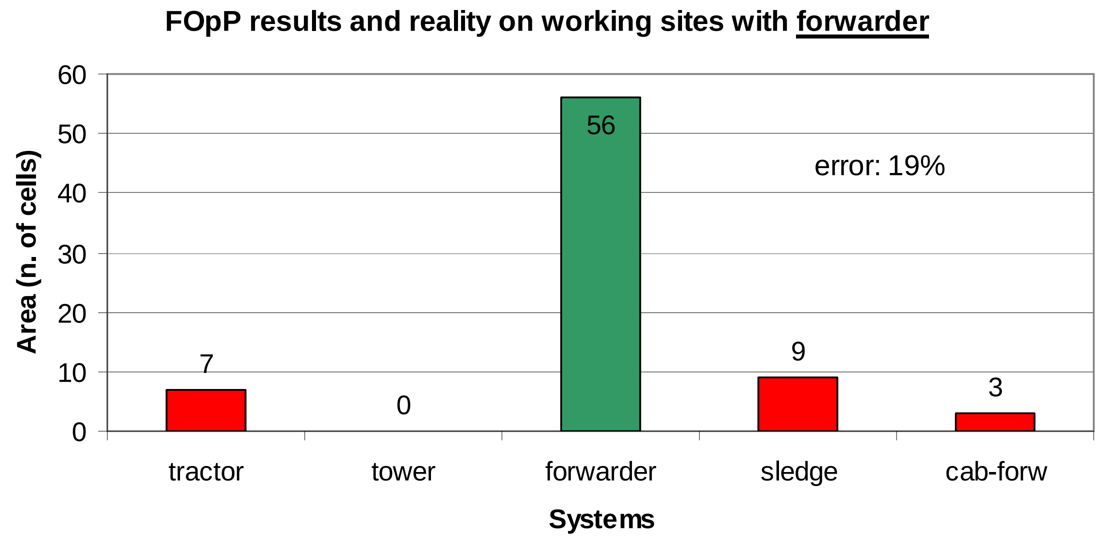


Figure 3.6.1.d: comparing the number of cells where FOpP results suggest the use of the forwarder against the other systems.

On those stand where the terrain parameters are too bad for the ground skidding operations the FOpP results suggest the use of cable systems. Then only two parameters influence the choice between a mobile tower yarder and a sledge yarder: the distance from forest road and the yield amount. Where the yield is very low is would be preferable the use of tower yarder because mounting and dismounting time and costs are lower than those of a sledge yarder line setting. The examples on figure 3.6.1.e show two stand well served by forest road where the use of cable systems is well estimated with a 32.4% error (figure 3.6.1.f). The stand on the left side may have some problems of setting the lines due to a terraced terrain and an average slope near the limit of function for gravity systems.

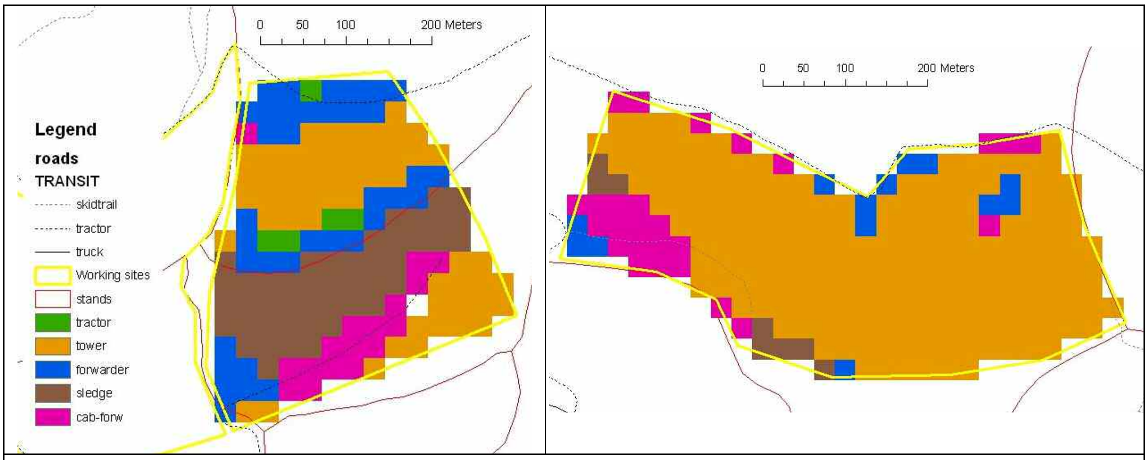


Figure 3.6.1.e: comparing FOpP results on two working sites where skidding operations were performed with cable cranes (mobile tower).

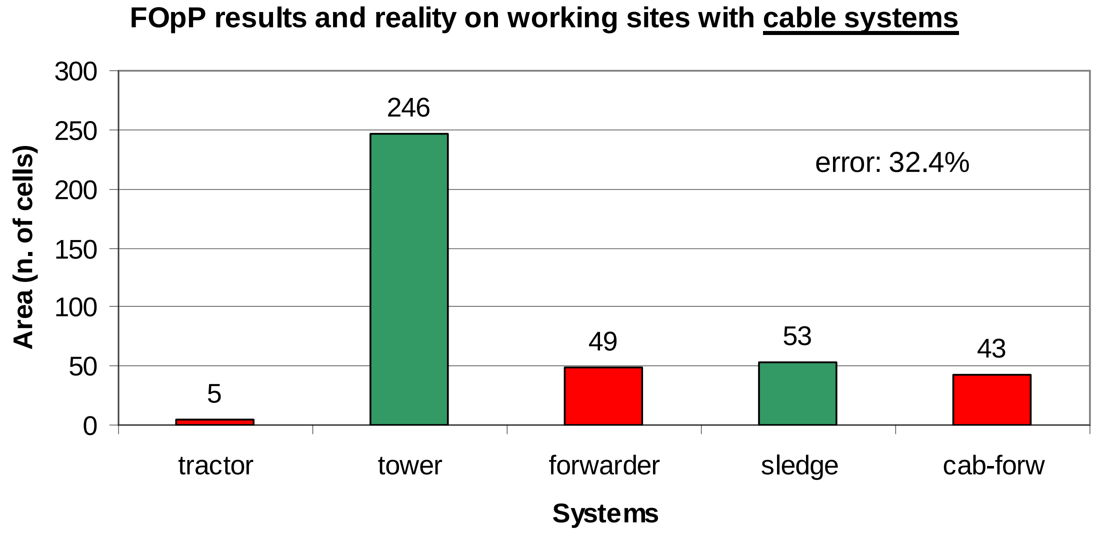


Figure 3.6.1.f: comparing the number of cells where FOpP results suggest the use of cable systems against the other ground extraction machines.

One working site was particular because two forest stands were cut at the same time and because two systems were used in parallel: a sledge yarder and a forwarder. The cable system was used on the steepest area while the forwarder extracted wood from the easiest ones (see pictures on figure 3.6.1.g). The model suggested these two systems because inside this area the road network is insufficient, there was only an old skidtrail created probably by a tracked tractor few year ago. Considering 11 cells that the model evaluated as un-reachable, the error was very low (4.4% - figure 3.6.1.h).

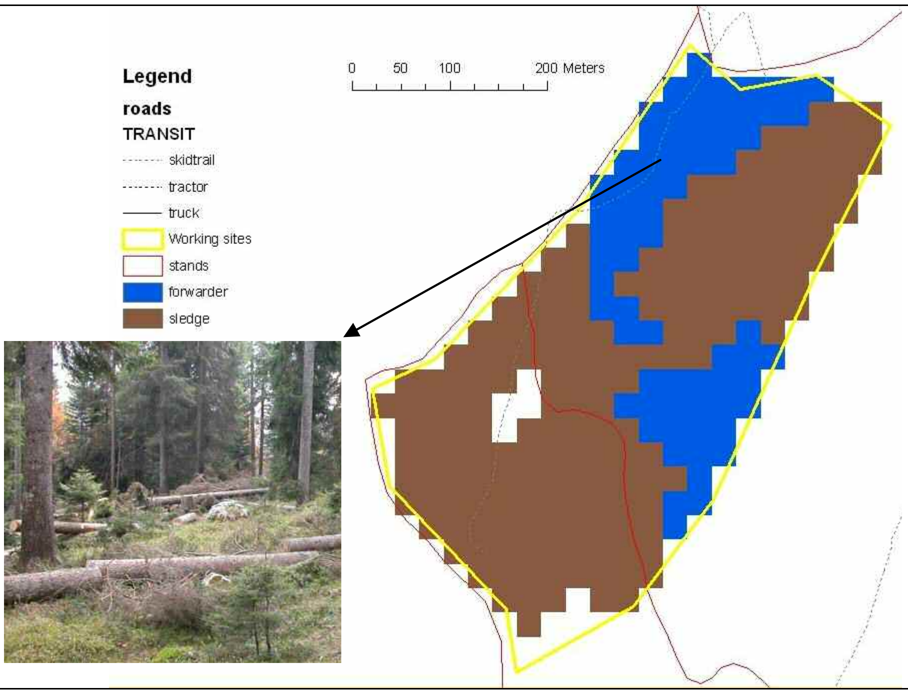


Figure 3.6.1.g: comparing FOpP results on one working sites where skidding operations were performed with cable cranes (mobile tower).

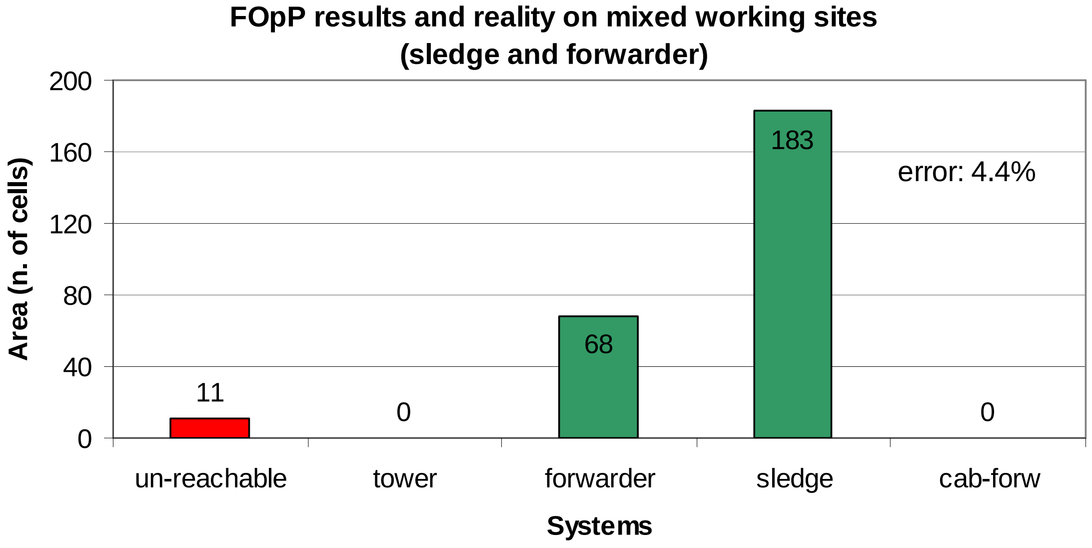


Figure 3.6.1.h: comparing the number of cells where FOpP results suggest the use of cable systems and forwarder together.

3.6.2 Comparing models on the same area

One good way to test the model was to check results comparing them with an other model built with more of less the same purpose. This had been possible thank to a strong collaboration between the University of Padova (Dept. TeSAF) and the University of Ljubljana (Dept. of Forestry).

KRČ (1999 and 2006) developed a SDSS model (called here IDRISI model, because it runs on IDRISI geographical software) to evaluate the suitability and costs of using different systems or machines for cutting and skidding operations.

The selection of skidding systems (technology) and skidding direction is derived by model, which make the determination of optimal skidding system and skidding direction (uphill, downhill)**.** Wood skidding map was determined by procedure of Multi-Criteria Evaluation (MCE) of influential factors summarized to Multi-Criteria Evaluation method (EASTMAN 1995). By the MCE method the optimal skidding model was determined. The first step of skidding model determination was procedure for selection of influential factors and their importance. The criteria for influential factor selection were related to significant terrain, stands and openness conditions of forest compartment. The weight of every influential factor had to be determined on the base of importance *ratio* among the selected *factors*. The weight was derived by *pairwise* comparison method (SAATY 1980). For every skidding model its suitability value showing suitability grade on concrete ground plot, represented by raster grid cell was calculated. The suitability *value* is related to terrain and stand conditions expressed by selected influential factors (terrain slope, skidding distance, rockiness, soil bearing capacity). The procedure for suitability value calculation was summarized to weighted linear combination of standardized values of influential factors. The standardized values were derived by positive correlation between influential factor value and its suitability for each skidding model separately. For instance steep terrain slopes have high standardized value for cable crane skidding model and low standardized value for tractor skidding model. The last step of skidding model determination was the comparison of suitability indexes on every ground plot expressed by raster grid cell. The suitability index comparison was enabled through using of pairwise comparison method which distributes the determination of skidding model on the altogether influence of selected influential factors.

Skidding method with some additional data (skidding distances, skidding direction) was used as input data into computer program, which had been developed for forest operation cost calculation (FireFox software, similar to Access). Basic unit is forest compartment with specific set of influential factors, derived from forest inventory (Slovenian Forest Service data). The program calculates potential cutting and skidding cost using standard times (KOŠIR 2003) multiplied by system hourly cost. There are also separated procedures developed for determination of standard times for each specific operational condition (mean three volume, skidding distance, terrain conditions etc.) and system hourly cost (KRČ and KOŠIR 2005).

3.6.2.1 Greece

We tested the models first on an area in Greece. The area (Valia Kyrna) is placed in the forest complex of Smolica at range mountain of Pindos – in Northern Greece. The forest is mainly composed by Pinus nigra, known in Greek language as “Robola”, and it is a unique biotope because many rare species are living there (brown bears, wolves, lynx, etc.). The road network is old, but every year the office of forestry improves the network in order to be accessible not only for logging; but also for multi-use purposes and recreational reasons (STERGIADOU 2007). In Greece the forestry is ecologically and less economically oriented and the main reason is that the forest land belongs mainly to the State (STERGIADOU 2006).
Input data were very rough and information about soils and forest management needed to be implemented before running the models. Results map (figure 3.6.2.1.a and 3.6.2.1.b) were compared showing that IDRISI model is strictly connected to the forest stand area, while ArcMap FOpP model considers the entire area. Both models consider the skidding direction, but on the FOpP final result map this is not showed.

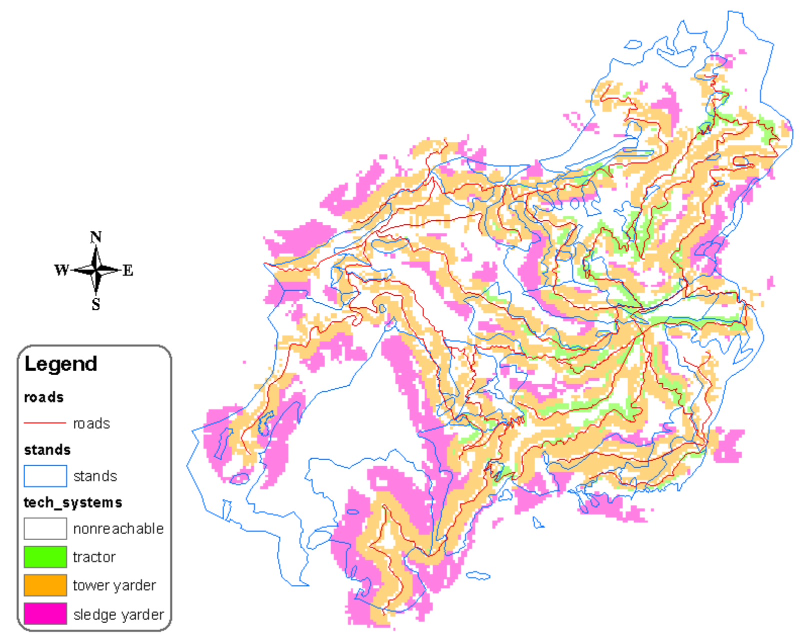


Figure 3.6.2.1.a: FOpP model results map

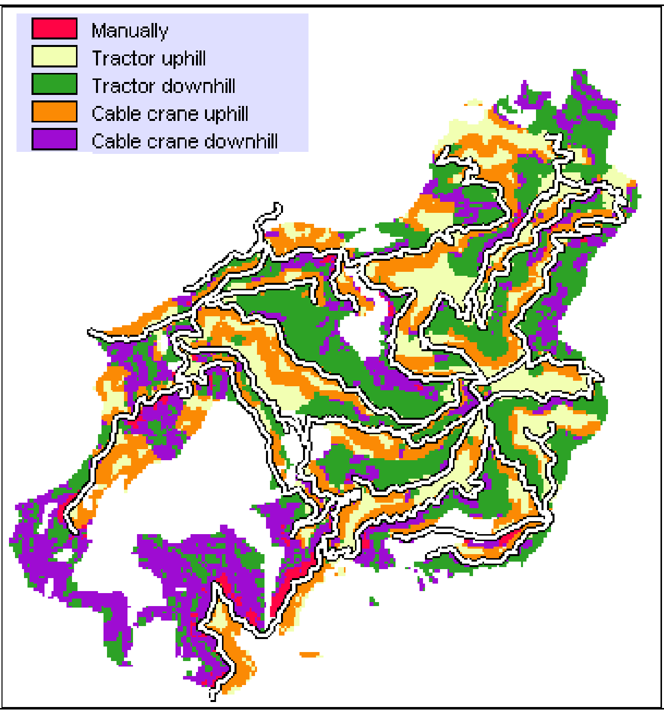


Figure 3.6.2.1.b: IDRISI model results map

Results were also compared on forest stand basis to check how the share of different systems change between models. On the IDRISI model (figure 3.6.2.1.c) the share (%) of systems varies very little and seems that only the selection of manual skidding method is correlated to the increment of yield (R^2=0.96). Inside the ArcMap model, the intensity of cuttings influences the choice of the skidding system so, it would be expected that increasing the yield, the share of skidding systems should vary and the most productive system should increase. Results on figure 3.6.2.1.d have no statistic approval, but the small tower cranes increase (R^2=0.59) while sledge yarders (low hourly productivity) slowly decrease. The difference on the *non reachable forest* is significant and it depend on the road density and on systems technical limits set before running the model. Here seems to be more exact the FOpP model defining a technical, environmentally and economical limit up to 900 m (sledge yarders). Forest areas sited farer from roads would require the building of new roads, but only if their function has production purposes (that is not the case of this Greek forest).

Table 3.6.2.1.a: comparing average results by stand typologies (tree species)

stands	yield	Slovenian model (%)				FOpP model (%)			
(species)	(m^3/ha)	manual	tractor	cable	non reach.	tractor	tower	sledge	non reach.
fagus	0,92	2,0	37,1	57,6	3,3	7,6	44,6	8,9	38,9
pinus heldr.	0,24	1,2	51,9	43,7	3,2	2,4	28,3	10,8	58,5
pinus nigra	0,71	2,2	47,7	47,6	2,5	8,7	35,8	12,2	43,3
quercus	1,73	3,7	44,3	47,1	4,8	3,5	42,3	8,8	45,4

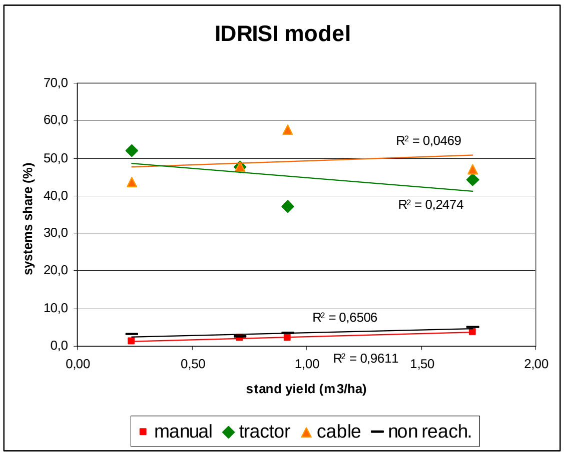


Figure 3.6.2.1.c: share of systems as from IDRISI output

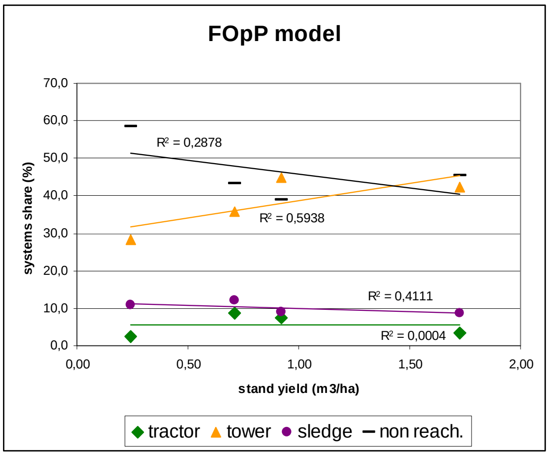


Figure 3.6.2.1.d: share of systems as from ArcMap output

3.6.2.2 Slovenia

After the first attempt to validate the model on the Greek area, the FOpP model was modified because an error was found on a process calculation. Some problems were related to the use of ArcMap tools which may incur on errors if working with floating numbers (double precision after commas). More over, the calculation with floating values takes longer time and it was checked all the model algorithm to make the calculation faster. After these changes, the model have been again compared with the IDRISI model on a huge productive forest area (ab. 1450 km^2), characterized by steep terrains and low yield forest coppices (figure 5.3.2.a). Here the running time took about 45 minutes.

Study area lies over the border between Slovenia and Italy (figure 5.3.2.a): it includes the mountain community of Torre, Natisone and Collio and four Slovenian municipalities (Tolmin, Kobarid, Kanal and Brda) raising a total of 143047 ha. About 70% (98340 ha) of the area is covered by forests which are mainly broadleaf trees (beech, oak, ash, hornbeam, maple). Only 10% of forest area is coniferous plantation. On Slovenian side, forestry databases (1087 compartments) and road *shape-files* were available and ready to be used. On Italian side only data coming from public assessed forests were available: for the private areas, information from Corine Land Cover and Use and forest typologies were joined to derive estimation of stocks and allowable cutting volumes. The input data preparing is a time consuming work (several days) which is needed to run the model without errors.

Running models on the same area was very useful: the forest and terrain characteristics are changing between Italy and Slovenia, so even the model results were expected to change. This is clear on table 3.6.2.2.a where FOpP results are compared according to the two country areas: on the Italian side the use of tractor and the un-reachable forest have lower values than in Slovenia, the use of small mobile cable systems decrease of 50%. This variation is due to two main reasons:

- the first is the terrain steepness which is very high on the Italian side (so it’s good to work with cable systems)
- second is the road network. In Slovenia there are 23.1 m/ha as average of truck roads, in Italy the average road density reach 20.5 m/ha. This means lower accessibility to forest. Nevertheless, the un-reachable forest in Slovenia reached 24% because there are big forest areas without access roads. The road density is more regular in Italy and so are consequently road distances.

IDRISI model had a problem that will be corrected in the future because what is farer than 1000 m it is considered to be skidded by tractor even if there are no roads (see also figure 3.6.2.2.a). In Slovenia is also still actual the manual skidding system on very steep terrains (by the use of gravity force). Comparing the share of cable systems and off-road systems, the results of both models are similar: in Italy off-road systems and cable have a proportion of 0.61 (29%/46%), in Slovenia the proportion is 0.66 (37%/56%).

Table 3.6.2.2.a: Comparing models output cell by cell (only forest area)

ITALY (ArcMap 40m GRID cell)			**SLOVENIA** (ArcMap 40m GRID cell)			**SLOVENIA** (IDRISI 25m GRID cell)		
system	cells (for.)	%	system	cells (for.)	%	system	cells (for.)	%
						Manual	66294	7
Tractor	3608	1.5	Tractor	33314	9	Tractor	328939	37
Tower	155962	63	Tower	113078	31	Cable	493808	56
Forwarder	38857	16	Forwarder	72086	20			
Sledge	28087	11	Sledge	60665	16			
Not reach.	21231	8.5	Not reach.	86490	24	Not reach.	0	0
TOTAL	247745	100	TOTAL	365633	100	TOTAL	889041	100

Costs of skidding operations are highly influenced by the yield density inside stands and by systems productivities. The choice of systems inside a forest should also be done trying to optimize the operations reducing all costs.

Comparing cost calculation results of the two models, there are some differences due to different ways of estimating hourly costs. Machine costs in Slovenia are probably different than those in Italy, that is why average costs per stand may be quite different. Each model used its own productivity functions and costs (table 3.6.2.2.b).

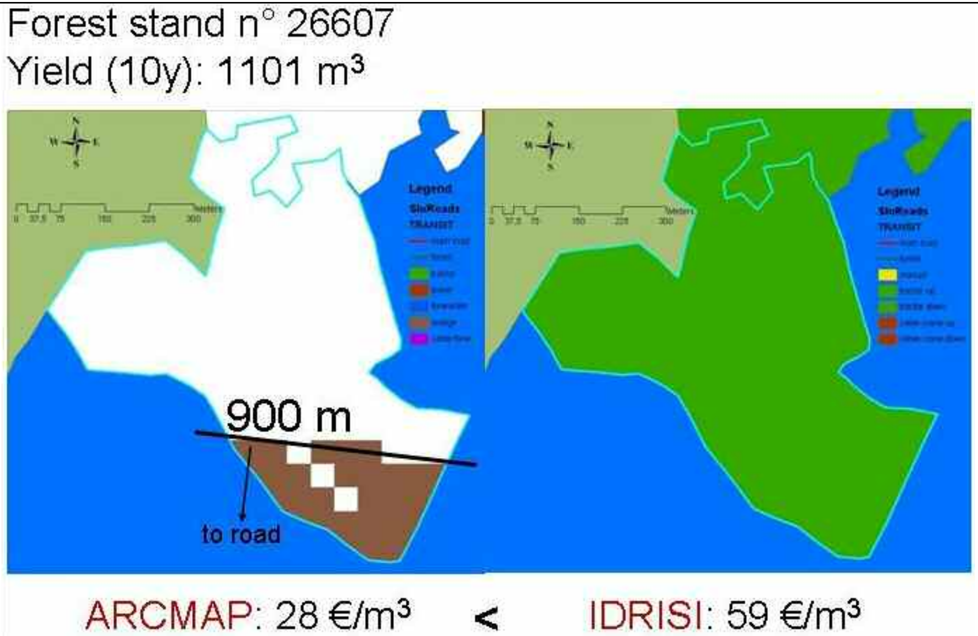


Figure 3.6.2.2.a: Forest stand n. 26607 has no access roads. The nearest road is on the south direction. ArcMap model suggest the use of sledge yarder (brown color) up to 900 m; IDRISI suggest the use of tractor even if slope is quite steep (green color). Skidding costs consequently increase because tractor has low productivities and longer skidding times than a cable system in such a situation.

Table 3.6.2.2.b: harvesting systems unit costs used by models.

SLOVENIA			**ITALY**		
SYSTEM	€/hour	€/m^3	SYSTEM	€/hour	€/m^3
Motor manual felling	11.64	9.12	Motor manual felling	20.68	8.27
			Mechanized felling	98.77	7.60
Tractor	43.58	11.25	Skidder/tractor + winch	34.95	8.74
Mobile tower crane	109.94	16.92	Mobile tower crane	63.00	12.60
			Forwarder	66.17	5.09
			Sledge yarder crane	98.00	24.50
			Cable-forwarder	70.00	7.85

As shown in figure 3.6.2.2.b, average skidding costs have different values on same forest stands. There are also some very high values (figure 3.6.2.2.c) that could not be explained (ArcMap model has no more than 45 €/m^3 as average extraction costs, that is feasible even on worst working situation, considering cutting costs and wood price), while values = 0 correspond on those stands which are not expected to be harvested during the forest assessmental plan period. The share of systems and cost calculation assumptions influence the result average costs: the FOpP model estimation is 1.6 €/m^3 cheaper than the IDRISI solution.

