Austro2007/FORMEC´07: Meeting the Needs of Tomorrows´ Forests – New Developments in Forest Engineering, October 7 – 11, 2007, Vienna and Heiligenkreuz – Austria

DIFFERENT APPROACHES ON SKIDDING OPERATION AND WOOD TRANSPORT INVESTIGATION: INTEGRATE TWO DIFFERENT APPROACHES IN ONE MODEL

Janez Krč*; Boštjan Košir
Department of Forestry
Biotechnical Faculty, University of Ljubljana
Vecna pot 83, 1001 Ljubljana, Slovenia
janez.krc@bf.uni-lj.si / bostjan.kosir@bf.uni-lj.si

Raffaele Cavalli; Stefano Grigolato; Daniele Lubello
Forest Operations Management Unit
Department of Land, Agriculture and Forest Systems
Agricultural Faculty, University of Padova
Viale dell'Università, 16 - 35020 Legnaro (PD), Italy
raffaele.cavalli@unipd.it / stefano.grigolato@unipd.it / daniele.lubello@unipd.it

Keywords: S-DSS model, GIS-based analysis, wood supply chain, cooperation.

Abstract: *In order to support an international cooperation in forestry operation, the Forest department of University of Ljubljana and the department of Land, Agriculture and Forestry of University of Padua are validating together a DSS model on forest operation in alpine condition. The project consists on first into verify partial models, independently developed, on valuating skidding operations and transportation of wood,. Models validation consists in exchanging independent approaches and consequently evaluates the results according to individual previous investigations. Once differences have been highlighted, a common DSS model will be developed and consequently apply in a common border productive forest area. The aim of the project is to aid a road map in forest operations in an area where wood raw material is becoming more and more attractive for both wood industry sectors. As a consequent it is becoming fundamental the optimization on wood allocation in terms of wood quality, assortments and supply cost.*

1. Introduction

Two neighbor countries with many common problems regarding efficient wood supply (Italy and Slovenia) are recently (Slovenia) both part of the common market of European Union (EU). One of the most evident common problems regarding forestry is small scale forestry with low level of owners' social capital associating their capacities and common appearing on forest operation and wood procurement market. Introduction of new technologies for forest operation (mechanized cutting, processing and forwarding, high efficient mountain logging with whole tree cable skidding and processing, wood biomass conversion in wood biofuels) represents great challenge for both forestry professions.

Borders usually represent a barrier for executing an optimal activities arrangement regarding forest operation and transportation. Also separated development of specific solutions does not lead to optimal simulation and predicting an optimal future management. In former situation (when Slovenia was not part of EU) with more or less closed border the trade between Slovenia and Italy was, anyway, very vivid. Natural condition and logistic infrastructure offer an excellent condition for cross border wood trade. Nationals economies are today not closed and self-sufficient – the EU frame shall promote international and interregional cooperation to achieve altogether more competitive economy.

Approach with modeling different solutions is nowadays a common tool for efficient forest management activities. Maximization of added value as a goal function shall be considered in an ecological and economic perspective (point of view). Climate changes play one of the most important roles in everyday efforts of scientists where renewable sources of raw material and energy will gain high priority. Forest as domestic and natural sound system has to be sustainable maintained and efficient applied.

The main aim of research is to highlight differences in forest operation and logistic modeling with evaluation of possibilities for common approach to develop wood supply chain models. Two separated tools for modeling wood flow cost from source (forest) to sinks (sawmills or CHP) were developed separately in Slovenia and Italy. There are also different sets of input data into applications which are connected to the local organization of forestry and available databases. After highlighting the condition for running both models the wood flow case study on 143 000 ha border area comprising both sides' forests productive area (sources) and local capacities for wood processing (sinks) was conducted.

1.1 Objectives

Both Slovenia and Italy have problems, connected to forestry sector, that don't permit to the wood supply chain to be competitive like in other European countries. Some of these problems are: fragmentation of forest properties and yield amount. Both influence forest operation system productivities and costs.
The research cooperation wants to point out the main problems of the actual situation and try to define common guide lines for supporting forest operation activities over boundaries. A decision support instrument will be based on GIS tools.

2. Materials and methods

2.1 Comparing two partial S-DSS models evaluating skidding systems

Both University of Padua (Lubello *et al.*, 2006) and University of Ljubljana (Krč, 2006) developed DSS models to evaluate the suitability and costs of using different systems or machines for cutting and skidding operations.

2.1.1 IDRISI model (University of Ljubljana)

The selection of skidding means (technology) and skidding direction is derived by model, which make the determination of optimal skidding mean 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, 1997). 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, 1977). 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. Basic unit is forest compartment with specific set of influential factors, derived from forest inventory (Slovenian Forest Service data). 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).

