

ACTA FORESTALIA FENNICA

188

A SPATIAL DATABASE – HEURISTIC
PROGRAMMING SYSTEM FOR AIDING DECISION-
MAKING IN LONG-DISTANCE TRANSPORT OF
WOOD

*SIJAINTIETOKANTA – HEURISTINEN
OHJELMOINTIJÄRJESTELMÄ PUUTAVARAN
KAUKOKULJETUKSEN PÄÄTÖKSENTEOSSA*

Reino Pulkki



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Seloste

*SIJAINTIETOKANTA – HEURISTINEN OHJELMOINTIJÄRJESTELMÄ PUUTAVARAN
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To be presented, with the permission of the Faculty of Agriculture and Forestry of the University of Helsinki,
for public criticism in Auditorium XII of the University Main Building, Fabianinkatu 33,
on the 15th of March 1985 at 12 o'clock noon.

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The applicability of operations research, database management systems and geographic information systems for decision-making in long-distance transport of wood in the Saimaa area were reviewed. Due to the complexity of the transport problem a geographic information system is the most applicable. However, investment in such a system for only long-distance transport decision-making is unjustified. A spatial database – heuristic programming system was developed. It was applied to studying the competitiveness and search for possible areas for rationalization of water transport in particular and long-distance transport in general. The system proved to be a useful aid in long-distance transport research. Also, with the increased use of computers for planning at the field level, a system similar to that described could be a powerful managerial aid.

Tutkimuksessa tarkasteltiin operaatiotutkimuksen, tietokannan hallintojärjestelmien ja sijaintitietojärjestelmien soveltuvuutta kaukokuljetusta koskevaan päätöksentekoon Saimaan alueella. Ongelman suuruuden ja monimutkaisuuden vuoksi olisi sijaintitietojärjestelmä sopivin menetelmä. Menetelmä vaatii kuitenkin niin suuria pääomia, ettei sitä kannata käyttää vain kaukokuljetuksen päätöksenteossa. Kehitettiin sijaintitietokanta – heuristinen ohjelmointijärjestelmä, jota käytettiin Saimaan alueen kaukokuljetuksen tarkastelussa. Järjestelmä osoittautui hyödylliseksi apuvälineeksi kaukokuljetuksen tutkimuksessa. ATK:n käytön lisääntyessä myös kentällä järjestelmä voi olla hyödyllinen apuväline kaukokuljetuksen päätöksenteossa.

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Symbols

ABS(a-b) - absolute value of (a-b)	s - sample standard deviation
BASDATSERCH - master program for aiding transport route decision-making	SS - sum of squares
CAD - Canadian dollar	SS(E) - sum of squares (error)
CAD/CAM - computer assisted design and manufacturing	TRIM - transport route information matrix
CPU - central processing unit	USD - United States of America dollar
CV - coefficient of variation	VR - variance ratio
DBMS - database management system	w_α - unit for stating significance
df - degrees of freedom	\bar{x} - sample mean
F - (estimate of s^2 from means)/(estimate of s^2 from individuals); (i.e. variance ratio)	95 % C.I. for $u_{y,x}$ - 95 % confidence interval for regression line
FIM - Finnish mark	95 % C.I. for Y - 95 % confidence interval for Y
GIS - geographic information system	ΣX - sum of X's
OR - operations research	$\Sigma x^2 = \Sigma X^2 - (\Sigma X)^2/n$
m^3 - solid cubic metre, bark included	$\Sigma xy = \Sigma XY - (\Sigma X)(\Sigma Y)/n$
$M(m^3)$ - mega (i.e. million) cubic metre, bark included	$\Sigma y^2 = \Sigma Y^2 - (\Sigma Y)^2/n$
MS - mean square	α - probability of making a TYPE I error (rejection of true H_0)
MS(E) - mean square (error)	* - significant (95 % level)
n - number of observations	** - highly significant (99 % level)
n_2 - error degrees of freedom	
N - north	
ns - not significant	
p - penny (0.01 FIM)	
p_m - number of means in comparison	
q_α - upper percentage point of a studentized range	
r - correlation coefficient	
r^2 - coefficient of determination	
R - multiple correlation coefficient	
R^2 - multiple coefficient of determination	

merkinnät

ATK - automaattinen tietojenkäsittely
KuK - kuusikuitupuu
KuT - kuusitukki
LeK - lehtikuitupuu
LeT - lehtipuitukki
MäK - mäntykuitupuu
MäT - mäntytukki

PREFACE

The topic for this study was initiated by Prof. Kalle Putkisto, Ilmo Rinkinen, L.Sc.(For.) and Chief Forester Tero Toivonen. Their guidance, comments and assistance have been greatly appreciated. Working closely with Chief Forester Tero Toivonen allowed me to benefit from his many decades of experience in transport economics. The author would also like to thank Prof. Rihko Haarlaa, Prof. Matti Keltikangas and Prof. Matti Kärkkäinen for their valuable guidance and comments. This study is the result of a cooperative effort between the National Board of Forestry and the Department of Logging and Utilization of Forest Products, University of Helsinki. Also, the author greatly appreciates the opportunity the National Board of Forestry gave to use this study

for his dissertation. A grant from the Kyösti Haataja Foundation (Osuuspankkijärjestön Kyösti Haatajan Säätiö) has been very helpful during the course of the study.

To list all people and organizations involved during this study is not possible. However, the author wishes to extend his gratitude to them. The support of the staff at both the Department of Logging and Utilization of Forest Products and the Technical Department of the National Board of Forestry is greatly appreciated. Finally, the author would like to thank his wife Helena, who had the formidable job of translating the Finnish text and who gave additional encouragement and understanding during the many hours spent preparing and finalizing this report.

1. INTRODUCTION

1.1. Study problem

As viewed from the firm, wood procurement begins with wood purchasing and ends with delivery of the wood to the mill. Mill-yard handling and inventories can also be held as a part of wood procurement. Wood can be purchased as standing trees, at roadside or delivered to the mill. When viewed by a Finnish firm, the wood procurement courses of action open to it are shown in Fig. 1. The courses of action open to the forest owner, whether State or private, are presented in Fig. 2. Calculating from forestry statistics published monthly by the Finnish Forest Research Institute, the distributions of industrial cuttings during the 1982-83 and 1983-84 harvesting years were as follows:

	1982-83	1983-84
Private forests		
- stumpage sales	52.8 %	50.3 %
- delivery sales	26.2 %	26.7 %
Company forests	9.0 %	10.0 %
State forests	12.0 %	13.0 %

Almost all wood harvested from State forests was by the delivery sale method; 95 % during 1982 and 1983. The distribution of sale methods and sources, particularly delivery sales from private forests, has a direct effect on the difficulty of wood procurement planning. As the share of delivery sales from private forests increases, planning in wood procurement becomes more difficult due to the more seasonal nature of cuttings and the smaller wood volumes per sale.

Wood procurement is subject to seasonal and multi-year cyclical variations, combined with developments in the forest industry, transport systems, harvesting techniques and the forest itself. The problem is further aggravated in Finland since there are many different wood purchasers with plants at many locations competing for the same wood and a very large number of wood sellers. If only

private forest owners are taken into account, there are about 311 000 forest holdings and the average size is about 33 ha (Yearbook of Forest Statistics 1984). As apparent from Fig. 1 and 2 there are also a wide range of long-distance transport choices available in the Saimaa area. The complexity of the problem makes decision-making in wood procurement and particularly in regard to this thesis, long-distance transport, very difficult. Although this thesis deals with the problem of long-distance transport decision-making, the problem outlined above can also be referred to as a part of the logistics problem in the forest industry.

Himanen (1981) defines logistics for a firm as the arriving, internal and leaving flows of materials and the associated information flows in planning and control. It also includes the physical movement of goods from raw material suppliers, through raw material storages, processing and finished product storages, to the consumer. The objective in logistics is to get the required raw materials, half-finished and finished products to the desired locations at the right time so that from the point of view of a firm, the best possible economic benefit ratio is obtained. Similarly, the objective of long-distance transport decision-making in a firm, should be to strive for the best overall economy of the firm.

A decision-maker can easily underestimate the importance of the cost or effect of long-distance transport on overall production costs, since its direct cost appears to account for only a small percentage of the final product price. For example, calculating from two examples given by Lallukka (1983), the shares of long-distance transport cost of final product price for sawn goods and sulphate pulp are 5.4 % and 7.4 %, respectively. In the Saimaa area long-distance transport accounts for 13 to 24 % of the cost of roundwood delivered to the mill, depending on the wood assortment in question. However, it is a vital part of wood procurement in which savings can be made or severe losses incurred. Himanen (1981) states that a greater return

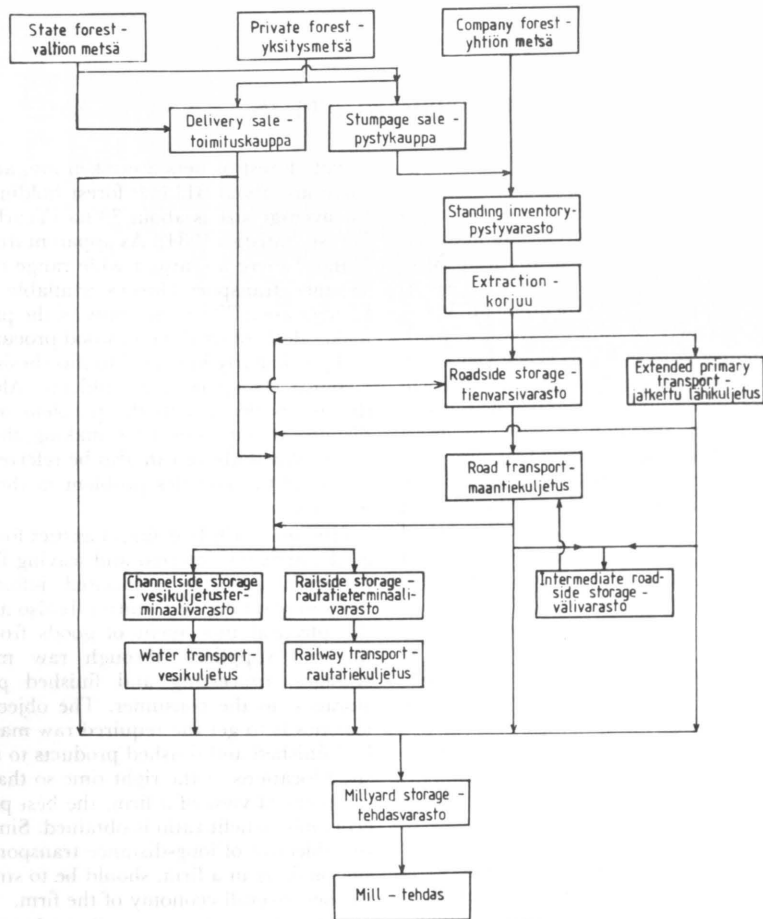


Fig. 1. Wood procurement courses of action open to a wood purchaser in Finland.
Kuva 1. Puun ostajan vaihtoehdot puunhankinnassa.

can be earned on money invested in logistics systems rationalization, than on production systems rationalization.

Finland is very dependent on the export of forest products, but due to competition on world markets, a firm is quite limited if trying to increase the selling price of its goods (Roitto 1975, Simula 1983). Also, regional stumpage prices prevail in Finland, resulting mainly from stumpage agreements negotiated

between forest industry and wood sellers' associations (Roitto 1975). Thus, at least in the short-term, a firm is faced with more or less fixed prices for its products and fixed stumpages for its wood raw material. Due to the above, a Finnish firm must strive to remain competitive through cost savings in its own wood procurement organization and by obtaining the best possible return on money invested in wood through efficient mill pro-

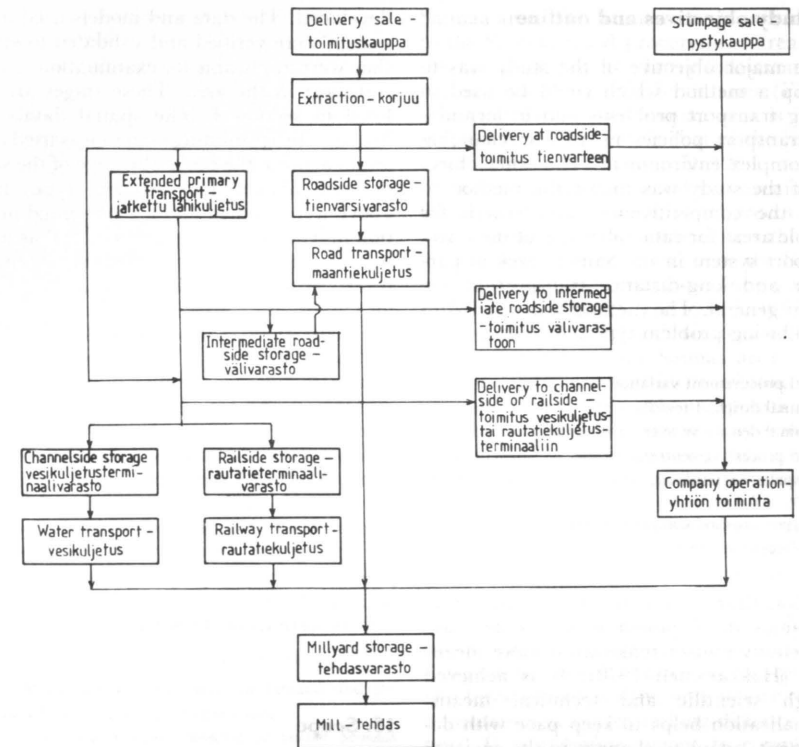


Fig. 2. Courses of action open to a wood seller in Finland.
Kuva 2. Puun myyjän toimitusvaihtoehdot.

cesses and production of high value products. Also, long-distance transport acts as the interface between the operations in the forest and at the mill. As a result, the importance of long-distance transport on the overall economy of a firm is much greater than would be apparent from its share of final product price. In addition, all phases of wood procurement, as well as their effect on the final product yield, must be accounted for in any long-distance transport policy of a firm.

On the other hand, it is expected that a wood seller generally wants to obtain the highest possible stumpage or delivery price for his wood. Thus, if profit maximization

(i.e. stumpage maximization) is the goal of the forest owner and he is selling by the delivery sale method at the mill or roadside, he would be expected to strive for long-distance transport cost and/or extraction cost minimization. The State on the other hand must take into account the well-being of the national economy. Taking the above factors into account, the objective set for long-distance transport decision-making in the study, was to strive to minimize the cost of wood procurement in an ever-changing and complex environment, while also accounting for its impact on wood processing costs and product yield.

and the National Board of Forestry. Geographical data of municipalities were from the National Board of Survey. Basic data for the spatial database were from special edition 1:200 000 scale maps of State forests, printed by the National Board of Survey. Costs for

truck, tractor and railway transport were from tariff tables published for 1983. Current data about wood transport and harvesting were also obtained from Metsäteho (the Forest Work Study Section of the Central Association of Finnish Forest Industries).

Table 1. Volumes of wood delivered to mills in East Finland by wood assortments (includes imported wood).
Taulukko 1. Tehtaalle toimitetut puumäärät Itä-Suomessa puutavaralajeittain (sisältää myös tuontipuun).

Year vuosi	Mill delivered wood volume - toimitetut puumäärät (1000 m ³)						Total yhteensä
	Softwood logs järeeä havupuu	Hardwood logs järeeä lehtipuu	Other softwood muu havupuu	Other hardwood muu lehtipuu	Forest chips metsähake	Industrial residue teollisuusjätetä	
1982	3 882	692	2 966	1 967	791	1 323	11 621
1981	4 130	805	3 293	2 618	192	1 186	12 224
1980	5 063	834	3 422	2 449	39	1 699	13 506
1979	4 800	684	2 896	2 170	37	1 319	11 906

volume of imported wood in 1982 - tuontipuun määrä vuonna 1982, 1.296 M(m³)

(Yearbook of Forest Statistics 1981, 1982, 1983, 1984)

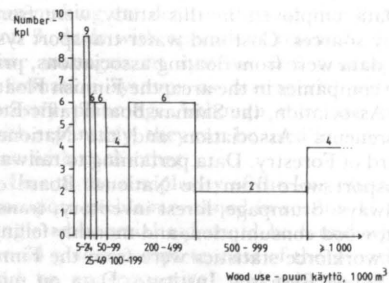


Fig. 4. Distribution of processing centres/points by wood-use (roundwood and forest chips) size classes.
Kuva 4. Puunjalostuskeskusten/-pisteiden puun käyttö.

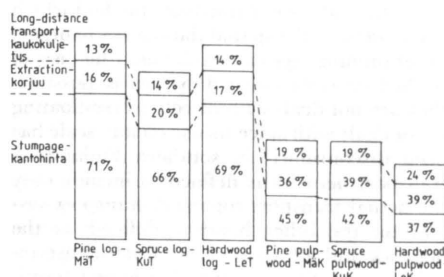


Fig. 5. Average composition of wood costs by wood assortments delivered to the mill in the Saimaa area.
Kuva 5. Puutavaralajeittainen keskimääräinen tehdashinnan jakauma Saimaan alueella.

2. DECISION-MAKING ENVIRONMENT AND FACTORS

2.1. Wood procurement environment

2.1.1. Wood processing industry

The wood industry in the area ranges from small portable sawmills using a few hundred m³ of wood for domestic use, to large integrated wood processing complexes capable of using in excess of 2 M(m³)/a. If sawmills using in excess of 5 000 m³/a are only accounted for, 40 sawmills were found to be operating in the area in 1983. However, it is possible that some small sawmills using in excess of 5 000 m³ were not accounted for: i.e. no information of their existence was available from any of the sources. There were also 19 wood-based panel mills (plywood 13, chipboard 5, particle board 1) and 10 pulp and/or paper mills in operation in the area. Wood processing mill locations are shown in Fig. 6 (p. 16). In all, there were 37 separate wood processing centres/points requiring various volumes of wood. Wood volumes used by the forest industry in East Finland during 1979 to 1982 are shown in Table 1. Fig. 4 presents a histogram showing the distribution of wood processing centres/points by wood volume requirements (roundwood and forest chips) during a good¹ year. We can see that the majority (57 %) of the centres/points require less than 100 000 m³/a. The mills in the Saimaa area account for about 25 % of industrial wood consumption in Finland. Total annual consumption of industrial roundwood and forest chips during a good year is slightly greater than 13 M(m³). Mill residues are also used to a large extent but their transport was not included in the study. Many other firms procure wood in the area in addition to the firms with mills in the area. Aarne (1981) gives the following data for the number of buyers of industrial roundwood in 1979 for the five major forestry board districts in the area: Southern Savo 72, Southern Karelia 65, Eastern Savo 42, Northern Karelia 57 and Northern Savo 51.