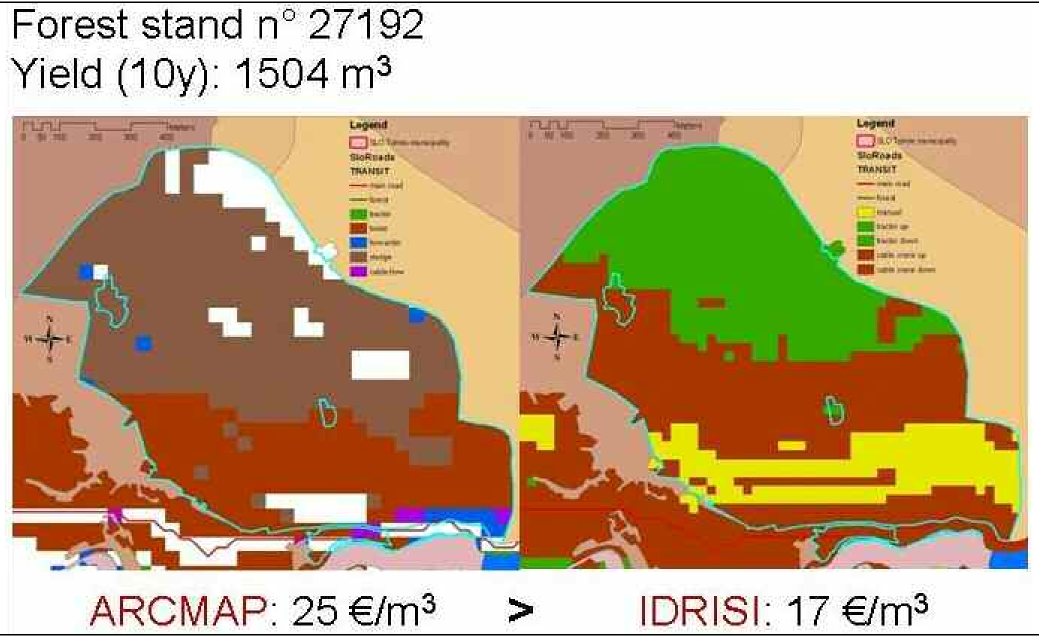


Figure 3.6.2.2.b: model results on stand n. 27192. The terrain has an uniform hillside from north to south where there is a forest road (the red line). Steep slope is more than 35%. The FOpP solution suggest the use of cable cranes up to 900 m from road, while IDRISI suggest the manual skidding up to 200 m and then cable systems up to 500 m. If cuttings will be planned near the road, IDRISI solution might be acceptable, if not, the use of sledge yarder will be the only way to skid wood. The use of tractor on the upper side of the stand (as IDRISI shows) is quite non-sense.

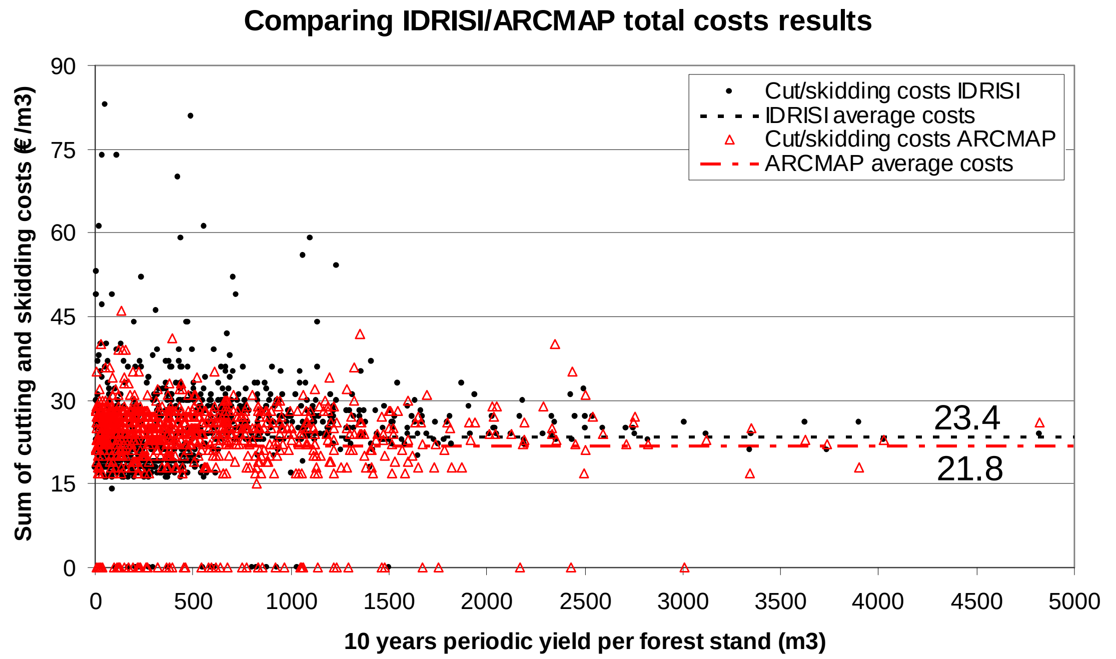


Figure 3.6.2.2.c: graph comparing IDRISI *vs* FOpP average costs (€/m^3) at forest stand level on Slovenian side.

Costs differences at forest stand level are quite better levelled when considering averages at “road basin” level (the road sites where wood is piled before its transportation to the mill, the cost includes also cutting operations). IDRISI model gives on average 0.8 €/m^3 higher costs than ArcMap model (figure 3.6.2.2.d). Source points costs coming from model outputs are very similar and near to reality. Comparing ArcMap results on different state sides, Italian operations are 6.3 € more expensive than Slovenian (figure 3.6.2.2.d) due to different share of systems as showed on table 3.6.2.2.a.

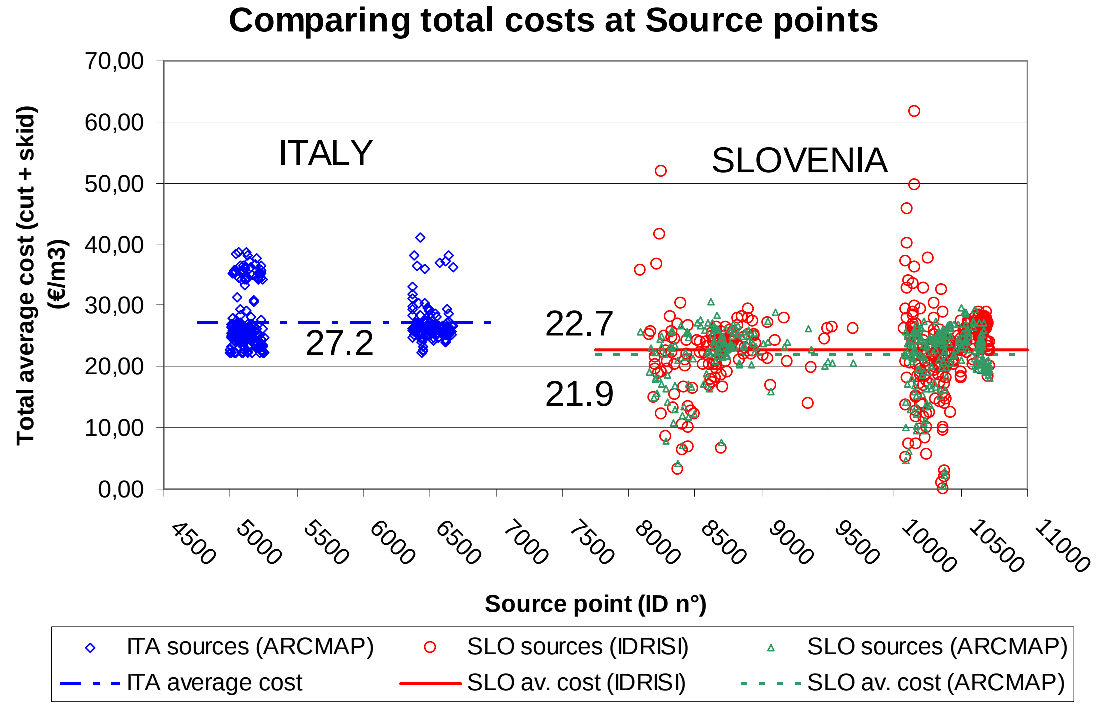


Figure 3.6.2.2.d: Graph comparing IDRISI vs FOpP average costs (€/m^3) at road side piling places.

3.7. MODEL EVALUATION

The objective of the model evaluation was to investigate how parameters influence the results. Between all inputs, the extraction distance is the most important because it determines the feasible working area of each skidding system and also the productivities, and consequently costs, in the optimization procedure. Other parameters as the productivity formulas, the gradeability slopes or the maximum terrain roughness are thought to be constant inside a study area where field studies have been conducted on purpose.

The effects of changing extraction distance were tested verifying the variation in the reachable area of systems, the technical and optimal share of systems and the variation of average and total stand skidding costs.

Running the *defining skidding systems* part of the FOpP model, tractor, forwarder and tower cable systems have been tested changing extraction distance from 100 to 600 meters and considering equal the downhill and the uphill distance. The first part of the model determines systems maps on the basis of maximum slopes and systems gradeability, while the terrain roughness is not taken in count (only on the next *optimizing systems and costs*). Comparing the total surface of each system, the mobile tower covers a larger area followed by the forwarder and then by tractor. This depends probably on the slopes distribution and on the road network which influence much more the tractor than the other two systems. The data correlation with a logarithmic trend is very high (figure 3.7.a) and it is interesting to notice that at the same extraction distance the downhill direction is easier than the uphill direction which covers about one third of each feasible system areas.

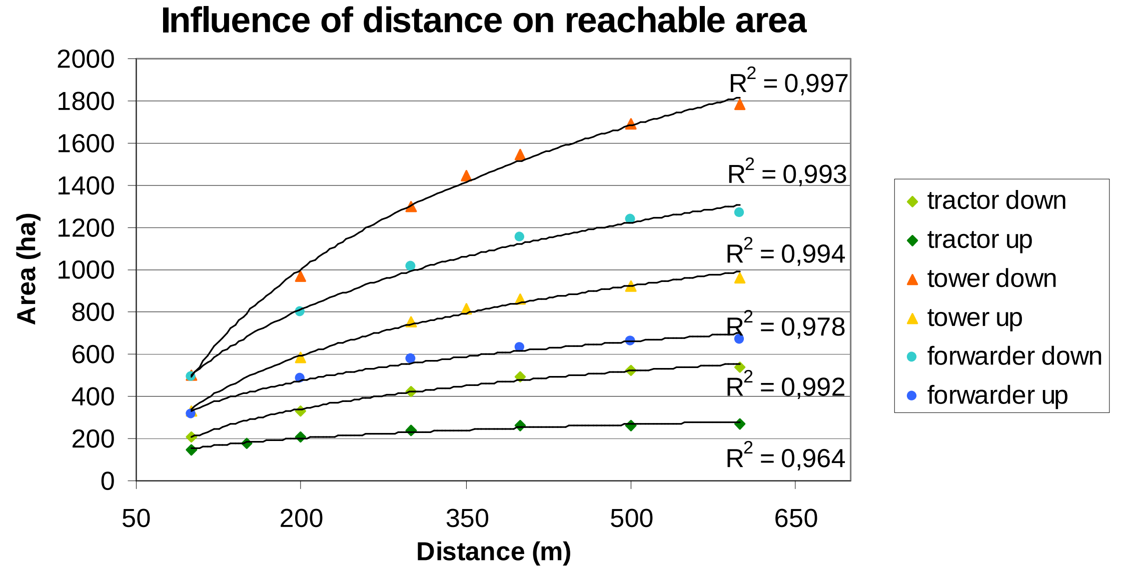


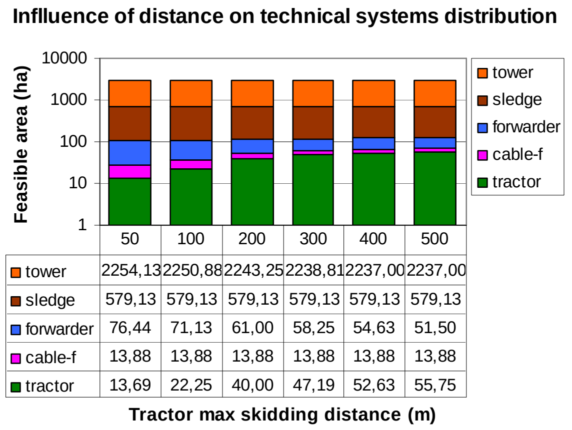
Figure 3.7.a: evaluating the variation of systems working areas according to extraction distance inside the Asiago forest stand study area.

The effect of extraction distance was tested on the technical and optimal output maps.

The evaluation on the technical map was performed by modifying the extraction distance of tractor between 50 and 500 m and considering fixed the other systems distance. Results show that the tractor working area increases with the same logarithmic trend than figure 3.7.a but the sledge yarder and the cable-forwarder systems are not influenced by this variation (figure 3.7.b and 3.7.d).

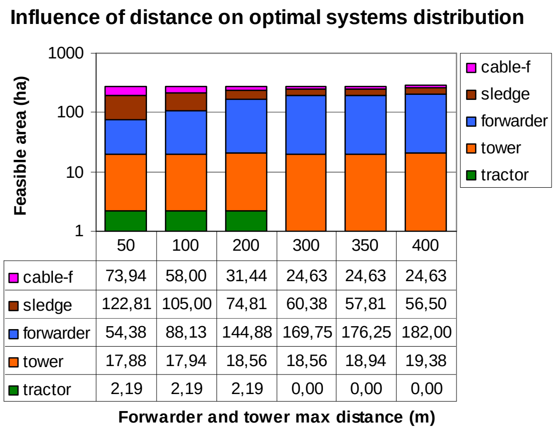
The evaluation on the optimized system map was performed modifying at the same time forwarder and tower extraction distances. Results (figure 3.7.c and 3.7.e) show that the tractor is substituted by forwarder if the extraction distance is farer than 200 m. The mobile tower area increases very slowly because forwarder and sledge yarder are cheaper when working at long distances with low cutting amount.

Comparing figure 3.7.d and 3.7e it is clear that the technical evaluation shows a well distributed share of all systems according to their technical limits while the optimized output map suggests the use of the cheapest systems.



	50	100	200	300	400	500
🟧 tower	2254,13	2250,88	2243,25	2238,81	2237,00	2237,00
🟫 sledge	579,13	579,13	579,13	579,13	579,13	579,13
🟦 forwarder	76,44	71,13	61,00	58,25	54,63	51,50
🟪 cable-f	13,88	13,88	13,88	13,88	13,88	13,88
🟩 tractor	13,69	22,25	40,00	47,19	52,63	55,75

Figure 3.7.b: effects of variation of tractor extraction distance on the technical output map



	50	100	200	300	350	400
🟪 cable-f	73,94	58,00	31,44	24,63	24,63	24,63
🟫 sledge	122,81	105,00	74,81	60,38	57,81	56,50
🟦 forwarder	54,38	88,13	144,88	169,75	176,25	182,00
🟧 tower	17,88	17,94	18,56	18,56	18,94	19,38
🟩 tractor	2,19	2,19	2,19	0,00	0,00	0,00

Figure 3.7.c: effects of variation of forwarder and tower extraction distance on the optimized systems output map

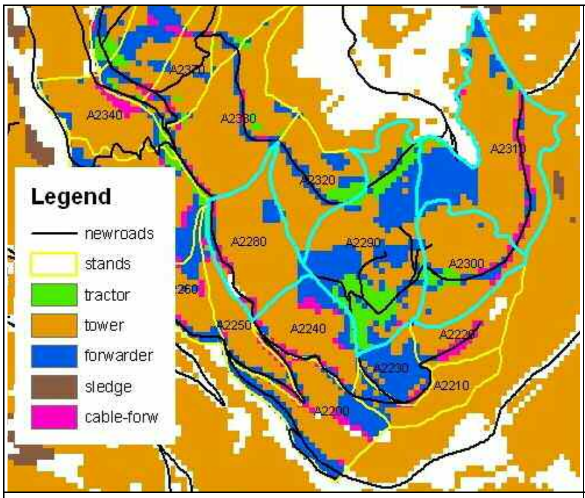


Figure 3.7.d: the technical output map obtained with 500 m tractor extraction distance. Blue stands are considered in the costs evaluation

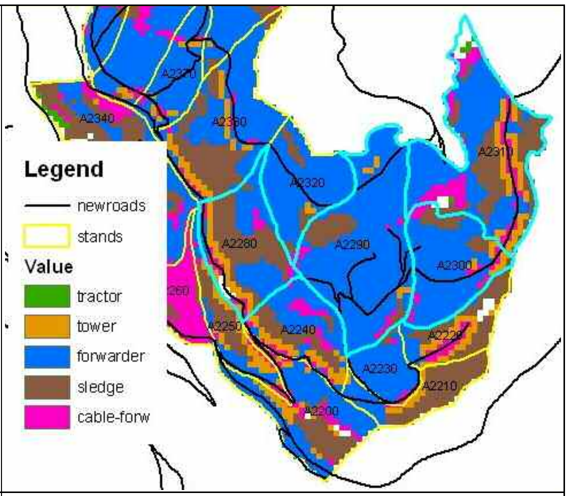


Figure 3.7.e: the optimized systems output map obtained with 200 m forwarder and tower extraction distance. Blue stands are considered in the costs evaluation

The variation of average skidding cost per cubic meter and total skidding costs per forest stand was tested. Four stands were chosen because of their different share of systems, distribution of slopes and allowed cutting amount (between 0,82 m^3/cell, stand n° 231, and 2.25 m^3/cell, stand 230). Costs were summarized per each stand testing the tractor distance between 50 and 500 m for the technical costs and the forwarder and tower systems between 50 and 400 m for the optimized costs (figure 3.7.f and 3.7.g). Results show that the variation of the tractor extraction distance has low impact on the average costs based on the technical systems map (figure 3.7.h). Also the sum of skidding costs per each forest stand is quite constant (figure 3.7.i). Correlation value is quite high so we could say that tractor extraction distance has no influence on technical unit costs. Stand 229 has lower costs (2 €/m^3 less) due to the low average slope and the large use of forwarder.

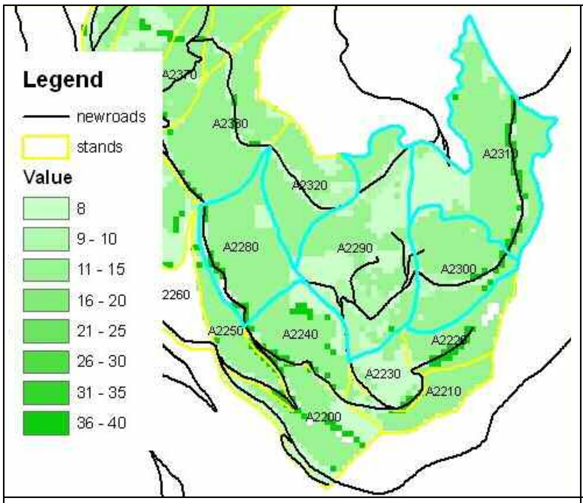


Figure 3.7.f: the unit costs based on the technical systems map

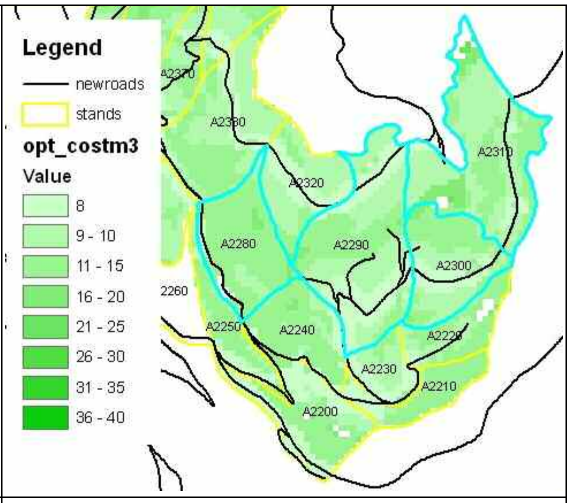


Figure 3.7.g: the unit costs based on the optimal systems map

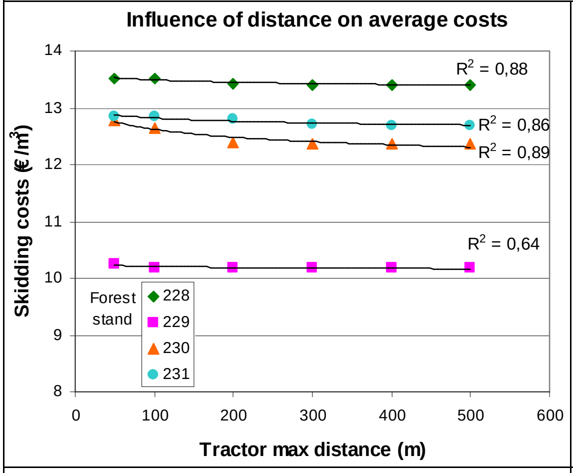


Figure 3.7.h: variation of average skidding costs according to tractor extraction distance

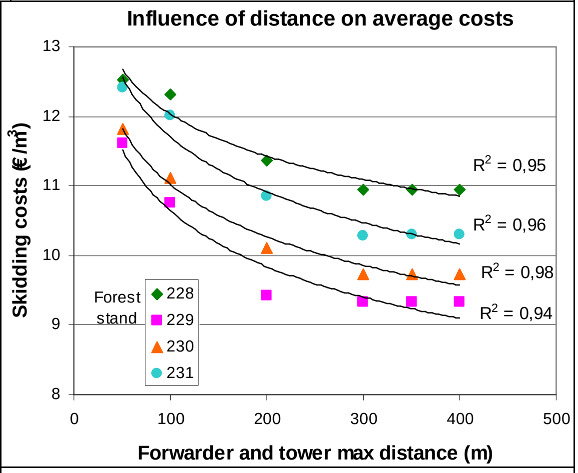


Figure 3.7.i: variation of average skidding costs according to forwarder and tower extraction distance

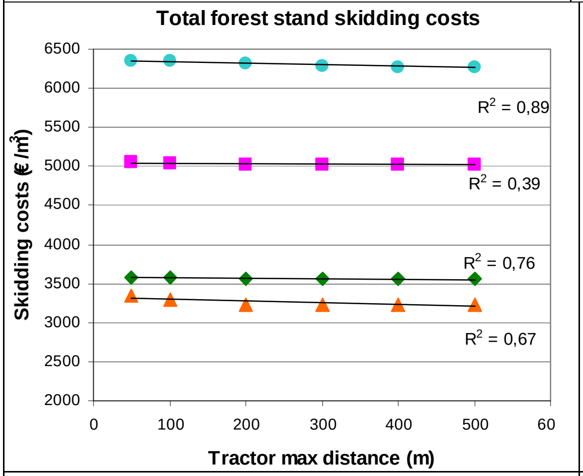


Figure 3.7.l: variation of total skidding costs according to tractor extraction distance

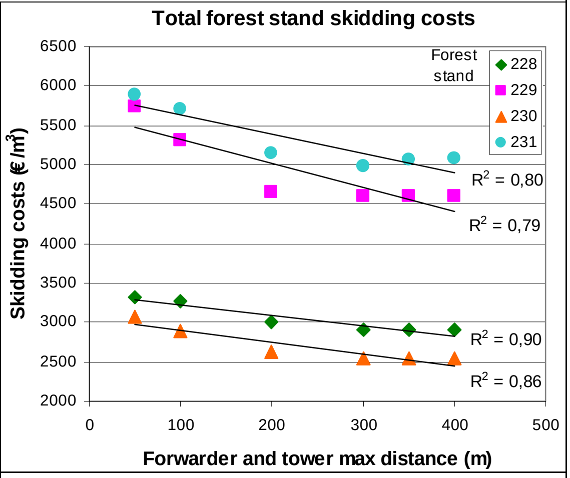


Figure 3.7.m: variation of total skidding costs according to forwarder and tower extraction distance

Total costs depend on the stand area, stands 228/230 and 229/231 have similar areas, but stand 229 has lower total skidding costs because wood can be easily skidded with the forwarder which has lower costs than cable systems.

The influence of the extraction distance on the optimized costs is more evident (figure 3.7.i). Average costs decrease first rapidly, then slowly (the logarithmic correlation has high statistical value), influenced by the share of forwarder and tower yarder which are the cheapest systems. Costs decrease of about 2 €/m^3 when extraction distance is more than 300 m. Total stand skidding costs vary at a different rate (figure 3.7.m) when the optimization does not change the share of systems inside the stand: this happens when the average slope is high or flat (stands 228 and 230), in fact cable systems or off-road systems will be selected as optimal skidding systems even if the extraction distance parameter is modified. The results highlight how a good system choice, when the road infrastructure is not adequate, could decrease utilization costs and so increase the wood value.

4. RESULTS

The model output results are grid maps and database tables. The skidding systems maps offer good information to the forester who has to make assessmental plans and may also be used to evaluate the road network.

4.1. MODEL OUTPUTS

The Forest Operations Planning model provides several output maps which by definition are spatially referenced. These maps can be used and interpreted by the forester who makes a planning to chose which skidding system would be the most convenient inside a well defined area. This is the meaning of a Spatial Decision Support System, in this case the FOpP model is a tool that allow to select the extraction systems. Here five skidding methods are considered, three of them are ground-based and two are cable-based. Output maps provide some solutions on a cell-by-cell basis, but as it is on the real life, they should be applied with consciousness. It is clear that a forest enterprise can not own all systems, so the planned cuttings inside a forest stand will be cut and skidded with only one system (or two). **The forester** has to use the outputs as a suggestion (a real “support”), but he **will take the final decision** that should be done also taking count of the local enterprises and of their skill and owned machines. Another possibility for the planner is to define the yield on an area which do not correspond to a single forest stand, for example on a smaller part or on several stands trying to conciliate both ecological an sylvicultural needs with technical limits. Moreover, the output cost maps allow the forester to estimate the wood standing price (called “macchiatico”) and could be used for dimensioning the yield by optimizing the enterprise income. If the forester makes a good planning and cuttings provide an economical gain, he might be sure that his work will be successful.

The model has no limit in the size of the area, but the running time is influenced by the cell size. For example the evaluation of the Greek case (§ 3.6.2.1) took about 20 minutes but the DEM in use had 70 m cell resolution. The running time for the Slovenian case and for the Asiago forest took about 45-50 minutes: the first area (§ 3.6.2.2) was 1450 km^2 with a 40 m cell size while the Asiago forest was about 50 km^2 with a 25 m cell size (figure 4.1.a).

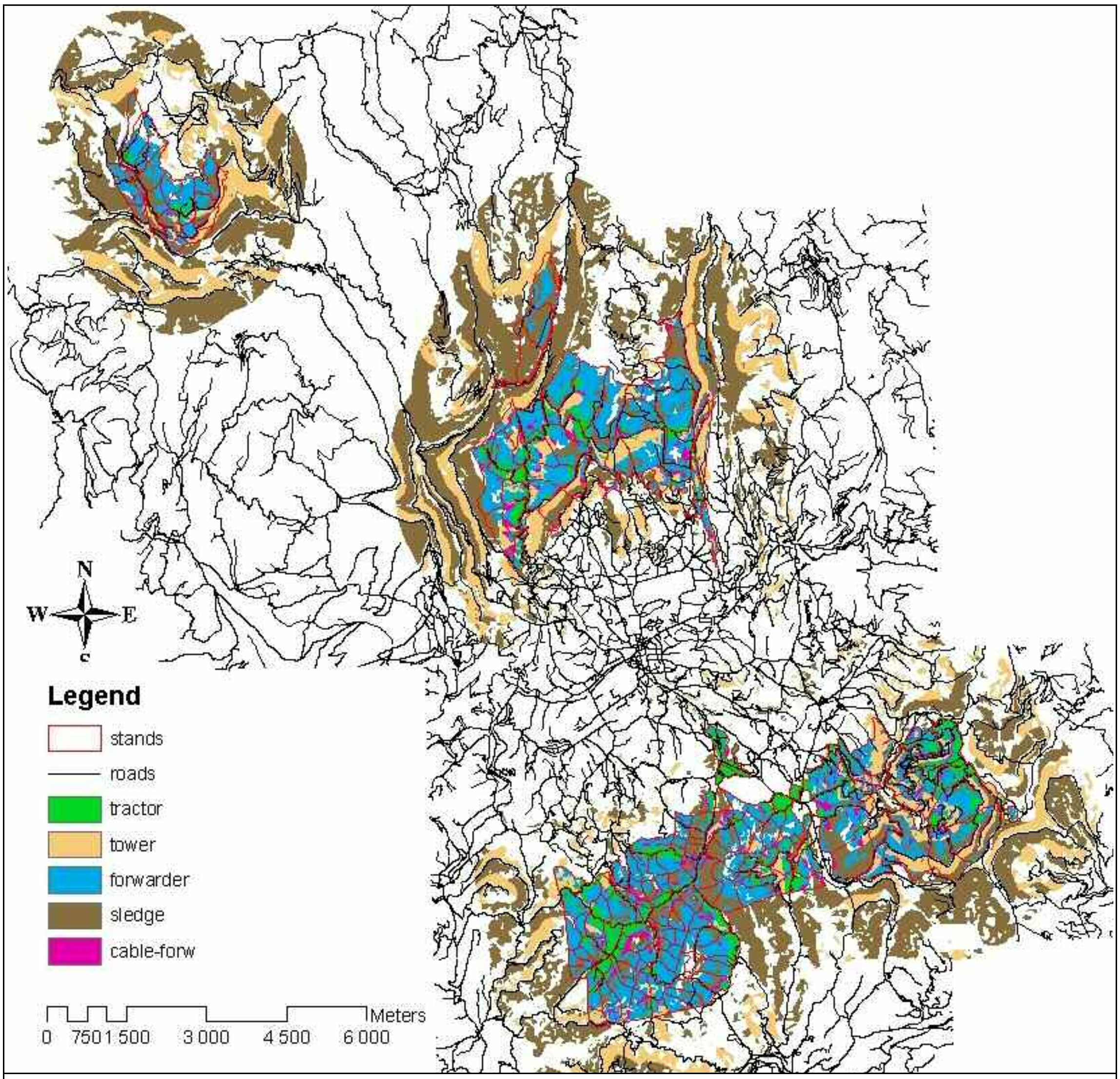


Figure 4.1.a: the technical systems output map on the Asiago forest stands property

The tractor with winch is the skidding system which has the strongest technical limits and for this reason its working area is smaller if compared to that of the other systems. Output maps show that the downhill skidding direction is preferred when the terrain is smooth, plain and highly stable. On figure 4.1.b (Asiago area), roads are sited on valleys so the downhill direction is mostly prevailing. On the Friuli-Venezia Giulia study area roads are sited both on the valley bottom and on the mountains ridge and shoulders so the uphill skidding direction is more spread. On figure 4.1.c it is also possible to notice inside the red rectangle the different skidding distance between the uphill and the downhill direction.