2.1.2 The ArcMap Forest Operation Planning (FOPP) model (University of Padova)

University of Padova built a similar model in ArcMap *Geoprocessing* combining processes in visual models using *ModelBuilder* environment (ESRI, 2007). The model is structured as an ArcMap *toolbox* and can be shared with other GIS users. A user interface allows to set input data, output directories and *geodatabases*, model parameter, rules and functions values.

It's a rule-based model so it is based on several input *shapefiles* and on calculated GRID files: the evaluation is done cell by cell (continuous surface) and it is based on several matrices and algorithms defining rules or functions used to calculate which skidding system (and their costs) is better to use.
Input files have to be prepared inside a geodatabase: usually they are not ready to be used and preparing them could take several hours or days. Inside user interface there are specific instructions on how they should be to suit the model without errors.
The functioning structure of the model could be resumed by points:

1. <u>Preparing and setting input files and databases</u>. All input files are necessary to the model to be run. They are five shape-files (study area, road network, management plan data, geology and precipitation) and one GRID file (Digital Terrain Model). Other information needed are systems productivity functions (as those in Cavalli and Lubello, 2006; Rizzi, 2007; Zanoni, 2007) and hourly costs (Miyata, 1980).
2. <u>Determining trafficability classes and gradeability</u>. Starting from geology and precipitation, the model defines a list of soil trafficability classes according to previous studies (AA.VV., 1961; Anderson, 1985; Bonasso, 1989). Gradeability (terrain steepness in percent) of each skidding system will be influenced according to soil classes (table 1) with the exclusion of cable systems (Samset, 1975; Rowan 1977; Mellgren, 1980; Löffler, 1984).

Table 1: matrices defining skidding systems gradeability rules

Soil stability Rain mm/year	HIGH	NORMAL	LOW
< 700	HIGH	HIGH	HIGH
700 - 1500	HIGH	HIGH	NORMAL
1500 – 2500	HIGH	NORMAL	LOW
> 2500	NORMAL	LOW	VERY LOW

=>

Gradeability Systems	HIGH	NORMAL	LOW	VERY LOW
Tractor	23	20	17	13
Forwarder	38	35	32	28
Cable-forw.	63	60	55	50

3. Calculating other variables. Consequently, also GRID files of terrain roughness, slope, distance from forest road and up-hill or down-hill direction to road are calculated.
4. Feasibility areas. Through user interface, technical limits of skidding systems (Cielo *et al.*, 2003; Hippoliti and Piegai, 2000) have to be set (table 2).

Table 2: technical limits used in the ArcMap model

Skidding system	Terrain roughness	Downhill		Uphill	
		slope	distance	slope	distance
Tractor/skidder	low	13-23	300	8-18	150
Tower cranes	high	100	350	100	350
Forwarder	medium	28-38	600	22-32	500
Sledge yarder	high	120	900	120	900

With this information, model is able to determine feasible areas for each selected skidding system. Output maps distinguish the skidding direction (up-hill/down-hill) (Heinimann, 1986 and 1994; Lüthy, 1998; Krč, 1999) and for cable systems the model verify that average inclination from each cell to the nearest road is enough to guarantee the gravity functioning (figure 1).

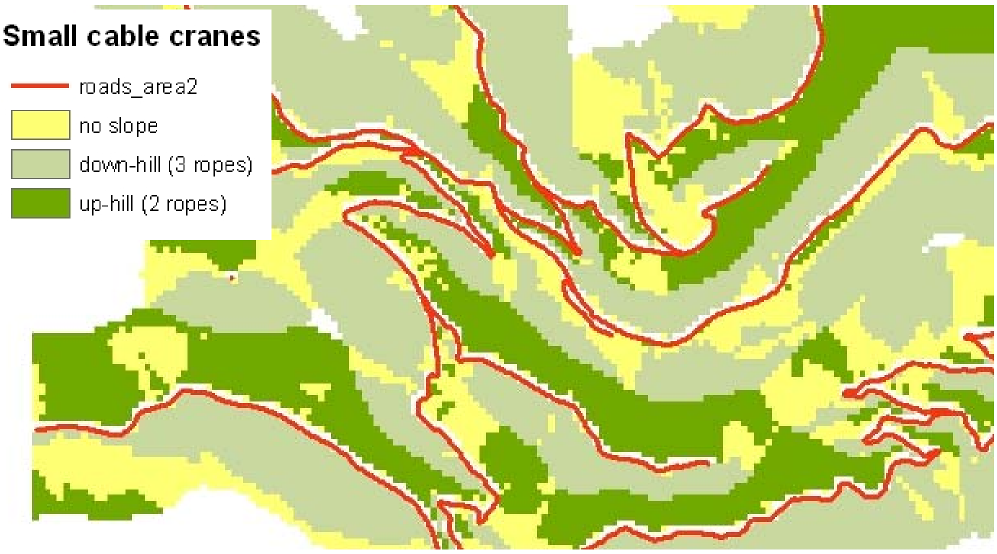

Figure 1: example of mobile tower cranes output map.