2.1.2. Wood procurement characteristics

The total land area in the Saimaa area is 44 580 km² and the lake coverage is 20.5 % (Seuna 1971). From the 7th national forest inventory (Kuusela and Salminen

1983, Yearbook of Forest Statistics 1984), the annual allowable drain for the area can be estimated to be about 15 M(m³). Total drain (commercial cuttings, fuelwood cuttings, domestic use, export, logging residues, floating losses and mortality) in East Finland during 1981 was 13.88 M(m³) (Huttunen 1983).

In Finland, 98 % of the volume logged is by the shortwood method (Salminen 1983). In the shortwood method the various wood assortments are cut in the stump area and in most cases a forwarder is used for forest transport. The use of agricultural tractors is more or less restricted to farmers who harvest their own wood and sell by the delivery sale method. Forwarders account for about 88 % of forest transport, while agricultural tractors and skidders account for about 10 % and 2 %, respectively (Vesikallio 1981). At the end of 1981 about 20 % of the annual volume harvested by companies and the State was by mechanized means; about 16 % of the total harvested volume (Vesikallio 1981). Due to the extraction methods in use, wood at roadside is more or less always found as wood assortments cut to lengths, with pulpwood and logs piled separately by species.

The average composition of wood costs by wood assortments delivered to the mill in East Finland is presented in Fig. 5. Stumpage forms the major part of the wood cost at the mill for logs, while extraction and long-distance transport form the major part for pulpwood. Average township stumpages from Rauskala (1984), were used to calculate the following average stumpages (weighted by township area) for the area during the 1982-83 harvesting year:

- pine logs	- 160.91 FIM/m ³
- spruce logs	- 131.34 "
- hardwood logs	- 153.45 "
- pine pulpwood	- 78.52 "
- spruce pulpwood	- 78.01 "
- hardwood pulpwood	- 60.46 "

2.1.3. Long-distance transport

Table 2 presents the volumes delivered to mills in East Finland from 1972 to 1982. As can be seen, the variations in the volume of wood delivered to mills in the area has fluctuated quite widely during the past years. This is due to market conditions, with cycle peaks occurring during 1974 and 1980. The largest change between successive

¹ Sum of wood use for individual mills based on maximum raw wood consumption during 1980 to 1982.

Table 2. Volumes of wood delivered to mills by transport method: includes roundwood, forest chips, industrial residues and imported wood.

Taulukko 2. Tehtaalle toimitetut puumäärät kuljetustavoittain: sisältää koti- ja ulkomaisen raaka- ja jätteen.

Year - vuosi	Tractor - traktori		Truck - auto		Railway - rautatie		Water - vesi		Total - yhteensä	
	1000 m ³	%	1000 m ³	%	1000 m ³	%	1000 m ³	%	1000 m ³	%
1982	2	0	5 618	48	1 617	14	4 384	38	11 621	100
1981	3	0	6 202	51	1 742	14	4 277	35	12 224	100
1980	31	0	6 689	50	2 264	17	4 522	33	13 506	100
1979	25	0	5 685	48	1 764	15	4 432	37	11 906	100
1978	26	0	4 406	47	1 155	12	3 896	41	9 483	100
1977	35	0	4 004	40	1 663	16	4 430	44	10 132	100
1976	43	0	3 368	35	2 338	24	3 899	41	9 648	100
1975	79	1	3 413	35	2 066	21	4 246	43	9 804	100
1974	122	1	8 306	52	2 623	17	4 778	30	15 829	100
1973	259	2	4 880	42	1 447	13	4 896	43	11 482	100
1972	210	2	3 936	41	915	10	4 514	47	9 581	100
\bar{x}	78		5 137		1 781		4 389		11 383	
s(+/-)	86		1 534		513		310		1 981	
CV		110		30		29		7		17

(Yearbook of Forest Statistics 1974a, 1974b, 1975, 1976, 1977, 1978, 1979, 1980, 1981, 1982, 1983, 1984)

years occurred between 1974 and 1975; a reduction of 6 M(m³) or 38 % from the volume delivered during the preceding year. The coefficient of variation (CV) for the whole period is 17 %. Also apparent is that the volume delivered by tractor has decreased steadily and is more or less insignificant in the area today. The volume delivered by water transport has remained fairly steady and the annual variations in total wood requirements have not had too much effect; the CV is only 7 %. The volume delivered by railway has varied widely and this is due to the combined effect of annual wood requirement variations and tariff policies; if the tariff schedule overly increases wood is easily transferred to truck transport. Truck transport seems to be the method which is the most susceptible to wood requirement variations.

The average transport distances and average direct transport costs for the long-distance transport methods available are presented in Table 3. The values given in Table 3 do not include initial transport to railway or water transport terminals. The per cent and absolute cost increases in average direct transport costs from 1972 to 1982 are as follows:

- tractor	18.2 %/a	116.4 p/(m ³ · km)
- truck	10.9 "	22.8 "
- railway	11.5 "	6.9 "
- water	11.6 "	4.8 "
- wholesale price index	12.8 "	"

When transport distance is also accounted for to obtain the transport output. Since the average transport distance is longer for both water and railway transport, their share of transport output is larger than for mill delivered volume. During 1982, the shares of transport output for truck, railway and water transport in the area can be calculated to be 23 %, 22 % and 55 %, respectively. For the country as a whole the corresponding values were 46 %, 21 % and 33 % (Laajalahti and Pennanen 1983).

Mikkonen (1984) found that tractor transport was competitive with truck transport for distances less than 2 km if an entire truck-trailer load could be loaded direct (i.e. shuttle loading not required). If a trailer cannot be used then the distance is increased to about 7 to 13 km depending on whether the wood is transported to a dumping terminal or directly to the mill (Mikkonen 1984). Similarly, when a truck-trailer unit could be used and the loading site class was 2, it was found that with 1983 costs extended primary transport by tractor was only competitive up to distances of 4.5 to 8.0 km, depending on the wood assortment and destination (e.g. mill, railway terminal with or without stationary crane, dumping terminal) in question. Vesikallio and Salminen (1978) state that in Finland on the average, the transport of logs by truck transport and bundle floating compete with one another over distances of 90 to 200 km, after which floating is cheapest in all cases. For pulpwood the

Table 3. Average long-distance transport distances and average direct transport costs in Finland.

Taulukko 3. Keskimääräiset kaukokuljetusmatkat ja välittömät kuljetuskustannukset Suomessa.

Year - vuosi	Tractor - traktorilla		Truck - autolla		Railway - rautateitse		Water - vesitse	
	km	p/(m ³ ·km)	km	p/(m ³ ·km)	km	p/(m ³ ·km)	km	p/(m ³ ·km)
1982	10	143.2	74	35.3	297	10.4	226	7.2
1981	13	101.7	75	34.2	289	9.7	249	6.5
1980	17	64.2	81	26.1	255	10.1	253	6.6
1979	14	75.5	84	23.0	246	9.0	236	5.0
1978	21	51.3	88	19.7	248	7.4	239	4.5
1977	16	48.7	81	20.2	250	7.2	231	4.7
1976	19	61.1	82	19.5	232	6.9	249	4.3
1975	16	66.2	72	19.8	178	7.3	243	4.2
1974	17	46.3	71	16.9	174	5.6	205	2.8
1973	18	34.8	67	14.0	237	3.6	211	2.8
1972	22	26.8	64	12.5	214	3.5	209	2.4

(Yearbook of Forest Statistics 1974a, 1974b, 1975, 1976, 1977, 1978, 1979, 1980, 1981, 1982, 1983, 1984)

corresponding distances are 60 to 120 km, after which floating is cheapest. Vesikallio and Salminen (1978) also state that railway transport is only competitive with truck transport once a distance of 200 km is reached and is not competitive with bundle floating if both methods can be used.

In the Saimaa area, railway transport is not used to as great an extent as truck or water transport to delivery wood harvested in the area to mills in the area. Of wood delivered by railway to mills in the area during 1980 to 1982, 25.3 % was imported wood (mainly from the Soviet Union) and 30.1 % was from other watershed areas (section 53., p. 56). Similarly, of wood dispatched from railway terminals in the area during the same period, the majority (63.8 %) was transported to mills outside the Saimaa area. This was mainly to mills in the southern part of the Kymi River watershed and on the coast of the Gulf of Finland; 55.0 % of the volume dispatched to terminals outside the area. Internally dispatched and delivered wood by railway was generally between areas where floating was not possible or a poor floating wood assortment was in question.

214. Long-distance transport system

In water and railway transport initial road transport by truck or tractor is required in almost all cases. In the Saimaa area the minimum average road distance to an active water transport terminal was 25 km, while to an active railway terminal it was 26 km. There were 88 water transport and 99 railway transport terminals servicing the area. However, during 1980 to 1982 only 86 of the water transport terminals were in continuous use.

Also, only 82 of the railway terminals were in use. Fig. 6, 7 and 8 present road, water and railway transport networks and terminals available.

Inland waterway channels are classified into four classes:

- I s deep channels depth \geq 4.2 m
- II s main channels 2.4 m \leq depth < 4.2 m
- III s side channels depth < 2.4 m
- IV s floating channels specified under floating regulations for each watershed but unmarked on inland waterway maps

The shallowest marked channel can be held to be 1.2 m in most cases. All channels have a 0.6 m safety margin, which can be added to the above values to get the actual channel depth. The channel depth in inland waterways is measured from the lowest water level during the navigation season (NW_{nav}). The minimum water depth required in bundle floating is 3.0 m. However, a depth of 2.5 m is generally sufficient in the upper reaches of the waterway. Table 4 presents waterway channel statistics for all of Finland. Of marked inland channels, 48 % lie in the Saimaa area, while the corresponding value for all inland channels is 35 %. The distribution of channels by classes in the Saimaa area is as follows (Väylätalasto . . . 1979):

- I s (\geq 4.2 m)	755.4 km
- II s (2.4-4.1 m)	1 123.1 km
- III s (0-2.3 m)	1 063.7 km
- total marked channels	2 915.2 km
- IV s (0 m -)	317.9 km
- total channel length	3 233.1 km

Table 4. Waterway channel lengths in inland and coastal waters in Finland by channel classes.

Taulukko 4. Sisävesi- ja rannikkoväylien pituudet.

Channel - väylä	Channel class väyläluokka	Length pituus, km
Inland waterway sisävesiväylät	Is - IIIs	6 069
Inland waterway sisävesiväylät	IVs	3 110
Coastal waterway rannikkoväylät	Im - VIIm	6 465
All channels kaikki väylät	marked merkityt väylät	12 534
	all classes kaikki luokat	15 644

(Väylätilasto . . . 1979)

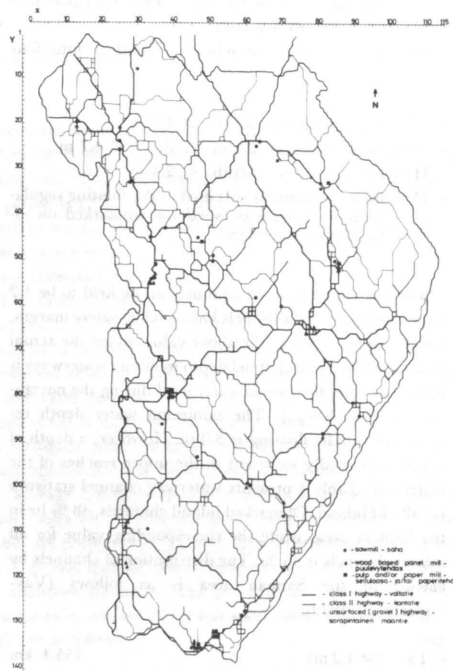


Fig. 6. Major road network and mill locations in the Saimaa area.

Kuva 6. Päätiät ja tehtaiden sijainti Saimaan alueella.

The total length of mainline railway servicing the area, determined from the railway information matrix, is about 1 400 km. From township public road information (Road and waterway . . . 1983) the length of public roads in East Finland in 1982 can be calculated to be 14 531 km. Unfortunately, an accurate estimate of the length of private roads in Finland today is lacking. Wiiala (1962) estimated that there were 375 000 km of private roads in Finland in 1961. If we add to this forest roads built since 1961 (about 75 000 km), we obtain a private road estimate of 450 000 km. If we assume that about 20 % of private roads have been built in the Saimaa area, since about 20 % of public roads lie in the area, we can estimate that the total road length is about 105 000 km. This gives us a road density of 23 m/ha. Wiiala (1962) stated that the average road density in Finland in 1961 varied from 10 to 30 m/ha, with public roads forming 10 to 15 % of all roads. Calculated from above we get the share of public roads in the area to be 12.6 %. From the above we can see that the area is well serviced by all three long-distance transport methods.

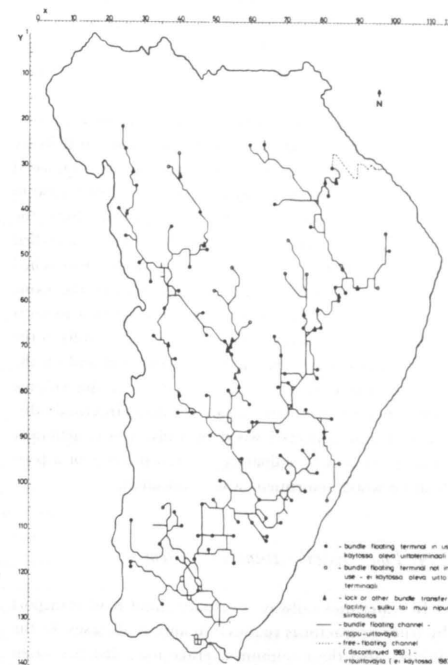


Fig. 7. Water transport channels, terminals and transfer facilities in the Saimaa area.

Kuva 7. Vesikuljetusväylät, terminaalit ja siirtolaitokset Saimaan alueella.

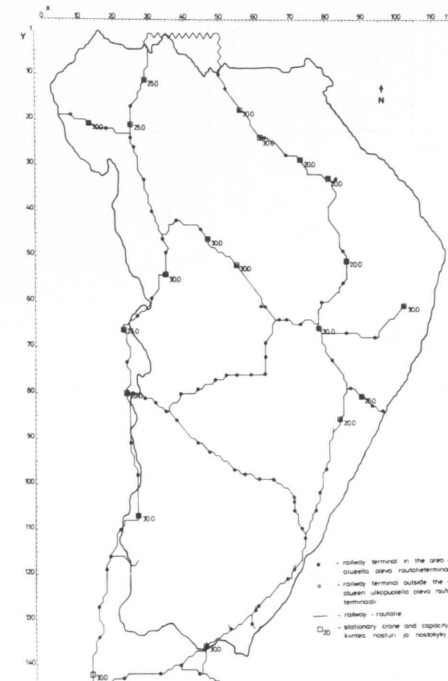


Fig. 8. Railway network and terminals in the Saimaa area.

Kuva 8. Rautatieverkosto ja terminaalit Saimaan alueella.

- 1) holding costs - i) interest cost
- ii) storage cost
- iii) handling cost
- iv) insurance cost
- v) depreciation/deterioration cost
- 2) set-up costs or ordering costs
- 3) shortage or penalty costs
- 4) production costs and purchase prices
- 5) demand
- 6) lead-time (e.g. for raw materials the period between order and arrival)

As apparent from the above list, interest cost only forms one of the many factors which would affect inventory policy. However, when the minimization of interest cost forms a high priority then minimum inventories and hot-logging techniques are favoured. As will become apparent, hot-logging techniques are only applicable when we have certainty in wood procurement. The business economic factors which should be accounted for when choosing a long-distance transport policy are as follows:

- 1) availability of wood for purchasing
- 2) harvesting schedule (i.e. availability of wood at roadside)
- 3) harvesting methods in use and costs
- 4) direct transport costs
- 5) time required for transport of wood from forest to mill
- 6) technical factors in regard to presence of suitable transport routes and effect on wood quality
- 7) wood holding costs (includes deterioration cost also)
- 8) dependability and service provided by each method
- 9) wood demand at the mill

Since private forests form the major source of wood used by the forest industry, the timing when wood becomes available is an important factor. Wood sales do not occur uniformly throughout the year. For example, during the 1982-83 harvesting year 71 % of the objective for stand marking for cutting was reached by the beginning of February (Tehotoimilla . . . 1983). Since stand marking generally begins in earnest in the fall, we can see that the majority of markings occur over a relatively short period. In addition to the above it is difficult to predict how wood sales will develop from one harvesting year to the next. This has been the case lately where the industry requirements have been larger than the volume of wood coming up for sale. Wood shortages at the mill have become an acute problem at many Finnish mills today. Mills which have resorted to minimal inventories are the ones most susceptible to wood shortages; excluding mills with small wood requirements. Mills which still employ water transport are able to keep larger inventories and thus have been able to draw on wood stored in

22. Factors affecting long-distance transport policy

22.1. Business economic factors

When choosing the most appropriate transport policy, a firm should strive to achieve the best overall economic result over the long-term. The inventory policy has a direct effect on the transport methods applicable. For example, if a firm wants to take a large risk of running out of wood, but keep holding costs at a minimum, it would choose minimum inventories and thus hot-logging techniques; for which road transport is most appropriate. In any decision on the most appropriate inventory the following factors must be accounted for:

water storages. Living hand to mouth also results in transport without regard to cost, since wood must be transported directly to the mill once it becomes available.

Although in past years there has been an attempt to schedule harvesting operations uniformly throughout the year, 64 % of commercial cuttings still occurred during November to April in the 1983–84 harvesting year: i.e. during the winter season. During the 1982–83 harvesting year the corresponding value was 68 % (Table 7, p. 50). The spring break-up period in April–May also has its effect on the uniform supply of wood from roadside (Fig. 9). The share of delivery sales from private forests of all industrial wood cuttings has increased to 26.7 %, from a low of 16.8 % in the 1980–81 harvesting year. With the increase in delivery sales from private forest, it appears that variations in wood procurement have also increased (section 52., p. 49). Also, there are more widely dispersed (i.e. smaller) wood storages at roadside. The average volumes sold by sale method from private forests in the 1982–83 harvesting season were as follows: delivery sales 76.5 m³/sale and stumpage sales 352 m³/sale (Rauskala 1984). Also, wood must not be stored in the forest during late spring and summer. This is due to insect damage directly to the wood and to surrounding stands, as well as damage due to blue stain fungi.

The harvesting methods in use also have an effect. All solutions in wood procurement should fit into the entire chain and not cause unreasonable cost elsewhere. In most cases transport forms a service function and must meet the demands imposed upon it by the wood assortments required at the mill and the conditions prevalent at the forest end. Seldom is wood harvested in a form to minimize only transport costs.