The forwarder has a higher mobility than the tractor due to its six or eight traction wheels and the height from the ground which allow the machine to work even on rough surfaces (roughness class n. 2). If the average slope is not so high it can easily work even on steeper terrains moving on easy paths and using the boom: on figure 4.1.d the forwarder cover an area two times bigger than the tractor area on figure 4.1.c.. This is also evident when the maps are overlaid as on figure 4.1.e. Considering that forwarder has a high productivity, three times more than tractor, and hourly costs are only two times more, its use should be increased. Safety of operators would be improved indeed.

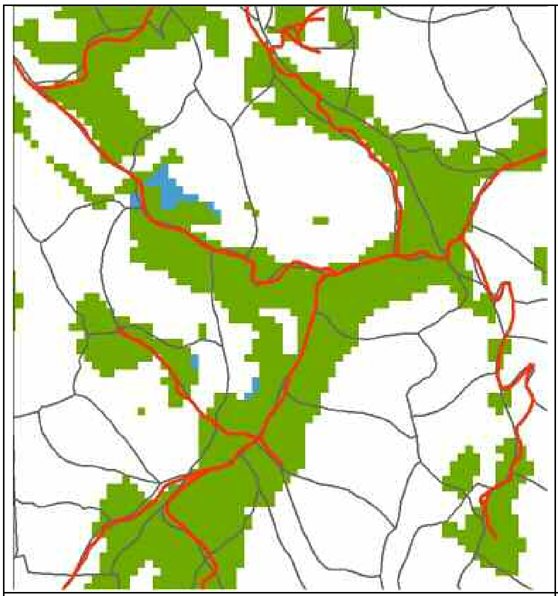


Figure 4.1.b: the tractor map on the Asiago forest area

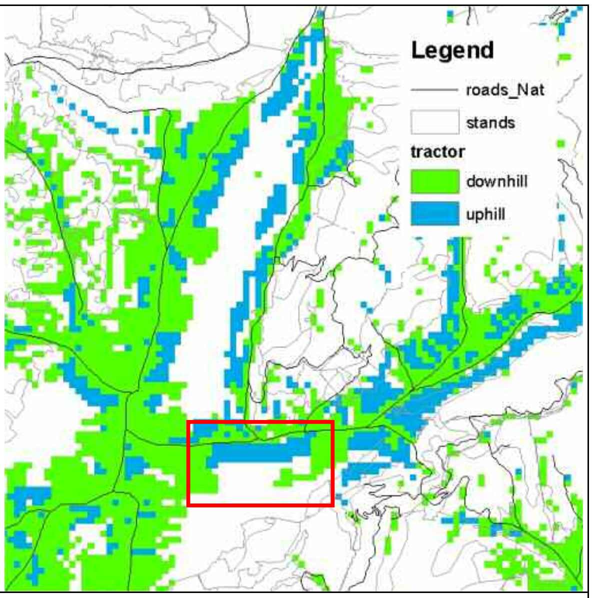


Figure 4.1.c: the tractor map on the FVG region

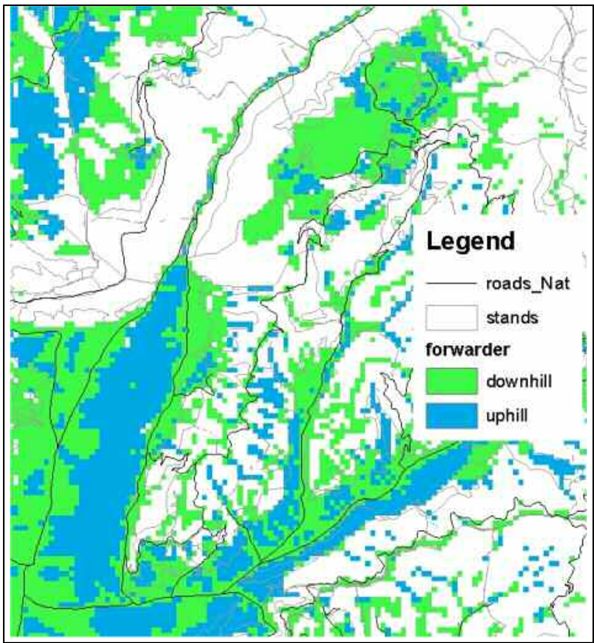


Figure 4.1.d: the forwarder skidding map

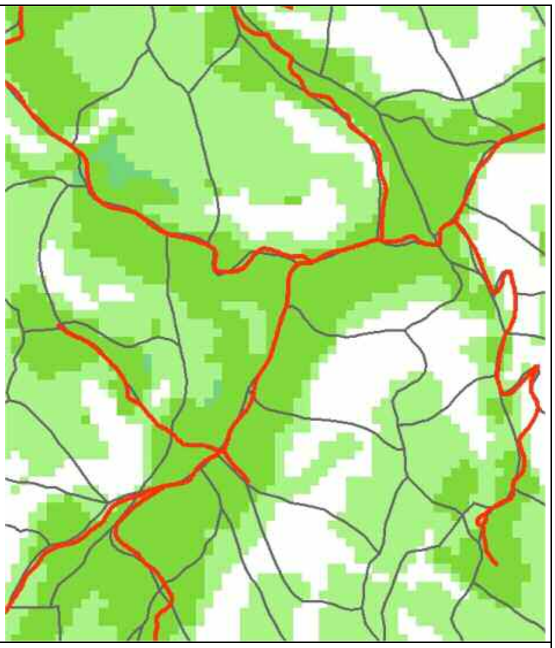


Figure 4.1.e: overlaying tractor (dark green) and forwarder skidding maps

When helped with a rear winch included on the forwarder frame it become a so called cable-forwarder. The technical limit of the machine is the distance from road that is limited to the cable length. Having the slope little importance, the skidding area is similar to a buffer of the forest roads (figure 4.1.f). If we consider forwarder and cable-forwarder as an unique machine we could skid wood from almost all the forest area with slope under 70%, as on figure 4.1.g.

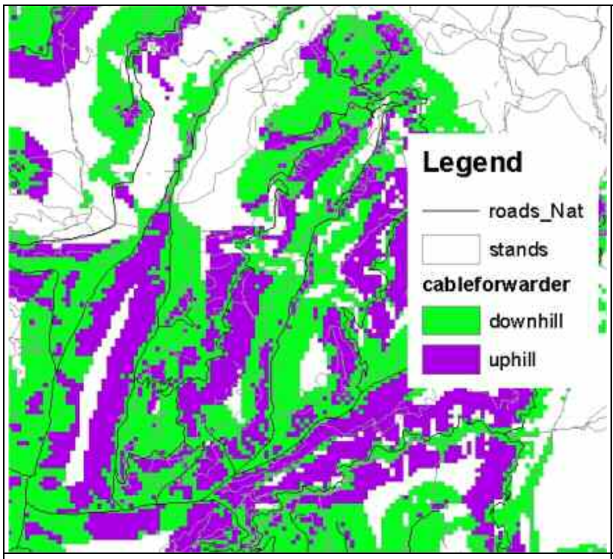


Figure 4.1.f: the cable-forwarder skidding map.

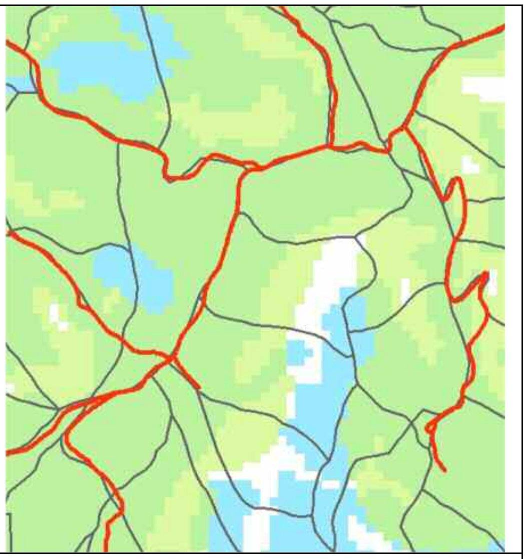


Figure 4.1.g: overlaying forwarder (blue) and cable-forwarder skid maps

The evaluation of skidding maps for cable crane systems considers, also on a cell-by-cell basis, the average slope between each point and the nearest road. Cable systems require a minimum slope to allow the system working. If the slope is too low, here considered less than 15%, the carriage may incur into two different problems, the first is that the gravity force has not enough power to push the load down and the second is that near the end of spans the carriage could not pass the jack or it could cause the falling of the rope from its saddle. Output maps have three different values, one is the skidding uphill area, which is required a two ropes systems (most used in Italy), the second value is the downhill area, where three ropes systems work better, and a third value where the wood would be reachable but the average slope is less than the minimum (figure 4.1.h). Watching the same results on a 3D scene (figure 4.1.i) it is clear that some areas are too flat for the cable systems and it is clear that other ground systems will work there. One example on how the forester has to interpret results is shown on figure 4.1.i: in the centre of the figure there are two parallel roads and the skidding direction is for a half uphill and for the other half downhill. This result is due to a model running tool that calculates the shortest distance from each grid point to the nearest road (*Path Distance Allocation*). The distance between the two roads is more or less 200 m, but any enterprise will never skid half wood on one direction and half on the other. Knowing that the two ropes systems are most spread in Italy, the forester will plan the use of such mobile tower crane skidding uphill to the highest road were probably he will need too plan a good place were installing the tower yarder and have enough space to allow piling logs.

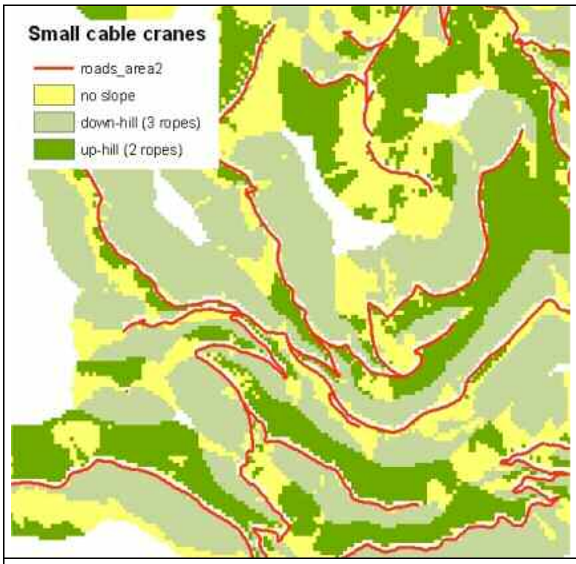


Figure 4.1.h: the small cable (tower yarder) skidding map

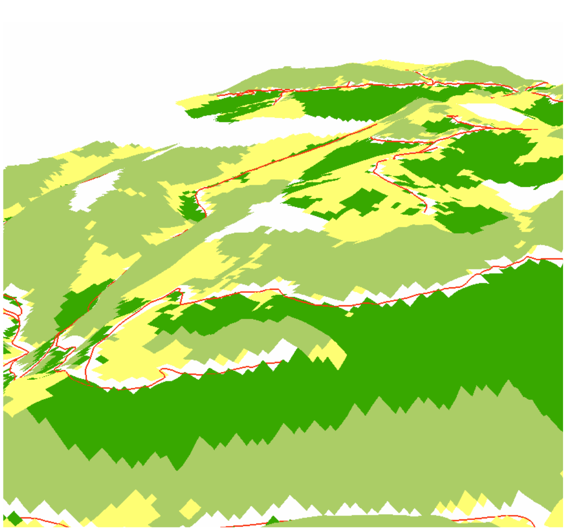


Figure 4.1.i: 3D scene of mobile cable systems skidding map

More or less the same evaluation is done for the bigger cable cranes systems which are usually mounted on a sledge. On figure 4.1.j feasible areas are well linked to forest roads.

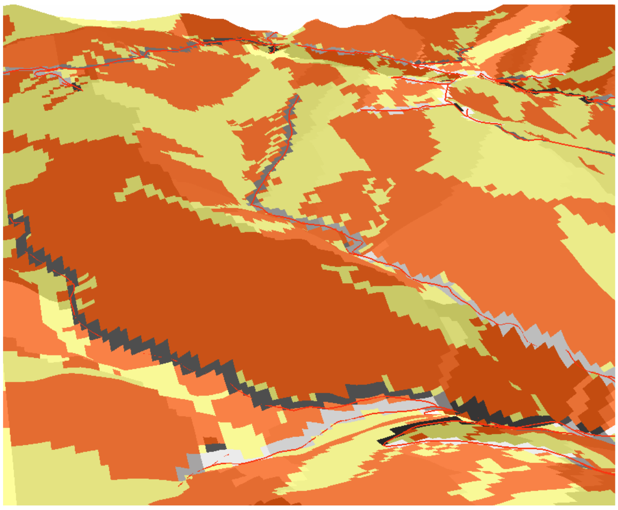


Figure 4.1.j: 3D scene of sledge yarders, red areas are feasible (shadows identify ridges), yellows has not enough steep slope

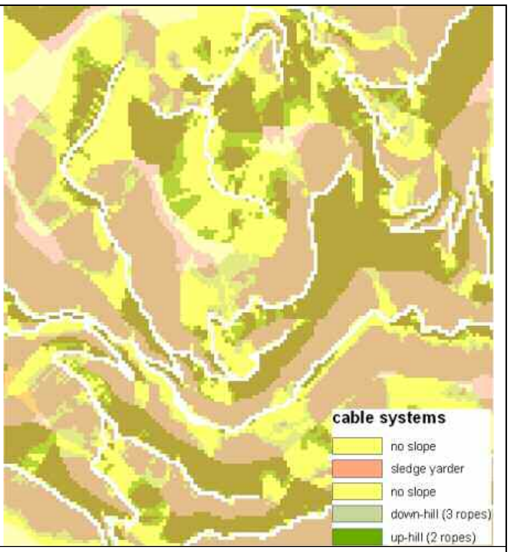


Figure 4.1.k: sledge yarder and tower yarder maps overlay

A better evaluation of working areas could be done by using an hydrological tool called *watershed* which identify the same falling rain direction on a mountain shoulder and it helps the forester to see mountain edges. In fact the sledge yarder system may work on long distances but it cannot go up and down over mountains as shown on figure 3.5.4.1.l. The sledge yarder minimum slope was set to 20% and the maximum distance up to 900 m. By overlaying the results with the tower yarder map (figure 4.1.k) the “no slope” areas coincide. There are only some areas where one of the two systems is excluded: where steep slope is between 15 and 20% can work only the tower yarder and farer than 300 m where only the sledge yarder can work. Figure 4.1.k shows very few areas that are not reachable by cable cranes so the road network could be considered as pretty good.

The second part of the FOpP model makes first a selection of systems by technical limits and after the selection is done by optimizing costs. On the technical selection all systems are shown in the output map because they are selected by an importance criterion which considers systems on the basis of their presence on the area and their importance. The skidding systems maps are overlaid in this order, first tractor, then tower yarder, forwarder, sledge yarder and cable-forwarder (figure 4.1.l). The evaluation of costs by cell is based on the productivity and unit costs of systems and the total amount of yield inside each grid cell. Values may reach very high values inside those stand with high amount of wood, as on figure 4.1.m. It is possible to observe that the evaluation of costs per cell is not so highly influenced by the choice of systems than by the stand cutting volume.

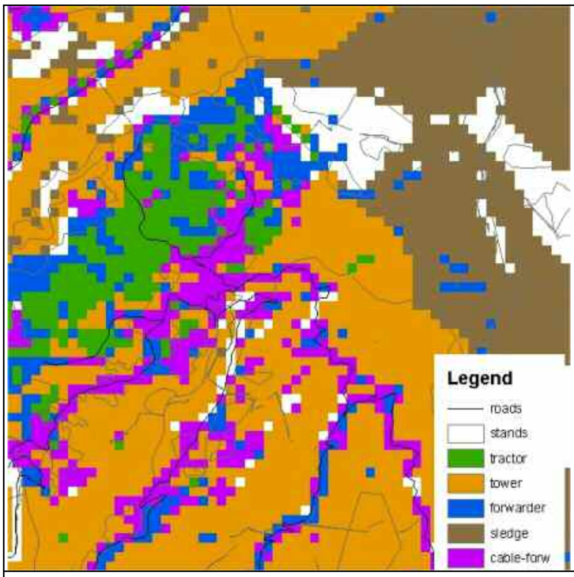


Figure 4.1.l: the technical systems output map

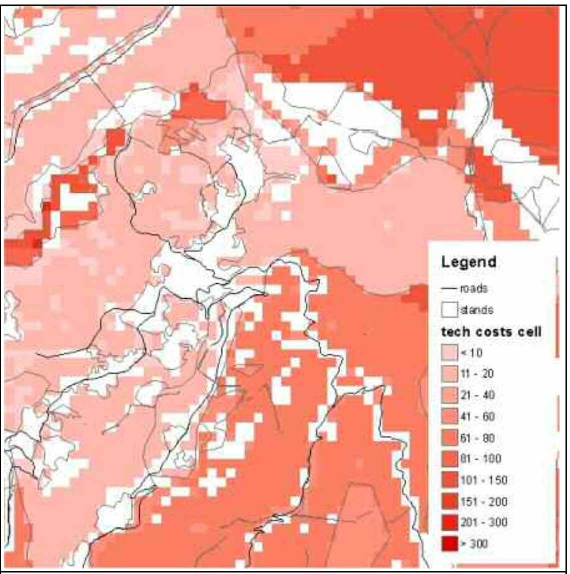


Figure 4.1.m: the technical costs evaluation map

The system optimization part of the FOpP model uses an algorithm to evaluate systems productivities according to the distance between the extraction cell and the nearest forest road. In fact skidding operations last longer if they are done far from road: the time for moving both the machine and the carriage increase with distance. Productivities and consequently costs increase as shown on figure 4.1.n and 4.1.o. In the case of the sledge yarder, costs are classified into categories to highlight the cost gradient and it is also possible to notice how the stand yield is influencing the results (inside the light green area, the yield is planned to be 11 m^3/ha).

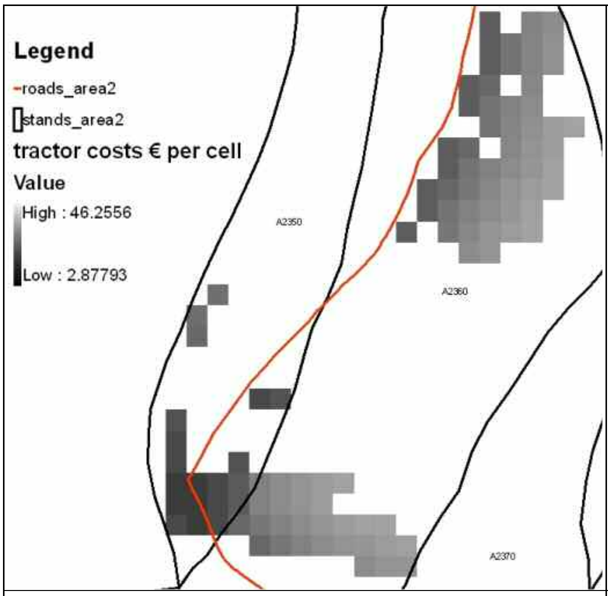


Figure 4.1.n: the tractor optimal costs map

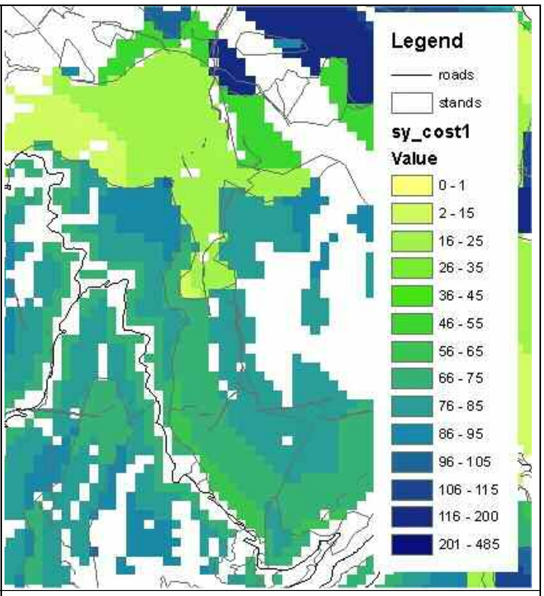


Figure 4.1.o: the sledge yarder cost map

The optimal skidding systems map (figure 4.1.p) is obtained by overlaying all optimal costs systems map and selecting the one which has the lower cost. This map can be compared with the technical system map (figure 4.1.l or figures 3.5.4.2.d and 3.5.4.2.h); what is clear is that the tractor disappear leaving place to more productive systems as the forwarder. The choice between cable crane systems depends on the amount of wood inside stands: if the yield is low, the sledge yarder is more convenient even better on large areas and big distances, if the yield is concentrated the tower yarder is more productive and may work faster with lower unit costs. Total costs per cell (figure 4.1.q) decrease if compared to figure 4.1.m, and inside the same forest stand it is possible to see a sort of gradient where costs increase with the distance from roads.

Costs per cubic meter are highly influenced by the choice of skidding systems: on figure 4.1.r costs are calculated starting from the technical cost map while on figure 4.1.s costs are obtained from the optimal costs map. The results show that optimized costs are in general lower than technical costs, as one could expect, but the optimal system map is not near the reality because it exclude the use of the tractor. The technical map gives better support to the forester who has to take decisions even if sometimes forest enterprises buy wood during public auctions and the forester has nothing to do.

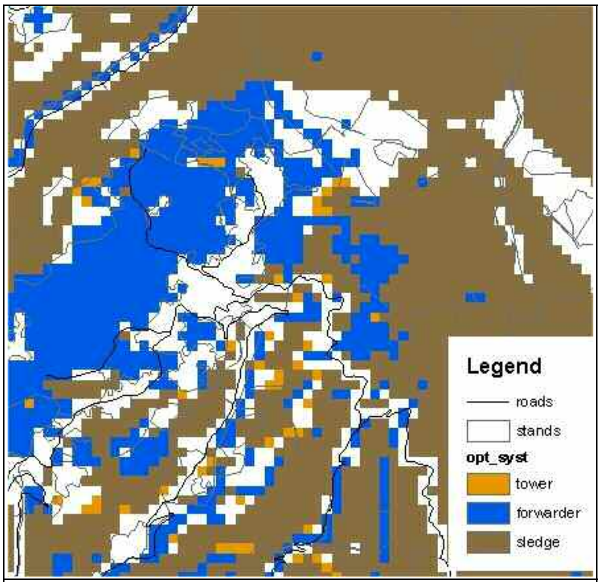


Figure 4.1.p: the optimal systems output map

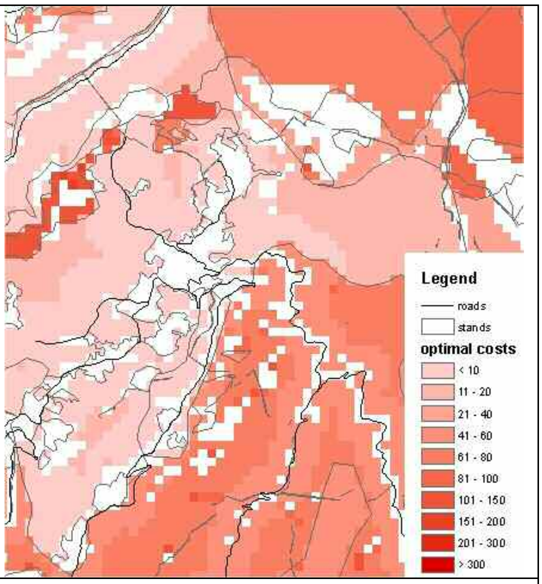


Figure 4.1.q: the optimal costs evaluation map

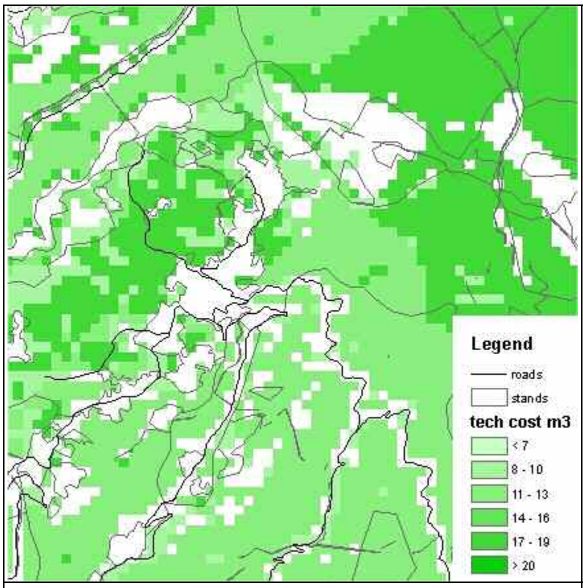


Figure 4.1.r: the technical costs per cubic meter

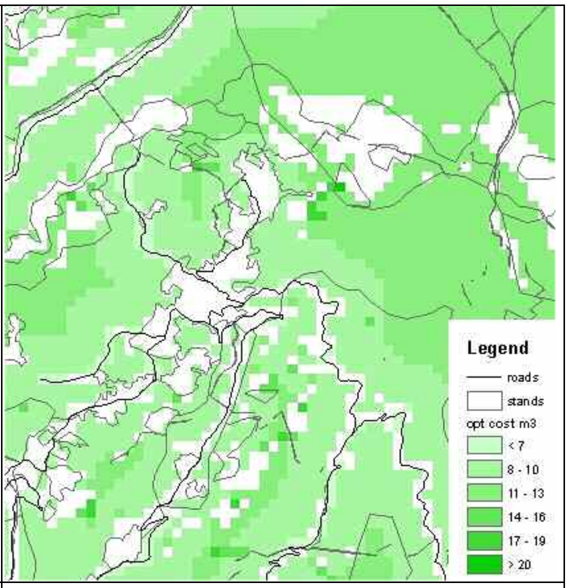


Figure 4.1.s: the optimized costs per cubic meter

The FOpP model may be used by the forester as a tool to identify areas where to cut trees with high or low cost, so that he could estimate the marginal profit that is calculated as the difference between wood sales price and operational cost. This consideration could be done for the first years of planning and used defining cuttings according to the current market value of wood. In fact it would be convenient to cut and skid wood from places where operations are expensive while the wood value is high. If cuttings are done on easy forested areas and the wood value will decrease in the future, only expensive areas are left and operations could not provide any income. The risk is that yield is not cut for economical reasons and the environmental and ecological aims of planning are not satisfied.

4.2. ROADS

The classification of roads into three different categories help the manager in planning the maintenance and the improvement of the existing road network. Only by a simple overlaying of forest stands and roads input file it is possible to evaluate a sort of road **permeability to truck transport** (figure 4.2.a). A good parameter which describes this permeability is the road density that can be easily calculated dividing the sum of road lengths by the sum of forested area. The obtained value in m/ha may be compared to other areas or countries. On the Italian Alpine area the road density varies from 15 to 27 m/ha, but in Austria or Switzerland this value is near 40 m/ha. The road density should be adapted to the forest functions (productive, protective or tourist) and to the mean terrain slope, in fact skidding operations on flat terrains are easiest and off-road systems can reach farer distances from road. On steep terrains may be used cable systems that do not require high road density, but they require at least a good road distribution (parallel roads) and frequent and large piling sites. These road structures are usually too small to let install both the tower yarder and use a tractor or pile logs for all the working site lasting time. Moreover they are insufficient for the use of truck-mounted processors (*Gebirgsharvester*) or for setting biomass harvesting sites which need place to park the chipping machine and the trailer which stores the material.

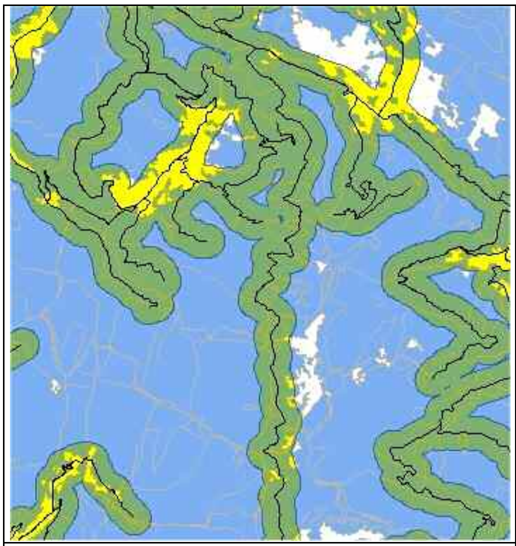


Figure 4.2.a: the road permeability map. Areas in blue are not accessible.