5. Systems productivities. By performing several time studies during forest operations and validating field data with literature (Piegai, 1990; Fanari *et al.*, 1999; Della Giacoma *et al.*, 2002; Zuccoli *et al.*, 2006), productivity functions were estimated giving correlation to skidding distance from forest road. The result gives a decreasing value (in m^3/hour) for each system working far from road (figure 2).

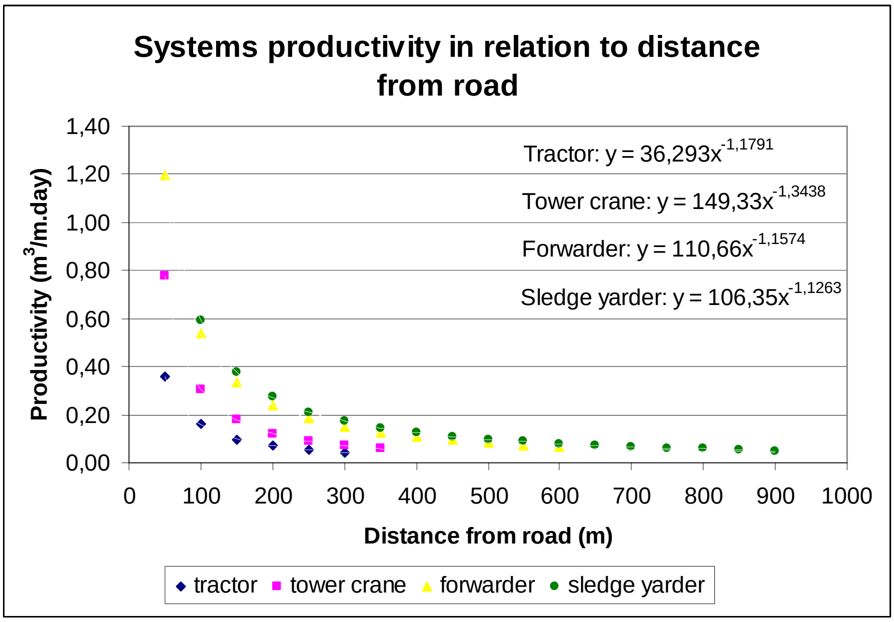

Figure 2: graph of systems productivity functions.

6. Calculating costs. Model calculates cell by cell allowable cutting yield (m^3). Dividing productivities by yield it is possible to know how much time skidding operations will last and how much they will cost (figure 3). This value is suddenly divided by the yield (cell by cell) and transformed in €/m^3.

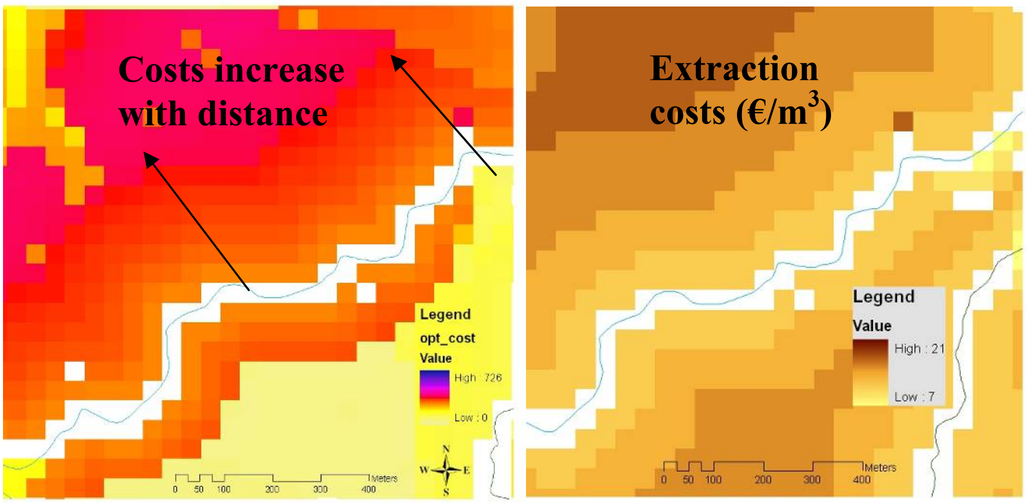

Figure 3: on the left side a general cost function map; on the right side a cost output map (€/m^3)

Running the model on the whole study area (1430 km^2) took about 45 minutes.

2.2 A common model for wood flow analysis

2.2.1 Study area

Study area lies over the border between Slovenia and Italy (figure 4): 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. It is linked to the European A5 axis that connects eastern to westerns countries. 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.