Due to the many factors mentioned above, the transport method giving the lowest direct cost is not always the one chosen. However, direct cost forms one of the basic criteria in transport method choice. The direct cost of truck transport to the mill is straight-forward; we have costs of loading, transport to mill and mill receiving. When dealing with railway or water transport we have many additional cost components. In both methods we have the additional cost of transport from the forest to the terminal, as well as terminal operational and maintenance costs. In bundle floating we also have the additional costs of bundle bindings, bundling and raft formation.

In bundle floating 40 to 60 % of the total direct cost is due to initial transport to the terminal, while terminal operations account for 15 to 20 %. The actual bundle towing operation only accounts for 20 to 30 % of the total direct cost, while the corresponding value for mill receiving is 5 to 10 % (Puutavaran uiton . . . 1980). From the above we can see that 70 to 80 % of the total direct bundle floating cost occurs over approximately 15 % of the total distance for the method. Vesikallio and Salmi-

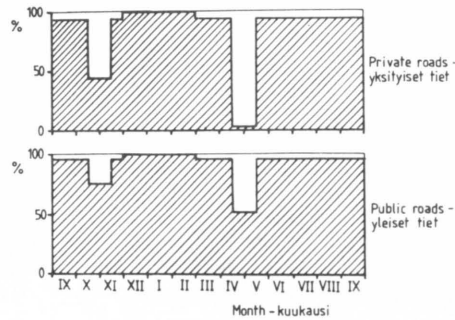


Fig. 9. Availability of roads for transport throughout the year in southern Sweden.

Kuva 9. Teiden käyttekelpoisuus eri vuodenaikoina Etelä-Ruotsissa.

(Ärvidsson et al. 1978)

nen (1978) give the cost distributions for the methods presented in Fig. 10.

Road transport is the most flexible of the three methods. This is because we are dealing with small truck-load units. In railway transport, discounts can be obtained by dispatching larger volumes of wood at a time (e.g. 1 000 m³ per train load) and throughout the year. However, time is required to gather the above mentioned volume at a railway terminal. Time is also spent in transporting the wood to the railway terminal. Water transport has the largest delay time of the three methods. One reason is due to seasonal factors; the waterways freeze over during winter and floating is only possible for 5 to 6 months from about the second week in May to mid November. The navigational period for water transport can be extended through the use of barges, however.

As mentioned earlier, the additional cost of interest on the wood investment is one factor affecting long-distance transport policy. For small unintegrated operations road transport is solely relied on. For small firms only a small buffer inventory is required and they are flexible to variations in market demands and wood supply. Since they have a low capital investment, as opposed to a pulp and paper mill, wood shortages do not pose a serious consequence. Also, the area from which wood is procured is quite small and thus suited to road transport. The cost of interest thus forms a much larger criteria for smaller firms.

When dealing with a large mill complex and thus large wood requirements, the importance of solely interest cost on money invested in wood decreases. The cost of capital

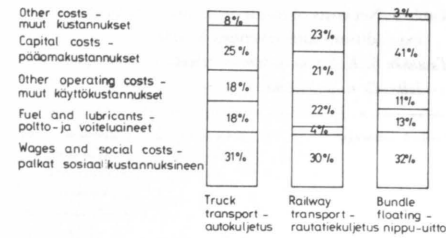


Fig. 10. Distribution of direct costs by cost types in truck and railway transport, and bundle floating.

Kuva 10. Välittömien kustannusten jakautuminen eri kustannusryhmiin.

(Vesikallio and Salminen 1978)

invested in the mill complex (i.e. cost of an idle mill complex), and start-up and shut-down costs require the presence of a buffer storage to ensure against wood shortages. The size of the buffer storage depends on the degree of uncertainty present in wood procurement and wood demands at the mill (i.e. market demand). Storages are also important to even out discontinuity between wood demanded and wood available on the market (i.e. lead time) between years. Trying to juggle 311 000 forest owners to sell or not sell an additional 5 or 10 M(m³) from one year to the next is not a simple task and does not occur instantaneously. As mentioned earlier, the seasonal nature of cuttings also results in wood inventories. Another point to remember when dealing with large wood volumes is that, even though truck transport is the quickest method to get a load of wood to the mill, the movement of an entire inventory by the other methods can be competitive. For example, the average raft size on Lake Saimaa is slightly larger than 20 000 m³: i.e. over 500 truck loads.

The choice of a long-distance transport method in the Saimaa area also assumes that the method services the point of dispatch and the destination. Once wood is transferred from road transport to actual railway or water transport, it should be delivered by that method to the destination. This is due to the high interface costs when transferring from one method to another. For example, lifting bundled wood out of water and onto truck costs from 7 to in excess of 10 FIM/m³, depending upon the conditions. This is equal to about a 30 to 40 km marginal increase in truck transport distance.

The use of concentration yards was not accounted for. Since water and railway transport are possible to the mills for which the use of concentration yards would come into question, it would seem best to use them and

take advantage of their built-in storage potential, while also benefiting from their cheaper direct transport costs. For this reason, the use of concentration yards to service only truck transport in the area is questionable. Also, Erdle et al. (1982) found that the savings derived from the use of a concentration yard in Canada were 14 000 CAD/a, while the extra costs for transportation and handling were 78 000 CAD/a. Generally, road transport can be used in all cases except when extraction occurs in island or shoreline forests accessible only by water.

Certain poorly floating wood assortments, for example chips, fresh hardwood pulpwood, birch logs and small diameter fresh softwood pulpwood, limit the use of bundle floating if additional floatation or barges are not used. The extent of wood deterioration over time differs between transport methods also. Wood deterioration has a direct effect on the final product value and processing costs. Generally, if wood must be stored, it should be stored in water to minimize deterioration due to fungi and insects. Wood stored on land (i.e. at roadside, railway terminal or millyard) would have to be continuously sprinkled with water or chemically treated. In bundle floating 10 to 15 % of the bundle is above the water's surface and thus subject to wood damaging agents and drying. Bundle rotating or sprinkling would reduce the above to a minimum (Tolonen 1983). Storage also has effects on barking, pulping processes, chemical requirements, pulp quality, yield of side products (e.g. pine oil and turpentine), and energy yield from bark and black liquor. Lönnberg (1983) states that there is very little value loss for water stored pine and birch used in sulphate pulping, but spruce used in sulphite pulping should be stored for as short as possible. As should be apparent, direct delivery of wood to the mill would give the best results. However, if storage is required water storage gives the best results (Vesikallio 1979, Lönnberg 1983). Also, since there is usually limited space at millyards, bundle floating allows an excellent opportunity to alleviate millyard congestion.

By service we mean the period when a method can be used. As mentioned earlier, the use of water transport is limited to the navigational season. Dependability reflects the susceptibility of a method to environmental and external factors. For example, waterways do not wear with use and water transport can be held as more or less totally a domestic (as opposed to import based) transport method.

Although it is best to view the available transport methods as forming an integrated transport system, it is also beneficial to view the methods as competitors. In this way competition is stimulated between the methods and costs are kept better in line. If one method becomes more competitive, the other methods must follow suit or lose their share of the transport volume.

222. National economic factors

When examining transport methods from a national economic point of view one must account for the investment required to establish, maintain and operate the different transport systems. The productivity of various resources (e.g. labour, energy and capital) must also be accounted for. A transport method's effect on the environment, and the ratio between domestic and imported materials required by each method are other factors. The dependability and applicability of each method in uncertain conditions should also be accounted for.

Heikkerö (1979) makes a comparison between the balance of expenditures and income for the State by transport method. According to Heikkerö (1979), in 1977 70 % of the State's expenditure on truck transport was recovered through taxes directly related to truck transport. To cover expenditures fully, a 5 % increase in truck transport tariffs would have been required. The corresponding values for railway transport and floating were 40 % and 20 to 40 %, respectively. Table 5 gives the net costs to the State by transport methods.

Puutavaran uiton . . . (1980) and Pertovaara (1982) give the additional information listed below, comparing the transport methods from a national economic point of view:

- 1) depending on conditions, the man-day productivity in floating is 7 000 to 25 000 m³ · km and for truck transport it is about 5 000 m³ · km; a corresponding value for railway transport is not available
- 2) the productivity for capital invested in floating equipment in 1980 was 265 m³ · km/1.00 FIM, while for truck transport it was 35 m³ · km/1.00 FIM and for railway transport (capital cost of railway cars only included) it was about 28 m³ · km/1.00 FIM
- 3) the use of fuel in actual transport by truck transport is 10 times greater than for bundle floating per m³ · km, while for railway transport it is 3 times greater
- 4) when taking into account energy required for actual transport, transport network construction and maintenance, and building the actual transport equipment, the energy requirements (oil equivalent, kg/ (m³ · km)) for truck and railway transport and floating are 0.042, 0.040 and 0.003, respectively
- 5) a decrease in the trade balance of 20 million FIM would result if 5 M(m³) were transferred from water transport to truck transport; inflated to 1984 costs about 30 million FIM
- 6) the domestic share of floating is 85 %, while for truck transport it is 30 %
- 7) environmental effect is only significant in free-floating; in bundle floating little water surface area is required and loss of bark and leeching of chemicals into the water is minimal due to bundling, however there is a local effect at large dumping terminals and mill water storages

Table 5. Net costs of transport methods to the State after expenditures and revenues in 1980.

Taulukko 5. Kuljetusmenetelmien aiheuttamat nettokustannukset julkiselle vallalle 1980.

Method - menetelmä	Net cost to State julkisen vallan nettokustannukset, p/(m ³ ·km)	National economic accident cost yhteiskuntatalou- dellinen onneto- muuskustannus, p/(m ³ ·km)
Truck transport <i>autokuljetus</i>	1.2	0.50
Railway transport <i>rautatiekuljetus</i>	5.8	0.04
Inland vessel transport <i>sisävesialustien</i>	1.0	—
Bundle floating <i>nippu-uitto</i>	1.0	—

(Pertovaara 1982)

- 8) transferring wood to roads, from either railway transport or bundle floating, would result in greater environmental effects and roadways would be further stressed near built-up areas, thus resulting in increased traffic risks
- 9) land storage of unbarked wood in the summer can cause damage to surrounding forests, while water stored wood generally has little effect, unless large quantities are stored unbarked near coniferous forests over a long time since 10 to 15 % of the bundle volume is susceptible to insect damage unless the bundles are rotated or sprinkled with water
- 10) the majority of waterway channels are usable for floating with little or no improvements required; also maintenance of waterways is minimal since they do not wear
- 11) a waterway transport network is the most dependable method in times of crisis

23. Rationalization of wood transport in practice

As mentioned in section 211. (p. 13), there are many firms with mills at different locations procuring wood in the area. In floating, the irrational operation of many different firms on the same channels became apparent quite earlier in industrial wood procurement as we know it today. Thus, the Yymi Floating Association was formed in 1873 (Seppänen 1937). In the Saimaa area, Pielis Elfs Flöttings Aktiebolag Oy was formed in 1886

by two companies floating on the Pielis River. Gradually, a number of floating associations and companies were formed in the area. In 1930 the Savo Floating Association and Northern Karelian Floating Association were formed (Seppänen 1937), and are still in operation today. The associations are responsible for floating in the northern half of the area and at two channel bottlenecks in the southern half (cooperative floating). Rationalization of private floating in the southern half of the area has also occurred and only two companies, Tehdaspuu Oy and Enso Gutzeit Oy, have floating operations today. Floating associations are non-profit organizations who transport wood in an area and distribute costs to the member companies according to their share of the transport output. In the private floating area, contracts are made between the companies with floating operations and other companies with wood to be transported.

The formation of Tehdaspuu Oy, which started operations in 1968, was another step in rationalization of wood procurement in the area. It is responsible for procuring wood for four separate companies. This cooperative venture allowed the elimination of overlapping organizations. Cross-hauling by the four companies could also be eliminated.

Tehdaspuu Oy and Enso-Gutzeit Oy, the two largest wood procurement organizations in the area, also employ optimization models for aiding long-distance transport decision-making. The decision areas are generally based on municipal areas and employ average costs from the areas to mills. Metsäteho, the Forest Work Study Section of the Central Association of Finnish Forest Industries, has also developed a number of methods for aiding wood procurement decision-making (Peltonen and Väisänen 1972, Eskelinen and Peltonen 1977, 1980, 1982, Eskeli-

nen et al. 1981, 1984, Eskelinen 1984). Sääksjärvi (1976) employs game theory for distributing the benefit from cooperative wood procurement among competing firms.

Other rationalization has occurred, resulting through practical experience and research. There have been major developments in truck transport to keep it competitive. This is apparent from section 213. (p. 14). Although railway transport and floating should be less susceptible to inflationary pressures than truck transport (Savolainen and Vesikallio 1974, Vesikallio and Salmiinen 1978), the rate of increase in truck transport costs from 1972 to 1982 was slightly less. In railway transport, special cars have been developed and unnecessary terminals discontinued. Improving the condition of terminals in use has also been another important development (Talkamo 1983). In water transport, floating operations have been concentrated into the main channels, and terminal, towing and transfer facility operations developed (Roitto 1954, Stolpe 1954, Roitto 1958, Roitto 1963, Roitto 1976, Uiton ongelmat ja . . . 1981). Many redundant terminals have been abandoned and today, based on average minimum distance to terminals, the optimum terminal distribution has almost been reached. Only in some individual cases are terminal location improvements required. However, some redundant terminals in both bundle floating and railway systems could be abandoned (section 54., p. 58).

It is beyond the scope of this thesis to go into all the ways in which long-distance transport has been rationalized or to cover the ones mentioned above in any greater detail. The purpose of the above was to give a reader who is unfamiliar with the wood long-distance transport situation in the area an overview of some of the areas in which development has occurred.

3. MANAGERIAL AIDS IN PLANNING

31. Operations research

311. General

In general, operations research (OR) can be held as the use of scientific technique to solve managerial decision-making problems. Management science is often used as a synonym for OR. Dykstra (1984) defines management science (MS) as the application of scientific method to the management of organizations or systems. Some hold OR to be the collection of theoretical knowledge, while MS is the practical application of this knowledge. Dykstra (1984) however, states that there is no clear-cut distinction between the two terms. Schultz and Slevin (1975) also hold OR and MS as synonyms. In this thesis OR and MS are held as synonyms, although OR will only be referred to.

Taha (1982) classes OR as both a science and an art. Although OR largely deals with the use of mathematical techniques for determining the most appropriate course of action out of many, there are other factors which must be accounted for other than just the construction and solution of mathematical models (Taha 1982). For example, there is the difficult to quantify human element in almost all decision-making problems. Schultz and Slevin (1975) stress the implementation gap; although OR is a well developed field, the actual frequency of its use in practice is low, especially when its potential is taken into regard. Gill et al. (1982) also stress the importance of applying OR techniques to practical decision-making problems. A method's utility depends on its ability to solve practical problems (applicability), ease of use (user orientation) and the degree to which it is actually used by management in practical problem solving.

Gass (1983) states that the applicability of OR to solve managerial problems depends on the ability of the analyst to model the decision problem and thus the OR method's ability to compare the extent to which the various alternatives satisfy the objective(s). Gass (1983) also states that the years from 1950 to 1970 were the most productive in using "standard" OR techniques. During this period the majority of OR analysts concentrated on solving technical and operational problems. The above work has continued but the complexity of the problems has increased and OR has been extended to problems dealing with policy formation. According to Gass (1983), many analysts and users question the applicability of OR

methods in the field of policy analysis. There should be no problem in using OR in policy formation as long as we remember that OR is an aid in decision-making and not a source of ready instructions to be followed.

The literature on OR is immense: e.g. at the summer conference of the Society of Computer Simulation in 1983, held annually since 1969, 180 papers on simulation alone were presented and the proceedings entailed 1 131 pages (The proceedings of . . . 1983). Craig and Corcoran (1982) list 135 references dealing with GPSS (General Purpose Systems Simulator). Even if we only take into account forestry related applications we find that the amount of literature is immense. For example, Some words on . . . (1969) lists a number of references dealing with topics ranging from the simulation of stand growth to the evaluation of long-term forestry investments. There is even one reference dealing with the adaptation of an ore mining program to the systematic logging of virgin timber. A bibliography compiled by Martin and Sendak (1973) lists 416 references dealing with OR in forestry. Of the above, 200 references deal with linear programming and 119 with simulation. The majority, 19 out of 27 references dealing with transport, entail the use of linear programming. Mikkonen (1983) states finding over 600 references related to the use of OR in forestry, with the major emphasis on simulation. There have also been a number of symposiums/workshops dealing entirely or partly with the use of OR methods in forestry (e.g. Wardle 1971, Planning systems . . . 1973, Planning and decisionmaking 1973, Integrated inventories . . . 1978, Simulation techniques . . . 1978, Planning and control . . . 1982). A number of extensive operational systems for aiding decision-making or optimization of wood harvesting and transport have been developed (e.g. Newnham 1975a, 1975b, Eskelinen and Peltonen 1977, 1980, 1982, Goulet et al. 1980, Dehlén et al. 1983, Eskelinen 1984). The "TAKU" system for material transports (Tavaran-kuljetusmallin . . . 1974, TAKU-tavarankuljetusmallin . . . 1976), was used to study the feasibility of developing bundle floating in the Kemi River watershed (Nippu-uittomahdollisuudet . . . 1984). In a search of forest harvesting simulation models, Goulet (1979) found 15 references dealing with complete systems and 10 references to modelling of a particular phase. Goulet (1979) also found that eight references dealt with fully developed systems. Although a large number of papers dealing with the application of all OR methods in forestry were reviewed during the study, it is beyond the

scope of this thesis to review and outline them individually.

When reviewing the literature on the use of OR in forestry, it became apparent that initial research dealt mainly with the application of mathematical programming; with the major emphasis on linear programming. This was followed by the increased application of simulation to more complex and unstructured problems. Most recently, the use of spatial information or geographic information systems, coupled with analytic methods (mainly simulation and heuristic programming), has become increasingly frequent. Work in all OR fields has advanced continuously, with new methods being developed to solve a host of different problems. Mikkonen (1983) presents a schematic diagram as to the applicability of different OR methods according to the degree of uncertainty, structure and complexity. For the most unstructured problems with uncertainty, simulation is the most appropriate method. For structured problems with certainty and single objectives, linear programming is the most suited. Methods can also be used in conjunction. For example, the operation of a system can be optimized by using information gained through simulation in mathematical programming. Lussier (1972) states that it has not been possible to find a revolutionary logging system which would reduce costs significantly. This is still true and it appears that management skill, which depends on the ability of the managers and the efficiency of available managerial aids in decision-making and control, is still the most significant factor for keeping wood procurement costs in line.

Of the wide range of OR methods available only mathematical programming, simulation and heuristic programming will be dealt with. Further information on the other methods can be obtained from a text on OR techniques (e.g. Taha 1982).