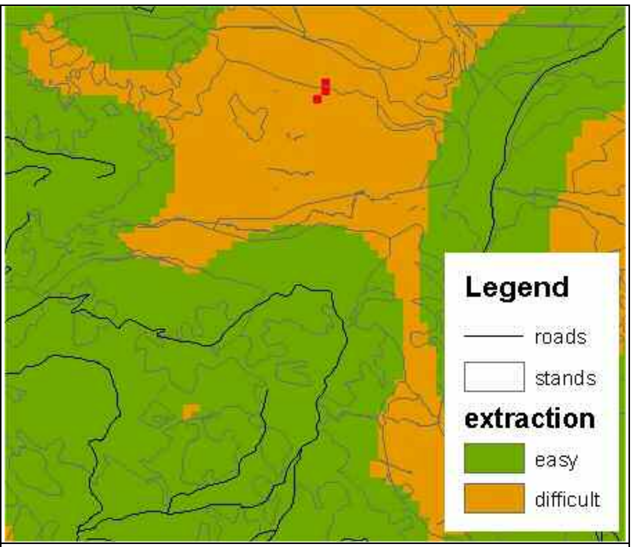


Figure 4.2.b: the forest accessibility and its classification. Areas in red are not reachable.

The FOpP model results highlight the areas that are **not reachable** by any of the selected skidding system (figure 4.2.b). This map is a good starting point for planning the building of new roads. A well planned road should be useful for as much possible forest stands and it should try to reach all the area if it is a productive forest. As said before, the **road density** is a good parameter that should help the forester in drawing a road track. Using the GIS software it is not easy to evaluate this value because it refers to a specific area and if this area is bigger, the obtained value may change (as shown in figure 4.2.c). A suggestion to evaluate road density is to consider a group of forest stands, for example all stands lying on the same valley or on the same mountain shoulder, with the same exposition or with the same assessmental needs. Then the forester could compare these groups and highlight where new roads are needed (example on figure 4.2.d). Building and construction parameters will be set according to the geography and geology (for example the average slope, the width, the road section, ditches or other rain catchments) and to the road transit destination (truck, tractor or public transit) and functions (forest access, wildfire protection or tourist).

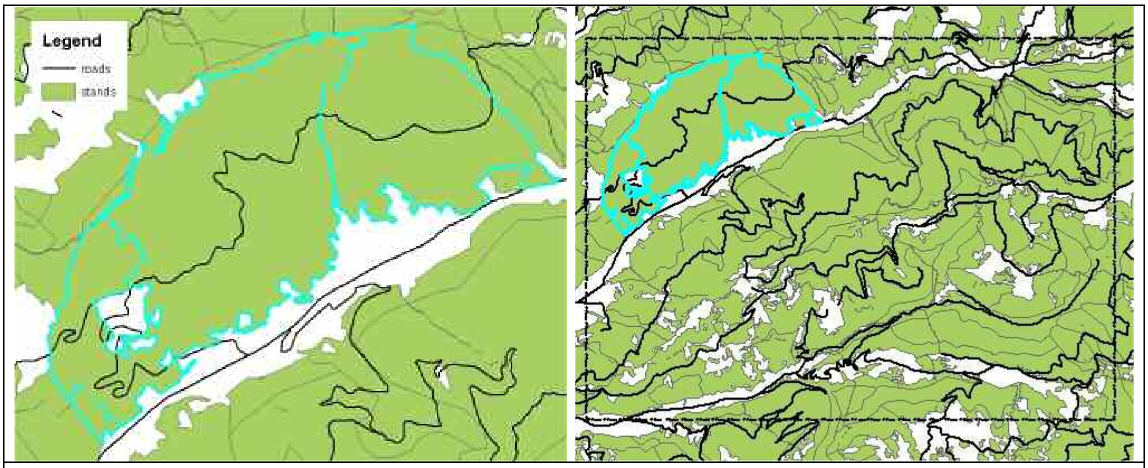


Figure 4.2.c: the road density vary according to the size of the area considered. On the left only one forest typology is considered with 29.7 m/ha; on the right side a bigger area is considered having 33.3 m/ha.

The cutting amount and the estimated costs may be used for a road network analysis. It is possible to quantify how much wood will be skidded to each road section in the next ten years of forest assessment by creating a sort of road catchments areas (similar to the idea of hydraulic basins). The total amount of wood is summed and can be showed as on figure 4.2.e where the symbol thickness is increasing together with the amount of wood. This is an important information because the forester will have an idea of how much space for piling wood will be required and might estimate the future **road transit**. Heavy truck traffic causes the road surface erosion together with rain so, making this analysis, it will be possible to classify roads by importance and have a rough estimation of **maintenance needs and costs** (KRČ 2006).

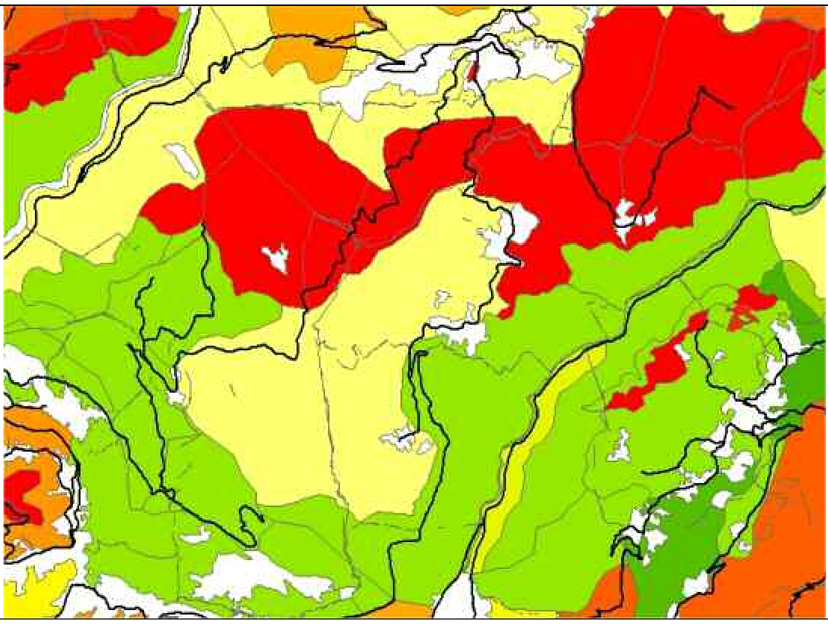


Figure 4.2.d: an example on how grouping forest stand and calculating road density may be helpful to highlight areas which need more roads. Inside green and yellow areas the road density is 31.9 and 32.1 m/ha while inside red areas, which are productive forest with very high stock and planned yield, the value is only 18 m/ha. Planning new roads inside this area should be done.

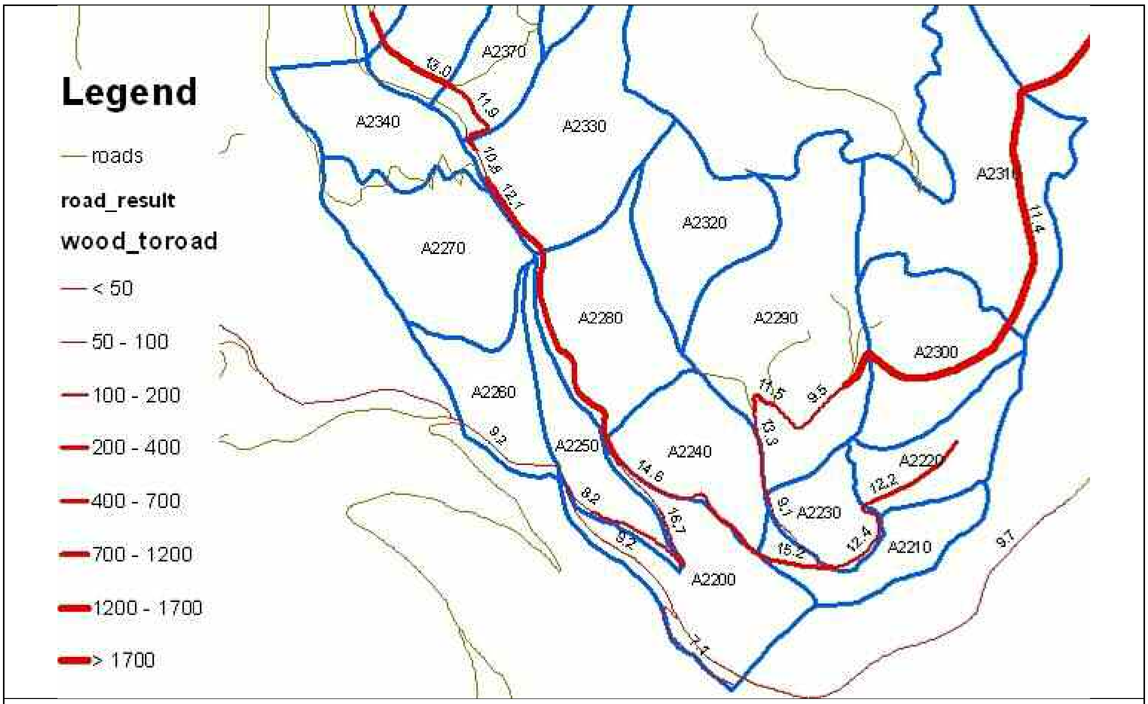


Figure 4.2.e: the wood and costs allocation to forest road sections

Figure 4.2.e shows also the average skidding costs as labels of each road section. This value in strictly connected to the shape and distribution of road network and can be used to evaluate the effect of a new planned road. Moreover it is a developing idea to use the FOpP

model results to evaluate and give an objective evaluation of each new road project inside the “Feltrina” Mountain Community in Veneto region. The idea is to give some parameters that have to be improved by each new project as for example the increase of road density, provide access to several stands and/or properties and to analyze how skidding costs are influenced by introducing a new road. This is possible running the model two times, the first before and the second after the introduction of the new road. Result maps of costs will change showing probably decreasing costs (figure 4.2.f and 4.2.g). The decreasing of skidding costs means that the standing wood value will increase (if the market selling value is fixed) and it will be possible to estimate the total gain that can be subtracted by the road building costs or used by the Region as parameter to judge the project and provide funds.

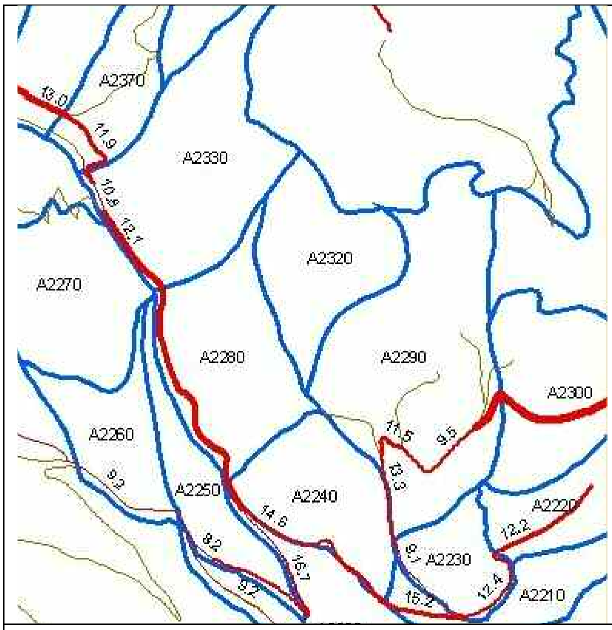


Figure 4.2.f: results before the new road building

Table 4.2.a: influence of building a new road: comparing skidding costs and estimation of total gain (wood value increment)

Stand n°	Before €/m^3	After €/m^3	Difference by stand total €:
A223	9.66	8.86	894.3
A224	16.91	10.59	2844.0
A225	12.52	10.32	1808.9
A227	14.24	9.79	-1856.5
A228	12.53	10.95	1126.5
A229	10.74	9.32	1970.7
A232	11.59	9.07	-277.7
A233	10.91	9.93	-344.8

Total gain: **6165.4**

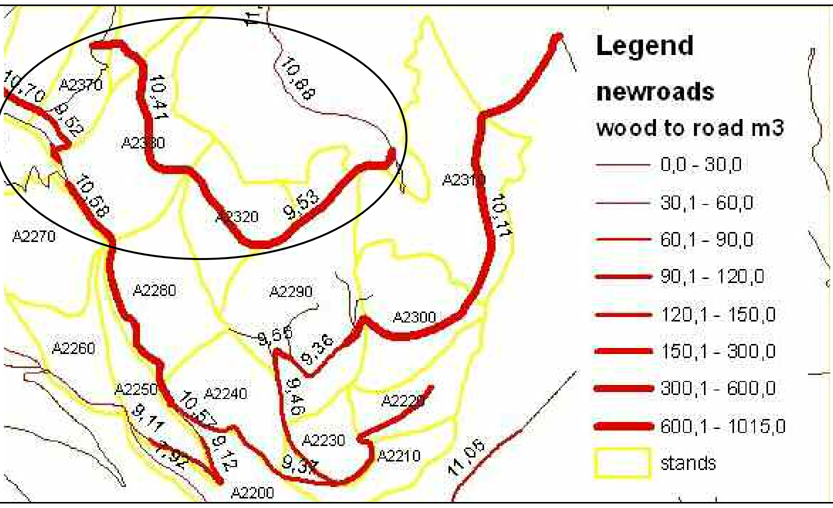


Figure 4.2.g: the evaluation of skidding costs (labels) and standing wood value after building a new forest road (inside the circle).

5. DISCUSSIONS

5.1. ECOLOGICAL AND FOREST HARVESTING PLANNING

The forest assessment is required in Italy for all the public properties and it is recommended inside all other private and associated properties. The aim of planning has two faces, the first is to guarantee a sustainable and environmentally sound management of forests, the second is to allow the owner to have an economical income by cutting and selling wood. Forests have several functions, but until now only the productive function provided some interesting money. The other functions are now gaining more and more importance but they are not well paid (it is also quite difficult to estimate their value) as for example the function of carbon sink, the tourist (including hunting and harvesting small fruits) and maintaining biodiversity functions. By European law, some forests are important for the habitat and the species (mostly vegetables and birds) which are living inside. Other sensitive forests are those located on wet areas or near the water catchments for human purposes. Planning should take count of all functions and provide "instructions" for the users to maintain forests always at the same level without provoking damages or decreasing of value (HEINIMANN 1994). The FOpP model is a helpful tool to help the forester in evaluating the accessibility of forest and make easier the definition of the forest function. The model can be used also to decide if a forest stand has to be cut or if it has not enough wood stock to make operations economical. Money are the main factor to make the planning operative. Inside productive forests, the planned yield should be well quantified to make happy both the owner who sells the wood and the forest enterprise which cut it and sell it to sawmills. Each step of the selling chain add some value to the material, in the case of the enterprise the income is strictly connected to the operational costs. The model results maps may help the forester estimating the average skidding costs inside each forest stand and so defining the standing value of wood (by subtracting operational costs from the wood market value). Inside stands with protection or tourist functions, cuttings are usually done on small areas and small quantities, so the economic gain is usually negative. This kind of management is usually funded by the Region through the forest services or should be done by inhabitants for their civil rights (a yearly amount of wood for heating purposes).

A simple method to determine the minimum size of planned yield was defined (LUBELLO *et al.* 2007). It is based on a well know economic procedure called break-even analysis (POLLINI 1983) which identify the value where income and fixed costs are equal. In the forestry sector fixed costs can be divided into two categories, the machine fixed costs and the administrative costs (including taxes for buying wood and working site related costs like translocation or mounting and dismounting). From the algebraic point of view, the condition to determine the break-even is:

$$(\mathrm{L}_{\min} \cdot Pimp) = C_{f\,TOT} \quad \left[m^3 \cdot \frac{€}{m^3} = € \right]$$

or $L_{\min} = \frac{C_{f\,TOT}}{Pimp}$ (a

where: L_{min}. = minimum yield size (m^3)
Cf_{TOT} = total fixed costs (€)
Pimp = price at road side (€/m3)

But the total fixed costs are divided into machine fixed costs and administrative costs: machine costs are usually referred to the unit of wood (m^3) while the administrative costs are not, so the (a) formula has to be changed into:

$L_{min} \cdot Pimp = Cf_{TOT} = Cf_{FOR} + (L_{min} \cdot Cf_{FIN})$, moving on the first part:
$(L_{min} \cdot Pimp) - (L_{min} \cdot Cf_{FIN}) = Cf_{FOR}$, combining L_{min}:
$L_{min} \cdot (Pimp - Cf_{FIN}) = Cf_{FOR}$ =>

$L_{\min} = \frac{Cf_{FOR}}{R_{UN}}$ (b

where: Cf_{FOR} = forest machines fixed costs (€)
Cf_{FIN} = administrative fixed costs (€/m^3)
R_{UN} = residual income coming from: $Pimp - Cf_{FIN}$ (€/m^3)

The obtained value is the minimum amount of wood that allow the enterprise to cover all fixed costs, but some more money are needed to make cutting interesting. This is called enterprise income (*udi*) and it is calculated as a percentage of the wood value at road side. The forester has to prepare a table (table 5.1.a) of costs to determine the minimum yield. He needs the standing wood value, the value at road side, machine's unit costs (which are planned to be used, considering for example the FOpP output maps) and an estimated enterprise income. By subtracting all cost voices from the road side wood value, the residual income is obtained (R_{UN}) and total fixed costs are divided by it.

Table 5.1.a: example of cost elements and calculation of the minimum yield

costs		unit	formula
Road side wood value	80	€/m^3	P*imp*
Standing price	30	€/m^3	mac
Cutting operations	0.14	€/m^3	tag (e.g. chainsaw)
Skidding operations	0.59	€/m^3	esb (e.g. tower crane)
Transport	2.08	€/m^3	lav (e.g. truck)
Enterprise income	24	€/m^3	udi = 30% · P*imp*
Residual income	23.19	€/m^3	R_{UN} = P*imp*-mac-tag-esb-lav-udi
Total fixed costs	2400	€	Cf_{FOR}
Minimum yield	**103**	m^3	$L_{min} = Cf_{FOR} / R_{UN}$

It is possible to draw on a graph how the minimum yield values change by modifying the input parameters. If the wood value at road side is fixed, the minimum yield increase together with the standing wood value. If the enterprise income is decreasing, the standing value may increase (figure 5.1.a) and vice versa. The forester may use estimated values or known market prices. This method is also useful for the entrepreneur who participate to an auction because, on the basis of the income he wants to reach, he may know which standing value has to offer. For example, paying a standing price of 49 € and estimating a 15% of enterprise gain, on the base of figure 5.1.a, the minimum size of cutting should be 182 m^3. If the cutting is already fixed to 1000 m^3 and the entrepreneur wants an income of 35%, his offer should not be more than 40 €.

By fixing the enterprise income, the minimum yield decrease with the increasing of standing and road side value (figure 5.1.b). From the graph it is possible to see that buying standing wood at 40 €/m^3 and selling it at about 70 €/m^3, the minimum yield should be at least 1000 m^3. On the opposite, knowing that 500 m^3 have been bought at 35 €/m^3 the selling price should be more than 68 €/m^3.

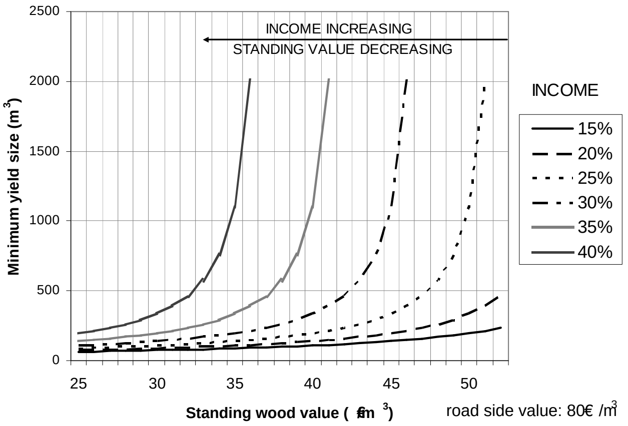


Figure 5.1.a: the variation of yield according to standing value and enterprise income.

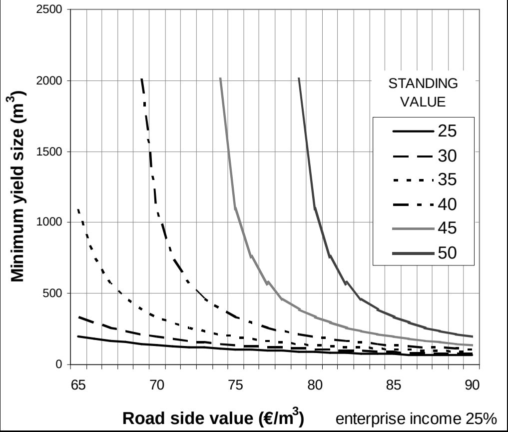


Figure 5.1.b: the variation of yield according to road side and standing value.

The minimum yield is influenced by the machine’s unit costs but also by the administrative fixed costs. In particular the working site costs may have important variations when considering a simple tractor or the translocation of huge machines like harvester and forwarder. These machines require a special transport with special trucks which require a driving permission because of the outsize dimensions. Even the mounting and dismounting operations for a cable systems may take several days and all these costs should be considered. Moreover, when the working site is far from home, also the costs for sleeping and eating of workers should be considered.

Table 5.1.b shows the yield calculation for different utilization systems: where administrative costs are high, even the yield is high because more wood is required to cover all fixed costs. It is possible to notice that the yield amount increase with the increasing of the mechanization level. The chipper evaluation considers a low standing price because such operations are done on first thinnings and are usually funded by the Region; the enterprise income of 15% guarantees 10 € income per each ton produced.

Table 5.1.b: yield calculation for different utilization systems.

System	Standing value	Machines Fixed costs	Enterprise income	Admin. costs	Road side value	Yield
	€/m^3	€/m^3	%	€	€/m^3	m^3
Traditional, bucked logs	35	1,6	25	1500	80	**82**
Bucked logs + tower crane	35	2,81	25	2400	80	**140**
Bucked logs + forwarder	35	4,58	25	2600	80	**169**
Full tree with cable crane and processed at road side	35	6,04	25	3000	80	**215**
Harvester + forwarder	35	12,13	25	3800	80	**483**
Full tree with cable crane and all chipped at road side	9	11,05	15	3000	32	**543**
	€/t	€/t	%	€	€/t	t
Firewood from coppice with p-hd slides	25	11,74	25	1500	120	**26**

After general planning, and before starting the working site, it is important to make a precise planning. This means to identify in which period of the year cuttings have to be done to prevent soil and tree damages or animals disturb, but also design operations in order to highlight the need of maintain forest roads or re-open a skidtrail. There are several elements that should be considered, for example:

A) the translocation of machines to the working site and the need of space. A sledge yarder would need the help of a helicopter when there are no roads or a tower crane would need a big site to be installed and have enough space for piling wood

B) the time to reach the working site and the time operators may need to reach the cutting area inside forest (for example it was measured for a sledge yarder site, where the machine was installed uphill and the skidding direction was downhill to the unique road, that the yarder operator needed 55 minutes walking to reach the yarder sited 400 m uphill). This time is a non productive time and must be considered estimating the site operation duration.

C) the possibility of having rainy days or respect the workers right of asking some hours or days of resting.

D) the operating site that could be risky for steep slope or instable ground.

E) the definition of skidding system and the width of cable corridor. For example the full tree or the short wood system may be done according to the site characteristics. The FT extraction need a big site where piling and working wood (delimbing and bucking) by the use of chainsaw or processor. The SWS is helpful when there is small place at road side or when working with firewood. It was demonstrated (ZANONI 2007) on the same corridor that skidding pieces of wood (2 m long) tied together into 1 ton logs makes in average 1.2 tons/hour more productive the cable system (figure 5.1.c). Obviously this operation is time consuming and cutting may last some days more. It could be a good solution if the piling site is small or if at the same time another crew is occupied in preparing the corridor and mounting the line.

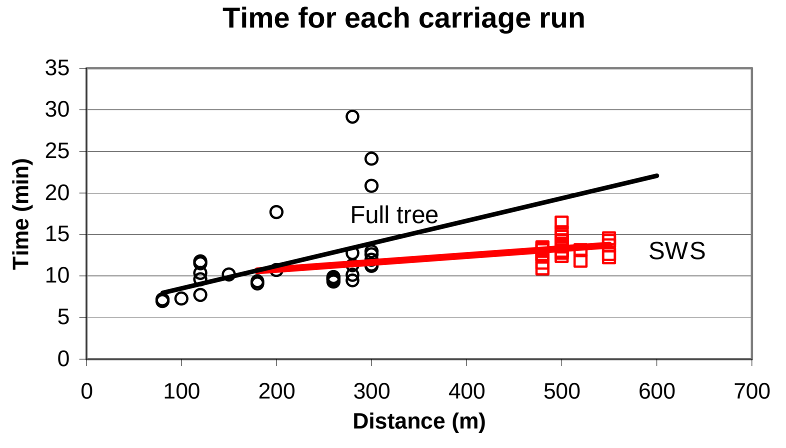


Figure 5.1.c: the time influence of full tree and SWS extraction system on the same cable line

Figure 5.1.d: a picture of the corridor

A project of Trento Province studied costs linked to firewood extraction. Results showed that times, productivities and costs are strictly connected to the working site geography, nevertheless a list price was built making averages of several studied cable cranes (table 5.1.c). The voice "other costs" can be quite high if all points mentioned above are not favorable; the skidding costs are lower if comparing private enterprises and the public service (forest services have their own crew and machines) due to lower interest rates and fixed costs. So the forest service may work on more difficult terrain with lower costs, providing inhabitants of their firewood rights and preventing the abandonment of forests and the wood import from other European countries.

Table 5.1.c: Operating costs and times for cable systems in Trento province.

Operation	Public service costs	Private enterprise costs	Unit
Cuttings	12.16	12.16	€/t
Tied firewood (2 m x 1 ton)	13.39	13.39	€/t
Mounting sledge yarder	144	144	Operator hours
Mounting tower yarder	48	48	Operator hours
Dismounting sledge yarder	85	85	Operator hours
Dismounting tower yarder	30	30	Operator hours
Skidding operations with sledge yarder	20.84	24.03	€/t
Skidding operations with tower yarder	12.86	17.38	€/t
Other costs	Up to 35	Up to 35	€/t

5.2. POSSIBLE UPDATES

The nature and real life in general is too much complicate to be well represented by any model, so even if the Forest Operation Planning model is quite intricate and considers different parameters, it is not perfect and might be improved in the future.

One of the most interesting things that are being developing is the application of a new integrated system called LIDAR which uses both GPS positioning and Laser scanner to gather terrain information (figure 5.2.a). The system is capable to catch several points on the same vertical position and save their xyz values; the points density is usually more than 1 per square meter, but could be more, with the only limitation of the file size that can be handled by GIS systems (the kriging geostatistical tool has some problems working with files with more than one million points) and for its storage place size (the Trento province file is about 150 Gigabites). Points may be divided into terrain and vegetation points (figure 5.2.b) and interpolated obtaining a very precise Digital Terrain Model (the precision can reach 0.2-0.5 m, figure 5.2.c) or a sort of vegetation canopy (figure 5.2.d). This precise DEM could be used in the future running the model on small areas. The Lidar data could provide also a more precise raster of terrain roughness and/or knowing the forest typologies and merging information with the Lidar canopy (which provide density and height of trees) a more precise raster of stock and yield could be obtained.

The FOpP model works on a cell-by-cell basis, but one lack of the input files was that all information were referred to the forest stand (figure 5.2.e). Stand may be very big, several hectares sized, and the data could be so quite rough. In the future the input data could be gathered through *ad hoc* surveys or defining fixed small surveys areas were terrain classification and standing tree information could be collected. Using such precise input rasters, the model should run better and provide more precise results. Figure 5.2.f shows how the input files should be created. These information could be gathered by the forester when he makes the forest planning and could be updates every ten years. The forester already do surveys on plot areas and we think that making more precise observations and saving this data should not be so highly time consuming if compared to the quality of information obtained.