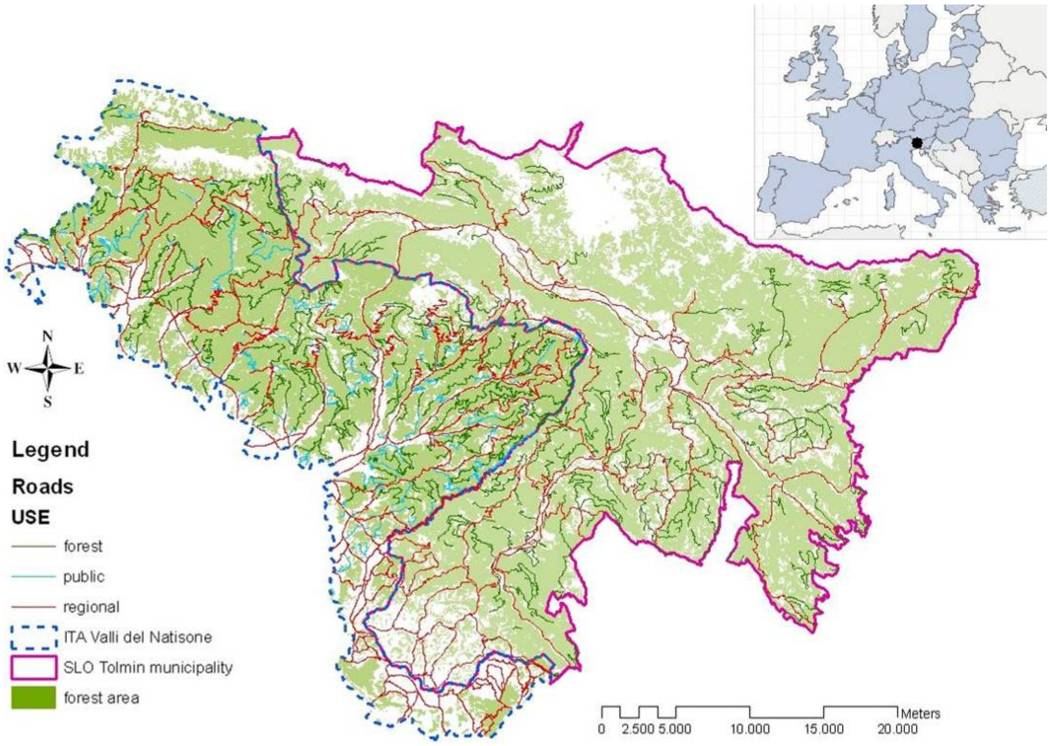

Figure 4: the study area.

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 we joined information from Corine Land Cover and use and forest typologies to derive estimation of stocks and allowable cutting volumes.

2.2.2 Harvestable wood allocation

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 (figure 5). 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).

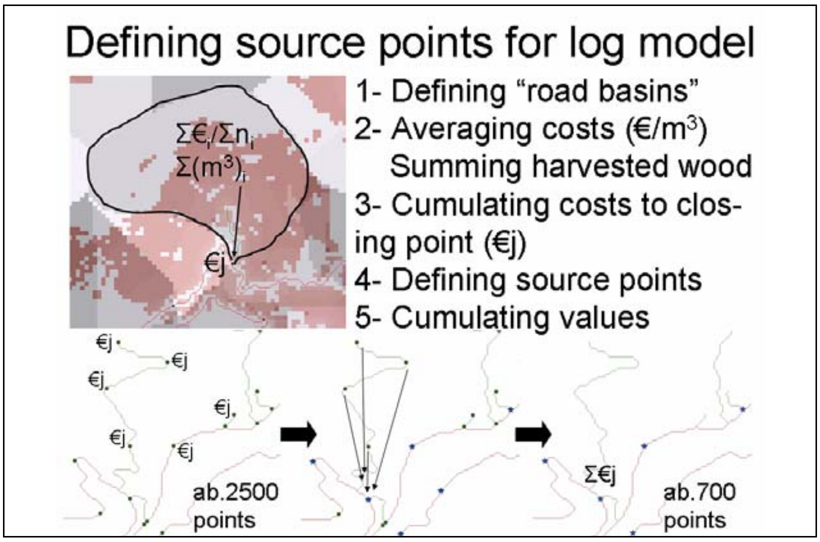

Figure 5: determining source points values procedure

2.2.3 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.In order to simplify the analysis, two terminals were considered: one on Italian side and the other on

Slovenian side. In the studied scenario, wood can flow and supply both terminals which corresponds to two main wood industrial districts inside the study area. 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.

3. Results and discussion

3.1 Differences of ITA and SLO forest operations approaches

We run both models on the Slovenian side of testing area. Initial results which we compared were separately produced wood skidding methods classification map (figure 6). The selection of skidding methods is different (Stergiadou *et al.*, 2007), but comparable to certain extension (table 3).