312. Operations research procedure

Models and modelling form the basis of OR (Taha 1982, Dykstra 1984). A model is an imitation of some object or situation and is used for comparison or for gaining further information about the object or situation itself. There are three major model groups: i.e. iconic, analog and symbolic models. An iconic model is a physical representation of some object or situation: e.g. maps, photographs and three dimensional scale models. An analog model has no physical resemblance of the object or situation being modelled, but corresponds to its functioning: e.g. schematic diagrams, computer models of material flow and tachometer cards. A symbolic model is the expression of abstract thought through the use of

symbols: e.g. mathematical equations and models, writing, and numbers. Modelling itself deals with the formation of models. In forestry we can find all three types of models in continuous use: e.g. forest stand maps, aerial photographs, digital maps, flow charts of organizations, growth equations and stand models.

Dykstra (1976) distinguishes between two types of models used in forest harvesting operations: i.e. forest planning models and policy formation models. Forest planning models provide information as to the expected effect of various harvesting proposals and the point of interest is generally the stand or working circle. Policy formation models, although similar to forest planning models, are more ambitious and are designed to provide information for upper management. The entire forest is the point of interest and the effect of policy choices on overall productivity of the forest is studied. Forest planning models would apply to tactical and operational planning, while policy formation models would apply to strategic planning.

It is important to remember that we do not have OR problems; we only have problems to which OR can be applied. When faced with a problem the first step is to determine what the objective(s) is/are, and identify what variables are present and under the control of the decision-maker. The constraints imposed on the system must also be determined. Before beginning model building, the accuracy desired from the model must be specified. Taha (1982) lists the following phases in an OR study:

- 1) definition of the problem
- 2) construction of the model
- 3) solution of the model
- 4) validation of the model
- 5) implementation of the final results

To the above list, we could add user feedback and follow-up. Once a method is in use, the critique and comments of the users can be beneficial in improving the system (e.g. making it more user oriented) and in locating possible errors in the system. Dykstra (1984) also points out we should distinguish between preliminary (or experimental) models and models developed to aid decision-making. Corcoran and Heij (1982) present the following outline for simulation modelling, which can be used for OR modelling in general:

- 1) idea formulation
- 2) conceptualization
- 3) rudimentary development
- 4) final development
- 5) verification
- 6) validation
- 7) marketing
- 8) utilization monitoring

Verification deals with checking to ensure the accuracy of data and actual data manipulation in the model (i.e. level of confidence). Validation tests congruence between the model results and the real world system being modelled.

Taha (1982) holds the symbolic or mathematical models as the most important model type in OR. Mathematical models assume that all relevant information relating to the problem is quantifiable: i.e. objective(s), variables, parameters and constraints. The general form of the mathematical model is as follows:

$$\text{optimize } z = f(x_1, x_2, \dots, x_n) \quad (1)$$

$$\text{subject to } g_i(x_1, x_2, \dots, x_n) \begin{cases} \geq \\ \leq \\ = \end{cases} b_i, \quad i = 1, 2, \dots, m \quad (2)$$

$$x_1, x_2, \dots, x_n \geq 0 \quad (3)$$

In the above (1) is the objective function, which can be either maximization or minimization, and (2) refers to the general constraints which can be either greater than, equal to or less than the constraining value. The non-negativity restriction (3) ensures that the variables have positive or zero value. Mathematical programming techniques are also often referred to as optimization techniques.

For more complex problems, which are difficult to model or solve mathematically, simulation and heuristic programming have been applied. These methods generally employ models to mimic the functioning of some system. Since both simulation and heuristic programming are wide concepts, a clear distinction between the two is difficult. Classical definitions of simulation broadly refer to it as the study of real systems through the use of working analogies (e.g. Chorafas 1965). Thus we can have deterministic or stochastic models used in simulations of deterministic or stochastic real systems. However, in this thesis simulation is defined as the imitation of the functioning of a system over time and/or using random numbers and probability distributions to produce data used in its models. Simulation does not produce optimum solutions. It is used to determine how some system will react if conditions are changed. Optimization of simulation models is possible, but difficult (Taha 1982). Dykstra's (1976) definition of heuristic programming as the formal and orderly presentation of aids to discovery is used in this thesis. Heuristic programming can be used to mimic a system through "intelligent" handling/manipulation of existing data. Heuristic models search for satisfactory solutions through procedures where movements toward the model's objective are made intelligently and thus the number of iterations required are reduced.

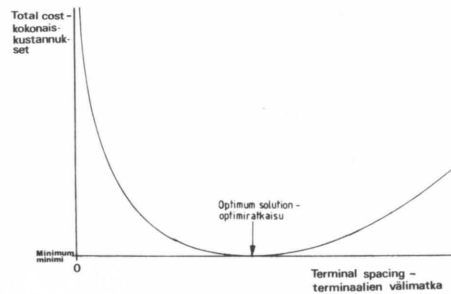


Fig. 11. General trend in the deviation from the value of the optimum solution with deviation from the optimum solution in a terminal density problem.

Kuva 11. Optimaarisuudesta poikkeaman vaikutus. Esimerkki tiheysoptimisesta.

The search for practical or satisfactory solutions is reasonable since in many cases the number of iterations required to find the optimum in mathematical programming is impractically large; each successive iteration results in increasingly smaller moves toward the optimum. Similarly, the deflection of the objective function about the optimum solution is generally quite small and thus heuristic programming solutions are generally quite close to the optimum (Dykstra 1976, Himanen 1981, LeDoux and Butler 1982, Pulkki and Aitolahti 1982). Fig. 11 presents the general trend for the deviation from the value of the objective function with variation from an optimum density solution. For example, when dealing with log deck density in cable yarding or borrow pit spacing when using a mobile crusher in forest road construction, there is generally a lower rate of increase in deviation from the value of the objective function with too sparse, rather than too dense a spacing (LeDoux and Butler 1982, Pulkki and Aitolahti 1982).

313. Mathematical programming

Mathematical programming was briefly introduced in section 312. The methodology of mathematical programming will not be covered here. Further information on mathematical programming can be obtained from Dykstra (1976), Taha (1982), Mikkonen (1983), and Dykstra (1984). This section will deal with some applications of mathematical programming in forestry, and its advantages and disadvantages. The following is a list of various mathematical programming techniques and special algorithms for solving different types of optimization problems:

- 1) Linear programming
 - i) standard linear programming
 - ii) transportation model
 - iii) assignment model
 - iv) transshipment model
 - v) network minimization
 - vi) shortest route problem
 - vii) maximal flow problem
 - viii) bounded variable(s) problem
 - ix) decomposition algorithms
 - x) parametric linear programming
- 2) Integer programming
 - i) cutting plane algorithm
 - ii) branch and bound method
 - iii) 0-1 implicit enumeration
- 3) Dynamic programming
- 4) Goal programming

Due to the very complex nature of wood procurement, the use of standard linear programming, which is the simplest to use of the mathematical programming techniques, must be limited to a very coarse level in wood transport and mill receiving problems (Kanerva 1976). Gillam (1969) goes as far as to state that linear programming is only applicable to hypothetical problems and is of little use in practice. However, when applied properly, and abundant and reliable information is available, standard linear programming can give valuable information and thus aid decision-making. There are many short-comings in standard linear programming and some of them will be discussed below. A number of the other mathematical programming methods listed above have been developed to cope with the disadvantages inherent to standard linear programming.

The major advantage of linear programming, and mathematical programming in general, is that it is a well known and documented field (Newnham 1975a). The methods also optimize the objectives set on the system according to conditions and constraints imposed on it. A number of adaptations of linear programming have been made to alleviate some of its short-comings. For example, Dykstra (1976) employs heuristic programming to eliminate feasible but poor solutions to reduce the number of iterations required in solving the linear programming problem. In this way the solution of large timber harvesting layout problems was made feasible. Integer programming takes into account non-divisibility. Goal programming on the other hand takes into account multiple and conflicting goals. For decision-making under uncertainty, Thompson and Haynes (1971) present a partially stochastic linear programming model. The model can give the decision-maker information, for example, as to the probability of the cost being above or below some level based on subjective probability distributions.

Mikkonen (1983) compares standard linear programming, parametric linear programming, goal programming and integer programming as tools in choosing

between forest harvesting systems. He found that goal programming and standard linear programming were the most applicable methods. One point to remember about linear programming is that it allocates fractional amounts. This may be impractical in practice and thus integer programming would be required. On the other hand, normal integer programming techniques are capable of satisfactorily solving problems with a maximum of about 100 integer variables (Dykstra 1976). However, Dykstra (1976) does mention Martin's method, by which a 0-1 integer programming problem with about 7 000 variables and 150 constraints was solved. Current standard linear programming software available for a UNIVAC 1100/60 size computer are capable of solving problems with a maximum of about 3 000 inequality constraint equations (UNIVAC 1100/60 . . . 1982).

Because of its simplicity in assuming a linear world, single objectives and perfect certainty, standard linear programming was found to be only fairly suited as a planning aid in harvesting operations (Mikkonen 1983). To obtain a complete conception of any situation with linear programming, extensive sensitivity analysis is required. Sensitivity analysis gives linear programming a more dynamic nature. However, repeated sensitivity analysis considerably increases the complexity of the problem and computer processing time required (Keipi 1978). Parametric linear programming also gives a sense of dynamism, but the computations required are considerable. Also, when dealing with the size of problems faced in planning harvesting operations, sensitivity analysis and even solution of the problem itself, is very difficult. For example, if we strip the wood transportation problem in the Saimaa area to a bare minimum with 81 municipalities, 6 wood assortments, 82 railway terminals, 87 water transport terminals and 37 wood processing centres/points, we would require 3 056 940 variables in the standard linear programming problem. By using heuristic algorithms to eliminate excessive variables, we could perhaps reduce the number of variables to about 50 000.

Keipi (1978) studied the applicability of the Dantzig-Wolfe decomposition method, price adjustment procedure, functional trading procedure, goal programming, simulation through system dynamics, discrete simulation and the approach of pure negotiations in decentralized wood procurement planning. Of the above only the Dantzig-Wolfe decomposition method and goal programming are mathematical programming techniques. Keipi (1978) found that of the seven methods mentioned above, the Dantzig-Wolfe decomposition method, goal programming and discrete simulation were the best methods for use in decentralized wood procurement planning. The criteria for judging the methods were: economicalness, applicability to changing wood procure-

ment conditions, stimulation of functional managers' motivation and ability to reach the global optimum. Keipi (1978) made the following conclusions:

- 1) if a manager desires a planning method with high applicability, with low cost and without demands on optimization, discrete simulation is best
- 2) if a fairly global optimum at a low cost with a low demand on applicability is desired, then goal programming is best
- 3) if there is no limitation on method cost and the global optimum has to be reached, then the Dantzig-Wolfe decomposition method is best
- 4) if proper optimization routines could be incorporated into discrete simulation, it could outrank the other approaches studied
- 5) discrete simulation is the most flexible of the methods, while the Dantzig-Wolfe decomposition method is the slowest and most costly method

To make mathematical programming operational for solving larger problems by itself, considerable simplification of the problem is necessary. This results in considerable loss of resolution. Galbraith and Meng (1981) also state that harvesting can rarely be represented mathematically and thus the application of mathematical programming methods is limited. Goal programming, found to be applicable in wood procurement planning by both Keipi (1978) and Mikkonen (1983), is also subject to subjectivity when setting the goals.

From the above, however, it appears that goal programming is the most suited of the mathematical programming techniques in planning forest harvesting operations. However, due to the world we live in, Lussier (1972) states that methods closer to the trial-and-error approach are more applicable to decision-making than the straight-forward mathematical programming approach. From the literature review it was concluded that mathematical programming by itself was not applicable to the study due to the complexity of the problem and the level of detail desired.

314. Simulation and heuristic programming

As defined in section 312. (p. 24), simulation relates to the imitation of the functioning of a system over time and/or using random numbers and probability distributions to generate data used in its models, while heuristic programming relates to the formal and orderly presentation of aids in solving decision-making problems. Neither of the above are optimizing methods. Simulation is generally used when we have a scarcity of data and uncertainty. It is generally used to answer questions such as; what will happen if a certain situation arises or some

variables change in some manner? In other words it is generally used to compare feasible solutions.

The most serious drawback of simulation is that it is an imprecise method subject to statistical error (Keipi 1978, Taha 1982). This is because in beneficial applications of simulation, stochastic models are employed and/or stochastic systems are studied. The application of simulation to study deterministic systems with deterministic models is questionable since mathematical programming is more suited for this type of problem. Thus, each simulation run must be treated as a statistical experiment and any conclusions derived from simulation must be subject to all appropriate statistical tests (Taha 1982, Law 1983). Statistical error is reduced by repeated simulation runs with different data sets and by running the simulation for a "sufficiently" long time to allow a steady state (equilibrium) to be reached and to also get a sufficiently large sample size. Newnham (1975a) feared that simulation techniques were falling into disfavor because their complexity made it difficult for anyone but their developer to understand or use them. This is the reason why user orientation must always be considered when developing any simulation model for general use. Generally, there is no point in developing a simulation model of a system already in existence, since it can be studied in reality (Newnham 1975a). Optimization by simulation is possible, but difficult and generally unreliable due to the randomness built into the models (Taha 1982). Simulation can be used, however, to generate missing data to be used in mathematical programming.

Many of the above disadvantages, are also advantages of simulation. Because of its nature, it is a very flexible method which can be used for analysing complex problems or systems. Keipi (1978) states that it is the most appropriate technique to the widest range of forestry problems. Newnham (1973) states that simulation has probably been the most widely used technique in forestry related problems. Newnham (1973) lists the following three major advantages of simulation:

- 1) a manager if forced to think of his problems in terms of a total system, thus avoiding sub-optimization which occasionally leads to disaster
- 2) in developing the model the manager is forced to make explicit statements about many of the assumptions in the model
- 3) the manager gains a good insight into the system being simulated

Since each managerial problem is unique, a simulation study must be tailor fit to the problem. This requires great skill from the modeller and a thorough understanding of the system being modelled; including the system's environment. Generally, programming needs are quite extensive in simulation studies. The most limiting factor

on simulation in the future will probably be programming. There is a serious shortage of skilled programmers and their cost is increasing, rapidly (Henriksen 1983). The benefit of simulation, as to cost savings derived from proper design versus additional expenses due to poor design, is difficult to obtain (Henriksen 1983). Seppälä (1971), who simulated wood harvesting systems with GPSS, found that its usefulness in studying harvesting systems was justified. Also, since simulation experiments rarely exceed 1 % of the total system cost, many managers have come to view simulation as a very inexpensive insurance policy (Henriksen 1983). With improvements in computer hardware and software, the popularity of simulation will likely still increase significantly (Law 1983).

Heuristic programming is a part of operations research which is not well documented and is easily confused with simulation. Thus in the definitions above, simulation was restricted to the use of stochastic models. As mentioned in section 312. (p. 24) heuristic programming is not an optimizing method, but rather one that searches for satisfactory solutions. This is achieved through "intelligent" examination of possible solutions with the objective of obtaining a "good" solution. The method relies on experience, inductive reasoning, and intuitive and empirical rules to move from one feasible solution to another (Dykstra 1976, Taha 1982). Once a "sufficient" number of possible solutions have been obtained the one giving the best possible result is chosen. The "sufficient" number of solutions depends on the desired closeness to the optimum, complexity of the problem and level of detail involved; and thus the computing time required. Of operations research methods it is the one closest to traditional problem solving, the major difference is that the search of feasible alternatives for the solution is done with a computer. There is no clear-cut procedure for heuristic programming and the methodology applicable depends on the problem in question.

Heuristic programming can also be used in conjunction with other operations research methods. As mentioned in section 313. (p. 25), Dykstra (1976) combined linear programming and heuristic programming for solving yarding landing location problems. Dykstra (1976) also states that the greatest number of published applications of facilities location theory have incorporated heuristic programming. This is due to the inherent complexity of facilities location problems.

During the early 1960's, heuristic programming was looked upon disfavorably since it only strives for satisfactory or practical solutions and not the optimum solution (Dykstra 1976). Its stature has continuously improved however. Its main premise, as mentioned in section 312. (p. 24), is that the area around the optimum solution is quite flat and thus deviation about the op-

timium solution does not have a great effect on the value of the solution.

Mikkonen (1983) states that we are in a new development phase, where more decision-making must be made at the field level. Recent developments in information processing hardware, as well as operations research software, will make the above much easier. Based on the literature review it was concluded that heuristic programming, supported by simulation, and mathematical programming where required, was the most applicable OR technique for the problem on hand.

32. Database management systems

The most widespread, practical and beneficial use of computers in forestry to-date has been in the storage, manipulation and retrieval of data used in everyday planning and control. This in turn has been directly linked to the development of database management systems. Glew et al. (1976) states that forest management practices can be substantially improved through the use of computer assisted resource planning techniques. Early computer based managerial aids dealt mainly with data used in accounting, budgeting, forest inventory, progress reports, control, etc., and a large central computer was generally employed (e.g. Einola 1968, Gillam 1969, Some words on ... 1969, Tyre and Srepetis 1978). The systems from the mid 1960's have developed into complex database management systems (DBMS), as well as geographic information systems (GIS) (e.g. Thornburn et al. 1973, Bloomberg et al. 1976, Glew et al. 1976, Kilkki and Siitonen 1976, Bare 1978, Macklin and Manning 1978, van Roessel 1978, de Steiger and Giles 1981, Bonner 1983, Fontaine 1983, Masse 1983). The use of computer systems is progressively being decentralized and being put at the disposal of field managers for everyday problem solving (Mikkonen 1983). Also, the use of desktop or micro-computers has increased considerably recently. In this section we will deal with DBMS, while GIS will be dealt with in section 33.

For the efficient use of computer stored information in managerial decision-making, more than just a mass of data stored in a computer memory is required. Bare (1978) states that any managerial information system must include data acquisition, data management, data processing and information display. The need for efficient storage, manipulation and display of information has led to the development of database management systems (DBMS). Frost (1984) defines DBMS as a collection of data which is used by more than one person and/or is used for more than one purpose. A DBMS is generally composed of a data store (database), privacy and security sub-system, a backup system in case of

system failure, and software for data input, information manipulation and output. Frost (1984) lists the following eight stages in the design of a DBMS:

- 1) specification of conceptual schema
- 2) specification of input/output requirements
- 3) specification of database schema
- 4) specification of physical storage structure
- 5) design of privacy sub-system
- 6) design of integrity sub-system
- 7) design of back-up and recovery sub-system
- 8) design of input/output application programs and report program generator, and query languages

The order in which the above stages occur is not necessarily that of above and many of the stages can occur in parallel. When specifying the conceptual schema we are defining what information is to be stored and what the relationships between the different types of data are. At this stage future requirements must also be taken into account to yield a system which does not immediately become obsolete. When specifying the input/output requirements one must determine what information is required, the form it is in, the data manipulation required and when and how it should be presented to the person using the system. Often too much emphasis is placed on data storage, retrieval and display, while too little is placed on the data manipulation or analysis sub-system, and/or user orientation of the system (Bare 1978, Beeman 1978).