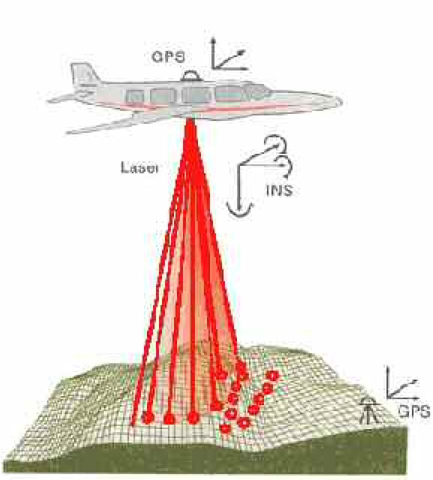


Figure 5.2.a: the LIDAR system functioning

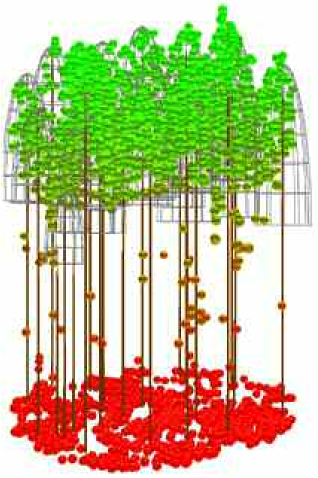


Figure 5.2.b: LIDAR output points

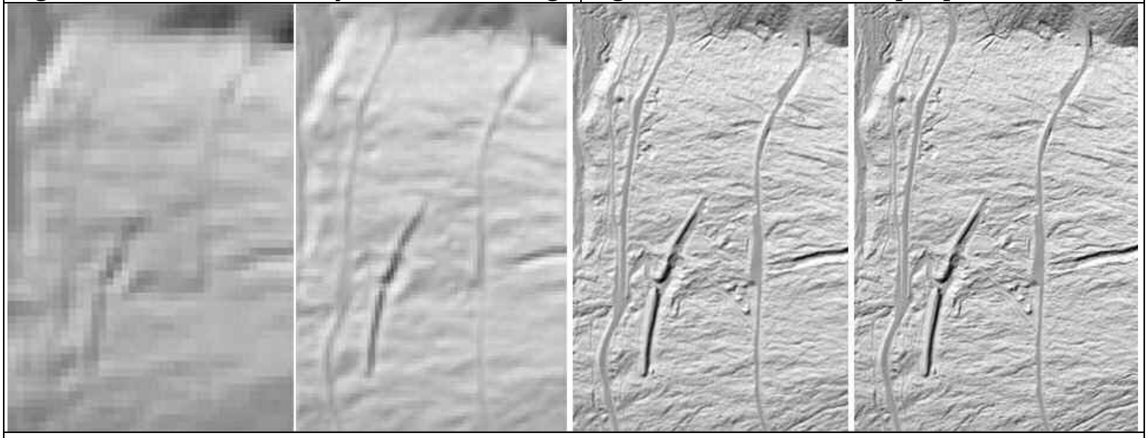


Figure 5.2.c: comparing DEM with 10 m, 5 m, 1m and 0.5 m precision. Increasing precision it is possible to see clearly forest roads and micro-scale geography (TAROLLI and DALLA FONTANA 2007).

Figure 5.2.d: a 3D scene of terrain and vegetation from Lidar data (TAROLLI and DALLA FONTANA 2007, CAVALLI *et al.* 2007).

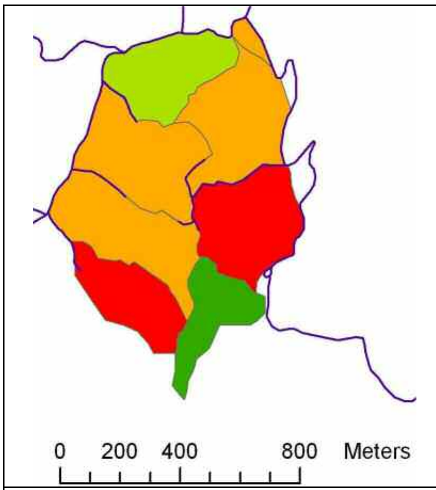


Figure 5.2.e: an example of terrain roughness or stock information, one value per each forest stand

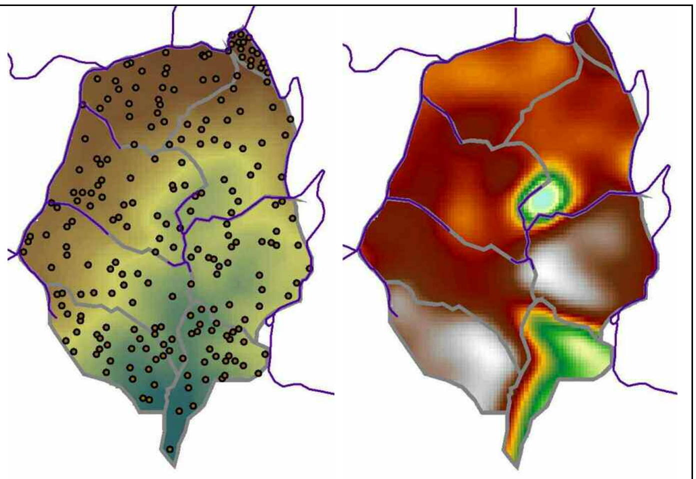


Figure 5.2.f: an example on how placing survey points (left) and interpolate data for a precise stock raster file (on the right)

A more precise evaluation of terrain gradeability would include the soil moisture and the Cone index measurement. The Cone Index represent the soil bearing capacity in kPa and would be a very good parameter to evaluate the accessibility of forest for different off-road systems. Many references show correlations between the Cone Index and the maximum slope that machines can climb without slippage. These formulas could be included inside the model and calculate gradeability exactly without matrices or complex rules.

The soil moisture is the water content of soil which influences the off-ground movement and the soil bearing capacity. It is common that on wet soils the frequent machines passages create muddy conditions and consequent soil compaction with damages that can be seen even after several years. A good implementation of the model would add the possibility to chose the period of the year or a monthly evaluation of forest accessibility. Data asked to the user could be no more than the average monthly rain frequency. This information could be referred to the soil types which is known they have different attitude to maintain water or not (gravel or well structured soils).

Another important aspect that here was not considered is the presence of streams and rivers. In a future version of the model they should be considered as limiting factors for the off-ground vehicles. In fact they are a physical obstacle (if they are large enough) and cannot be crossed by machines, moreover near their edges the soil moisture is higher or on flat terrain it is frequent to find marshes or peat lands. A shapefile of river should be asked to the user as input file and the model could make a buffer of it and assign to this area a very low gradeability. Then rivers could be used as barriers when the model run the path distance allocation but this will limit also the cable systems and some solutions should be found to solve new programming problems.

These are the main possible implementation of the model, but each of them require new information to the user and complicate the model functioning. A compromise should be done, if we want the model is used it should not be too much complicate and require too many inputs because the user will not understand its functioning and will not found data, on the other side the model results will not be perfect, but should be interpret and used as an objective support (this is the aim of Decision Support Models!) for taking operational decisions.

The Model Builder was a good tool even for building complicate models because its schematic window makes clear the model structure and when testing it is very easy to understand where are errors or which tools have not functioned properly. After have tested the model several times we think that it should be translated into a more stable programming language as the Visual Basic for Applications that inside the ArcGis software uses the so call ArcObjects. The VBA language is not so difficult and allow to create a more interactive user window and outputs or reports with predefined legends (colors and labels) which make results more clear and easy to understand and apply.

5.3. PRACTICAL PLANNING APPLICATIONS/EXPERIENCES

Planning is important when forest enterprises or land owner associations want to ask for public funds. The Rural Developing Plans provide money according to specific approved actions. One of the actions is for example the technical development and skill improvement of forest enterprises. So new machines like harvesters or forwarders or processors and cable cranes are financed, but their number should be the result of a studied environmental planning and politic strategies. It should be take in count for example the yearly available cutting amount that is necessary for the high level forest mechanization to get machines productive and the work economically feasible. Forest associations (both of landowner or enterprises) may assure work continuity and more attention to safety and teaching of workers. A careful regional planning should provide funds for a well defined number of machines to make them work at higher level and correctly (for the operator safety), this would be the basis for a social and economic sustainable development.

On the next two paragraphs two types of planning are presented.

The first case is the estimation of the right number of harvester that could be founded by regional politics. The GIS software is used here just to run simple algorithms on a geographical area defining a working basin for each machine, optimizing translocation distances and total working site costs.

The second is the application of the FOpP model on a sub-regional scale. The model is used to estimate cutting and skidding costs, then the wood amount is allocated to road side and transportation cost to the nearest mill are calculated. The study was performed to evaluate strength and weakness of wood chain between State boundaries.

5.3.1. A simple regional-scale application

The Veneto region rural development plan for the next years (2007-2013) defines some actions to develop the forest work (AA.VV. 2007). The axis n. 1 actions provide funds to forest enterprises to buy new technological machines with the aim of innovate and exploit the wood chain. It is clear that not all the enterprises may buy an harvester or a forwarder, because there will not be enough wood to make them work properly and probably they will stop with an evident public money wasting. This is the reason for such a regional scale planning.

As input data we used the registered data of all cuttings inside the Veneto region (thank to the Direzione Foreste ed Economia Montana of Veneto region) during the years 2004 and 2005 inside both private and public properties. All information have been georeferenced for the next calculation and analysis (figure 5.3.1.a). In the year 2005, 283246 m^3 have been cut inside the region, 64% on private assessed properties and 36% inside private properties. The average amount per working site is 184 m^3 for public and 141 m^3 for private properties, but the median value is less than 40, that it means that inside more than half working sites no more than 40 m3 are cut. This is a very low value that could not justify the use of high technology machines, and the costs of their translocation indeed.

The present study did not take care of the harvesting head technical limits, like the maximum diameter of debarking knives, but considered only the stand slope as parameter limiting the machine off-road movement. We used the slope limit at 35% as reported by many authors (HEINIMANN *et al.* 1998; STAMPFER 1999; SPINELLI and STAMPFER 2002). This is not the upper limit for the harvester mobility, but it is a value that should not influence its working productivity. With the spatial analyst tool in ArcGIS we create a slope map and we did a zonal statistics to quantify how much of a stand surface can be reached by the machine. The relation between average stand slope and reachable area is shown on graph (figure 5.3.1.b) (EMER 2005). The obtained values were multiplied by the cutting volume to evaluate the “reachable wood”, called here M_u.

Speaking with entrepreneurs (CIECH 2006; DECOL 2006) we defined that 400 m^3 is the minimum wood amount which should be cut to cover all variable and translocation costs of the harvester (M_{400}). We selected the working sites with more than 400 m^3 and then we decided that at least 2/3 of working sites will be cut with the traditional methods (small enterprises),so we randomly reduced the number of possible working sites according to the formula:

$$M_u = 1/3 * \Sigma M_{400} \qquad (1)$$

After this evaluation the average amount of wood was 34054 m^3, the 14% of total cuttings.

In the Northern Europe, it is usually known that the economical yearly cut wood for an harvester would be at least 9000-10000 m^3. The same would not be possible in the Alpine mountains so we defined the upper limit at 6000 m^3 per year.

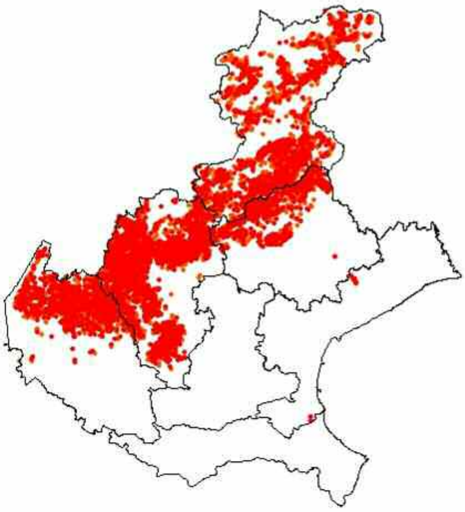
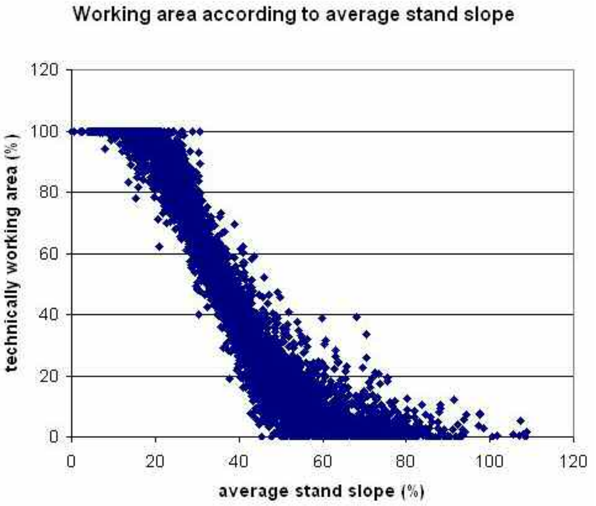
	

Figure 5.3.1.a: all cuttings inside Veneto region in the 2004 and 2005 years	Figure 5.3.1.b: increasing average stand slope, the machine reachable area decreases.

With the help of GIS tools we started to analyse the working sites distribution first thinking to only one machine working and continuing increasing the number of machines up to five inside all the region. For each step we calculated the sum of distances between the centre of the area and all working sites with the formula:

$$D_a = \Sigma(2*D_i*f) \qquad (2)$$

where D_a = sum of distances (km)
$2*D_i$ = distance between each working site and the centre of the area
f = 1.6, conversion factor to transform straight line distances into real distances (sort of road curvy factor)

and also the total amount of wood inside each area:

$$M_a = \Sigma M_{i400} \qquad (3)$$

where M_a = cutting wood sum (m^3)
M_{i400} = working site amount with more than 400 m^3

The working areas were located taking care that the sum of wood amount would be similar between them. The same procedure was done considering the two years together and after this making an average.

Other useful information were calculated as:

- the number of days necessary to cut all the wood amount inside each area:

$$G_{ef} = M_a / P_{hv} \qquad (4)$$

where P_{hv} = average harvester productivity, about 80 m^3/day

- the average distance between all sites and the centre of the areas:

$$D_m = D_a / c \qquad (5)$$

where c = number of cutting sites

- the average yield (m^3):

$$R_m = M_a / c \qquad (6)$$

After the areas optimization, some costs were calculated as the: average net gain G_n (€/m^3), the average net gain per working site (€) and the yearly gain per each area (€).
The average net gain (G_n) is obtained with the following formula:

$$G_n = V - (C_{ab} + C_{es} + C_{mc} + C_{op} + C_p) \qquad (7)$$

where: V = average wood market value at road side (about 80 €/m^3)

C_{ab} = felling costs using the *harvester*, estimated 17 €/m^3 as calculated with the adapted MIYATA (1980) and BRINKER *et al.* (2002) methods.

C_{es} = skidding costs using *forwarder*, estimated 6 €/m^3

C_{mc} = translocation costs (€/m^3), obtained with the formula:

$$C_{mc} = (D_m \cdot i) / R_m \qquad (8)$$

where *i* = unit costs for moving machine with special transport truck. The costs vary from 1.3 to 20 €/km on the basis of the driving distances.

C_{op} = operators living costs (€/m^3). Thinking a daily cost (*g*) of about 35 €, it is calculated as:

$$C_{op} = g / (M_a / G_{ef}) = (g * G_{ef}) / M_a \qquad (9)$$

C_p = average standing wood value, about 30 €/m^3

The average gain per working site (Gc, €) allows to verify if the working sites translocations costs are higher than the total gain (the convenience). The used formula is:

$$G_c = G_n \cdot R_m \qquad (10)$$

The yearly gain is calculated considering if the number of necessary working days (G_{ef}, see formula n. 4) are more or less than the estimated machine working days, here 200. The number of working sites will be consequently reduced to adapt it to harvester productivity:

$$G_a = G_c * (c / (G_{ef} / 200)) = (G_c * c * 200) / G_{ef} \qquad (11)$$

Results show that the maximum number of machine should not exceed five because there is not enough cutting wood. The yield distribution is spread all over the regional mountainous area, while the site amount is highly variable and influence the size of working areas (figure 5.3.1.c. On table 5.3.1.a, results about cutting volumes are shown. The distribution and the wood amount per site made quite difficult the optimization of the different areas.
We think that the optimal number of machines is four.

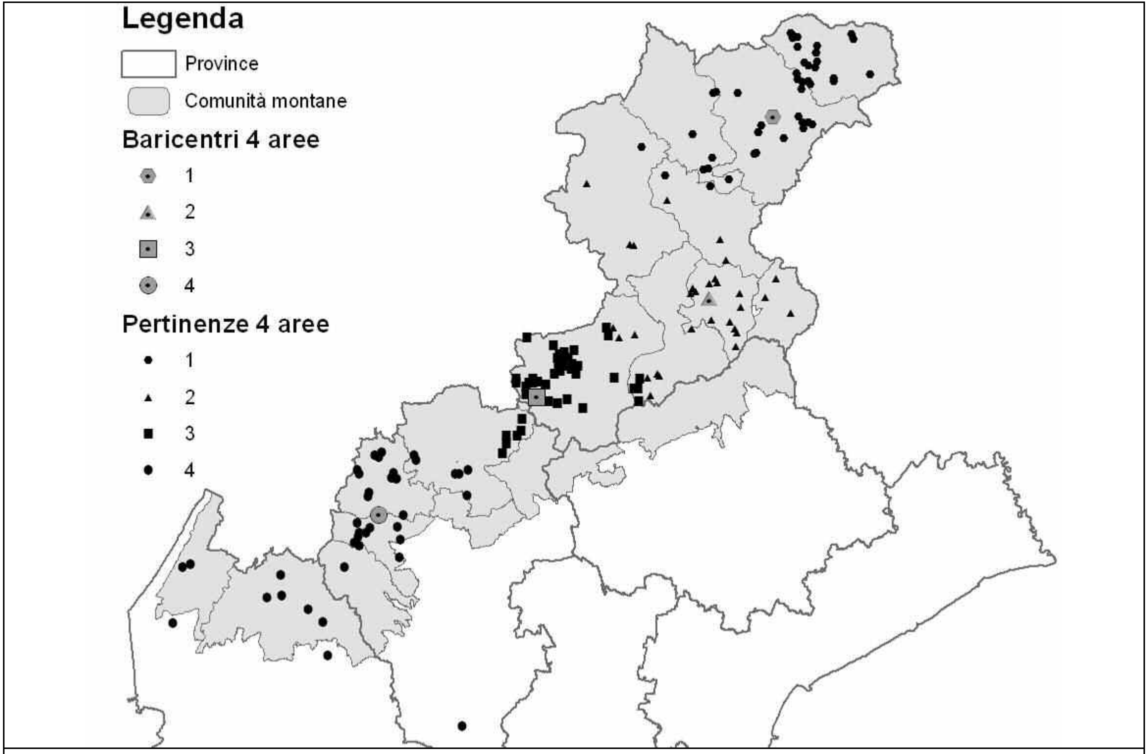


Figure 5.3.1.c: the optimal areas and working sites distribution.

Table 5.3.1.a: optimal distribution of wood cutting amount (m^3).

	Area 1	Area 2	Area 3	Area 4	Area 5
1 area/machine					
2004	27884	-	-	-	-
2005	40056	-	-	-	-
2004-2005	34054	-	-	-	-
2 areas/machines					
2004	12036	15848	-	-	-
2005	14387	25670	-	-	-
2004-2005	13296	32626	-	-	-
3 areas/machines					
2004	10471	13762	3820	-	-
2005	22001	9973	8083	-	-
2004-2005	10939	11262	11853	-	-
4 areas/machines					
2004	9142	3820	13361	1561	-
2005	12737	8083	9577	9659	-
2004-2005	10939	7449	7433	8233	-
5 areas/machines					
2004-2005	10939	5705	11458	4286	1665

The table 5.3.1.b shows the average translocation costs inside each area. Knowing that they consider also the operators daily costs, we should say that they are quite low. Increasing the number af working areas, the average distance decrease and consequently costs decrease.

Four areas make average distances lower than 60 km, this means that the operators might come back home every day spending no more than one hour.

Table 5.3.1.b: the translocation costs according to the number of working areas. The average distance is shown between parenthesis.

	Area 1	Area 2	Area 3	Area 4	Area 5
1 area/machine					
2004	**1,4**	-	-	-	-
Distanza media	(120)	-	-	-	-
2005	**1,3**	-	-	-	-
	(144)	-	-	-	-
2004-2005	**1,4**	-	-	-	-
	(133)	-	-	-	-
2 areas/machines					
2004	**1,0**	**0,8**	-	-	-
	(75)	(88)	-	-	-
2005	**1,1**	**0,9**	-	-	-
	(85)	(92)	-	-	-
2004-2005	**1,0**	**0,9**	-	-	-
	(82)	(91)	-	-	-
3 areas/machines					
2004	**0,6**	**0,5**	**0,8**	-	-
	(71)	(48)	(63)	-	-
2005	**0,8**	**0,4**	**1,1**	-	-
	(80)	(43)	(63)	-	-
2004-2005	**0,7**	**0,5**	**0,9**	-	-
	(76)	(45)	(63)	-	-
4 areas/machines					
2004	**0,4**	**0,8**	**0,3**	**0,2**	-
	(40)	(45)	(32)	(55)	
2005	**0,4**	**0,7**	**0,3**	**1,1**	-
	(45)	(62)	(30)	(28)	
2004-2005	**0,4**	**0,8**	**0,3**	**0,3**	-
	(43)	(56)	(32)	(36)	-
5 areas/machines					
2004-2005	**0,4**	**0,3**	**0,3**	**0,4**	**0,8**
	(42)	(33)	(30)	(31)	(8)

As final results we calculated total costs for the four areas hypothesis. Considering the average price of wood about 80 euros, the net gain per cubic meter (Gc) is always higher than 24 euros, a 30% that we consider very good. The distribution of yield determine a negative year inside area 4, but the average distribution (years 2004-2005) allow to four machines an economically working. In fact, the average working site gain is between 4000 and 10000 euros while the average yearly gain is between 47000 and 180000 euros. This means that in the worst case the enterprise will cover the value of a new machine in 5 or 6 years, that become 3 or 4 if asking the regional funds. Considering that an harvester, according to its use, has an average machine life of about 4-6 years, and after this period it has still a quite high salvage value, the number of four machines seems to be optimal to allow a sustainable technology improvement.

Table 5.3.1.c: costs evaluation in the case of four working harvesters

year	area	Total costs	Gc	Gn	Ga
2005	Area 1	54,7	25,3	4188	45591
	Area 2	55,1	24,9	10451	165497
	Area 3	54,7	25,3	9321	129765
	Area 4	54,5	25,5	-4952	-43743
2004	Area 1	54,7	25,3	4737	52512
	Area 2	55,0	25,0	11050	215980
	Area 3	54,6	25,4	3883	41850
	Area 4	55,4	24,6	10647	254699
average 2004-2005	Area 1	54,7	25,3	4422	48513
	Area 2	55,1	24,9	10812	184090
	Area 3	54,6	25,4	6796	81561
	Area 4	54,6	25,4	4328	47319

5.3.2. An interregional approach: ITA-SLO cooperation

The aim of the research was to investigate the difference between regional and interregional wood chains. This was possible by determining forest operation and wood transporting rough costs inside Italian and Slovenian study area (figure 5.3.2.a). FOpP model results were used in order to identify common areas where wood supply can be sorted out at the same effective cost from both Italian and Slovenian forest enterprises.

After the evaluation of skidding systems and their costs (figure 5.3.2.b), the values and the harvestable wood needed to be shifted (or allocated) to the nearest road section for the evaluation of road transportation to mills.

In order to generate wood sources along road network, from each forest road segment (public and forest) a road catchment area was created. Catchment areas represent areas where each GRID cell of a continuous surface is allocated to the same road segment: it consists thus in “moving harvestable wood amount” from each GRID cell to the closest road segment by an Euclidean Allocation (ESRI 2007). Road segments presented thus a sum of harvestable wood amount (m^3/10y) and its average forest operations unit cost: cutting, skidding and administration cost as calculated by S-DSS models. In order to distinguish transportation from forest to public road and transportation along public road to terminals (sawmill, heating plant, fibre board mill), a further allocation was done only for wood allocated along forest roads. This second procedure moved wood from forest roads to the nearest crossing point where a forest road crosses public road (figure 5.3.2.c).

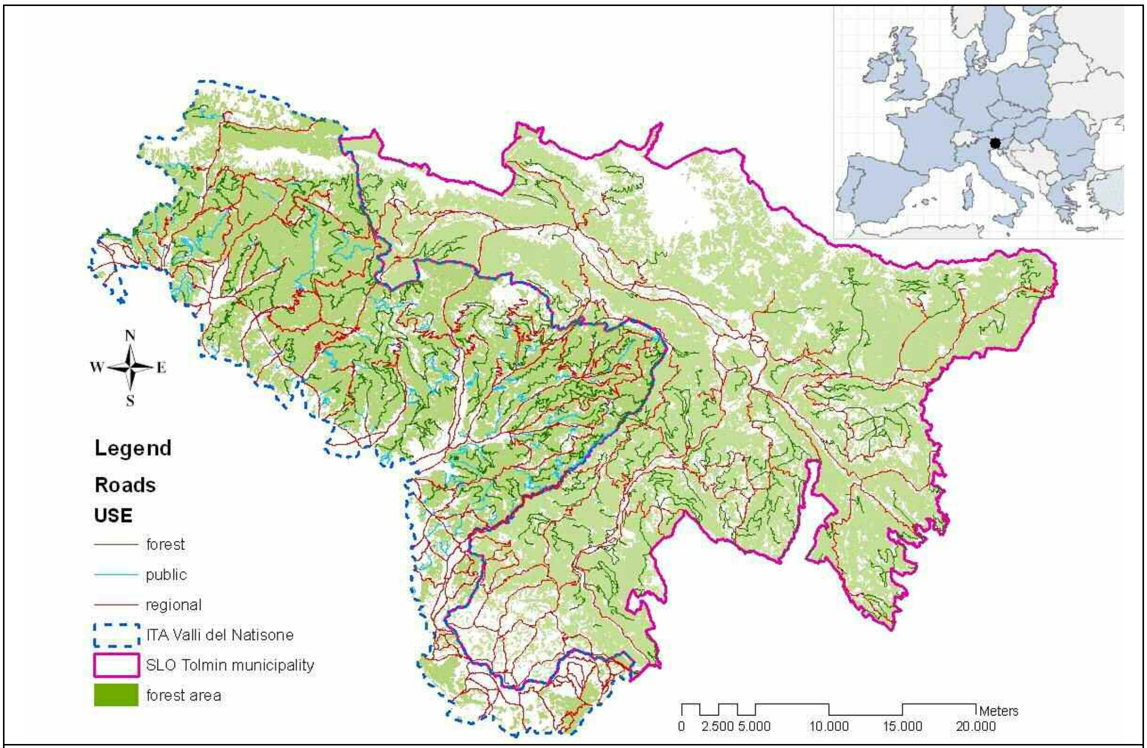


Figure 5.3.2.a: Study area lies over the borders between Italy and Slovenia

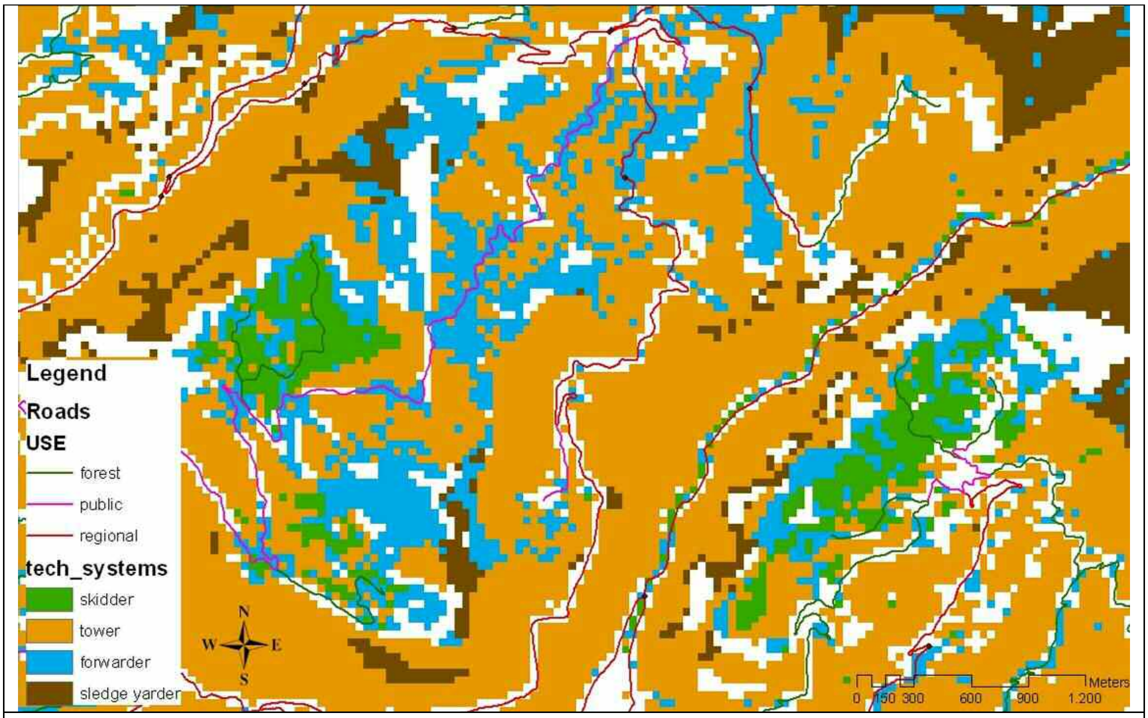
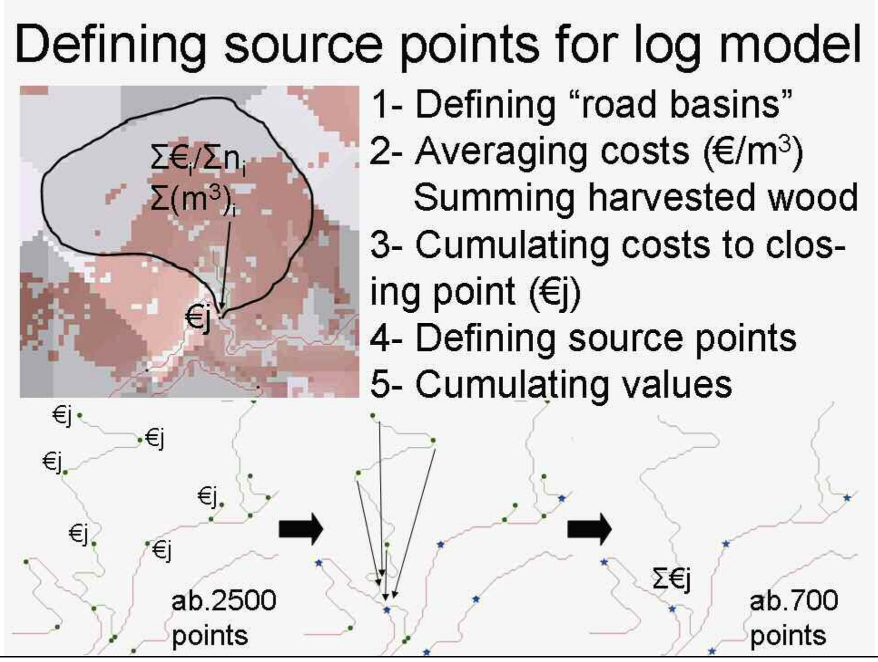


Figure 5.3.2.b: skidding systems output map



Defining source points for log model

1- Defining “road basins”
2- Averaging costs (€/m^3)
Summing harvested wood
3- Cumulating costs to closing point (€j)
4- Defining source points
5- Cumulating values

Figure 5.3.2.c: determining source points values procedure.