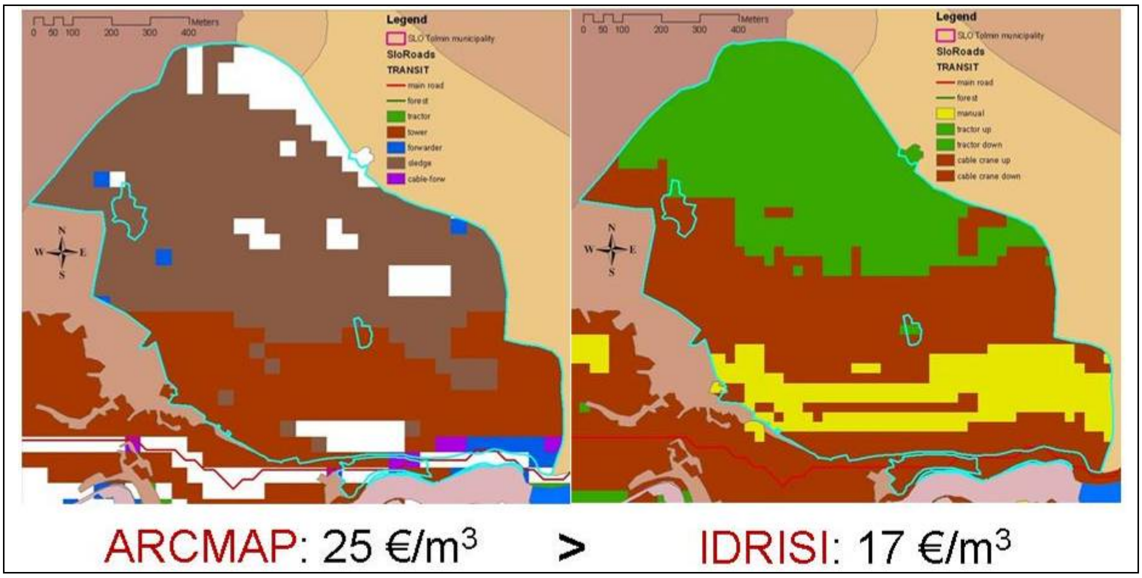

Figure 6: comparing skidding systems results on the same stand

Table 3: comparing skidding systems feasible areas (in %) on the Slovenian side of testing area

SLO model	%	ITA model	%
Manually	7	--	--
Tractor uphill	5	Tractor	9
Tractor downhill	32	Forwarder	20
Mobile tower crane uphill	25	Tower	31
Mobile tower crane downhill	31	Sledge	16
--	--	Not reachable	24
Sum	100		100

The similarity can be noticed comparing tractor (SLO) with tractor together with forwarder areas (ITA) model. Slovenian model does not foresee closed areas, but Italian classified a quarter of productive forest areas as “not reached”. This option shall be added to Slovenian model because also in Slovenia there is declaration for closed forests. All forest stands with skidding distance over 1200 m in flat terrain (tractor) and 800 m in steep terrain (cable systems) are declared as closed for forest operations.

3.2 Comparing models output costs

Total predicted costs for cutting and skidding operations were compared. Both models are able to calculate costs: Slovenian does it for every compartment, Italian for every grid cell of 40 m basic resolution. Simple GIS *spatial statistics* enable transforming and summing grid result to compartment based averages. After that, on forest compartment level. Figure 7 show the result of cost comparison by forest compartment: for each stand a prevailing skidding methods is defined and its average forest operation costs are compared between the two models results.