While the first four stages are in progress, the system designer must also gather information to ensure the security, privacy and integrity of the system. The security and privacy part of a DBMS controls unauthorized access to the system or changing of data. Integrity refers to controlling the input of erroneous or contradictory data. With the above stages in mind, the designer specifies the database schema, which is basically a schematic diagram of the interactions between data, as well as between the various parts of the DBMS. The specification of the physical storage structure refers to choosing the computer hardware most suitable to the situation, as well as deciding on the form in which data will be stored. The last four stages generally occur simultaneously and refer to the actual development of the computer software required for the system's operation. More detailed information on the designing and building of a DBMS can be obtained from texts on the subject (e.g. Frost 1984). However, the success of a DBMS is ultimately dependent upon the degree of cooperation between the designer, data sources and users in the design and formation of the system, as well as the final acceptance of the system by the users.

What is the advantage of using a DBMS? With one

central database used by a number of people, resources are used more efficiently since there is no duplication of data. Also, the possibility of errors in the data is reduced. Information from many different sources is gathered and thus made readily available to all authorized users of the system. Otherwise, a person may be forced to search for data from many different sources before obtaining all data required. Bloomberg et al. (1976) stresses the above advantage due to the trend toward multidisciplinary research. Himanen (1981) states that information is required in all logistics systems and has a marked effect on a system's operability. With all relevant information readily available, decision-making is made much easier. Frost (1984) lists a number of disadvantages of DBMS:

- 1) since the DBMS must be centralized, considerable transmission of information from sources is required, as well as transmission of output to the end-users
- 2) since there are many users, security and privacy sub-systems are required to prevent unauthorized use or changing of data
- 3) standard formats for data have to be used to make the system operational due to the many possible users

In the past two decades there has been considerable development in DBMS and in 1981 there were over 50 business oriented DBMS commercially available (Marble and Peuquet 1983). Marble and Peuquet (1983) also expect that the use of DBMS will increase at a rate of 25 to 35 % annually through to the end of this decade. However, like operations research methods, orthodox DBMS do not account for the spatiality of the data (van Roessel 1978, Hokans 1983). This has thus led to the development of spatial databases and geographic information systems. A GIS is the major tool for handling of spatial databases (Marble and Peuquet 1983).

33. Geographic information systems

Erdle and Jordan (1984) state that geographic information system (GIS) technology has arisen from recent advances in merging computer graphics and DBMS. GIS is defined as essentially a hardware/software system, specifically designed for storing, maintaining, analysis and display of geographically referenced data. Thus, at the heart of any GIS we have a spatial database, composed of spatial and descriptive data. In a spatial database each entity is defined in terms of its location in space through the use of points, lines or areas. de Steiguer and Giles (1981) depict a GIS as a basemap of an area on which a number of overlays have been placed to depict different resource themes. Depending upon the complexity of the system in use, a host of information about the

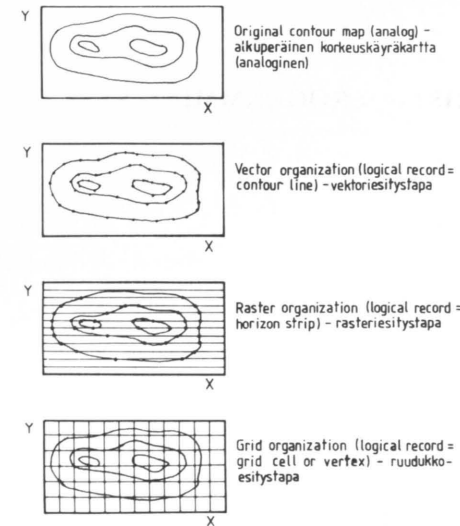


Fig. 12. Methods of spatial data organization.
Kuva 12. Menetelmää sijaintitietojen järjestelyssä.

(Marble and Peuquet 1983)

area can be retrieved and produced in tabular or map form. de Steiguer and Giles (1981) state that the list of possible applications is almost endless, with the only limitations being the imagination and skill of the designers and programmers, and the budget of the system.

Whether a GIS is more DBMS or graphics oriented will ultimately depend on the intended use of the system. However, both capabilities are required. For this reason, the spatial regional supply model presented by Garbini et al. (1984) and the simulation/graphical animation model presented by Rose et al. (1984) cannot be held as GIS, while the system presented by van Roessel (1978) qualifies as a GIS. Similarly, computer assisted design and manufacturing (CAD/CAM) technology, which is closely allied with automated cartography, cannot be classified as a GIS either (Marble and Peuquet 1983, Erdle and Jordan 1984). GIS technology differs from that of CAD/CAM since analytical ability is emphasized with the resulting loss of graphical resolution.

Although the first GIS were developed in the mid 1960's, widespread interest in their use has not increased until lately (Bonner 1983, Erdle and Jordan 1984). This

is probably due to recent developments in computer hardware and software for GIS, resulting in more inexpensive and powerful systems. Marble and Peuquet (1983) state that the major reasons for failure of many GIS in the past was due to improper design, failure to properly adjust to severe institutional problems and technical problems (e.g. too costly). Detailed information on GIS design is available in texts on the subject (e.g. Marble and Peuquet 1983). However, some of the basic design features in GIS will be discussed shortly below.

As mentioned above, an entity's spatial location is defined through the use of points, lines or areas. Spatial information is organized according to vector, raster or grid organization (Fig. 12). Vector organization refers to the representation of lines through a sequence of short straight lines defined by their end points. In a raster organization, horizontal strips are used (i.e. spatial data is recorded from narrow strips placed across the data surface). A grid organization is a special form of raster where information is recorded at regular intervals along the raster and the smallest logical unit is the grid cell (i.e. pixel) (Marble and Peuquet 1983). Thus, basically we have GIS where the format of data representation is in polygon or grid form. Polygon representation (i.e. the use of vector organization) of data is best, if high graphical resolution is required. Also, data storage requirements are higher if using the grid method. On the other hand, if data manipulation is most important, then grid representation is best (Dyksta 1976, de Steiguer and Giles 1981, Marble and Peuquet 1983). Various data overlays are easily cross-referenced due to the fixed structure (matrix) form in which data is stored. The grid method is generally the least expensive and easiest method to use. If spatial relationships must be examined in polygon represented data, very complex software is required. To overcome the weaknesses of both methods, modern GIS tend to incorporate the use of both methods.

Although there are many advantages of GIS, the difficulties must also be kept in mind. The computer hardware and software required make GIS quite expensive, and skilled programmers are required to obtain the full benefit from the system. de Steiguer and Giles (1981) stress that "in house" development or use of GIS by small inexperienced firms is not wise and they should contact government organizations, universities or private firms dealing with GIS. Sufficient and productive use of the system is also necessary to justify investment in a GIS. Erdle and Jordan (1984) stress the importance of a thorough cost-benefit analysis before investment in a GIS; otherwise you may end up with a modern-day white elephant on your hands.

4. A SPATIAL DATABASE – HEURISTIC PROGRAMMING SYSTEM

41. General

The preceding sections have outlined the long-distance transport decision-making problem, wood procurement and transport situation in the Saimaa area, factors affecting long-distance transport decision-making and some managerial aids which could be applicable in further rationalization of long-distance transport, particularly water transport. After the literature review of OR methods which could be applicable to the objectives of this thesis, it was concluded that any OR method by itself was not applicable. Similarly, a DBMS is not applicable to the problem on hand by itself. For example, both OR and DBMS do not account for spatial arrangement of data and thus their applicability to the size of problem on hand is limited. GIS with specially developed software would seem to be applicable. But investment in such a system for just aiding decision-making in long-distance transport of wood is unjustified: e.g. the purchase price of a small-size GIS employed by Great Northern Paper Co. of Maine, U.S.A. (Boss 1984), is about 500 000 USD. In addition to the cost of hardware and associated software, additional software would have to be developed, personnel are required to run the system and the extensive database of the system must be continuously updated. For the above reasons a simple system adaptable to any existing computer system (excludes micro-computers) was developed. The system is based on the combination of a spatial database and heuristic programming. The programming language was FORTRAN IV.

After reviewing the literature on the spatial delineation of data it was decided that the grid method was more applicable than the polygon method or grid/polygon method. This was because considerably more emphasis was placed on data manipulation and developing a low cost system in the study, than on graphical resolution of output. As mentioned in section 33. (p. 29), Dykstra (1976), de Steiguer and Giles (1981), and

Peuquet (1983) all state that the grid method is superior to the polygon method when it comes to the manipulation of spatial data. Also, not all computer systems are equipped with a graphical plotter. The display (i.e. hard copy maps) of spatial characteristics and relationships with the accuracy available from a line printer or typewriter console was deemed satisfactory. Also, a large amount of data can be displayed in tabular form. It must be remembered that the spatial database – heuristic programming system was developed specifically to deal with long-distance transport and particularly bundle floating problems. Also, it is not an optimization method; its purpose is to aid in solving problems through the use of an extensive database and the spatial relationships between the data. Also, if some organization currently employs a GIS based on the polygon method or a grid/polygon method, the starting point is different and any programs should be designed to meet the system available. However, if dealing with only a polygon method and complex spatial relationships must be examined, the programming requirements may be too complex for a normal forestry related organization: e.g. Dykstra (1976) compares the analysis of polygon data as trying to analyse the spatial relationships between individual strings of pasta in a bowl of spaghetti.

Although the spatial database in this study cannot be classed as a DBMS, a number of the DBMS features presented in section 32. (p. 28) were employed. By having a thorough understanding of the study problem and environment, all relevant map information for the spatial database was obtained simultaneously, and stored in a manner easily accessed for editing of errors, updating and use. The map information was stored by grid cell coordinates. Each grid cell is referenced by computer matrix coordinates for the grid; grid cell (1, 1) is in the upper left hand corner of the grid. In this thesis the matrix coordinates are referred to as they are in computer notation and not in vector notation: i.e. (Y, X) and not

(X, Y). A number of catalogues containing descriptive information and information matrices were added to the spatial database.

Since no standard OR techniques could be found which were applicable to the problem on hand, a set of heuristic programming models were developed to aid in determining relationships in wood procurement in the Saimaa area and to mimic wood flow through the transport systems available. The following sections will deal with the theory and development of the spatial database – heuristic programming system.

42. Transport system spatial database

421. Uniform coordinate system

Due to the curvature of the earth's surface the use of geographic coordinates (i.e. longitude and latitude) is not possible in a grid system. This is because lines of longitude converge at the poles. The Universal Transverse Mercator Grid (UTM) overcomes this problem. The grid was designed for world use between 80° S and 84° N latitude and the earth's surface is divided into corridors 6° longitude wide. These projection corridors are numbered 1 through 60, progressing from the 180° meridian of longitude eastward (Map reading 1960). The corridors taken into use in Finland in 1922, however, are 3° longitude wide and the central meridians are at 21°, 24°, 27° and 30° E longitude (Karttaprojektio 1962). In the grid, the lines of longitude are of true length, but the grid lines drawn perpendicular to the central meridian are not of true length. This effect is reduced by using narrow corridors. For the 3° wide corridors used in Finland, the correction required at the corridor extremes is less than 1 m (i.e. less than 2 seconds) over a 10 km distance (Karttaprojektio 1962). The equator forms the base line with true length and is perpendicular to the central meridians.

The uniform coordinate system was developed from the UTM grid. In Finland, one corridor with a central meridian at 27° E, is used to cover the entire country. Ruutujärjestelmätoimikunta (1970) gives recommenda-

tions for use of the uniform coordinate system in Finland. Any point on the grid can be given accurate grid coordinates. Map reading (1960) and Ruutujärjestelmätoimikunta (1970) present the indexing of locations with the system. A map of the Saimaa area with the uniform coordinate grid superimposed on it, along with the information matrix coordinates for the area, is presented in Fig. 13.

The use of a grid system allows easy indexing of location. The advantage of a grid system over geographic coordinates is that each grid square has the same area and linear distances can be easily calculated between points. With geographic coordinates angular measurements would be required (Map reading 1960). Due to the above, easy storage of information in matrices by grid coordinates, as well as the use of heuristic programming models, are thus made possible. De Steiguer and Giles (1981) state that the UTM is the best system to use in a grid GIS.

422. Grid applied

The basic transportation system data for the Saimaa area was obtained from National Board of Forestry maps of scale 1:200 000, which are printed by the National Board of Survey. Maps covering the area were formed into a map mosaic. A transparent sheet was overlaid onto the map mosaic and a grid drawn based on the uniform coordinate system. All information not included or clearly delineated on the maps had to be procured, located on the map mosaic and drawn onto the transparent overlay: e.g. bundle floating terminals, transfer facilities, railway terminals, mills, forestry board districts, municipalities and watersheds. When determining the grid line spacing the following factors were taken into account:

- 1) accuracy of the transport system location desired, including all transport system infrastructure, such as, railway stations, spurs, dumping terminals, wood transfer facilities, sources, destinations, etc.
- 2) detail of transport system description desired in the information matrices (i.e. number of characteristics to be registered)
- 3) matching of distance between grid lines and map scale to allow easy conversion between map and actual distances and areas

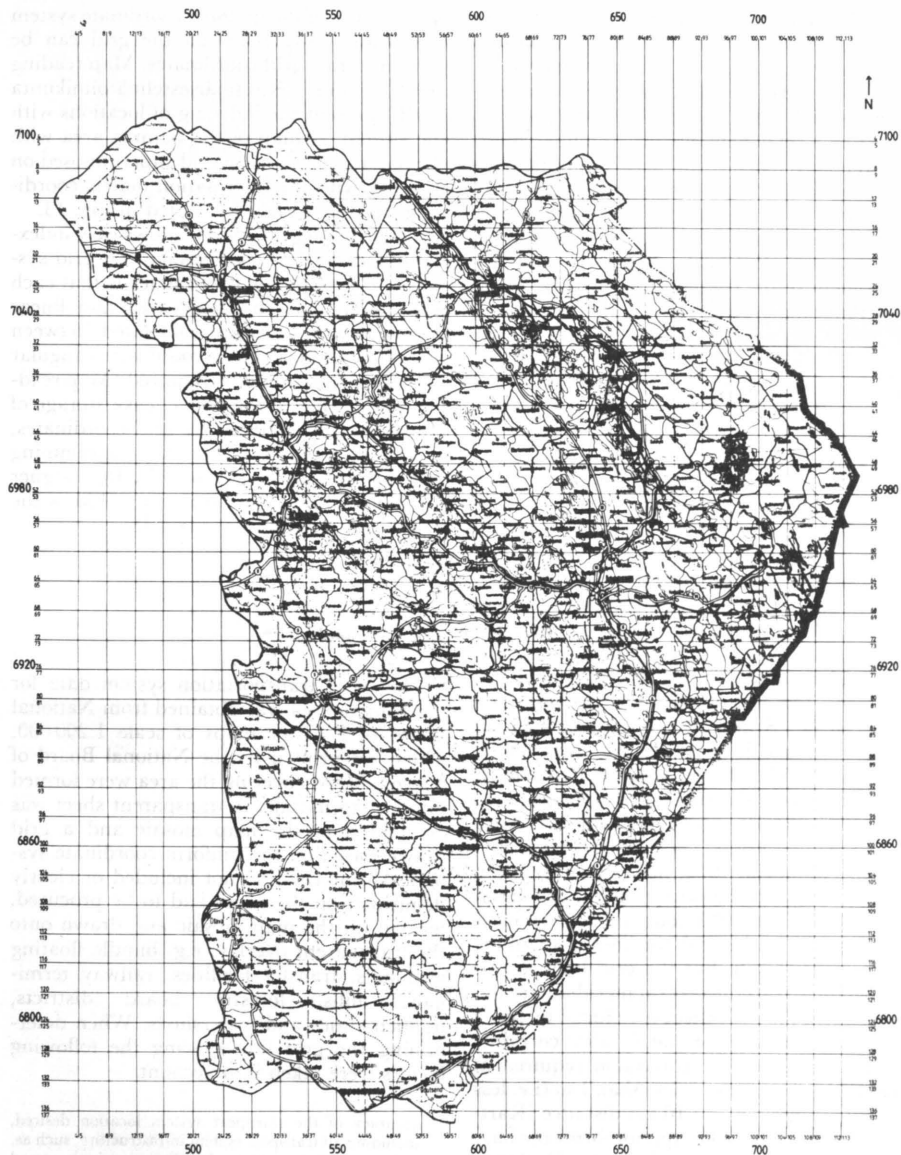


Fig. 13. Map of the Saimaa area with uniform coordinate grid (large numbers) and corresponding information matrix coordinates (small numbers).

Kuva 13. Yhtenäiskoordinaattikartta Saimaan alueesta (isot numerot) ja sijaintitietomatriisin koordinaatit (pienet numerot).

- 4) size and shape of the area to be covered by the information matrices
- 5) complexity of the transport system in the area
- 6) computer resources available for data storage and during CPU (central processing unit) operation
- 7) line printer width, which limits the width of hard copy output of information matrices

Taking all the above factors into account, the distance between grid lines chosen was 1.25 cm; this is equal to 2.5 km at a scale of 1:200 000. Each grid cell, also known as a pixel, covers an area of 6.25 km². The grid cell is the basic unit of the grid, which has dimensions of 144×114 (length × width). Due to the shape of the Saimaa area, 9 048 of the total 16 416 grid cells lay in the study area. The remaining grid cells were coded as other watershed areas lying in Finland, the major ones being the Kymi River watershed lying to the west and the Oulu River watershed lying to the north, and areas lying in the Soviet Union.

For data processing, an UNIVAC 1100/60 was used; 65 000 bytes of CPU workspace were available at one time without special expansions of usable workspace. Whenever needed, the workspace could be expanded and thus large matrices could be accommodated. Also, disk and tape storage (memory) resources posed no limitation. Since line printer width is generally 132 columns, the width of the grid with headers was just under the maximum width allowable if the information matrix output was single character.