Transporting analysis

Transporting analysis was based on a networking methodology. Network is a system through which distribution and transportation of a generic good occurs. It can be modelled as a one-dimensional non-planar graph or geometric network composed by features, where network connectivity is based on geometric coincidence. The main purpose of this research approach was to evaluate wood transporting costs by a real road network distance optimization. The analysis is thus based on the spatial distribution of wood *sources* and *sinks* (terminals) along road network.

Transporting analysis consisted in two analyses according to the allocation procedure applied. First calculation consisted on evaluating wood transporting from forest road to road network crossing points by analysing results on distance allocation results. Consequently a second calculation was sorted out on transporting wood from sources (crossing point between forest roads and public roads and allocation points along public road) to terminals (sinks) by network analysis.

According to GIS-based results concerning the allocated wood from forest roads to public roads, the straight line distance between forest road catchments site and public road crossing point was as average 607 m for Slovenian area and 561 m for Italian area (one way). To define a close to real transportation distance, a coefficient based on the rate between average slope of forest area and maximum average slope parameter for forest road (fixed in 12%) was considered (BERNETTI and FAGARAZZI 2003). Therefore average transportation distance of wood along forest roads to sources were: for Slovenian area 1.81 km (one way) and for Italian area 1.71 km (one way).

In order to evaluate forest road transporting to main road sources, cost of 0.90 €/km per cubic meter (two ways) was considered in allocation analysis from forest to main road. At this stage wood transportation is done by tractor and trailer and then from public roadside to terminals by truck and trailer combination. Same costs were considered for both countries. In this study, transportation of 6 m length logs by truck and trailer was supposed. The maximum payload considered was 40 t (20 t for truck and 20 t for trailer) corresponding to 54 m^3 of timber (with a wood density of 930 kg/m^3 - average value for different broadleaves wood at 50% of moisture content). According to some studies (SPINELLI *et al.* 2007; GRONALT and RAUCH 2007), a cost index of 0.25 €/km per cubic meter was considered. Distance between each source and sink was calculated by a networking analysis (GRIGOLATO *et al.* 2005). Therefore each source was characterized by transporting distance optimised by the shortest way according to road network results. For each source, the total amount of harvestable wood and its average supply cost was set.

Wood flow analysis: defining scenarios

Two scenarios were defined in order to evaluate wood flow between Italy and Slovenia. The first scenario (SA) aims to consider costs and wood flows as constrained at regional scale: wood flow of both countries within the country borders. Second scenario (SB) aims to show wood flow over countries borders. In order to simplify the analysis, two terminals were considered: one on Italian side and the other on Slovenian side. In SB scenario wood can indistinctly flow on both terminals (supply points for wood). The two sinks correspond to two main wood industrial districts inside the study area.

Scenarios (SA and SB) present results concerning the total cutting volume available that could be supplied (m^3) and its supply cost (€/m^3).

In the SB case study, wood flow can supply both terminals. Total amount and average cost supplying wood to Italian or Slovenian terminal were calculated with excel spreadsheet calculations on matrices obtained by a road networking GIS based analysis.

Regional scale (SA)

According to FOpP forest operations results (harvestable amount and cost), allocation and transportation costs were added in order to define the total cost of wood flow at regional scale. A GIS-based network analysis defined the amount and supply cost of wood according to the distance between the same wood sources and sinks. On table 5.3.2.a and figure 5.3.2.d, results of regional scale flow are reported for both terminals investigated. Results concern 10 years scheduled forest planning and distance class is related to the supply distance (one way). Transportation cost includes two ways. Results at regional scale are showed on map (figure 5.3.2.e). Supply costs are identified at wood sources location.

Table 5.3.2.a: constraint of wood flow at regional scale

ITA	Distance	Sources	Volume	Accumulated volume	Forest operation	Transporting	TOTAL
	km	n°	m^3	m^3	€/m^3	€/m^3	€/m^3
	<10	58	175 196	175 196	26.60	4.9	31.5
	10-20	85	372 611	547 807	27.16	6.8	34.0
	20-30	61	237 233	785 040	26.73	9.4	36.1
	30-40	72	231 046	1 016 086	28.40	11.9	40.3
	40-50	45	233 821	1 249 907	26.78	14.3	41.1
	50-60	19	180 261	1 430 168	28.10	16.6	44.7
	> 60	1	55 974	1 486 142	32.96	18.5	51.5
			m^3		€/m^3	-	€/m^3
		TOTAL	1 486 142	AVERAGE	28.11	-	39.88
SLO	Distance	Sources	Volume	Accumulated volume	Forest operation	Transporting	TOTAL
	km	n°	m^3	m^3	€/m^3	€/m^3	€/m^3
	10	39	67 951	67 951	27.81	4.8	32.6
	10-20	40	48 016	115 967	18.66	7.4	26.0
	20-30	72	114 311	230 278	20.37	9.8	30.2
	30-40	120	200 878	431 156	22.43	11.9	34.3
	40-50	69	126 163	557 319	25.02	14.8	39.8
	50-60	12	3 912	561 231	24.42	16.2	40.6
	>60	0	-	561 231	-	-	-
			m^3		€/m^3	-	€/m^3
		TOTAL	561 231	AVERAGE	22.32	-	33.92

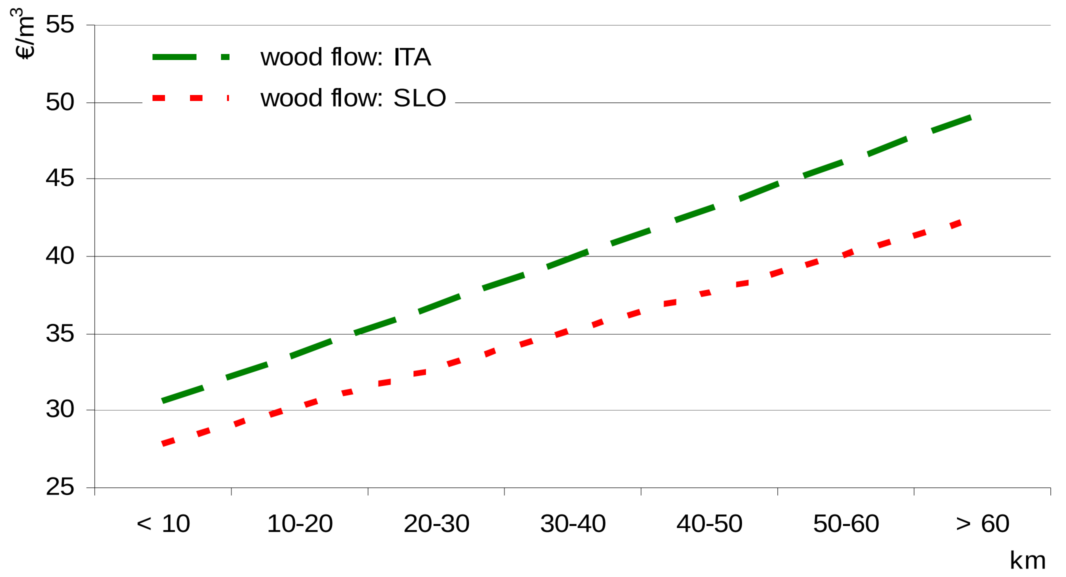


Figure 5.3.2.d: supply cost in relation to distance (two way) from sinks (constrained wood flow at regional scale)

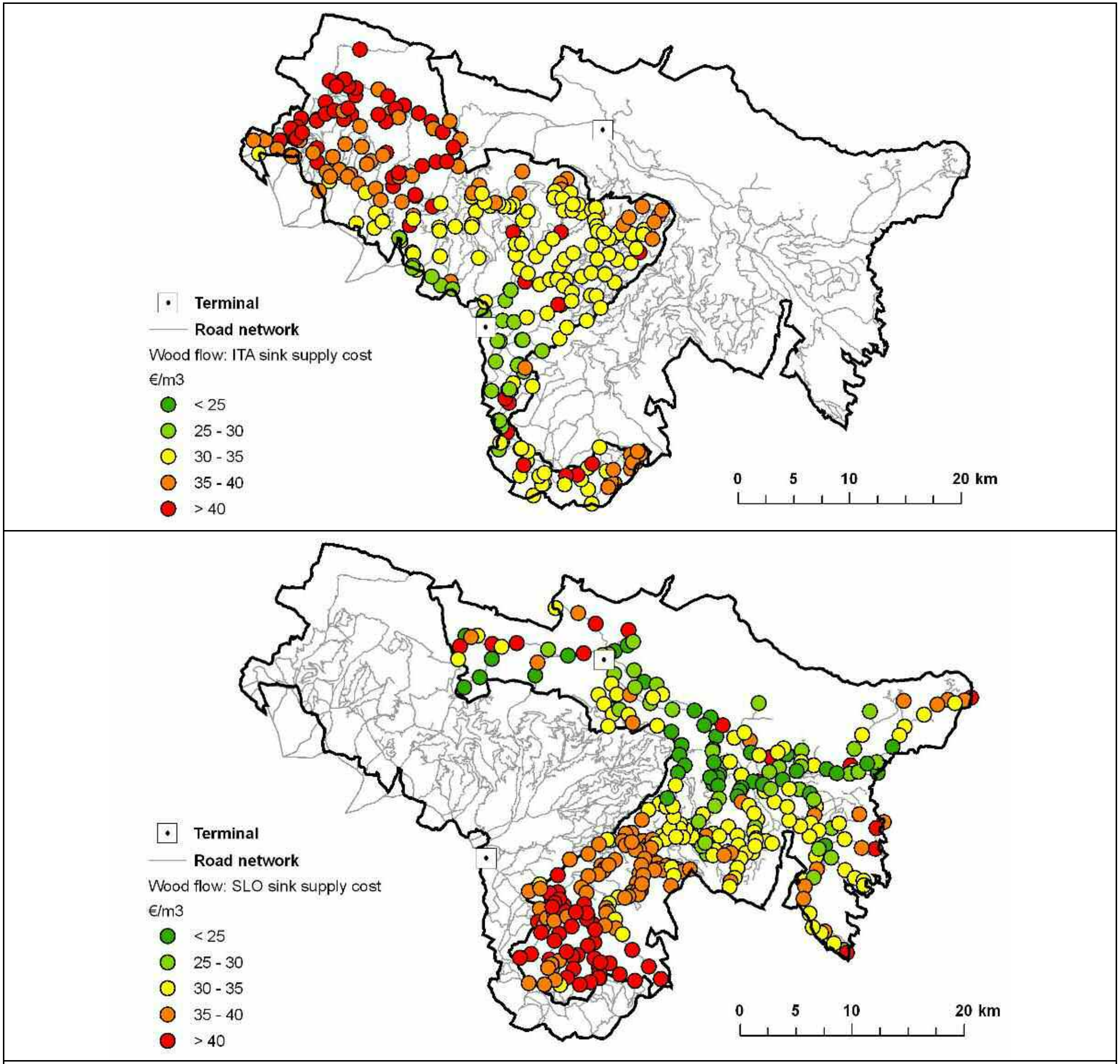


Figure 5.3.2.e: spatial distribution of wood sources and its supply cost (constrained wood flow at regional scale)

Large scale (SB)

Large scale wood flow analysis supposed that terminals can be supplied from all sinks of the area, without considering borders.

As it is shown on figure 5.3.2.f for the specific case study on inter-regional supply analysis, Italian terminal is more cost-efficient when it is supplied by wood source over 30 km. On the other side, Slovenian terminal is more cost-efficient when it is supplied from sources within 30 km.

On figure 5.3.2.g, map shows an inter-regional supply area, where wood sources have approximately a corresponding supply cost for both terminals: the supply basin presents an area of 20000 ha, with an available cutting volume of 690000 m^3/10y and a maximum difference on supply cost between the two terminals of ± 2 €/m^3.

Results over the inter-regional supply basin evidence that Slovenian terminal, even if it has a lower efficiency in long distance supply over Italian area (figure 5.3.2.f), can have advantage by increasing its interest on Italian wood availability. Inside the inter-regional basin area, as it is reported on table 5.3.2.b, Slovenian sources generally show a higher supply cost but a lower forest operation cost than Italian sources. Slovenian terminal can find advantage of this situation expanding the supply area over Italian boundaries. Therefore, Slovenian terminal can potentially take advantage increasing supply amount of 572000 m^3/10y. On the other side, Italian terminal could potentially take advantage of 118000 m^3/10y coming from Slovenian side. Transportation cost have an influence between 24 and 32% on total cost: this means that if we want to try reducing wood cost we have to intervene in cutting and skidding operations. One solution could be introducing new technology with higher productivity or cutting more wood per unit area where forest has prevailing productive function.

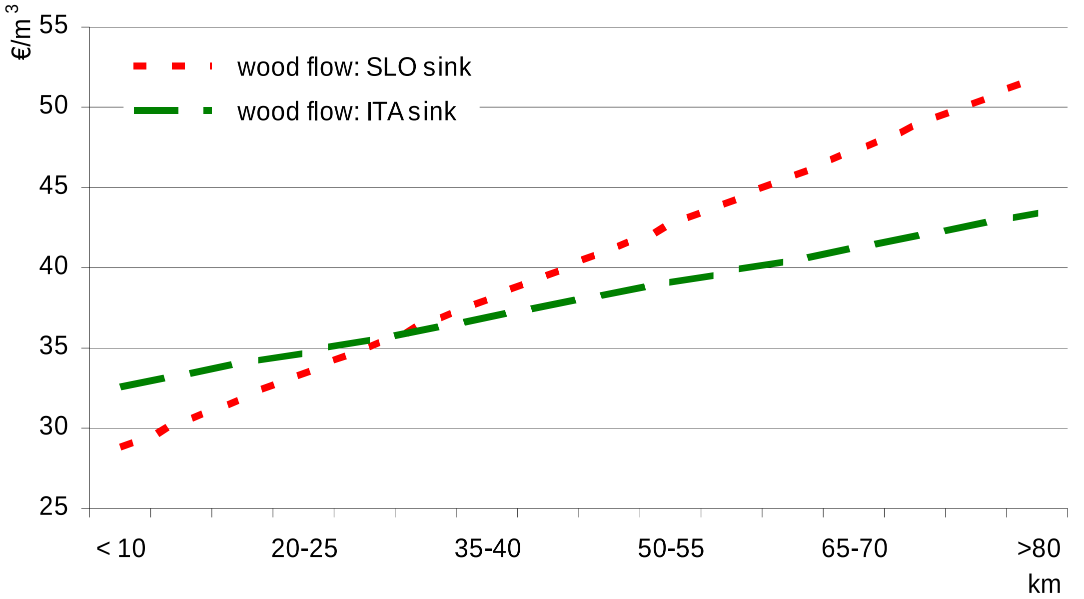


Figure 5.3.2.f: supply cost in relation to distance (two way) from sinks for wood flow at inter-regional scale

For this stage of development the results showed that the approach has been successful: as it was expected the scenario which includes regions in both countries showed better results. The procedure is almost suitable for practical use, where specific recommendations should be presented to the stakeholders on both sides of the state border. Models showed good flexibility and readiness for practical use even if some gaps and pits have been discovered (see for example § 3.7.2.2).

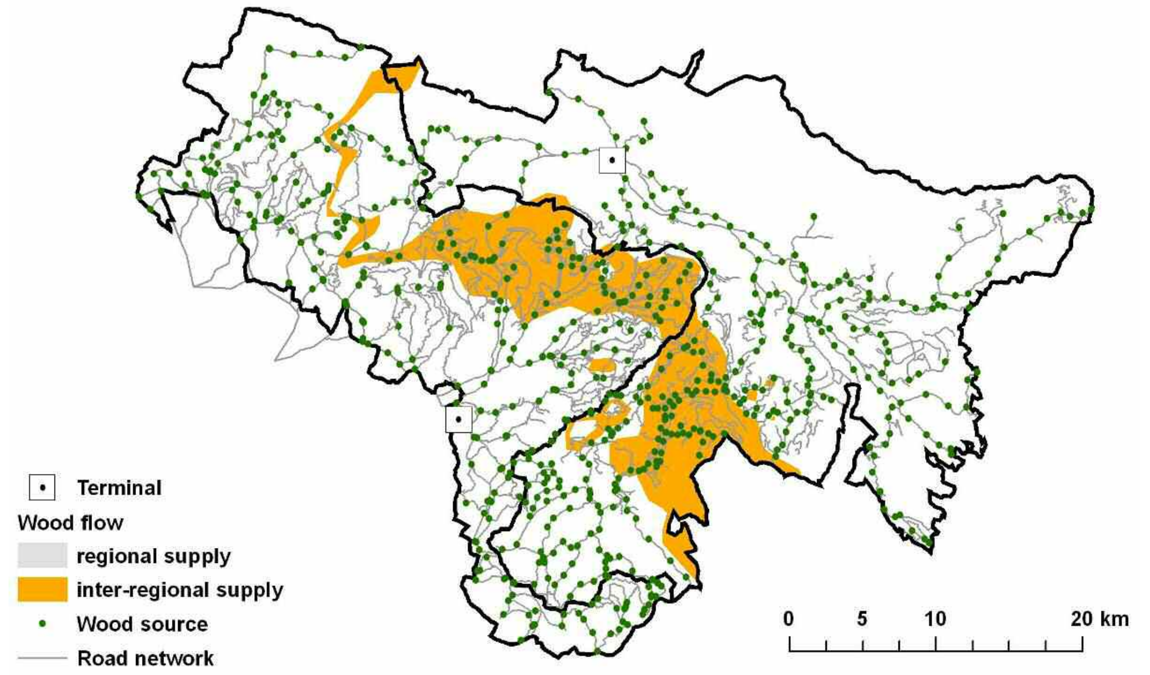


Figure 5.3.2.g: supply basin resulting as inter-regional supply area by considering maximum difference on supply cost between the two terminals of ± 2 €/m^3

Table 5.3.2.b: Source points located inside the interregional effective-cost area analysis according to their location and destination over borders

		DISTANCE			COST			WOOD FLOW
					Forest operations	Allocation + transport	Total	
FROM	TO	average	maximum	minimum	average	average	average	
sources	*terminals*	km	km	km	€/m^3	€/m^3	€/m^3	m^3/10y
ITA	ITA	22	46	10	27.67	8.72	36.38	572 000
ITA	SLO	27	68	10	27.67	9.94	37.61	572 000
SLO	SLO	31	48	12	23.42	11.13	34.55	118 000
SLO	ITA	31	45	12	23.42	11.12	34.54	118 000

Further studies should follow the common market development of this region on one side and peculiarities of each country on the other side. In the future the study area should be larger and should include greater number of mills, platforms, harbours and power plants along the border between Italy and Slovenia. In this it would be possible to see how the results vary with the size of area – it is the question of cutting volume available, transport costs and market opportunities. More wood assortments should also be considered as their different values on the side of sources (where they are produced) and sinks (where they are consumed or processed). Larger area should give better result of optimal scenarios. For this purpose the same technological models for specific terrain and stand conditions on both sides of border should be chosen, and typical machine and labour configuration should be defined for each technology including long distance transport. Technologies can be same with minor specific differences between countries. The same is true also with cost calculations, which differ in some degree, and daily performances, which should be calculated for chosen machines on the basis of future time studies.

The results of this study showed in some cases (by forest compartment on figure 3.6.2.2.c) extreme differences, but closer analysis showed that it is normal result under certain combination of variables. It was already discussed (LUBELLO *et al.* 2007) the possibility to use in minor extend a stochastic (randomised within chosen range) variables (i.e. daily performances, skidding distances, tree size, assortment structure within stand type etc.) instead of pure deterministic approach. On this way we could level different influences on larger scale. There is always a challenge to validate and prove the results by observation (or questionnaire) in the real life, but this is for the time being a distant future goal.

6. CONCLUSIONS

The Forest Operation Planning model was thought as a helpful decision support tool for an integrated forest and harvesting planning. The integration of different aspects like terrain evaluation, skidding systems and their technical limits, productivities and costs, assessmental plans data and forest road network was successful. Requiring only five input files (we admit that they are not always so easy to fulfill!) the model provide precise output maps which can be used and interpreted for different purposes. As showed inside this work, outputs may be helpful both on small and on big scale planning and can be integrated with other simple applications. The use of GIS softwares is still increasing and we think that also the number of tools and models will increase. The FOpP model here presented is surely not the first and last version, but it will slowly change in the future, implementing it with new functions or new algorithms, programming language and user windows. The introduction of new technologies as Lidar and new forest planning procedures as the data and surveys required, might allow more and more precise evaluations. So we hope that in the future foresters will use the model during the planning phase: we tried to demonstrate that it is helpful evaluating the cheapest and environmentally sound skidding system, calculating and optimizing utilization costs and that is a good instrument to judge the road network inside a forest area.

If all operators of the forest sectors apply for improving their “ring” of the wood chain, the wood might be the best material for the future for any kind of use, from building houses to heating and maybe producing fuel… and it will be ecologically and environmentally sound.

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REFERENCES

AA.VV., 1961. Trafficability of soils. Soil Classification. Technical Memorandum n° 3-240, 16th supplement. U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

AA.VV., 1975. Soil taxonomy. U.S. Department of Agriculture, Soil Conservation Service, Washington D.C. Agriculture Handbook n. 436.

AA.VV., 2002. Operations protocol for eco-efficient wood harvesting on sensitive sites. Owende P.M.O., Lyons J. and Ward S.M. (Editors), Dublin.

AA.VV., 2004. Italy's country report. COST Action E30, Economic integration of urban consumers' demand and rural forestry production.

AA.VV., 2007. Programma di Sviluppo Rurale per il Veneto 2007-2013. Regione del Veneto, Giunta Regionale, Segreteria Regionale al Settore Primario.

ACKERMAN P., DE WET P., ALCOCK L., OBERHOLZER F., 2002. Articulated Skidders. CoFOM Centre of Forest Operations Management, South Africa. Technical Note 1/5-2002.

AKAY A.E., SESSION J., 2004. Roading and transport operations. In Burley J., Evans J., Youngquist J.A. eds.: Encyclopedia of Forest Sciences. Elsevier Academic press, Oxford, UK.

ALEXANDER G.R., HANSEN E.A., 1986. Sand bed load in a brook trout stream. North American Journal of Fisheries Management, 6 (1): 9-23.

AMMAN H, 2004. Coûts-machines 2005. Coûts occasionnés par les parties du bâtiment et les installations mécaniques. Rapport FAT n. 621/2004. (Tänikon: FAT)

ANDERSON M.G., 1985. Forecasting the trafficability of soils. In Richards K.S., Arnett R.R., Ellis S. - Geomorphology and Soils. George Allen & Unwin LTD, London: 397-416

ANONYMOUS, 1975. The forestry Commission system of terrain description and classification. British Forestry Commission, Harvesting and marketing division, Edinburgh.

APAT, 2005. Agenzia per la Protezione dell'Ambiente e per i servizi Tecnici. Corine land Cover maps. http://www.clc2000.sinanet.apat.it/cartanetclc2000/clc2000/index.asp

ARONOFF S., 1993. Geographic information systems: a management perspective. WDL Pubblications, Ottawa, 3° ed.: 294 pp.

ASAE, 2004. ASAE EP496.2. Agricultural machinery management. ASAE Standards, engineering practices and data. St. Joseph, MI: ASAE.

AXELSSON S.Å., PONTÉN B., 1990. New ergonomic problems in mechanized logging operations. International Journal of Industrial Ergonomics, 5: 267–273.

AZZALINI O., 2004. Il Consorzio Gestione Forestale (Co.Ge.For). Un'Associazione di imprese a servizio dell'ambiente. Sherwood, 3 (n. 98): 37-39.

BALDINI S., POLLINI C., 1998. Interaction between network of services: forestry and wood harvesting systems. Proceedings of the seminar on environmentally sound forest roads and wood transport, Sinaia, Romania, 17-22 June, 1996. FAO, Rome: 337-341.

BALOCCO F., GUBETTI C., PEROTTO V., 1994. Piste o peste? Ed. Pro Natura, Torino, 50 pp.

BAKER W.L., YUNMING C., 1992. The r.le programs for multiscale analysis of landscape structure using the GRASS geographical information system. Landscape Ecology 7: 291–302.

BEKKER M.G., 1956. Theory of land locomotion: the mechanics of vehicle mobility. The University of Michigan Press. Ann Arbor.

BEKKER M.G., 1969. Introduction to terrain-vehicle systems. University of Michigan Press, Ann Arbor. 846 pp.

BENGSTON D.N., FAN D.P., 1999. The public debate about roads on the National Forests: an analysis of the news media, 1994-98. Journal of Forestry, 8: 4-10.

BERG S., 1992. Terrain classification system for forestry work. Forest Operations Institute “Skogsarbeten”, Sweden. 28 p.

BERNETTI I., FAGARAZZI C., 2003. BIOSIT: una metodologia GIS per lo sfruttamento efficiente e sostenibile della "risorsa biomassa" a fini energetici. Firenze: D.E.A.R.T, Dipartimento di Economia Agraria e delle Risorse Territoriali.

BIDINI M., 2004. Scheda tecnica Forwarder. Tecniko & Pratiko, supplemento n°1 di Sherwood 10 (7).

BILL R., FRITSCH D., 1994. Grundlagen der Geo-Informationssysteme – Hardware, Software und Daten. Band 1,2, ed. Herbert Wichmann Verlag GmbH, Heidelberg: 415 pp.

BOMBOSCH F., SOHNS D., NOLLAU R., KANZLER H., 2003. Are forest operations on steep terrain (average of 70% slope inclination) with wheel mounted forwarders without slippage possible? In Proceedings "Austro 2003: High Tech Forest Operations for Mountainous Terrain", eds. Limbeck-Lilienau, Steinmüller and Stampfer. Schlaegl, Austria, October 5-9, 2003.

BONASSO R.P. 1989. Toward a naïve theory of trafficability. In Antonisse H.J., Benoit J.W., Silverman B.G., Proceedings of The Annual AI systems in government conference. March 27-31, 1989. Washington, D.C. IEEE Computer Society Press.

BORTOLI P.L.. 2001. La viabilità per la valorizzazione delle aree protette e della selvicoltura naturalistica. In Atti del Convegno internazionale U.N.I.F. “Viabilità forestale: aspetti ambientali, legislativi e tecnico-economici” Lago Laceno 2-3 ottobre 1998 (Av). Ed. A.G.R.A. s.r.l., Roma, 101-128.

BORTOLI P.L., SOLARI V., 1996. Le gru a cavo forestali: la pianificazione, i costi, la sicurezza. In Le moderne teleferiche forestali. Manuale II, 65-78. Regione autonoma Friuli-Venezia Giulia, servizio della selvicoltura.

BOVIO G., 2001. La viabilità forestale e gli incendi. In Atti del Convegno internazionale U.N.I.F. “Viabilità forestale: aspetti ambientali, legislativi e tecnico-economici” Lago Laceno 2-3 ottobre 1998 (Av). Ed. A.G.R.A. s.r.l., Roma: 38-50.