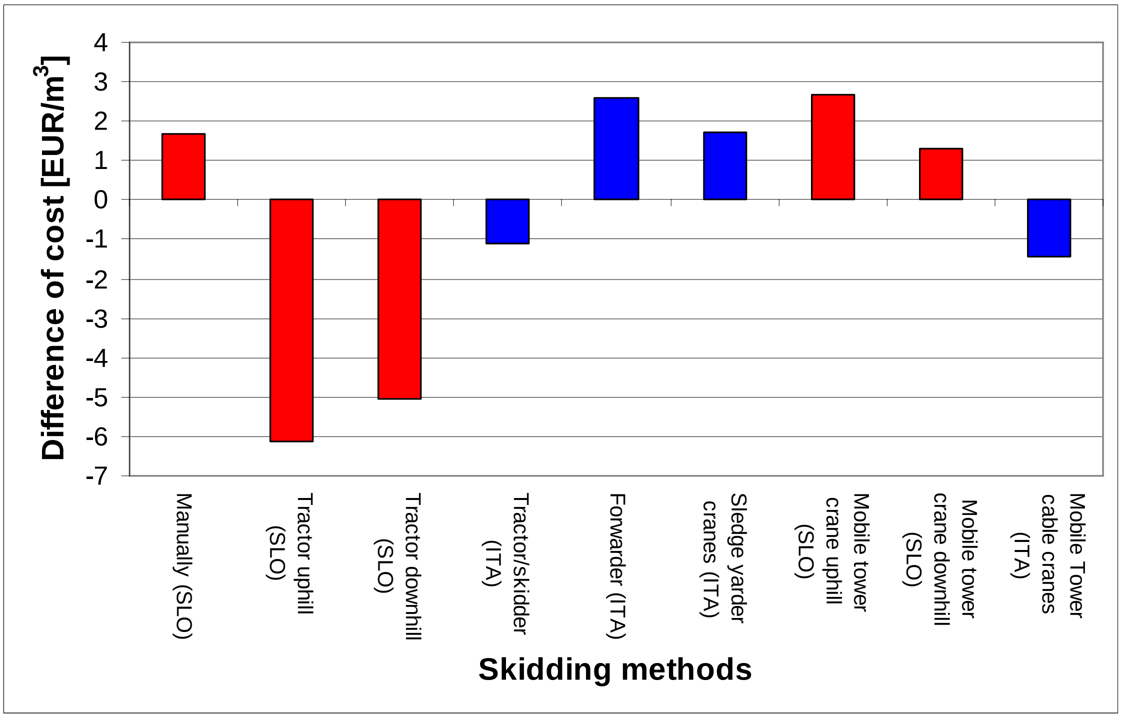

Figure 7: average differences in forest operation costs (cost SLO – cost ITA) analyzed by different skidding methods

Results on figure 7 point out some differences: in Italy manual skidding is not considered because it is not used anymore (with the exclusion of slides for firewood extraction) while in Slovenia it has quite high costs. Tractor skidding is 5 € cheaper in Italy because of higher productivities maybe due to a higher level of technology and more powerful or new models of tractors (recently, small forest enterprises had some help from region providing founds to renew machines). Productivities used in SLO model calculation were derived from national standard times which are pretty old and not suitable for using in contemporary tractor skidding operation. Cost of cable crane extraction is similar if comparing Slovenian mobile tower with Italian sledge yarder system. Mobile tower in Italy is cheaper because it is used usually for lines shorter than 300 m with installation times of 2 or 3 hours. Forwarder is a new system in Italian forestry sector but its use is growing fast: first studies shows high hourly costs (table 4), but huge productivities if compared to skidder. The so called cable-forwarder (a winch-aided forwarder that ArcMap model could also consider) may also reach 70 % terrain steepness.

For better explanation of average differences (figure 7), derived by subtracting SLO and ITA cost of cutting and skidding operation, the input data on efficiency and system hour costs have to be available (table 4).

Table 4: system hour costs for SLO and ITA model

System		Motor manual felling	Mechanized felling	Skidder/ tractor+ winch	Mobile Tower crane	Forwarder	Sledge yarder crane	Cable-forwarder
€/hour	ITA	20.68	98.77	34.95	63.00	66.17	98.00	70.00
€/m^3		8.27	7.60	8.74	12.60	5.09	24.50	7.85
m^3/hour		2.5	13	4	5	13	4	9
€/hour	SLO	14.64		43.58	109.94			
€/m^3		9.12		11.25	16.92			
m^3/hour		1.6		3.9	6.5			

Differences in efficiency by specific operations are evident. Felling operation (motor manual) is much more efficient in Italy, while cost efficiency in skidding operation differs mostly through higher system hour costs in SLO. Lower cost on "tractor" terrains in Italy come mostly from efficient forwarder and also skidder systems.

3.3 Wood flow results and supply evaluation

As it is shown on figure 8 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 9, 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 8), could take advantage by increasing its interest on Italian wood availability. Inside the inter-regional basin area, as it is reported on table 5, 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.