Due to the difference between in-line character density and between-line density of the line printer, there is a difference in scale of the Y and X axes: i.e. 285 km (114 grid cells) requires 36.25 cm on the Y axis of the line printer output, while the same distance on the X axis requires 29.0 cm. Thus, maps of the area produced by the line printer show the area to be more elongated than it actually is. This is apparent from the maps drawn from information matrix hard copies presented in Fig. 6, 7 and 8 (pp. 16 and 17) and the actual map of the area presented in Fig. 13. This distortion could have been removed from the line printer produced maps by using rectangular and not square grid cells. The north/south grid cell dimension would have to be enlarged to 1.25 times that of the east/west dimension to match the wider spacing

between lines and thus obtain equal scales on both Y and X axes of the line printer output. However, since ease of data manipulation was held to be more important than graphical display accuracy, square grid cells were chosen. Also, with further development, the system could be linked to a graphical plotter. This would result in the elimination of all Y-X axes distortion.

423. Spatial database formation

The capture and input of the data into the spatial database can be held as the most tedious and one of the most important parts involved in the formation of the spatial database – heuristic programming system. The applicability of the system is only as good as the quality and accuracy of the information stored in the spatial database. Therefore, when forming the spatial database great care had to be taken to record all the information that was required. Accuracy was also of utmost importance to minimize the time required to edit errors from the data. Marble and Peuquet (1983) state that for each data type the most important consideration is usually getting the data into the system, since data input generally accounts for the greatest costs and difficulties.

When registering the transportation system information the map area covered by each grid cell was examined manually; input of spatial data in modern GIS is generally through pencil tracing or automatic scanning. If the grid cell did not lie in the study area it was labelled according to whether it was in another area of Finland or in the Soviet Union. Otherwise, the presence/absence or description of the following features were recorded for each grid cell:

- 1) roads
 - 11) highway network
 - 111) class I highway (primary national highway)
 - 112) class II highway
 - 113) unsurfaced highway
 - 12) community road
 - 121) bound surface
 - 122) unsurfaced
 - 13) private road (generally unsurfaced)
- 2) railway system
 - 21) actual railway
 - 22) railway terminal
 - 221) terminal with stationary crane
 - 222) terminal without stationary crane
 - 23) railway spur

- 3) water transport system
 - 31) water transport channel
 - 311) bundle floating channel currently in use
 - 312) bundle floating channel currently not in use
 - 313) free-floating channel
 - 32) wood (bundle) transfer facility
 - 321) bundle crane/track
 - 322) lock
 - 33) water transport terminal
 - 331) bundle dumping terminal currently in use
 - 3311) dumping ramp only
 - 3312) ice storage area only
 - 3313) dumping ramp and ice storage area
 - 332) bundle dumping terminal in sporadic use
 - 333) abandoned bundle dumping terminal
 - 334) harbour
- 4) watershed
- 5) water coverage percentage
- 6) mill
 - 61) sawmill
 - 62) wood-based panel mill
 - 621) plywood mill
 - 622) particleboard mill
 - 623) chipboard mill
 - 63) pulp and/or paper mill
- 7) forestry board district
- 8) municipality

In some cases transport system information had to be recorded from grid cells beyond the Saimaa area. To maintain continuity of the railway system, all railway system information for the Kouvola-Kuopio, Kouvola-Lappeenranta and Vainikkala-Luumäki/Lappeenranta track sections were recorded irrespective of whether they were in the Saimaa area or not. Also, wherever the continuity of a major road artery was broken due to the road extending beyond the Saimaa area, the road sections lying beyond the area were recorded.

One data line was used to record and store all information for each grid cell. The above information was recorded with a spatial accuracy having a maximum error of 1.77 km (distance from grid centre to corner). Putkisto (1949) gives the following equation for calculating the average straight-line distance within a square to its centre:

$$k = 0.383 \cdot a$$

where k is the average straight-line distance to the centre
 a is the side length

Employing the above equation, the average straight-line distance within squares to the centre is 0.9575 km.

When examining the actual transport arteries (i.e. major roads, railways and water transport channels) some adjustment was necessary to avoid "zig-zagging" due to the location of the artery in relation to the grid (Fig. 14). When examining areas and a grid cell bordered on two or more areas, the area assigned to the grid cell was the area making up the larger part of that particular grid cell. The water coverage was measured by placing a dot grid (25 dots) over groups of four grid cells and counting the number of dots lying in a waterbody. The same water coverage in per cent was assigned to all four grid cells. Later in the data analysis it was found that it would have been better to analyse the water coverage for each grid cell separately. When it came to forming a lake information matrix there was no way to say which grid cells should be assigned as lake: e.g. if we had 50 % water coverage over four grid cells which two cells were to be assigned as lake. Thus, breaks in waterbodies occurred where there should not have been any and manual correction of the data was required.

Additional information relating to the area was also gathered: i.e. annual allowable drain by wood assortments and forestry board districts, wood volumes dispatched from terminals, industrial cuttings, wood consumption at mills, wood delivered to mills, channel costs, payment rates, stumpages by municipalities, and terminal and transfer facility names and descriptions. The majority of the above information was stored in catalogues formed with the aid of and referenced to the spatial database.

As should be evident from the large mass of information recorded, the storage and manipulation of the spatial data is only possible with a computer having fairly large CPU and memory capacities. All grid referenced information recorded for this study is referred to as a spatial database. With the data readily available for each grid cell in digital form, by just addressing the grid coordinates and data required, information matrices and catalogues for the area could be developed. The information matrices and catalogues developed from the spatial database are also held as a part of it.

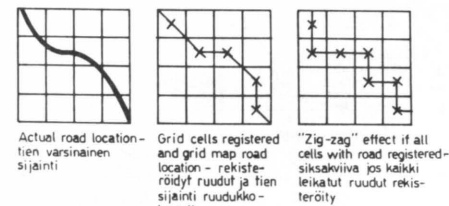


Fig. 14. Method used in registering major transport arteries.

Kuva 14. Kuljetusreittien merkintä.

424. Information matrices and catalogues

With transport system data stored in the spatial database it was simple to form information matrices which could be used to simplify data manipulations or to present some relationship of spatial data after data manipulation. The information matrices can be thought of as map overlays containing some type of information of interest. For example, the maps presented in Fig. 5, 6 and 7 (pp. 16 and 17) were drawn from hard copies of information matrices.

Most of the information matrices are of character format (i.e. any of the symbols available in the computer language used), although depending on the information involved, they can be in integer or real number format. Output of information matrices with data containing more than one character becomes more involved if a map of the entire area is to be obtained. For example, if the information matrix contains two digit integer numbers, only one-half of the entire area can be printed at one time since the printer width is a maximum of 132 characters. Another similar problem related to the grid method is that output of maps with different scale is limited: i.e. limited to factors of 1X, 2X, 3X, etc.

As mentioned earlier, two types of information matrices were used in the study. One type contained information to simplify data manipulation and analysis of the area. When information matrices were used the entire spatial database containing all information would not have to be accessed with each computer run. Similarly, when a special set of data was used often, excessive computer time

was avoided by employing information matrices. The other type of information matrix stored spatial information gained through data manipulation for output.

To briefly outline the formation of an information matrix the procedure required when forming the information matrix of the watersheds in the Saimaa area is outlined below:

- 1) a matrix space (144 × 114) was reserved in the CPU workspace according to the type of data to be contained in the matrix: i.e. in our case character data was used, as opposed to integer or real numbers. Character data refers to any of the symbols available in the computer language being used, including blank spaces
- 2) the spatial database was accessed and information in regard to watersheds was read into the CPU workspace
- 3) working through information for all 16 416 grid cells, a code was assigned to each corresponding matrix location as to which watershed in the Saimaa area the grid cell was in, or whether it was in another part of Finland or the Soviet Union; i.e.
 - "1" = Jänis River watershed
 - "2" = Kitee River - Tohma River watershed
 - "3" = Hiitola River watershed
 - "4" = Vuoksi watershed
 - "." = area beyond Saimaa area but in Finland
 - " " = area beyond Saimaa area and in the Soviet Union
- 4) once all grid cell information had been examined the new information matrix (i.e. map) of the area was stored on disk for future use

Fig. 15 presents the actual hard copy of the above information matrix.

Information catalogues are files of descriptive information referenced to some feature recorded in the spatial database. For example, one catalogue of dumping terminals included the matrix coordinates for each terminal, as well as name, class and volumes dumped over the past five years. As additional information becomes available (e.g. new data on volumes dumped) it is added to the catalogues. The catalogues were used to give descriptions of the points recorded in the spatial database and thus make analysis possible and conceptual realization easier: e.g. dumping terminal (25, 64) could be referred to as Kannaslahti which would make information about the point more meaningful to a possible user. Also storage of point data required less space when using information catalogues. A number of information catalogues for the following point features, as well as areas, were formed:

- 1) dumping terminals
- 2) railway terminals
- 3) bundle transfer facilities
- 4) wood processing mills
- 5) forestry board districts
- 6) municipalities

43. Heuristic transport routing and costing

43.1. Heuristic transport route searching

Due to the large number of possible transport route sources and destinations, and the large number of possibilities for transporting wood from a source to a destination, heuristic search algorithms were developed. To manually determine the transport routes and distances for all situations arising in problems of the size in this study would be very time consuming.

There are two distinctive forms of transport network configuration possible: i.e. branching and interconnected loop configurations (Fig. 16). In the Saimaa area, road and railway transport networks have interconnected loop configurations, while water transport has a branching configuration. All transport networks have branching infrastructures, however the above classification only refers to the major arteries. The classification of a network as either branching or interconnected loop often depends on the size of the area under consideration. For example, a small area examined by itself will generally have a branching network, while the interconnected loop configuration becomes more prominent as the scope of the area is widened. Inland waterways, due to drainage patterns, can be held as more or less always having a branching configuration; unless dealing with an extensive interconnected canal system or a large lake with many separate channels due to reefs or islands.

Depending on the transport network configuration, special considerations had to be accounted for when classifying the transport network information into the information matrices used for route searching. Transport route information matrices (TRIM) were formed for each transport method with the aid of the information matrices of the various

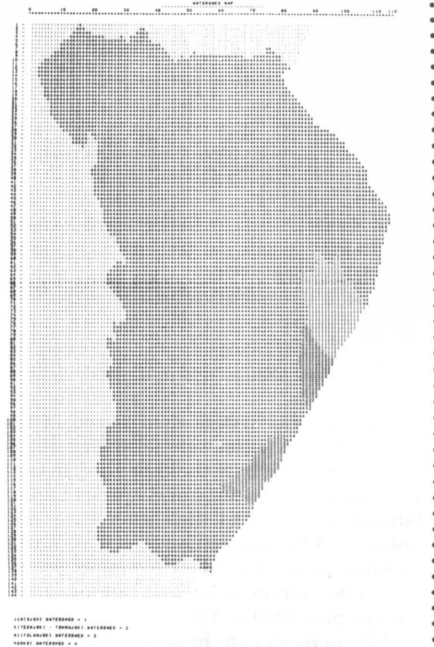


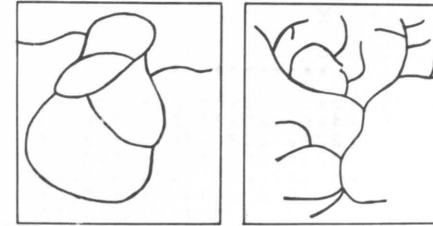
Fig. 15. Hard copy of the information matrix of water-sheds in the Saimaa area.

Kuva 15. ATK-tulostus vesistöalueiden sijaintitietomatriisista.

route classes available. To form the road TRIM all the road class information matrices were overlaid. Each grid location was labelled according to the highest road class present; since the area of a grid cell is 6.25 km² there is a possibility that all road classes are present. The integer labels for the different road classes are as follows:

- primary highways, looped (1)
- primary highways, not looped (2)
- secondary highways, bound surface (3)
- community roads, bound surface (3)
- secondary highways, unbound surface (4)
- community roads, unbound surface (5)
- private roads (6)
- grid cells having no road or lying beyond area (9)

Primary highways were labelled according to two classes to minimize the search of dead-end routes and thus reduce CPU time re-



Interconnected loop configuration - yhdistetty rengasmuoto
Branching configuration - haarautuva muoto

Fig. 16. Transport network configurations.

Kuva 16. Kuljetusverkkomuodot.

quirements: i.e. sections which form loops in the Saimaa area (1) and sections which are not looped because they truly end or continue beyond the boundary of the area (2). The unlooped primary highway sections were labelled manually.

The railway TRIM was formed in the same manner as the preceding, with manual labelling of unlooped sections. The different track sections were labelled as follows:

- railway track, looped (1)
- railway track, not looped (2)
- rail spur (3)

As mentioned in section 423. (p. 34), some sections of the railway network beyond the Saimaa area had to be taken into account since vital loops would have otherwise been broken. Sections lying to the west and south of the area were recorded in the spatial database. However, a dummy track had to be constructed to the north to complete a loop formed at Kontiomäki, which is just beyond the range of grid coverage.

When forming the water transport TRIM another classification procedure was followed. The major channel branches were labelled as (1), while labels (2), (3), (4) and (5) were assigned as further branching occurred. No regard was paid to whether channels were in current use for bundle floating or not: i.e. only to degree of branching. To reduce CPU time requirements, gates were placed at strategic major branches; the gate label is (6). A gate is opened when the area serviced by the particular branch contains a source or destination. Similar to the road and railway

TRIM, label (9) was assigned to grid cells containing no channel or lying beyond the Saimaa area.

With all methods, special consideration had to be taken to ensure that there were no intersections between major arteries where there should be none; referred to as a cross-over. This could occur since the distance between opposite sides of adjacent grid cells is 5.0 km; between opposite corners of diagonal grid cells it is 7.1 km. Therefore, although the routes may not intersect (e.g. due to a river or peninsula) the route search algorithms would assume they intersect if contained in adjacent or diagonal grid cells. Wherever the possibility of a cross-over existed the TRIM data was manually changed to remove the cross-over possibility. The TRIM only contain information pertaining to the actual roads, railway tracks and channels. Information pertaining to terminals, transfer facilities, destinations and cost of bundle floating by channel sections are held in information catalogues.

Due to differences in complexity and configuration of the road, railway and water transport TRIM, separate search algorithms were developed for each. However, the basic search pattern is the same for all three algorithms. Although the road and railway search algorithms are similar, the road search algorithm had to be designed to account for the higher complexity of the road TRIM. Fig. 17 presents a part of the road TRIM with source (28, 23) and destination (49, 37), and the best feasible road route found connecting the two points by the road route search algorithm (29.6 km). The algorithms are designed to search for a "good" solution and not the optimum. However, the railway and water transport route search algorithms can be held to give the best route in all cases. This is due to the simplicity of their network configurations when compared to the road network. The basic search pattern, while referring to Fig. 17, is as follows:

- 1) the labels of the grid cells for the source and destination are examined to ensure that both are serviced by the transport network in question. If a label (9) exists in either one, the search is stopped and a message given that no route exists between the two points
- 2) the coordinates of the source and destination are registered into separate vectors which contain the coordinates of the route as the search reaches out

from both points; the last entered route coordinates correspond to the vector head

3) search iterations alternate between the two vector heads. For all iterations the labels of the vector heads are examined. If the label of the vector head to be moved is smaller than that of the other vector head, the search shifts to the other head. This prevents the vector heads from passing one another. Also, with the road and railway route search algorithms, once the route advancing from the destination encounters a route label of (1) the search from that head is stopped and all searching is shifted to the route vector extending from the source. With the water transport route the searching continues from both heads until they meet

4) the grid cell labels, corresponding to the vector head to be advanced and the eight surrounding cells, are registered in a special (9x9) search matrix. For Fig. 17 we would have the following search matrix for the first iteration, which is always from the source

3	6	6
6	5	6
6	5	4

5) the absolute values of the differences between the route coordinates last entered into the route vectors for Y and X axes are calculated, and the axis having the largest difference is given axis priority; for Fig. 17 $ABS(28-49) = 21$ and $ABS(23-37) = 14$, thus the Y axis is given priority. If the two are equal, the Y axis is given priority. If the absolute difference for both Y and X axes is zero the search is stopped since intersection of vector heads has occurred and a route found

6) once the axis priority is given the directional priority is determined for both Y and X axes according to the position of the vector heads in relation to each other. The axis coordinates of the vector head toward which searching occurs are always subtracted from the coordinates of the vector head being advanced. Thus in the first search iteration (i.e. searching from the source toward the destination), we know the destination lies to the south and east of the source since the differences between the Y axis coordinates is -21 and between the X axis coordinates -14. If only one directional priority can be given (i.e. either Y or X axis coordinate difference is zero), special search sequences are followed

7) the sequences of search for the most appropriate cell to advance to, for the 12 priorities possible are as follows

axis priority - Y
directional priority -

south and east	south and west	north and east	north and west	south only	north only
8 6 7	7 6 8	5 1 3	3 1 5	8 6 7	4 1 5
4 X 2	2 X 4	4 X 2	2 X 4	3 X 2	3 X 2
5 1 3	3 1 5	8 6 7	7 6 8	4 1 5	8 6 7

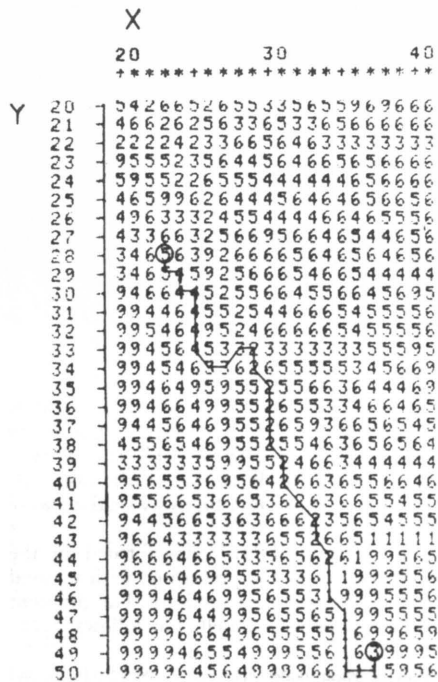


Fig. 17. A part of the road TRIM with source (28, 23) and destination (49, 37), as well as the best route between the points found by the road route search algorithm (route length is 29.6 km).