BOYD J., NOVAK W., 1977. Estimate wood cost, productivity and investment needs for 84 logging system combinations. Pulp and Paper Canada, 78 (5): 69-78.

BRACK C.L., MARSHALL P.L., 1996. A test of knowledge-based forest operations scheduling procedures. Canadian Journal of Forest Research 26: 1193-1202.

BRINKER R.W., KINARD J., RUMMER B., LANFORD B., 2002. Machine rates for selected forest harvesting machines. Circular 296, Auburn, AL. Alabama Agricultural Experiment Station, 29 pp.

BRIXIUS W.W., 1987. Traction prediction equations for bias ply tires. American Society of Agricultural Engineers, paper n. 87-1622.

BUONGIORNO J., GILLESS J.K., 2003. Decision Methods for Forest Resource Management. Academic Press, San Diego, California, 439 pp.

BURGESS J.A., CUBBAGE F.W., 1989. Comparison of machine rate and cash flow approaches for estimating forest harvesting equipment costs. Paper 89-7548. Presented at the 1989 Meeting of the American Society of Agricultural Engineers. St. Joseph, MI: ASAE. 24 p.

BURROUGH P.A., 1986. Principles of Geographical Information Systems for land resources assessment. Oxford: Oxford University Press Inc.

BUTLER D.A., DYKSTRA D.P., 1981. Logging equipment replacement: a quantitative approach. Forest Science, 27 (1): 2-12.

CALVANI G., MARCHI E., PIEGAI F., TESI E., 1999. Funzioni, classificazione, caratteristiche e pianificazione della viabilità forestale per l'attività di antincendio boschivo. L'Italia Forestale e Montana 3: 109-125.

CALVO E., CAROVIGNO R., GUGLINI M., MOGAVERO F., 1998. Indirizzi e criteri di pianificazione e gestione multifunzionale dei sistemi forestali e naturali del fondovalle valtellinese. Genio rurale 7/8.

CALVO E., 2004. Il ruolo dei sistemi verdi territoriali nei processi di sviluppo sostenibile del territorio rurale. Alcuni casi applicativi nella Regione Lombardia. In atti Convegno Internazionale "Il sistema rurale: una sfida per la progettazione tra salvaguardia, sostenibilità e governo delle trasformazioni". Politecnico di Milano, 13-14 ottobre 2004. Milano.

CALVO E., BODOARDO W., GHIOTTI N., NORIS M., 2004. Piano di indirizzo Forestale della Provincia di Milano. Provincia di Milano, 152 pp.

CAMCOM 2006a. Veneto Import-Export. Unioncamere del Veneto, Pubblicazioni centro studi. http://www.ven.camcom.it/pubblicazioni/pub5.htm

CAMCOM 2006b. Progetto Legno - Relazione illustrativa anno 2005. Camera di Commercio Industria Artigianato e Agricoltura di Trento.

CAMCOM 2007a. Rapporto sull'economia della provincia di Udine. 5^{a} giornata dell'Economia, 10 maggio 2007, Udine. Camera di Commercio di Udine, Studi e ricerche. http://www.ud.camcom.it/studi/frame.htm

CAMCOM 2007b. Riepiloghi dei lotti di legname posti all'asta nel Mercato Locale. Camera di Commercio Industria Artigianato e Agricoltura – Trento "Progetto Legno".

CARBONE F., 2007. Il costo del lavoro per l'impresa forestale. Alberi e Territorio IV (4-5): 24-31.

CARLSSON B., SVENSSON A., TROEDDSSON H., 1969. Terrangtypsschema for Svenskt Skogsbruck. Forskningsstiftelsen Skogsarbeten, Redogorelse nr. 9, Stockholm, 12 pp.

CARVER S.J., 1991. Integrating Multi-Criteria Evaluation with Geographical Information Systems. International Journal of Geographical Information Systems, 5 (3): 321-339.

CAVALLI R., 1997. Il trattore agricolo a 4 RM e il verricello nel concentramento e nell'esbosco del legname. Sherwood 21 (3): 31-39.

CAVALLI R., MENEGUS G., 2003. Lavorare sicuri per migliorare l'ambiente, linee guida per l'esecuzione delle utilizzazioni forestali. Regione del Veneto, Direzione Foreste ed Economia Montana. Venezia.

CAVALLI R., 2004. Le utilizzazioni forestali nell'Italia nord-orientale. L'Italia Forestale e Montana, 6: 453-465.

CAVALLI R., 2005. Valutazione dell'impatto delle attività forestali. In La gestione forestale per la conservazione degli habitat della rete Natura 2000. Accademia Italiana di Scienze forestali. Non pubblicato.

CAVALLI R., ZUCCOLI BERGOMI L., 2005. Productivity and costs of a tractor-mounted processor in thinning operations under alpine conditions. In Bostjan K: FORMEC 2005: scientific cooperation for forest technology improvement. Conference proceedings, Ljubljana, Slovenia 26-28 Semptember 2005.

CAVALLI R., LUBELLO D., 2006. Firewood cable yarding on steep terrain in Alpine conditions. In proceedings of FORMEC 2006, 39th International Symposium on Forestry Mechanization. 24-28 sept. 2006, Sofia, Bulgaria.

CAVALLI R., ZUCCOLI BERGOMI L., 2006. Funzionalità di un harvester in ambiente alpino. L'Italia Forestale e Montana 61(3): 181-191.

CAVALLI R., ZUCCOLI BERGOMI L., STAMPFER K., WRATSCHKO B., 2006. Productivity, costs and ecological impacts of a cable-forwarder employed under alpine conditions. In proceedings of FORMEC 2006, 39th International Symposium on Forestry Mechanization. 24-28 sept. 2006, Sofia, Bulgaria.

CAVALLI M., TAROLLI P., MARCHI L., DALLA FONTANA G., 2007. The effectiveness of airborne LiDAR data in the recognition of channel bed morphology. Eos Trans. AGU 88 (52): Fall Meet. Suppl., Abstract H52E-07.

CECUTTI C., 2001. Impact environmental de lubrifiants d'origin vègétale utilisés dans l'exploitation forestière. Rapport final de la convention AGRICE n. 0001013. 50 p.

ČERMAK J., NERUDA J., NADEZDINA N., ULRICH R., MARTINKOVA M., GEBAUER R., POKORNY E., PRAX A., NADEZDIN V., HRUSKA J., GASPAREK J., CULEK I., 2006. Identification of tree root system damage caused by heavy machinery using new measurement technology suitable for precision forestry. In Ackerman P.A., Langin D.W., Antonides M.C. (eds) 2006. Precision Foretry in plantations, semi-natural and natural forests. Proceedings of the International Precision Forestry Symposium. Stellenbosch University, South Africa. 5-10 March 2006. Stellenbosch University. South Africa.

CHIRICI G., MARCHI E., ROSSI V., SCOTTI R., 2003. Analisi e valorizzazione della viabilità forestale tramite GIS: La foresta di Badia Prataglia (AR). L'Italia Forestale e Montana, LVIII, 6: 460-481. Ed. Accademia di Scienze forestali, Firenze.

CHUNG W., SESSIONS J., HEINIMANN H.R., 2001. Optimisation of cable harvesting equipment placement and road location using Digital Terrain Models. Paper presented at the Joint FAO/ECE/ILO Committee on Forest Technology workshop on New Trends in Wood Harvesting with Cable Systems for Sustainable Forest Management in the Mountains, 18-24 June 2001, Ossiach, Austria.

CIANCIO O., NOCENTINI S., 1996. La gestione forestale tra ecologia, economia ed etica. In: CIANCIO O. "Il bosco e l'uomo". - Accademia Italiana Scienze Forestali, Firenze, 225-238.

CICCARESE L., PETTENELLA D., SPEZZATI E., 2004. Le biomasse legnose. Un’indagine delle potenzialità del settore forestale italiano nell’offerta di fonti di energia. APAT, Agenzia per la Protezione dell’Ambiente e per i Servizi Tecnici, Roma. Report 30/2003: 99pp.

CIECH A., 2006. Personal communication.

CIELO P., GOTTERO F., MORERA A., TERZUOLO P., 2003. La viabilità agro-silvopastorale: elementi di pianificazione e progettazione. IPLA – Regione Piemonte, 106 pp.

CIELO P., GOTTERO F., 2004. Il piano della viabilità. Finalità, analisi ed elaborati. Sherwood 10 (7): 33-38.

CIOTTI M., 2005. L’andamento nel lungo periodo del prezzo del legname: un caso di studio in provincia di Belluno. Relatore Pettenella D. Dipartimento Territorio e Sistemi Agro-Forestali, Facoltà di Agraria, Università di Padova, Legnaro.

CIVIDINI R., 1983. Elementi di tecnologia forestale. Edagricole, Bologna. Pp. 162, 164-199, 206-426.

COLPI C., PETTENELLA D., URBINATI C., 1999. Forestry in Italy. In: P. Pelkonen et al., 1999, “Forestry in changing societies in Europe – Part II: Country reports”. Silva Network.

CORN P.S., BURY R.B., 1989. Logging in western Oregon: responses of headwater habitats and stream amphibians. Forest Ecology and Management, 29: 39-57.

COSTANZA R., WAINGER L., FOLKE C., MALER K., 1996. Modeling complex ecological economic systems: toward an evolutionary, dynamic understanding of people and nature. In Ecosystem Management: selected readings. Springer, New York. pp. 148-163.

CRAIG W.J., DAVID M.D., 1991. Progress on the Research Agenda: URISA '90. URISA Journal, vol. 3 (1): 90-96.

CROSS T, 1998. Machinery cost calculation methods. AE&RD n. 13. U.S. Department of Agriculture, University of Tennessee, Institute of Agriculture, Knoxville, Tenn. http://economics.ag.utk.edu/pubs/

CROSSLAND M.D., PERKINS W.C., WYNNE B.E., 1995. Spatial decision support systems: an overview of technology and a test efficiency. Decision Support Systems, 14 (3); 219-235.

CROVELLO, 1981. Quantitative Biogeography: an Overview. Taxon, 30 (3): 563-575.

CUBBAGE F.W., BURGESS J.A., STOKES B.J., 1991. Cross-sectional estimates of logging equipment resale values. Forest Products Journal, 41 (10): 16-22.

CULLINAM V.I., THOMAS J.M., 1992. A comparison of quantitative methods for examining landscape pattern and scale. Landscape Ecology 7:211–227.

DANTZIG G.B., WOLFE P., 1960. Decomposition principle for linear programs. Operations Research, vol. 8: 101-111.

DAVIS G., 1974. Management Information Systems: Conceptual Foundations, Structure, and Development. New York, ed. McGraw-Hill, Inc.

DECOL L., 2006. Personal communication.

DEL FAVERO R., BORTOLI P. L., SOLARI V., S.T.A.F. S.n.c., VANONE G., MORO E., 2000. Direttive per i piani di gestione delle proprietà forestali nella Regione Friuli Venezia Giulia. Regione Autonoma Friuli Venezia Giulia Udine, pp. 256.

DEL FAVERO R. (a cura di), 2001. Biodiversità e indicatori nei tipi forestali del Veneto. Regione del Veneto, Giunta Regionale.

DEL FAVERO R., 2004. I boschi delle regioni alpine italiane: tipologia, funzionamento, selvicoltura. Padova, Ed. CLEUP, 599 pp.

DELLAGIACOMA F., PIEGAI F., VETTORI S., 2002. Esbosco a strascico con trattore e verricello. Alcune esperienze. Sherwood, 8 (1): 21-26.

DELLAGIACOMA F., 2005. Foreste, produzione di legno, filiera e biomasse in Trentino. Servizio Foreste e Fauna - Provincia Autonoma di Trento.

DENSHAM P.J., 1991. Spatial Decision Support Systems. In Maguire D.J., Goodchild M.F., Rhind D.W. Geographical Informations Systems – principles and Applications. Longman Scientific & Technical. Essex, 1: 403-412.

DENSHAM P.J., GOODCHILD M.F., 1989. Spatial decision support systems: A research agenda. In Proceedings GIS/LIS'89, Orlando, FL., 707-716.

EASTMAN J.R., JIN W., KYEM P.A.K., TOLEDANO J., 1995. Raster Procedures for Multi-Criteria / Multi-Objective Decisions. Photogrammetric Engineering & Remote Sensing vol. 61 (5): 539-547.

EBDON D., 1977. Statistics in Geography. A Practical Approach . Blackwell, Oxford.

EDWARDS W, 2001. Estimating farm machinery costs. PM 710. U.S. Department of Agriculture, Iowa State University of Science and Technology, Ames, Iowa. http://www.extension.iastate.edu/pubs/

EICHRODT A.W., 2003. Development of a spatial Trafficability Evaluation System. Vdf, ETH Zürich. 184 pp.

EMER B., 2005. Simulation of harwarder concepts under Italian north-eastern Alps conditions. Master thesis, University of Padova, Dept. TeSAF.

EMER B., GRIGOLATO S., LUBELLO D., CAVALLI R., 2007. A GIS-based approach on wood chips supply chain in North-eastern Italy. In proceedings of the IEA workshop “Sustainable forestry systems for bioenergy: integration, innovation and information”. 29 aug.-3 sept. Joensuu, Finland.

ENGELBART D.C., 1962. Augmenting Human Intellect: A Conceptual Framework. Air Force Office of Scientific Research, AFOSR-3233, URL www.bootstrap.org/-augdocs/friedewald030402/augmentinghumanintellect/ahi62index.html .

ESRI, 2005. ArcGIS Desktop Help. Release 9.1, april 26, 2005. http://webhelp.esri.com

ESRI, 2007. ArcGIS Desktop Help. Environmental Systems Research Institute. Redland, CA. http://webhelp.esri.com/arcgisdesktop/9.1/

EVERETT R.R., ZRAKET C.A., BENNINGTON H.D., 1963. Sage: A Data Processing System for Air Defense. http://ed-thelen.org/sage.html

FABBRI A.G., 1991. Spatial data analysis in raster-based GIS: an introduction to geometric characterization. In: Belward A.S., Valenzuela C.R. (ed.). Remote Sensing and Geographical Information Systems for Resource Management in Developing Countries. ECSC, EEC, EAEC, Brussels and Luxembourg, pp. 357–388.

FABIANO F., 2002. La pianificazione dei lavori forestali, criteri di scelta dei sistemi d’esbosco. Sherwood 81 (9): 35-38.

FAO, 1977. Planning forest roads and harvesting systems. Food and Agriculture Organization of the United Nations, forestry department, Rome.

FAO, 1992. Cost control in forest harvesting and road construction. Forestry Paper 99. Food and Agriculture Organization, Rome. 106 pp.

FAO, 2007. Import / Export of Forest Products - Trade of Forest Products for 2002. FAO, Rome. www.fao.org/forestry/site/22056/en/ita

FEDRA K., FEOLI E., 1998. GIS Technology and Spatial Analysis in Coastal Zone Management. EEZ Technology, 3: 171-179.

FEIERING R.B., 1986. Linear Programming, An introduction to Quantitative Applications in the Social Sciences. 60

FEOLI E., ZUCCARELLO V., 1996. Spatial pattern of ecological process: the role of similarity in GIS applications for landscape analysis. In: Fisher M., Sholten H.J., Unwin D. (ed.) Spatial analytical perspectives on GIS, GIS DATA 4, Taylor and Francis, London, pp. 175-185.

FERGUSON R.L., JONES C.H., 1969. A Computer Aided Decision System. Management Science 15 (10): 550-562.

FOREST SERVICE, 2000. Code of Best Forest Practice. Ireland: planning the thinning operation: 124-128. Forest Service, Department of the Marine and Natural Resources, Dublin, Ireland.

FORMAN R.T.T., FRIEDMAN D.S., FITZHENRY D., (and others), 1997. Ecological effects of roads: toward three summary indices and an overview for North America. In: Canters K., Piepers A., Hendriks-Heersma D., eds. Proceedings of the international conference: Habitat fragmentation, infrastructure and the role of ecological engineering. September 17-21 1995, Maastricht – the Hague, The Netherlands. Delft, The Netherlands: Ministry of Transport, Public Works and Water Management: 40-54.

FORMAN R.T.T., HERSPERGER A.M., 1996. Road ecology and road density in different landscapes, with international planning and mitigation solutions. In Evink G., Garrett P., Berry J., eds. Proccedings of: Transportation and wildlife: reducing wildlife mortality and improving wildlife passageways across transportation corridors. Florida Dep of Transportation/Federal Highway Administration transportation-related wildlife mortality seminar. April 3 – may 2, 1996, Orlando, FL: 1-23.

FURNISS M.J., LOVE M.A., FLANAGAN S.A., 1997. Diversion potential at road-stream crossings. Water/Road Interaction Technology Service 9777-1814-SDTDC. San Dimas, CA: USDA Forest Service, Technology and Development Program, 12 pp.

GANDASECA S., ACAR H., YOSHIMURA T., 2001. Occupational safety and health of forest workers of cable harvesting in Turkey. Paper presented at the Joint FAO/ECE/ILO Committee on Forest Technology workshop on New Trends in Wood Harvesting with Cable Systems for Sustainable Forest Management in the Mountains, 18-24 June 2001, Ossiach, Austria.

GARDNER R.B., 1966. Efficient logging system for Northern Hardwoods, using equipment production capabilities and costs. USDA. Forest Service Research Paper NC-7.St Paul, Minnesota: North Central Forest Experiment Station.

GARDNER R.H., O’NEIL R.V., 1991. Pattern, process, and predict-ability: the use of neutral models for landscape analysis. In: Turner M.G., Gardner R.H. (ed.). Quantitative Methods in Landscape Ecology. Springer-Verlag, New York, pp. 289–307.

GELLRICH M., BAUR P., ZIMMERMANN N. E., 2006. Natural forest regrowth as a proxy variable for agricultural land abandonment in the Swiss mountains: a spatial statistical model based on geophysical and socio-economic variables. Journal of Environmental modelling & assessment, Springerlink online http://springerlink.metapress.com/ content/1573-2967/

GELLRICH M., ZIMMERMANN N. E., 2007. Investigating the regional-scale pattern of agricultural land abandonment in the Swiss mountains: a spatial statistical modelling approach. Landscape and urban planning 79: 65-76.

GEOFFRION A.M., 1983. Can OR/MS Evolve Fast Enough? Interfaces 13: 10-25.

GERRITY T.P. Jr., 1971. Design of Man-Machine Decision Systems: An Application to Portfolio Management. Sloan Management Review 12 (2): 59-75.

GOLOB T.B., 1978. Current progress in research on terrain properties. Environmental Canadian Forest Service, Forest Management Institute, Ottawa, Ontario. FMR-X-110

GOODALL D.W., FEOLI E., 1988. Application of probabilistic methods in the analysis of phytosociological data. Coenoses 3: 1-12.

GOODCHILD M.F., DENSHAM P.J., 1990. Spatial Decision Support Systems: Scientific Report for the Specialist Meeting, technical Report 90-5, National Centre for Geographic Information and Analysis.

GORRY A., SCOTT MORTON M.S., 1971. A Framework for Information Systems. Sloan Management Review 13 (1): 56-79.

GPA 2005. Dati dei Piani di Assestamento. Regione del Veneto, Direzione Foreste ed Economia Montana. Cd-rom

GRAYSON R.B., HAYDON S.R., JAYASURIYA M.D.A., FINLAYSON B.L., 1993. Water quality in mountain ash forests separating the impacts of roads from those of logging operations. Proceedings of an international symposium on forest hydrology. 22-26 nov. 1993, Canberra, Australia. In Journal of Hydrology, 150 (2-4): 457-480.

GREULICH F.E., 1997. Optimal economic selection of road design standards for timber harvesting operations – a corrected analytical model. Forest Science, 43 (4): 589-594.

GRIGOLATO S., FIRTH J., HOCK B., NIELSEN P., BERND M., CAVALLI R., 2005. Supply of Logging Residues for Energy Production a GIS-Based Study. A Case Study in New Zealand and in Italy. In proceedings of 14th European Biomass Conference & Exhibition. Biomass for Energy, Industry and Climate Protection. Palais de congres: Paris, 17–23 October.

GRIGOLATO S., 2006. Logistica dell'approvvigionamento di residui delle utilizzazioni forestali a fini energetici in ambiente alpino. PhD thesis, supervisore prof. Cavalli R., Dipartimento TeSAF, Università di Padova.

GRIGOLATO S., LUBELLO D., 2006. Applicazione di un modello di pianificazione della meccanizzazione avanzata nella foresta di Pramosio. Presentation of the workshop: “Quali opportunità per la meccanizzazione forestale avanzata in ambiente alpino”. 23 giugno 2006, Centro Servizi per le Foreste e le Attività Montane – Cesfam, Paluzza (UD).

GRONALT G., RAUCH P., 2007. Designing a regional forest fuel supply network. Biomass and Bioenergy, 31 (2007): 393-402.

GUBIANI M., 2004. Studio degli effetti idroerosivi della viabilità minore in montagna. Tesi di dottorato, Università degli studi di Padova, Facoltà di Agraria, dip. TeSAF.

GUCINSKI H., FURNISS M.J., ZIEMER R.R., BROOKES M.H., 2001. Forest roads: a synthesis of scientific information. General technical report PNW-GTR-509, may 2001. USDA Forest Service, Pacific Northwest Research Station, Portland, Oregon.

GUSTAFSON E.J., PARKER G.R., 1992. Relationships between landcover proportion and indices of landscape spatial pattern. Landscape Ecology 7:101-110.

HAARLAA R., ASSERSTAHL R., 1972. The internodic forest terrain classification project in 1969-1972. Helsinki, 66 pp.

HALEY P.W., JURKAT M.P., BRADY P.M., 1979. NATO reference mobility model, Edition I, User guide, Volume I, Operational modules. Technical Report 12503. US Army tank-automotive research & development command. Warren MI, 174 pp.

HEINIMANN H.R., 1986. Seilkraneinsatz in den Schweizer Alpen: eine untersuchung über die Geländeverhältnisse, die Erschliessung und den Einsatz verschiedener Seilanlagen. Diss. ETH n° 7929, Zürich. 169 pp.

HEINIMANN H.R., 1994. Conceptual design of a Spatial Decision Support System for Harvest Planning. In: Session J. et al., proceedings of International NEFU/IUFRO/FAO/FEI Seminar on Forest Operations under Mountainous Conditions. July 24-27, 1994. Harbin, P.R of China. Dept. of Forest Engineering, Oregon State University, Corvallis: 19-27.

HEINIMANN H.R., 1998. A computer model to differentiate skidder and cable-yarder based road network concepts on steep slopes. Journal of Forest Research (Japan), 3 (1): 1-9.

HEINIMANN H.R., VISSER R.J.M., STAMPFER K., 1998. Harvester-cable yarder system evaluation on slopes: a Central European study in thinning operations. In COFE Proceedings “Harvesting logistic: from woods to markets”, ed. Schiess P. and Krogstad F.: 41-46. Portland, OR, 20-23 July.

HEINIMANN H.R., 1999. Ground-based harvesting systems for steep slopes. In Proceedings of the International Mountain Logging and 10th Pacific Northwest Skyline Symposium, J. Session and W. Chung (eds.), Corvallis OR, March 28 – April 1, 1999, p.1-19. Department of Forest Engineering. Oregon State University. Corvallis, OR 97331.

HEINIMANN H.R., 2007. Forest operations engineering and management – the ways behind and ahead of a scientific discipline. Croatian journal of forest engineering 28 (1): 107-121.

HELLRIGL B., 2005. Personal communication.

HEMM M., ZIESAK M., WARKOTSCH W., 2006. Simulating harvesting procedures to evaluate different working systems based on discrete single-tree events. In Ackerman P.A., Längin D.W., Antonides M.C., 2006. Precision Forestry in Plantations, semi-natural and natural forests. Proceedings of the International Precision Forestry Symposium. Stellenbosch University, South Africa. 5-10 march 2006. Stellenbosch University. South Africa.

HEYWOOD V.H., WATSON R.T., 1995. Global biodiversity assessment. New York: Cambridge University Press, 1140 pp.

HINRICHS L., 2006. Automatic generation of treatment paths for mixed forest stands of spruce (*Picea abies*) and beech (*Fagus sylvatica*). In Ackerman P.A., Längin D.W., Antonides M.C., 2006. Precision Forestry in Plantations, semi-natural and natural forests. Proceedings of the International Precision Forestry Symposium. Stellenbosch University, South Africa. 5-10 march 2006. Stellenbosch University. South Africa.

HINZE D., 1990. The influence of seasonal moisture changes on soil strength. Proceedings of the 10th ISTVS Conference, Kobe 20-24 August, 1990: 107-116.

HIPPOLITI G., 1988. Precisazioni su alcune caratteristiche di strade e piste forestali. Monti e Boschi 6: 40-41.

HIPPOLITI G., 1989. Lavoro in bosco e strade. Dendronatura 2: 15-17.

HIPPOLITI G. 2003. Note pratiche per la realizzazione della viabilità forestale. Ed. Compagnia delle Foreste, Arezzo, 96 pp.

HIPPOLITI G., 2004. La gestione delle utilizzazioni forestali. L'Italia Forestale e Montana, 6: 415-420.

HIPPOLITI G., 2006. Taglio a raso su piccole superfici. Sherwood 12 (7): 24-25.

HIPPOLITI G, MARINELLI A, UZIELLI L, PIEGAI F, 1980. La valorizzazione delle risorse forestali italiane, Volume IV. Accademia Nazionale di Agricoltura, Accademia Economico Agraria dei Georgofili, Accademia Italiana di Scienze Forestali, Firenze.

HIPPOLITI G., MARCHI E., FABIANO F., 1997. Appunti di meccanizzazione forestale. Il piano della viabilità principale, cap. 9.2. Studio editoriale fiorentino, Firenze.

HIPPOLITI G., PIEGAI F., 2000. Tecniche e sistemi di lavoro per la raccolta del legno. Compagnia delle Foreste, Arezzo.

HOLSAPPLE C., WHINSTON A., 1996. Decision Support Systems: A Knowledge-Based Approach. Minneapolis/St. Paul, MN. Ed. West Publishing.

HRADETZKY J., SCHOPFER W., 2001. Das Softwareprodukt Holzernte – Eine Entscheidungshilfe fur die Holzvermarktung. AFZ – Der Wald 21: 1100-1101.

IENTILE F., 2003. Valutazione dell'impiego delle gru a cavo nella Comunità Montana Comelico-Sappada. Relatore Cavalli R., Dipartimento Territorio e Sistemi Agro-Forestali, Facoltà di Agraria, Università di Padova, Legnaro.

IGNIZIO J.P., 1985. An algorithm for solving the linear goal-programming problem by solving its dual. Journal of Operational Research Society, 36: 507-515.

INFC, 2007. Inventario Nazionale delle Foreste e dei serbatoi forestali di Carbonio. Corpo Forestale dello Stato. http://www.sian.it/inventarioforestale/jsp/home.jsp

IPLA, 2001. Norme tecniche regionali di pianificazione silvo-pastorale – i Piani Forestali Territoriali. Istituto per le Piante da Legno e l'Ambiente – Regione Piemonte.

ISOMÄKI A., KALLIO T., 1974. Consequences of injury caused by timber harvesting machines on the growth and decay of spruce (Puunkorjuukneiden aiheuttamien vaurioiden vaikutus kuusen lahoamiseen ja kasvuun). Acta Forestalia Fennica 136. 24 pp.

ISTAT, 2000. Censimento dell'agricoltura. Istituto Nazionale di Statistica. http://www.istat.it/dati/db_siti/

ISTAT, 2003a. Valore aggiunto ai prezzi di base dell'agricoltura per regione - Produttività del lavoro nel settore forestale. Istituto Nazionale di Statistica. http://www.istat.it/dati/catalogo/20051220_00/

ISTAT, 2003b. La misura dell'occupazione non regolare nelle stime di contabilità nazionale: un'analisi a livello nazionale e regionale. Anni 1992-2001. Roma. http://www.istat.it/Economia/index.htm

JOHNSEN K., SAMUELSON L., TESKEY R., MCNULTY S., FOX T., 2000. Process models as tools in forestry research and management. Forest science 47 (1): 2-8.

KEEN P.G.W., SCOTT MORTON M.S., 1978. Decision Support Systems: An Organizational Perspective. Reading, MA: Addison-Wesley.

KEENAN P., 1995. Using GIS as a DSS Generator. Working paper MIS No. 95-9, Graduate School of Business, University College Dublin, Department of management Information Systems, Dublin: 9 S.

KELLOGG L.D., BETTINGER P., 1994. Thinning Productivity and Cost for a Mechanized Cut-to-Length System in the Northwest Pacific Coast Region of the USA. Journal of Forest Engineering, 5 (2): 43-54.

KELLOGG L.D., BETTINGER P., EDWARDS R.M., 1996a. A comparison of logging, planning, felling, and skyline yarding costs between clearcutting and five group-selection harvesting methods. Western Journal of Applied Forestry, 11 (3): 90-96.

KELLOGG L.D., MILOTA G.V., MILLER M.Jr., 1996b. A comparison of skyline harvesting costs for alternative commercial thinning prescriptions. Journal of Forest Engineering, 7 (3): 7-23.