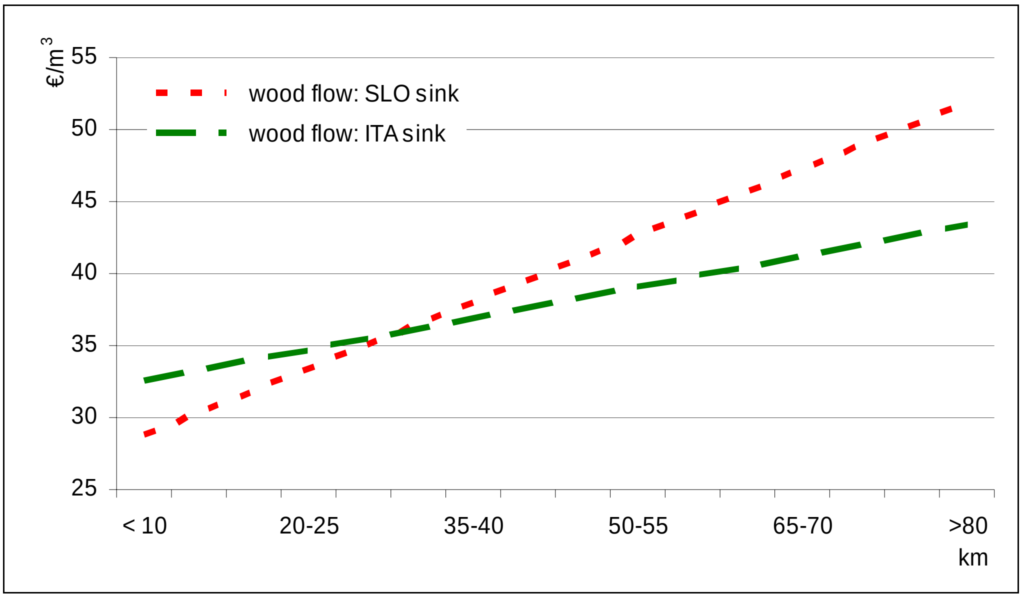

Figure 8: supply cost in relation to distance (two way) from sinks for wood flow at inter-regional scale

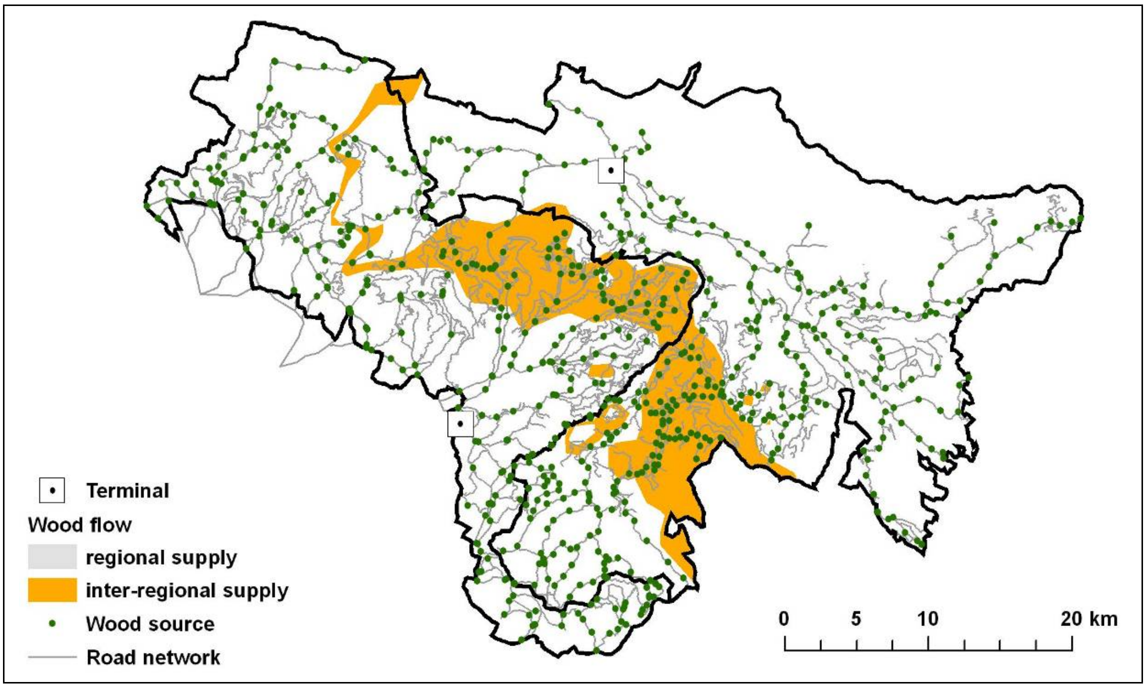

Figure 9: supply basin resulting as inter-regional supply area by considering maximum difference on supply cost between the two terminals of ± 2 €/m^3

Table 5: Source points located inside the inter-regional 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

4. Conclusions

For efficient predicting of wood flow beside cost of forest operation and logistic some additional questions have to be addressed. Very important issue is wood quality. The assortment has to be sold by many specific trade possibilities. Forest owner has free decision in timber sale activities. He shall be advised by professionals about sale possibilities and potential financial success of sale process. Decision support system shall foresee variants comprising complex solutions with optimization efficiency calculations.

Second open question is influential territory of the raw wood trade market. We know that a lot of round wood produced in testing area is sold outside its borders. The vicinity of developed market of wood processing industry (north Italy, Austria) influence to a great extend on wood flow on regional, national and international level. Great sink and also source of wood raw material represents harbors in Monfalcone and Koper. The source point on Oversee location influences on wood raw material balance, great massive of undivided forest region is located on Slovenian- Croatia border. There are some wood processing industries placed in the area, which are using mainly imported wood from different destinations.

Domestic using of available wood sources has to be considered too: small scale forest property which is present on testing area has specific model of using wood out of private forests. In fact, there are many small installations of sawmills and boilers for heating of private houses and domestic processing of saw logs.

Chosen model should be consistently used over all testing area – regardless if it is located on Italian or Slovenian side of the border. Through unique model we will test efficiency of different solution and not differences in model approach.