Kuva 17. Osa tien sijainti- ja matrisista, alkupiste (28, 23), päätepiste (49, 37) ja lyhin reitti (29.6 km).

axis priority - X
directional priority -

east and south	east and north	west and south	west and north	east only	west only
8 4 5	7 2 3	5 4 8	3 2 7	8 3 4	4 3 8
6 X 1	6 X 1	1 X 6	1 X 6	6 X 1	1 X 6
7 2 3	8 4 5	3 2 7	5 4 8	7 2 5	5 2 7

- the search progresses through the search matrix according to the sequence above corresponding to the axis and directional priorities on hand
- to prevent searching in the direction just come from, the search matrix cells corresponding to the last cell moved from and the cells adjacent to it, are assigned large numbers and thus blocked. This forces the vector

head forward and prevents it from turning back on itself

- during the first pass through the search matrix the first cell encountered containing a minimum specified label (e.g. label 1 or 2) is advanced to
- if the minimum specified label is not found in any of the possible locations then another pass is made
- if a second pass is made the first cell encountered containing a label less than or equal to the label of the vector head TRIM cell is advanced to
- in Fig. 17 the first advance would be to grid cell (29, 23) which has a road class label of 5
- the coordinates of the grid cell moved to are entered into the route vector in question (i.e. into the route vector projecting from the source in the above example) and thus forms the new vector head
- if no cell can be advanced to (i.e. dead-end encountered) the TRIM cell corresponding to the route vector head is assigned a label of 8 and erased from the vector. A new attempt is made to find a route between the two points; i.e. the search backs-up until it can advance again
- once a new vector head is found the search shifts to the vector head projecting out from the other point; in this example, to the destination
- the same search procedure as outlined above occurs; i.e. (3) onward. The search matrix for the destination is

6	9	9
6	3	9
1	1	5

- since in this case we have Y axis priority, with north and west directional priority the search sequence is as follows

3	1	5
2	X	4
7	6	8

- searching through the information matrix we find the first move from the destination is directly south to grid cell (50, 37), which is entered into the route vector projecting out from the destination
- the search now shifts to the other vector head
- as mentioned above the search continues until the heads meet; i.e. differences between coordinates of both heads is zero

Due to the configuration of the water transport network, the first route which is found is also the best, although the algorithm is heuristic in nature. This is because it is the only route available in the water transport TRIM. Because the road and railway networks contain interconnected loops, it is possible that the search occurs in the wrong direction around a loop and the initial route obtained is

not sufficiently close to the optimum. Also, if only major road arteries are searched once intersected (i.e. labels 1 and 2), possible lower class road connections may not be searched. This is especially important over short distances and when moving east/west in the area. For long distances the importance of "short-cuts" is much less.

To alleviate the above outlined problem resulting from the presence of the interconnected loops, the loops lying between the source and destination must be searched in both directions. The grid cell coordinates of the pivot points at which loops intersect, were determined and registered into the algorithms. Once the initial route is found it is examined to determine if any of the pivot points have been intersected. For each pivot point intersected, the route search is rerun. In the rerun the initial route direction at the pivot point is closed off and the search forced in the opposite direction. Also, once a road label (1) is intersected by the vector projecting out from the source, the direction taken in the initial route is blocked and the search forced in the other direction. Of all the possible routes found along major arteries, the one giving the shortest distance is chosen. In the road route search, the possibility of a "short-cut" had to be accounted for also. The route search is rerun and road label classes (3) and (4) are assigned to the minimum road label for the first pass through the search matrices. Therefore, the search could advance, for example, from a road label (1) cell to one of (3) and/or (4) depending on the rerun in question. As mentioned above, the search for a possible "short-cut" is most beneficial over short distances and when moving east/west. If a shorter road route is found with the inclusion of either labels 3 or 4, it is chosen as the best feasible route found. However, the shortest route along major arteries is also given in case it is required.

For all algorithms the location of the entire route is registered in the route vectors. The distance is calculated by summing the distances between individual grid cells forming the route: adjacent 2.5 km and diagonal 3.54 km. Additional features were built into the algorithms to save CPU time requirements, to cut off searches if they extended too long or entered into an internal loop, as well as for output of the results.

432. Transport cost determination

To obtain the costs of using the various transport methods available, separate cost subroutines were developed for truck, tractor and railway transport, as well as bundle floating. The cost subroutines for truck, tractor and railway transport are based on tariff schedules available for each method. The cost subroutine for bundle floating is based on actual bundle floating costs for individual channel section in the area. All costs are for 1983 and the programs for truck, tractor and railway transport costs are based on the tariff schedule format for 1983. With cost changes the programs can be easily updated by exchanging the cost values used. However, if the format used for costing changes, the subroutine must be modified accordingly. The explanations and definitions of the various costs and factors are included in the tariff schedules (Puutavaran autokuljetuksen . . . 1983, Puutavaran metsätraktorimaksut . . . 1983, Tariffitaulukot . . . 1983).

The basic truck transport rates by wood assortments, species, transport distance, dryness class and loading site class were registered in a separate file. Additional costs due to self-unloading, bundling, dumping and loading railway cars were included in the program itself. The truck cost subroutine can calculate truck transport cost for the following conditions:

- 1) distance
- 2) wood assortment
 - softwood pulpwood (green), 3 m
 - softwood pulpwood (half-dry), 3 m
 - hardwood pulpwood (green), 3 m
 - hardwood pulpwood (half-dry), 3 m
 - spruce logs (green)
 - spruce logs (half-dry)
 - pine logs (green)
 - pine logs (half-dry)
 - birch logs (green)
 - birch logs (half-dry)
 - softwood forest chips (green)
 - softwood forest chips (half-dry)
 - birch forest chips (green)
 - birch forest chips (half-dry)
 - other hardwood forest chips
- 3) loading site class
 - site class 1
 - site class 2
 - site class 3
- 4) wood source
 - roadside (i.e. at roadside in forest)
 - buffer storage (i.e. intermediate landing)

- 5) unloading method
 - large crane, bridge, forklift (min. 0.5 bunk/lift)
 - mobile unloader
 - truck self-unloading
 - dumping (i.e. tipping to side)
- 6) unloading destination or form
 - railway car
 - storage pile
 - grapple pile
 - heap or spread into water
 - bundle (wire rope with lock binding)
- 7) payment rate
 - basic rate schedule (factor = 1.0)
 - objective (goal) rate schedule (factor = 0.95)
- 8) truck type
 - 3 axle truck and 2 axle trailer
 - 3 axle truck and 3 axle trailer
 - 4 axle truck and 2 axle trailer
- 9) number of bindings per bundle; the type of binding used is wire rope with lock

By entering into the subroutine the transport distance, wood assortment, species and loading site class, the basic rate is obtained. The codes corresponding to the remaining conditions are examined and additional costs added accordingly: e.g. if unloading method code = 4 then additional cost of 10.00 FIM per truck. Some additional cost factors were not included in the subroutine since they had no direct effect on this study: e.g. poor forest road, shuttle loading, trailer use not possible, gathering of small piles, partial loads, sorting, waiting delays, transport on Sunday or other special holidays, winter road bonus and international transport. Of the many different pulpwood lengths differentiated in the tariff schedule, only 3 m pulpwood was included. Also, all loading was by self-loading.

In the tractor transport cost subroutine the sections of the cost schedule dealing with extended primary transport, transport from roadside and buffer storage, and the additional costs involved were only included. All costs were included directly within the subroutine. The cost of tractor transport could be determined in a manner similar to the truck transport cost subroutine by entering the codes for the following conditions into the program:

- 1) distance
- 2) wood assortment
 - softwood pulpwood (2.6–3.5 m)
 - hardwood pulpwood (2.6–3.5 m)
 - softwood logs (< 7 m)
 - hardwood logs (< 7 m)

- 3) dryness class
 - green (i.e. fresh)
 - half-dry
 - dry
- 4) payment rate
 - basic rate schedule (factor = 1.0)
 - objective (goal) rate schedule (factor = 0.95)
- 5) unloading destination or form
 - railway car (self-unloading)
 - water (bundling rack and wire rope with lock)
 - storage pile
 - crane (railway terminal)
 - crane (millyard)
- 6) driving speed of tractor on road
 - minimum speed is 4.0 km/h
 - maximum speed is 30.0 km/h
- 7) type of transport
 - extended primary transport (max. dist. 40.0 km)
 - transport from roadside storage (max. dist. 40.0 km)
 - transport from buffer storage (max. dist. 1.0 km)

The railway transport cost subroutine incorporated the use of a file containing the basic costs and the subroutine itself. Costs are calculated in the same manner as with the above subroutines. Only cost data for average wagon loads of 25 m³ (2 axle wagons) and 50 m³ (4 axle wagons) were included. The railway transport cost is determined according to the following conditions:

- 1) distance (max. dist. 500 km)
- 2) wood assortment
 - softwood pulpwood (green)
 - softwood pulpwood (dry)
 - hardwood pulpwood (green)
 - hardwood pulpwood (dry)
 - spruce logs (green)
 - spruce logs (dry)
 - pine logs (green)
 - pine logs (dry)
 - birch logs (green)
 - birch logs (dry)
- 3) railway terminal class (dispatch)
 - railway terminal without stationary crane
 - railway terminal with stationary crane
- 4) discount rate

Special discounts are given in railway transport if a certain volume is transported per year and per train. The discount given also varies by transport distance. During the time period of this study larger discounts were given on shorter distances. However, an across-the-board discount of 30 % was used in all cost calculations during the study, irrespective of transport distance. The use of the

above uniform discount allows easy conversion of the cost functions presented in section 57. (p. 66), if desired, according to a firm's own negotiated discount schedule.

Since cost schedules are not employed in bundle floating, the cost subroutine had to be designed in another manner. As mentioned in section 23. (p. 21), bundle floating in the northern part of the area and at two channel bottlenecks in the southern part is by cooperative floating. For this reason there are very accurate costs available by channel sections. In the private floating area, there are no major channel restrictions affecting the cost significantly. For this reason average costs could be assigned to the various channel classes: i.e. channels Is, IIs, IIIs and IVs. In the northern half, the channels are restricted at many points and the presence of individual bundle transfer facilities, narrow bridges, etc., have a significant effect on the cost competitiveness of individual channels.

Depending on the homogeneity of a watercourse in the cooperative floating areas, the channel sections used in costing vary from 1 to 93 km in length. To obtain the cost to tow wood through each channel section for the bundle floating cost subroutine, bundle towing costs statistics from 1970 to 1982 were examined. Linear regression was used to project costs for 1983. Linear regression was used to even out variations in costs between years and allowed the projection of costs where current floating cost data were unavailable. The cost projections for subsequent years can be obtained by replacing the oldest costs with new costs as they become available and re-running the linear regressions. If a certain channel was no longer in use, the linear regression cost projection was based on the costs from 1970 up to the year last floated in.

Some adjustment of the costs may be required. One example during this study was on the Iisalmi channel where the construction of two locks significantly reduced towing costs. Whenever physical changes occur in a channel and thus the basis for cost comparisons changed, only the costs following the change are taken into account.

After the 1983 projected costs were obtained for floating wood through each channel section, the coordinates of all grid squares containing a floating channel were listed. The grid cells corresponding to the channel sec-

tions were assigned the projected costs. For the channels in the private floating area actual average bundle towing costs by channel classes were obtained from the companies floating in the area and assigned by grid cell coordinates. The same costs were used irrespective of wood assortment.

In addition to actual bundle towing, there are a number of other costs which must be accounted for. Binding fastening and dumping costs are included in the truck and tractor cost subroutines and are thus omitted from the bundle floating cost subroutine. However, the following additional costs (i.e. terminal costs) were taken into account:

- 1) bundle bindings
- 2) dumping terminal maintenance (equipment, ramps and site)
- 3) forming of dumping stores on ice
- 4) raft forming

After examining all cost statistics for the Saimaa area, an average terminal cost of 5.00 FIM was assigned irrespective of terminal location or volume dumped. In reality annual terminal costs vary according to volumes dumped, maintenance costs for the year (e.g. more extensive maintenance work may only be done every second or third year at some terminals), winter conditions (e.g. effect on ice thickening and snow removal) and terminal improvements (e.g. effect on depreciation costs). However, a separate study is required to isolate the effect of volume dumped on terminal cost. Due to the above cost differences, the floating associations assign dumping terminal costs by districts to avoid "favouring" of terminals: e.g. if some larger investment was made at one terminal its depreciation cost would be higher and thus its user cost higher.

The direct cost of bundle floating is calculated by summing the bundle towing costs for each grid cell forming the floating route between the source and destination, and the terminal cost.

In the cost subroutines the cost of mill receiving is not included. This is because it varies widely between mills. At some mills there is no difference between road, rail and water transport, while at other mills there are large differences. If actual mill receiving costs

are not available to the reader, then the following general costs can be added to the final costs if desired (determined from actual mill receiving costs): road transport 3.50 FIM/m³, railway transport 5.00 FIM/m³ and bundle floating 5.00 FIM/m³. Interest costs on money invested in wood, due to the various transport methods, were not included in the cost subroutines. With an integrated transport policy employing all methods available in harmony, the effect of interest is not decisive in transport method choice due to the seasonal and annual variations inherent to wood procurement (section 52., p. 51). The cost effect of transport method on wood quality and mill processing is not included in the subroutine due to their unavailability. Vesikallio (1979) states that protecting wood quality during transport is as important as the direct transport costs themselves. As apparent from sections 221. and 222. (pp. 19 and 20), if wood must be stored due to incongruence between wood procurement and mill consumption, bundle floating has the least impact on total wood holding costs of the methods available; especially if bundles are rotated or sprinkled with water.

433. Search algorithm and cost subroutine synthesis

BASDATSERCH is the name given to the master program combining the heuristic search algorithms for road, railway and water transport routes between two points, and cost subroutines for truck, tractor and railway transport, and bundle floating. For truck and tractor transport the objective wage rate (factor = 0.95) was used. Tractor transport was extended primary transport. The operation of the program is as follows:

- 1) the grid coordinates of the source and destination are fed into the program
- 2) the type of wood assortment to be transported, as well as the loading site class are entered
- 3) the program then checks that both the source and destination are serviced by a road; if not the run is stopped and a message given that no transport is possible. The program does not account for the logging of shore and island forests where water transport is the only possible transport mode
- 4) the program determines whether the destination is serviced by a railway and/or water transport chan-

nel. If access to the destination by one or both methods is not possible, the route search for the method(s) in question is not initiated. Similarly, the search by either method is only activated if a transportable wood assortment is in question

- 5) if wood can be delivered by bundle floating then the program will determine the five closest bundle floating terminals based on straight-line distance. The program has the capacity for ten terminals but it was found that five was sufficient
- 6) road routes and distances are determined between the source and five terminals, and the cost of initial transport to each terminal calculated for both truck and tractor transport. If the distance exceeds 40 km no tractor transport cost is calculated
- 7) bundle floating routes are then determined between the five terminals and the destination, and the direct cost of bundle floating from each terminal calculated
- 8) total bundle floating cost to the destination is calculated via all five terminals using tractor and truck transport
- 9) all information obtained above is outputted. The dumping terminal class is also printed to give the decision-maker knowledge about terminal availability for dumping (i.e. 1 – summer use, 2 – winter use, 3 – all year). Ten terminals which are no longer in use were included in the list of available dumping terminals to determine if they had been justifiably abandoned and are referred to by class 4
- 10) steps 5) through 9) are repeated for railway transport. In addition, the type of railway terminal (i.e. stationary crane or not) has to be examined when calculating the cost of initial transport to the terminal
- 11) the road route connecting the source and destination is determined, and the truck and tractor costs calculated and outputted

An example of the BASDATSERCH output for the transport of 3 m (half-dry) softwood pulpwood and loading site class 2, between source (47, 45) and destination (54, 35) is given in Appendix A (p. 87).

BASDATSERCH only presents information for the decision-maker to employ in choosing the best long-distance transport method and if applicable, the best terminal via which wood should be transported. The above information would have to be combined with the other factors listed in section 22. (p. 17) affecting the choice of transport method. A more detailed analysis would be required at marginal zones where there is little difference between transport method costs. BASDATSERCH is not an optimization technique, although information gained from it can be used in mathematical programming if desired. Each run of BASDATSERCH only gives information between one

point and destination. Thus, in the form it is now, the program must be rerun entirely if costs for multiple sources and/or destinations are required. There would be no difficulty in expanding the program to handle multiple destinations in one run and thus reduce processing time requirements. The inclusion of multiple source handling in one run would not appear to have much benefit in regard to reducing processing time. The inclusion of a learning function to store route distances and floating routes as they become known for future use would also seem to be applicable. It must be remembered that BASDATSERCH is a prototype and there is much room for improvement.

434. Dirichlet tessellations

A dirichlet tessellation is a mosaic formed of dirichlet pavements. Lehnhausen and Lohmann (1981) define a dirichlet pavement as containing all points of a plane under consideration which are closest to a focal point: e.g. dumping terminal, railway terminal or mill. The dirichlet pavements are polygons which intersect each other only at their edges. Adjacent dirichlet pavements are called dirichlet neighbours. Determining dirichlet pavements from spatial data for analysis can be held as a part of heuristic programming. They are derived through heuristic means and can be employed in further heuristic investigation, for example:

- 1) determining interface/fringe areas where detailed attention can be focused
- 2) determining theoretical spheres of influence based on shortest straight-line distance
- 3) demarcation of an area, either preliminary or final

The formation of dirichlet pavements employing grid referenced spatial data is straightforward. First, the coordinates of the focal points must be specified. Straight-line distances are then calculated between each grid cell and all focal points, and the grid cell is assigned the code of the closest focal point. Once all grid cells have been assigned to a focal point we have a dirichlet tessellation.

Straight-line distance is calculated by determining the difference between Y and X

axes coordinates for the grid cell to be assigned and the grid cell containing the focal point. To get the distance the coordinate differences are multiplied by 2.5 km. Pythagorean's theorem is used to calculate the length of the straight-line between the two points (i.e. the hypotenuse). Straight-line distance between points was also used for the basic comparisons between the transport methods. This is because distances of transport routes from the same point vary according to method (section 57., p. 66).

When using dirichlet tessellations it must be remembered that the only priority for demarcation is straight-line distance. Other factors, such as geographic obstacles, should be accounted for in any analysis using dirichlet tessellations. However, the major use of dirichlet tessellations relates to heuristic programming. This is because it can be used to focus further attention on certain areas, while other areas can be excluded from the problem. Also, the approximation algorithm using "cascading fixed charges" presented by Dykstra (1976), and Dykstra and Riggs (1977) could be used in more detailed examinations of facilities location problems.

435. Other heuristic programming applications

The remaining heuristic programming applications cannot be defined in any structured way in this section. Since each application was unique they will be outlined along with the results in section 5. The practical applications of the spatial database – heuristic programming system outlined in section 5., employ combinations of the methods outlined above, as well as special manipulation of data stored in the system or obtained during some of the analyses. Heuristic programming was used to employ the above information and thus shed additional light on the transport problem in the area. Also, in no way do the applications in section 5. exhaust the possible uses of the spatial database – heuristic programming system in long-distance transport decision-making.

44. Verification and validation

441. Spatial database

Verification refers to ascertaining the correctness, while validation refers to ascertaining whether the desired result is obtained, and whether it is sound and well justified. As mentioned in section 423. (p. 33), the usefulness of the system is only as good as the information contained in it. Therefore, considerable editing of the data was required to verify that the data was correct.