KIELLAND-LUND J., 1963. Vegetasjonstypenes betydning for den praktiske skogskjøtsel. Norsk Skogbruk nr. 7/8, Oslo, 5 pp.

KLEIN M., METHLIE L.B., 1995. Knowledge-based Decision Support Systems with Applications in Business. Chichester, UK. Ed. John Wiley & Sons.

KOŠIR B., 2003. Some observations of Syncrofalke cable crane skidding in Slovenian conditions. XXX CIOSTA-CIGRV Congress, Turin, Management and technology applications to improve agro-food systems, p. 55-63.

KRČ J., 1999. Modelni izračun vpliva ceste na povečanje vrednosti dolosa godza. Zbornik godzdarstva in lesarstva 59, Ljubljana. pp121-139.

KRČ J., KOŠIR B., 2005. Stroški dela v različicah delovnih pogojev in izkoriščenosti strojev za sečnjo = Labour costs in diverse forest work conditions and utilization of wood harvesters. Zb. gozd. lesar., 2004 [i.e. 2005], št. 75, str. 105-120.

KRČ J., 2006. A model for evaluating forest road load by forest operations. In Ackerman P.A., Langin D.W., Antonides M.C. (eds) 2006. Precision Foretry in plantations, semi-natural and natural forests. Proceedings of the International Precision Forestry Symposium. Stellenbosch University, South Africa. 5-10 March 2006. Stellenbosch University. South Africa.

KRČ J., BOŠTIAN K., CAVALLI R., GRIGOLATO S., LUBELLO D., 2007. Different approaches on skidding operation and wood transport investigation: integrate two different approaches in one model. In Proceedings of the Austro2007/FORMEC´07: “Meeting the Needs of Tomorrows´ Forests – New Developments in Forest Engineering”, October 7 – 11, 2007, Vienna and Heiligenkreuz – Austria. In press

LAARIBI A., CHEVALLIER J.-J., MARTEL J.-M., 1993. Méthodologie d’intégration des SIG et de l’analyse multicritère. Revue de géomatique, vol. 3 n. 4: 415-435.

LAMBERT M.B., HOWARD J.O., 1990. Cost and productivity of new technology for harvesting and in-woods processing small-diameter trees. Research paper PNW-RP-430. USDA Forest Service, Pacific Northwest Research Station, 37 pp.

LANFORD B.L., STOKES B.J., 1996. Comparison of two thinning systems. Part 2: productivity and costs. Forest Products Journal, 46 (11/12): 47-53.

La Rocca P., 1996. Il regime giuridico delle strade comunali e vicinali. Maggioli editore, Rimini, 533 pp.

Laurent A., Petit S., Maeker V., 1996. Routes forestières, environment et paysages. Forêt-Entreprise, 110: 58-61.

Legendre L., Legendre P., 1983. Numerical ecology. Developments in environmental modelling, 3. Elsevier Scientific Publications Co., Amsterdam, xvi + 419 p.

Levine P., Pomerol J-Ch., 1995. The role of the Decision Maker in DSSs and Representation Levels. In proceedings of the 28th annual Hawaii international conference on System Science. IEEE 1995.

Licklider J.C.R., 1960. Man-computer symbiosis. IRE Transactions on Human Factors in Electronics, vol. HFE-1: 4-11.

Limbeck-Lilienau B., 2003. Residual stand damage caused by mechanized harvesting systems. In proceedings of the Austro2003 "High tech forest operations for mountainous terrain". 5-9 october 2003, Schlaegl, Austria.

Little J.D.C., 1970. Models and Managers: The Concept of a Decision Calculus. Management Science 16 (8): 466-485.

Little J.D.C., 1975. Brandaid, an On-Line Marketing Mix Model, Part 2: Implementation, Calibration and Case Study. Operations Research 23 (4): 656-673.

Little J.D.C., Lodish L.M., 1969. A Media Planning Calculus. Operations Research 17 (Jan.-Feb.): 1-35.

Löffler H.J., 1979. Recording and classification of soil-conditions within the scope of terrain classification. Proceedings of IUFRO symposium "Stand establishment techniques and technology". Not published.

Löffler H.J., 1984. Terrain classification for forestry. Report TIM/EFC/WP.1/R.51 24 August 1984. EU Timber Committee and FAO-ILO. 55 pp.

Lubello D., Cavalli R., 2006. Ambiti applicativi della Precision Forestry. Sherwood 12 (8): 11-16

Lubello D., Del Favero A., Cavalli R., 2007. Un metodo tecnico-economico come ausilio alla determinazione della ripresa. L'Italia Forestale e Montana, on printing.

Lubello D., Grigolato S., Krč J., Emer B., Cavalli R., Boštian K., 2007. Evaluating costs on wood supply chain for supporting Slovenian and Italian forest cooperation. In proceedings of the FERIC - 3rd Forest Engineering Conference, October 1-4, 2007, Mont Tremblant – Canada.

Lubello D., Rizzi C., Zanoni M., 2007. Le imprese forestali venete e trentine a confronto. Unpublished data.

Lucchini O., 2006. La Borsa del legno. Legno Servizi FVG. Personal communication

Lüthy D., 1998. Entwicklung eines „Spatial Decision Support"-Systems (SDSS) für die Holzernteplanung in steilen Geländeverhältnissen. Zurich, Eidgenössische Techn. Hochsch. (ETH). PhD diss n. 12618.

Macal C.M., 2005. Model verification and validation. In proceedings of the Workshop on "Threat Anticipation: social science methods and models", April 7-9 2005, Chicago IL. The University of Chicago and Argonne National Laboratory.

Malczewski J., 1997. Spatial Decision Support Systems, *NCGIA Core Curriculum in GIScience*. http://www.ncgia.ucsb.edu/giscc/units/u127/u127.html

MALCZEWSKI J., 1999. GIS and Multicriteria Decision Analysis. John Wiley and Sons, New York.

MARCHI E., 1997. Le gru a cavo nel settore forestale, aspetti tecnici e classificazione. Sherwood, 20 (2): 11-21.

MARCHI E., PIEGAI F., 2001. Sistemi di utilizzazione forestale a basso impatto ambientale. L'Italia Forestale e Montana 56 (6): 477-490.

MARCHI E., SPINELLI R., 1997. L'impatto ambientale delle strade forestali. L'Italia Forestale e Montana, LII (4): 221-239.

MARTELLO G., 2005. Progetto strada di collegamento pista "Portados". Not published.

MATTHEWS D.M., 1942. Cost control in the logging industry. New York: McGraw-Hill, 374 pp.

MCDONALD T.P., SEIXAS F., 1997. Effect of slash on forwarder soil compaction. Journal of Forest Engineering, 8 (2): 15-26.

MCNEEL J.F., RUTHERFORD D., 1994. Modelling harvester-forwarder system performance in a selection harvest. Journal of Forest Engineering, 6 (1): 7-14.

MELLGREN P.G., 1980. Classification du terrain pour la foresterie du Canada. Institut Canadien de recherche en génie forestier (FERIC), 13 pp.

MELLGREN P.G., 1980b. Terrain classification for Canadian forestry. Canadian Pulp and Paper Association, Montreal, Quebec, Canada.

MEYER T., STÜCKELBERGER J., HOLLENSTEIN K., ATTENBERGER M., HÄNGGLI T., 2001. Effor2: Holzerntekonzept für die Untersuchungsbetriebe im Kanton Schwyz. Swiss federal Institute of technology Zurich, ETH-Zurich D-Fowi Forstliches Ingenieurwesen, interne Berichte nr. 11.

MIYATA E.S., 1980. Determining fixed and operating costs of logging equipment. Gen. Tech. Rep. GTR NC-55, St. Paul, MN. US Department of Agriculture, Northcentral Forest Experiment Station, 16 pp.

MILNE B.T., 1991. Lessons from applying fractal models to landscape pattern. In: Turner, M.G., Gardner R.H. (ed.). Quantitative Methods in Landscape Ecology. Springer, New York, pp. 199–235.

MOON G., 1992. Capabilities Needed in Spatial Decision Support Systems. GIS/LIS '92, vol. 2: 594-600.

MUNDA G., 1995. Multi-criteria Evaluation in a Fuzzy Environment. Physica-Verlag, Heidelberg, pp. 255.

MURPHY P., CASTONGUAY M., OGILVIE J., CONNORS T., ARP P.A., 2006. Forest operations planning based om high resolution wet areas mapping: verifications. In Ackerman P.A., Langin D.W., Antonides M.C. (eds) 2006. Precision Foretry in plantations, semi-natural and natural forests. Proceedings of the International Precision Forestry Symposium. Stellenbosch University, South Africa. 5-10 March 2006. Stellenbosch University. South Africa.

NCGIA, 1992. A Research Agenda of The National Center for Geographic Information and Analysis. Technical Report: 92-7.

NUGENT C., KANALI C.L., OWENDE P.M.O., NIEUWENHUIS M., WARD S.M., 2002. Characteristic site disturbance due to harvesting and extraction machinery traffic on sensitive forest sites with peat soils. Forest Ecology and Management, 180 (1): 85-98.

OLSEN H.J., WASTERLUND I., 1989. Terrain and vehicle research with reference to forestry at the Swedish university of agriculture. The Swedish university of agricultural sciences, Department of operational efficiency. Uppsatser och resultat n. 149, 60 pp.

OLSEN E.R., RAMSEY R.D., WINN D.S., 1993. A Modified Fractal Dimension as a Measure of Landscape Diversity. Photogrammetric Engineering. Vol. 59 (10):1517-1520.

ORLÓCI L., 1978. Multivariate analysis in vegetation research. 2nd ed. Dr. W. Junk B. V., The Hague, ix + 451 p.

PAT - PROVINCIA AUTONOMA DI TRENTO, 1991. Progetto Legno – Studio per la valorizzazione della produzione legnosa. Servizio foreste e caccia, 66 pp.

PAT – PROVINCIA AUTONOMA DI TRENTO, 2002. relazione annuale sull'attività del Servizio Foreste. Attività svolta nel corso dell'anno 2001. Provincia Autonoma di Trento, Servizio Foreste, 101 pp.

PELLIZZARI L., 2002. Proposta metodologica per la produzione di cartografia di supporto agli interventi AIB con l'impiego di un sistema integrato GPS/GIS. PhD thesis, University of Padua, Dept. TeSAF, Legnaro (PD).

PETTENELLA D, CUTOLO N, 1987. La valutazione dei costi di utilizzo delle macchine forestali. Genio rurale, 50 (4), 51-58.

PETTENELLA D., FRANCESCATO V., ANTONINI E., 2004. La filiera del cippato in Italia. Domanda, offerta e aspetti economici. Legno Energia, 1: p. 18-23.

PETTENELLA D., KLÖHN S., BRUN F., CARBONE F., VENZI V., CESARO L., CICCARESE L., 2004. Economic integration of urban consumer's demand and rural forestry production: Italy's country report. COST Action E30.

PETTENELLA D., TALUCCI G.R., PAOLUCCI M., 2004. La cooperazione forestale in Italia. Suppl. 2, Sherwood 106, pp. 24.

PETTENELLA D., SECCO L., 2004. L'organizzazione economica delle imprese di utilizzazione boschiva. L'Italia Forestale e Montana, 6: 533-546.

PETTENELLA D., 2007. Non-wood forest products and services. In: Niskanen A., Slee B., Ollonqvist P., Pettenella D., Bouriaud L., Ramesteiner E. (eds.), Entrepreneurship in the forestry sector in Europe. University of Joensuu, Faculty of Forestry. Silva Carelica, 52: 73-103.

PETTENELLA D., CICCARESE L., 2007. Come remunerare i gestori delle foreste per la CO_2 fissata? Alberi e Territorio, 4 (3): 36-42.

PICMAN D., PENTEK T., PORŠINSKY T., 2001. Relation between forest roads and extraction machines in sustainable forest management. Paper presented at the Joint FAO/ECE/ILO Committee on Forest Technology workshop on New Trends in Wood Harvesting with Cable Systems for Sustainable Forest Management in the Mountains, 18-24 June 2001, Ossiach, Austria.

PIEGAI F., 1990. Produttività dell'esbosco con gru a cavo in confronto all'esbosco per avvallamento ed all'esbosco a strascico con trattori. pp. 22-45. Moena, Italia, 24-25 Settembre.

PIEGAI F., QUILGHINI G., 1993. Esbosco a soma con trattore. Monti e Boschi 1: 36-44.

POLLINI C., 1983. Analisi e controllo della produttività e dei costi nelle operazioni di utilizzazioni forestali. Quaderni I.T.L. N° 4. S. Michele all'Adige, Trento: C.N.R. Istituto per la tecnologia del legno.

POSTIGLIONE A., TROIANI L., 2001. La legislazione sulla viabilità forestale. In Atti del Convegno internazionale U.N.I.F. “Viabilità forestale: aspetti ambientali, legislativi e tecnico-economici” Lago Laceno 2-3 ottobre 1998 (Av). Ed. A.G.R.A. s.r.l., Roma, 54-72.

POWER D.J., 2007. A Brief History of Decision Support Systems. DSSResources.COM, http://DSSResources.COM/history/dsshistory.html version 4.0, March 10, 2007.

POZZATI A., 1979. La viabilità nella gestione pianificata del bosco. Terra Trentina, 1869-1879, Ispettorato Ripartimentale delle Foreste di Trento.

POZZO D., 2007. Formazione e aggiornamento per addetti forestali. 31.01.2007, http://www.inforesta.net

PRETZSCH H., BIBER P., DURSKY J., 2002. The single tree-based stand simulator SILVA: construction, application and evaluation. Forest Ecology and Management 162: 3-21.

PSR, 2007. Programma di Sviluppo Rurale per il Veneto 2007-2013. Regione del Veneto, Giunta Regionale. pp. 83-92

PULKKI R.E., s.d. Machine specifications and operative techniques. Lakehead University. Canada.

PURFÜRST T., ERLER J., 2006. The precision of productivity models for the harvester, do we forget the human factor? In Ackerman P.A., Längin D.W., Antonides M.C., 2006. Precision Forestry in Plantations, semi-natural and natural forests. Proceedings of the International Precision Forestry Symposium. Stellenbosch University, South Africa. 5-10 march 2006. Stellenbosch University. South Africa.

PUTKISTO K., 1964. Principles of terrain classification for logging. Proceedings of the IUFRO, section 32, Montreal, pp. 97-116.

RAYMOND R.C., 1966. Use of the Time-sharing Computer in Business Planning and Budgeting. Management Science 12 (8): 363-381.

REED W.J., 1986. Optimal harvesting models in forest management – a survey. Natural resource modelling 1 (1): 55-79.

REED R.A., JOHNSON-BARNARD J., BAKER W.L., 1996. Contribution of roads to forest fragmentation in the Rocky Mountains. Conservation Biology, 10 (4): 1098-1106.

RICKARDS P.A., PASSMORE A.L., 1977. Planning for profit in livestock grazing systems. Professional Farm Management Guidebook No. 7, Agricultural Business Research Institute, University of New England, Armidale.

RIGGS J.L., 1977. Engineering economics. New York: McGraw-Hill. 617 pp.

RIGONI A., 2006. L’evoluzione dei prezzi di vendita del legname grezzo: un’analisi dei risultati delle aste nel Comune di Asiago. Relatore Pettenella D. Dipartimento Territorio e Sistemi Agro-Forestali, Facoltà di Agraria, Università di Padova, Legnaro.

RIZZI C., 2007. Confronto di sistemi di esbosco della legna da ardere di faggio. Relatore Cavalli R., Dipartimento Territorio e Sistemi Agro-Forestali, Facoltà di Agraria, Università di Padova, Legnaro.

ROSENTHAL R.E., 1985. Concepts, theory and techniques: Principles of multi-objective optimization. Decision Sciences 16 (2): 133-152.

ROWAN A.A., 1977. Terrain classification. Forestry Commission, Forestry Record 114. Her Majesty’s Stationery Office (HMSO), Edinburgh. 24 pp.

RUMMER R., KLEPAC J., 2002. Mechanized or hand operations: which is less expensive for small timber? In Small Diameter Timber: Resource Management, Manufacturing, and Markets proceedings from conference held February 25-27, 2002 in Spokane, Washington. Compiled and edited by D.M. Baumgartner, L.R. Johnson, and E.J. DePuit. Washington State University Cooperative Extension. (Bulletin Office, WSU, PO Box 645912, Pullman, WA 99164-5912. MISC0509. 268 pp.

SAATY T.L., 1980. The Analytical Hierarchy Process. McGraw Hill, New York.

SAMBUGARO G., 2006. Personal communication.

SAMSET I., 1971. Classification of terrain and operational systems. Joint FAO/ECE/ILO Committee on Forest Working Techniques and Training of Forest Workers, Symposium on forest operations in mountainous regions, 30 ago. – 11 sept. 1971, Krasnodar (USSR), TIM/EFC/WP. 1/1., 22 pp.

SAMSET I., 1972. Cost calculation of forest machines (in Norwegian with English summary). Tidsskrift for Skagbruk, Oslo, Norway, 80 (IV): 357-374.

SAMSET I. 1975. The accessibility of forest terrain and its influence on forest conditions in Norway. Reports of The Norwegian Forest Research Institute n° 32.1,Ås-NLH, Norway: pp 45-91.

SARTORI L, GALLETTO L, 1992. Costi di riparazione e manutenzione dei trattori nella provincia di Padova. Rivista di ingegneria agraria, 2: 81-89.

SCOTT MORTON M.S., 1967. Computer-Driven Visual Display Devices - Their Impact on the Management Decision-Making Process. Doctoral Dissertation, Harvard Business School.

SCOTT MORTON M.S., 1971. Management Decision Systems; Computer-based support for decision making. Boston, Division of Research, Graduate School of Business Administration, Harvard University.

SECCO L., BRUNORI A., 2005. La certificazione Fsc e Pefc in Italia, dati e prospettive. Alberi e Territorio 2 (6): 31-35.

SEGEBADEN von G., STRØMNES R., WINER H.I., 1967. Proposal for an international system of terrain classification. In proceedings of the XIV IUFRO world congress, Vol. III (section 31-32).

SHIBA M., ZIESAK M., LÖFFLER H., 1990. Der Einsatz moderner Informationstechnologie bei der forstlichen Erschliessungsplanung. Forstarchiv 61 jg.: 16-21.

SILVERSIDES C.R., 1980. Innovative transportation in the 2000s. In Forest-to-Mill challenges of the future, Weyerhaeuser Science Symposium, pp 23-48. September 15-17, Tacoma, Washington. Ed. By Weyerhaeuser Co.

SIMON H.A., 1947. Administrative Behavior. New York, NY, ed. Macmillan.

SIMON H. A., 1960. The new science of management decision. NewYork, ed. Harper & Row.

SYNWOLDT U., GELLERSTEDT S., 2003. Ergonomic initiatives for machine operators by the Swedish logging industry. Applied Ergonomics, 34 (2): 149-156.

SMITH T.R., MENON S., STARR J.L., ESTIS J.E., 1987. Requirements and principles fort he implementation and construction of large-scale geographic information systems. International Journal of Geographic Information Systems, 1: 13-31.

SOL H.G., 1983. Processes and tools for decision support: Inferences for future developments. In Processes and Tools for Decision Support, 1-6, ed. Sol H.G., North Holland, Amsterdam, the Netherlands.

SOLARI V., 2005. Realizzazione strada Bosco Cavallo. Progetto definitivo, Comune di Ampezzo (Udine).

SPINELLI R., 2004. L'harvester in Italia. L'Italia Forestale e Montana, 6: 511-523.

SPINELLI R., STAMPFER K., 2002. Un harvester per i primi diradamenti dei boschi in pendenza. Sherwood 8 (2): 39-46.

SPINELLI R., NATI C., MAGAGNOTTI N., 2007. Recovering logging residues: experiences from the Italian Eastern Alps. Croatian Journal of Forest Engineering 28 (1): 1-9.

SPRAGUE R.H. Jr., 1980. A Framework for the Development of Decision Support Systems. Management Information Systems Quarterly, vol. 4 (4): 1-26.

SPRAGUE R.H. Jr., CARLSON E.D., 1982. Building Effective Decision Support Systems. Englewood Cliffs, N.J, ed. Prentice-Hall, Inc..

SPRAGUE R.H. Jr., WATSON H.J., 1979. Bit by Bit: Toward Decision Support Systems. California Management Review XXII (1): 60-68.

SPRAGUE R.H., WATSON H.J., 1986. Decision Support Systems: Putting Theory into Practice. Prentice Hall, New Jersey.

SPRAGUE R.H. Jr., WATSON H.J., 1996. Decision support for management. Upper Saddle River, N.J. ed. Prentice Hall.

STAMPFER K., 1999. Influence of terrain conditions and thinning regimes on productivity of a track-based steep slope harvester. In Proceedings of the International Mountain Logging and 10th Pacific Northwest Skyline Symposium, ed. J. Sessions and W. Chung. 78-87. Corvallis, OR, March 28 – April 1.

STAMPFER K., STEINMÜLLER T., 2004. Harvester und Seilgerät am Steilhang: Valmet 911.1 X3M und Syncrofalke. Eigenverlag des Instituts für Forsttechnik, Universität für Bodenkultur, Wien. 25 S.

STAMPFER K., KANZIAN C., 2006. Current state and development possibilities of wood chip supply chain in Austria. Croatian Journal of Forest Engineering 27 (2): 135-145.

STENZEL G., WALBRIDGE T.A., PEARCE K., 1985. Logging and pulpwood production. 2nd Ed. New York: John Wiley & Sons. 358 pp.

STERGIADOU A., 2006. Environment impact assessment (E.I.A.) for the evaluation of forest roads in mountainous conditions (Case study: Valia Kalda). In Proceedings of the International Conference of Sustainable Management and Development of Mounainous and Island Areas, September 29 – October 1, Insel Naxos, Greece, V.II, 125 -129.

STERGIADOU A., LUBELLO D., CAVALLI R., KRČ J., 2007. Estimating forest harvesting operations to achieve sustainable rural development in Valia Kyrna (Greece). In Proceedings of the IUFRO European Congress "Forests and Forestry in the Context of Rural Development". Warsaw, Poland, September 6-7, 2007.

STÜCKELBERGER J., HEINIMANN H.R., BURLET E.C., 2006. Modeling spatial variability in the life-cycle costs of low-volume forest roads. European Journal of Forest Research 125: 377-390.

TAROLLI P., DALLA FONTANA G., 2007. Potenzialità della tecnologia LiDAR per l'analisi e l'interpretazione delle caratteristiche del sistema alveo-versante in area alpina. Presentazione convegno AIIA, Milano, 27-28 marzo.

TAROLLI P., DALLA FONTANA G., 2007. Analysis of the headwater basins' morphology by high resolution LiDAR-derived DTM. Proceedings of the 5th International Symposium on Mobile Mapping Technology, Padova 28-30 Maggio 2007.

TERLESK C.J., 1983. A proposed terrain classification for harvesting in New Zealand. Technical officer, Forest Research Institute, Rotorua. New Zealand Journal of Forestry, pp 43-57.

TOMASINI M., 1996. Analisi dell'operatività della gru a cavo a stazione motrice mobile in alcune tipologie di utilizzazione forestale sull'Altopiano dei Sette Comuni. Relatore Cavalli R., Dipartimento Territorio e Sistemi Agro-Forestali, Facoltà di Agraria, Università di Padova, Legnaro.

TOMLINSON R.F., 1987. Current and potential uses of geographical information systems – The North American experience. International Journal of Geographical Information Systems, vol. 1, n.3: 203-218.

TREZSNIOWSKI A., 1990. Waldershliessung im Gebirge Österreichs. Forstarchiv, 61: 22-26.

TSAY T.B., 1979. An approach to terrain classification for forestry in Canada. IUFRO symposium on stand establishment techniques and technology, Moscow.

TUČEK J., 1994. Using the GIS environment for opening-up of forests, Proceedings of the International IUFRO, FAO, FEI seminar on forest operations under mountainous conditions, Harbin, China: 58-65.

TUČEK J., PACOLA E., 1999. Algorithms for skidding distance modelling on a raster digital terrain model. Journal of Forest Engineering, 10 (1): 67-69.

TUFTS R.A., MILLS W.L., 1982. Financial analysis of equipment replacement. Forest Products Journal, 32 (10): 45-52.

TUFTS R.A., STOKES B.J., LANFORD B.L., 1988. Productivity of grapple skidders in southern pine. Forest Products Journal, 38 (10): 24-30.

TUFTS R.A., BRINKER R.W., 1993a. Productivity of a Scandinavian cut-to-length system while second thinning pine plantations. Forest Products Journal, 43 (11/12): 24-32.

TUFTS R.A., BRINKER R.W., 1993b. Valmet's Woodstar series harvesting system: a case study. Southern Journal of Applied Forestry, 17 (2): 69-74.

TURBAN E., 1967. The Use of Mathematical Models in Plant Maintenace Decision Making. Management Science 13 (6): 342-359.

TURNER M.G., 1989. Landscape ecology: the effect of pattern on process. Annual Review of Ecology and Systematics, 20: 171–197.

UNESCO, 1993. Environment and Development BRIEFS. United Nations Educational, Scientific and Cultural Organization, Paris.

UNCEM, 2006. Tabella retribuzioni operai forestali in vigore dall'1/08/2006 al 31/12/2006. http://www.uncem.it/gems/tabelle_forestali.pdf

URBAN G.L., 1967. SPRINTER: A Tool for New Products Decision Makers. Industrial Management Review, 8 (2): 43-54.

U.S. ARMY, 1961. Trafficability of soils. Soil classification. Supersedes TM 3-240, 16th supplement. U.S. Army Engineer Waterways Experiment Station. Corps of engineers. Vicksburg, Mississippi.

VÄÄTÄINEN K., LIIRI H., RÖSER D., 2006. Cost-competitiveness of harwarders in CTL-logging conditions in Finland – a discrete-event simulation study at the contractor level. In Ackerman P.A., Längin D.W., Antonides M.C., 2006. Precision Forestry in Plantations, semi-natural and natural forests. Proceedings of the International Precision Forestry Symposium. Stellenbosch University, South Africa. 5-10 march 2006. Stellenbosch University. South Africa.

VISSER R.J.M., STAMPFER K., 1998. Cable extraction of harvester-felled thinnings: an Austrian case study. Journal of Forest Engineering, 9 (1): 39-46.

VOOGD H., 1983. Multi-Criteria Evaluation for urban and regional planning. PION, London.

WEMPLE B.C., JONES J.A., GRANT G.E., 1996. Channel network extension by logging roads in two basins. western Cascades, Oregon. Water Resources Bulletin, 32 (6): 1195-1207.

WELSH H.H.Jr., 1990. Relictual amphibians and old-growth forests. Conservation Biology, 4 (3): 309-319.

WIEST L,. 1998. A landowner’s Guide to Building Forest Access Roads. U.S.D.A. Forest Service, Norteastern Area State and Private Forestry, 47 pp. (electronic vers.)

WILLIAMS D., 1992. Forest management decision support systems: An overview and survey of current initiatives. Cortex consultants. Cited by: Moore, T. 1993. Forest management decision support systems (FMDSS) message archive. *URL: www.spatial.ca/~tmoore/fmdss/1993/msg00033.html*.

WOLYNSKY A., 2005. Sviluppi recenti dell’assestamento forestale in Italia settentrionale. SAFE-infoblatt Nr 19:6-7.

WONG J.Y., 1993. Theory of ground vehicles (2nd ed.). John Wiley & Sons, New York, 435 pp.

WONG J.Y. 1994. Applications of a computer aided method to parametric study of tracked vehicles with rigid links. Procedural Instruments for Mechanical Engineers, Part D, Journal of Automobile Engineering, 208: 251-257.

WOOD D.B., DEWHURST S.M., 1998. A decision support system for the Menominee legacy forest. Journal of forestry, 96 (11): 28-32.

WRONSKI E.B., STODART D.M., HUMPHREYS N., 1989. Trafficability assessment as an aid to planning logging operations. Appita, 43 (1): 18-22.

WRONSKI E.B., HUMPHREYS N., 1994. A method for evaluating the cumulative impact of ground-based logging systems on soils. Journal of forest engineering, 5 (2): 9-20.

ZANONI M., 2007. Valutazione economica dei costi dell’esbosco di legna da ardere con gru a cavo in provincia di Trento. Relatore Cavalli R., Dipartimento Territorio e Sistemi Agro-Forestali, Facoltà di Agraria, Università di Padova, Legnaro.

ZIESAK M., 2003. Avoiding soil damages caused by forest machines. In Maria Iwarson Wide & Berit Baryd (eds.): 2nd Forest Engineering Conference. Skogforsk Arbetsrapport, Nr. 536, Maj 2003, Uppsala.

ZUCCOLI BERGOMI L., 2006. Produttività e costi di cantieri di utilizzazione avanzata: harvester, forwarder, processor. Presentation of the workshop: “Quali opportunità per la meccanizzazione forestale avanzata in ambiente alpino”. 23 giugno 2006, Centro Servizi per le Foreste e le Attività Montane – Cesfam, Paluzza (UD).