It will be promising to extend the cooperation on this research field to be comparable with real wood flow on regional, interregional and international level. Our proposal is pointed to research group in Austria and Croatia. Together we are able to predict and evaluate different scenarios which are more realistic for wood procurement market. To be efficient we shall avoid of long distance transport in round wood market activities. Decision support system like the presented one shall overcome short-term interests of single stakeholders on wood market which are not in sound with forest and wood processing strategy on higher levels.

5. 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.

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. pp 397-416.

Bernetti I. and 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.

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.

Cavalli R. and Lubello D. (2006) Firewood cable yarding on steep terrain in Alpine conditions. In Proceedings of the 39th International Symposium on forestry mechanization, Sofia, Bulgaria. 24-28 september 2006. In press.

Cielo P., Gottero F., Morera A. and Terzuolo P. (2003), La viabilità agro-silvopastorale: elementi di pianificazione e progettazione. IPLA – Regione Piemonte, 106 pp.

Della Giacoma F., Piegai F. and Vettori S. (2002), Esbosco a strascico con trattore e verricello: alcune esperienze. Sherwood 8 (1):21-26.

Eastman J.R. (1997), IDRISI for Windows: A grid-based geographic analysis, Version 2.0. Graduate School of Geography, Clark University, Worcestor, MA.

ESRI (2007), ArcGIS Desktop Help. Environmental Systems Research Institute. Redland, CA http://webhelp.esri.com/arcgisdesktop/9.1/

Fanari F., Bolognani R. and Piegai F. (1999), Produttività nelle operazioni di abbattimento, allestimento ed esbosco con gru a cavo in utilizzazioni forestali della Magnifica Comunità di Fiemme. Sherwood 5(9):23-28.

Grigolato S., Firth J., Hock B., Nielsen P., Bernd M. and Cavalli R. (2005), Supply of Logging Residues for Energy Production a GIS-Based Study. A Case Study in New Zealand and in Italy. On proceedings of 14th European Biomass Conference & Exhibition. Biomass for Energy, Industry and Climate Protection. Palais de congres: Paris, 17–23 October.

Gronalt G. and Rauch P. (2007), Designing a regional forest fuel supply network. Biomass and Bioenergy. 31 (2007): 393-402.

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 Proceedings, International NEFU/IUFRO/FAO/FEI seminar on forest operations in mountainous conditions. (Session J. ed.) July 24-26, 1994. Harbin, P.R. of China. Dept. of Forest Engineering, Oregon State University, Corvallis.

Hippoliti G. and Piegai F. (2000), Tecniche e sistemi di lavoro per la raccolta del legno. Compagnia delle Foreste, Arezzo. 157 pp.

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.

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.

Lüthy D. (1998), Entwicklung eines "Spatial decision support"-Systems (SDSS) für die Holzernteplanung in steilen Geländeverhältnissen. Diss. ETH n° 12618, Zürich. 225 pp.

Mellgren P.G. (1980), Classification du terrain pour la foresterie du Canada. Institut Canadien de recherche en génie forestier (FERIC), 13 pp.

Miyata E.S. (1980), Determining fixed and operative costs of logging equipment. USDA Forest Service, General Technical Report nc-55 USDA. St Pail, Minnesota: North Central Forest Experiment Station.

Piegai F. (1990), Produttività dell'esbosco con gru a cavo in confronto all'esbosco per avvallamento ed all'esbosco a strascico con trattori. L'Italia Forestale e Montana 39 (6): 419-439.

Rizzi C. (2007), Confronto di sistemi di esbosco della legna da ardere di faggio. Master thesis, Dept. TeSAF, University of Padova.

Rowan A.A. (1977), Terrain classification. Forestry Commission, Forestry Record 114. Her Majesty's Stationery Office (HMSO), Edinburgh. 24 pp.

Saaty, T.L., (1977), A Scaling Method for Priorities in Hierarchical Structures. J. Math. Psychology, 15, 234-281.

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 pp 45-91.

Spinelli R., Nati C. and Magagnotti N. (2007), Recovering logging residue: experiences from the Italian Alps. Croatian Journal of Forest Engineering. 28 (2007): 1-8.

Stergiadou A., Lubello D., Cavalli R. and Krč J. (2007), Estimating forest harvesting operations to achieve sustainable rural development in Samarina (Greece). In Proceedings of the IUFRO European Congress "Forests and Forestry in the Context of Rural Development". Warsaw, Poland, September 6-7, 2007. In press.

Zanoni M. (2007), Valutazione economica dei costi dell'esbosco di legna da ardere con gru a cavo in provincia di Trento. Master thesis, Dept. TeSAF, University of Padova.

Zuccoli-Bergomi L., Cavalli R. and Stampfer K. (2006), Productivity, costs and ecological impacts of a cable-forwarder employed under Alpine conditions. In proceedings of the 39th International Symposium on forestry mechanization, Sofia, Bulgaria. 24-28 sept. 2006. In press.