The data was verified by examining each information matrix formed for the characteristics stored in the spatial database. All discrepancies found were corrected. The information matrices and catalogues were cross-referenced to each other, as well as to the original map mosaic. Names of terminals, classes, volumes dispatched, etc., were all verified. Field experts familiar with the area examined the data to ensure there were no discrepancies. Some dumping terminals were found to have two names. In these cases the name which seemed to be more commonly used was employed. Also, the spatial database and associated data had to be continuously updated as new information became available. This is an integral part of a system employing a large database. Another integral part of such a system is to monitor the results to pick up any errors which may have been overlooked: e.g. a ferry with limited carrying capacity may effectively block truck transport along a route. The TRIM for the route searching matrices required extensive editing to ensure that cross-overs were not possible. The results from the heuristic search algorithms were continuously monitored to remove any discrepancies which appeared.

To validate that the proper area, watersheds and water coverage had been registered, information matrices for the above were examined to determine how closely they corresponded to the values given by Seuna (1971). Information relating to the comparison are presented in Table 6.

When comparing the values above, we find that the spatial database information (database) for watersheds gave areas slightly larger than Seuna (1971). However, the differences between the two sets of data was very

Table 6. Saimaa area watershed information determined from the watershed and lake coverage information matrices (database) and by Seuna (1971).

Taulukko 6. Saimaan alueen vesistöjen pinta-alat ja järvisyys.

Watershed vesistö	Area lying in Finland pinta-ala Suomessa, km ²		Lake coverage järvisyys, %	
	Database	Seuna (1971)	Database	Seuna (1971)
Jänis River	1 975	1 970	9.5	6.1
Kitee River – Tohma River	756	755	9.8	7.4
Hiitola River	988	960	19.8	18.0
Vuoksi	52 831	52 390	24.1	21.3
Total	56 550	56 075	23.3	20.5

small and for the total area the difference was only 0.8 %. We can therefore conclude that the area covered by the spatial database corresponds very well to the actual area. For the calculations of lake coverage it was found that the spatial database gave higher lake coverage percentages than given by Seuna (1971); 2.8 % higher for the area on the whole. It appears that over-estimation of the lake coverage occurred. Therefore, a new information matrix for lake coverage was formed by reducing the lake coverage values of the grid cells in each watershed according to the differences between the spatial database and Seuna (1971).

The TRIM for the route searching algorithms were verified in connection with the validation of the route searching algorithms.

442. Route searching algorithms

After the subroutines for the road, railway and water transport route search algorithms were written, they had to be verified to ensure they contained no programming errors. All syntax and major programming errors were labelled by the computer. However, the programs had to be examined to ensure they were no hidden programming errors. Once the subroutines had been verified, they were used to search for transport network inconsistencies in the TRIM.

Analysis of variance (one-way classification with sub-sampling), combined with Student-Newman-Keul's multiple range test, were used to analyse the accuracy of the route search subroutines: i.e. validate that they work properly. The objective was to determine if differences existed between: manually measured and search algorithm route distances; distances for the three transport methods; and direction of search (i.e. from source to destination and from destination to source). For an explanation of the statistical methodology refer to Steele and Torrie (1960).

Twenty-six grid cell locations were chosen throughout the area. Each location was close to or at a railway and water transport terminal intersection, and all three transport networks intersected at the locations (Fig. 18). The distances from each grid cell to the remaining 25 were determined for the following experimental units:

- 1) water transport – manually measured – destination to source
- 2) water transport – manually measured – source to destination
- 3) railway transport – manually measured – destination to source
- 4) railway transport – manually measured – source to destination
- 5) road transport – manually measured – destination to source
- 6) road transport – manually measured – source to destination

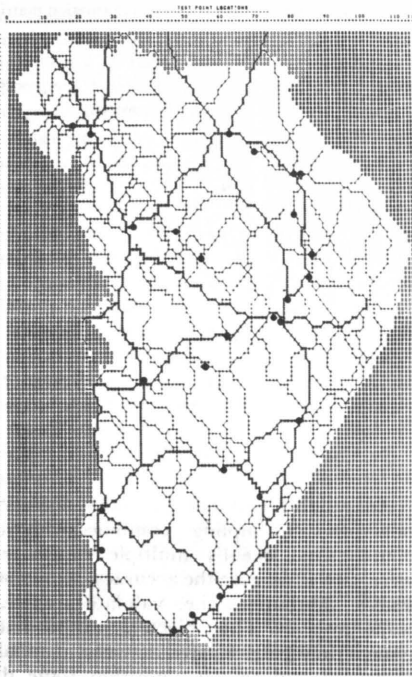


Fig. 18. Highway grid map showing the 26 grid cell locations for the analysis of the route search algorithms.

Kuva 18. Reittien etsimisalgoritmien tarkistuspisteiden sijainnit valtateiden ruudukkokartalla.

- 7) water transport – search algorithm – destination to source
- 8) water transport – search algorithm – source to destination
- 9) railway transport – search algorithm – destination to source
- 10) railway transport – search algorithm – source to destination
- 11) road transport – search algorithm – destination to source
- 12) road transport – search algorithm – source to destination

The manually measured road and waterway transport distances were minimum distances between points measured manually from the map mosaic. The manually measured distances for railway transport were from distance tables of the State Railways.

The analysis of variance and Student-Newman-Keul's multiple range test results were as follows (distances are km):

ANOVA TABLE

Source of variation	df	SS	MS	VR
SU	11	4 337 722		
- treatment	1	12 952	12 952	0.03 ^m
- EU/TR	10	4 324 770	432 477	31.56 ^{**}
SU/EU	4 200	57 546 401	13 702	
Total	4 211	61 884 123		

EU = experimental unit
 SU = sampling unit (i.e. replications)
 EU/TR = variation among experimental units within treatments (i.e. experimental error)
 SU/EU = variation among sampling units within experimental units (i.e. sampling error)

Treatment means were as follows:

- treatment (1) = 191.0
- treatment (2) = 194.5

Experimental unit means were as follows:

- EU mean (1) = 234.2
- EU mean (2) = 234.2
- EU mean (3) = 184.5
- EU mean (4) = 184.5
- EU mean (5) = 154.3
- EU mean (6) = 154.3
- EU mean (7) = 236.9
- EU mean (8) = 236.9
- EU mean (9) = 183.5
- EU mean (10) = 183.5
- EU mean (11) = 162.1
- EU mean (12) = 164.3

There was no significant difference between manually measured and search algorithm distances. There were highly significant differences between the experimental unit means within the treatments.

Least Significant Range Table

Value of p _m	q ₀₅ (p _m ,n ₂)	w ₀₅	q ₀₁ (p _m ,n ₂)	w ₀₁
2	2.77	17.31	3.64	22.74
3	3.31	20.68	4.12	25.74
4	3.63	22.68	4.40	27.49
5	3.86	24.12	4.60	28.74
6	4.03	25.18	4.76	29.74
7	4.17	26.05	4.88	30.49
8	4.29	26.80	4.99	31.18
9	4.39	27.43	5.08	31.74
10	4.47	27.93	5.16	32.24
11	4.55	28.43	5.23	32.68
12	4.62	28.87	5.29	33.05

Table of Mean Differences

Mean	6	5	11	12	10	9	4	3	2	1	8	7
7	83	83	75	73	54	54	52	52	3	3	0	0
8	83	83	75	73	54	54	52	52	3	3	0	0
1	80	80	72	70	51	51	50	50	0	0		
2	80	80	72	70	51	51	50	50	0			
3	30	30	22	20	1	1	0	0				
4	30	30	22	20	1	1	0					
9	29	29	21	19	0	0						
10	29	29	21	19	0							
12	10	10	2	0								
11	8	8	0									
5	0	0										
6	0											

Table of Significance Levels

Mean	6	5	11	12	10	9	4	3	2	1	8	7
7	**	**	**	**	**	**	**	**	ns	ns	ns	
8	**	**	**	**	**	**	**	**	ns	ns		
1	**	**	**	**	**	**	**	**	ns			
2	**	**	**	**	**	**	**	**				
3	*	*	ns	ns	ns	ns	ns					
4	**	**	ns	ns	ns	ns						
9	**	**	ns	ns	ns							
10	**	**	*	*								
12	ns	ns	ns									
11	ns	ns										
5	ns											
6												

From the Table of Least Significant Differences the following conclusions can be made:

- 1) there were no significant differences within transport methods (i.e. no difference between manual and search algorithm distance, or whether the search began from the source or the destination)
- 2) water transport route distances were (highly) significantly longer than for the other methods
- 3) there was no significant difference between manually measured railway distance and search program measured road distance
- 4) there was no significant difference between search program railway distance and search program road distance when the search was from the destination to the source, otherwise the railway route distance was significantly longer than road route distance
- 5) manually measured road route distances were (highly) significantly shorter than for railway or water transport routes

Although there was an insignificant difference between the two directions of search for the road route search algorithm, both road and railway route search algorithms were improved. The small difference which did exist was due to a situation where searching occurred in the wrong direction around a loop. To correct the situation the use of pivot points (section 431., p. 39) was added to both algorithms. Following the improvement there was no difference between direction of search. Inclusion of road route classes 3 and 4 in the initial pass through the search matrix (i.e. search for a "shortcut") reduced the difference between the manually measured and algorithm determined distances.

A new test of the road route search algorithm was made. The goal of the second test was to determine if any difference still existed between manually and algorithm determined road distance after the improvements to the algorithm. Searches in opposite directions were no longer required due to the algorithm improvements. Actual road distances measured in the terrain were included to determine if any differences existed. Nineteen road routes were tested throughout the area, having a total actual road distance of 1 535.9 km. All public road classes were included. The route distances varied between 15.1 and 299.0 km (actual road distance). The results from the analysis of variance (one-way classification) were as follows:

ANOVA TABLE

Source of variation	df	SS	MS	VR
Treatment	2	53.1	26.6	0.006 ^{ns}
Error	54	239 908.4	4 442.7	
Total	56	239 961.5		

1) map measured distance	- \bar{x} = 78.5 km - ΣX = 1 491.0 km
2) actual road measured distance	- \bar{x} = 80.8 km - ΣX = 1 535.9 km
3) algorithm determined distance	- \bar{x} = 79.6 km - ΣX = 1 512.3 km
straight-line distance	- \bar{x} = 58.6 km - ΣX = 1 112.5 km

As apparent from the analysis of variance there were no significant differences between map measured distance, actual road distance and road route search algorithm distance. The algorithm now gave an average road distance 1.014 times longer than the average map measured distance; compared to 1.051 times longer before the improvements to the algorithm. Of special interest was that the actual average road distance was the longest of the three, while the algorithm average distance was between map measured and actual average distance. The actual distance is longer due to elevation changes which are not accounted for in the map measured distance. Also, when measuring distances on a map the corners tend to get "rounded off". When compared to the straight-line distance, average map (manual), actual and algorithm measured road distances were 1.34, 1.38 and 1.36 times longer, respectively. From the above tests it can be concluded that the heuristic search algorithms give sufficiently "good" routes and distances, and are thus valid for finding the routes between points in subsequent analyses.

443. Costs subroutines

The basic cost information used for the truck and railway transport, and bundle floating cost subroutines were verified to ensure no errors existed. Following this each subroutine was validated by running the programs for all possible conditions built into the subroutines and checking the results with values calculated manually. It was found that distances from the route search algorithms had to be rounded off: e.g. the distance 59.95 km fell neither into interval 50.0–59.9 nor 60.0–69.9.

The route search algorithms also give the possibility of using cost functions for determining road transport costs. The lengths of travel over different road classes are available from the road route search algorithms. Once cost functions are available, keeping the cost subroutines up-to-date would be much simplified. Since railway transport tariffs are determined by government policy it is difficult to use cost functions. However, if the actual cost figures are available a cost function could be developed for what the cost should be. The importance of the cost of individual channel sections in water transport would preclude the use of a cost function.

444. BASDATSERCH

Since all data used in the route search algorithms and cost subroutines, as well as the programs themselves, were verified and validated, all that was required for verification and validation of BASDATSERCH was to ensure that all the separate parts worked properly together. For a number of different situations each part was run separately and then added together manually for the final result. The results obtained from BASDATSERCH were then compared to the above to ensure there were no differences. BASDATSERCH results were compared to standard cost employed by Tehdaspuu Oy to ensure reliable results were obtained.

5. PRACTICAL APPLICATIONS

51. General

The spatial database – heuristic programming system was applied to achieve the other goal of the study. At the same time the system's applicability as an aid in long-distance transport decision-making was tested. Most of the following examples deal mainly with bundle floating. However, in no way do the examples below exhaust the possible uses of the system. Also, the techniques used can be further refined to obtain more information. Information gained through the examinations can in turn be used for further examination: e.g. in mathematical programming. As mentioned earlier, the spatial database – heuristic programming system is meant to provide information to aid decision-making and not to be a source of ready answers.

52. Wood procurement variations

Variations between the amount of wood available for delivery and required at the mill directly effect the size of inventories required. Peltonen and Vesikallio (1979) state that if wood procurement was uniformly distributed throughout the year, a saving in wood procurement costs of 4 to 5 FIM/m³ (1979 cost) would accrue. However, if wood storage is required during the summer, water storage is generally held as the best method (section 221., p. 19); thus favouring water transport. On the other hand, most critics of water transport state that overly large inventories are required, since wood can only be delivered during the navigational season and thus interest costs make it uneconomical to use. For example, Eskelinen (1984) employs an interest cost of 11.90 FIM/m³ for bundle floated wood, while there is no interest cost for truck or railway transported wood. The question therefore is; what is the direct effect of bundle floating on inventories required at roadside, in transit and at the millyard?

Monthly statistics of industrial cuttings for all Finland published by the Ministry of Labour Affairs until 1981 and since then by the Finnish Forest Research Institute, were examined to determine if seasonal variations in wood procurement have decreased. To ensure the data is comparable, each harvesting year was examined separately. Fig. 19 presents the monthly industrial cuttings since mid 1964.

The monthly cutting volumes were examined to determine the shares of winter (November to April) and summer cuttings (May to October) of total cuttings, as well as the standard deviations (s) and coefficients of variation (CV), for each harvesting year. The share of delivery cuttings from private forests of all industrial wood cuttings was also determined. The above information is presented in Table 7.

During the last four harvesting years, an average of 63.75 % of industrial wood cuttings still occurred during the winter. As apparent from Fig. 19, cuttings during July are at a minimum. When the data in Table 7 is examined closer, it appears that there is a positive relationship between the size of CV and the share of delivery fellings from private forests: i.e. CV was smallest when the share of delivery sales from private forests was at a minimum (1980–81) and has increased in past years with the increase in the share of delivery cuttings from private forests. If the share of delivery sales from private forests remains at its present level, it appears there is not much industry can do to distribute cuttings more uniformly throughout the year. Also, even when the share of delivery sales from private forests was at a minimum of 17 %, 60 % of cuttings still occurred during winter.

There are other factors which would also seem to limit uniform cutting throughout the year: e.g. forest accessibility due to ground bearing strength (Haarala 1973, Saarihahti 1982), and detrimental effects of harvesting operations to the site and residual stand

Table 7. Information about industrial wood cuttings by harvesting years.
Taulukko 7. Markkinahakkuutiedot hakkuuvuosittain.

Harvesting year hakkuuvuosi	Share of cuttings osuus hakkaista, %		s, +/- M(m ³)	CV	Share of delivery sales from private forests toimituskappojen osuus
	Winter talvi	Summer kesä			
1964-65	71.5	28.5	1.634	0.57	0.45
1965-66	63.5	36.5	0.984	0.40	0.41
1966-67	69.0	31.0	1.219	0.51	0.42
1967-68	67.7	32.3	1.199	0.50	0.43
1968-69	71.0	29.0	1.438	0.51	0.42
1969-70	69.1	30.9	1.472	0.48	0.39
1970-71	67.8	32.2	1.376	0.43	0.33
1971-72	66.4	33.6	1.278	0.45	0.31
1972-73	68.7	31.3	1.316	0.46	0.29
1973-74	63.5	36.5	1.056	0.36	0.25
1974-75	63.0	37.0	0.957	0.34	0.22
1975-76	60.3	39.7	0.774	0.39	0.18
1976-77	62.1	37.9	0.808	0.33	0.18
1977-78	64.9	35.1	0.897	0.39	0.19
1978-79	63.8	36.2	0.867	0.48	0.22
1979-80	59.2	40.8	1.083	0.36	0.20
1980-81	60.2	39.8	0.916	0.28	0.17
1981-82	62.9	37.1	1.270	0.36	0.20
1982-83	68.2	31.8	1.529	0.44	0.26
1983-84	63.7	36.3	1.177	0.37	0.27

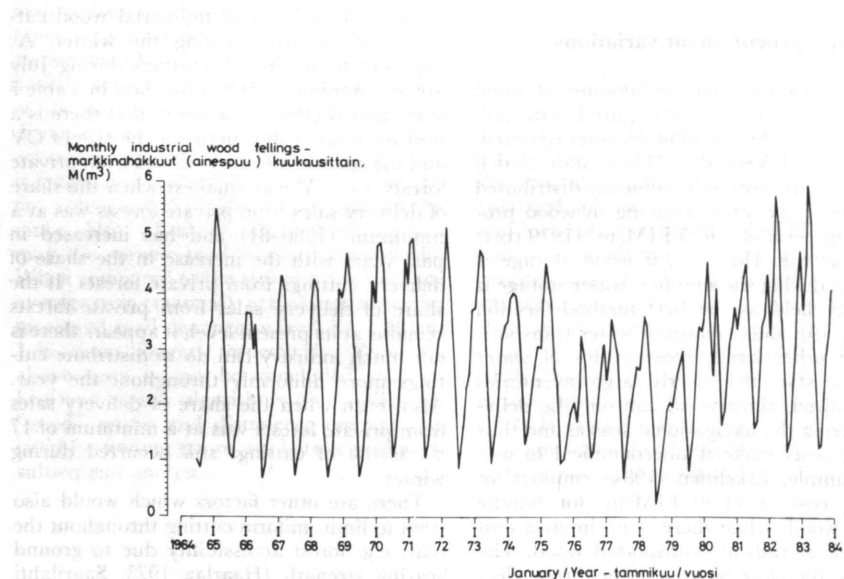


Fig. 19. Monthly industrial wood cuttings.

Kuva 19. Markkinahakkuut (ainespuu) kuukausittain.

(Kärkkäinen 1973). Adverse winter conditions, such as deep snow and severe cold, increase the cost of winter cuttings on the other hand. Another factor is the availability of roads for transport, since it varies throughout the year (Fig. 9, p. 18) and between years. There are also large variations in wood requirements between years (i.e. market conditions) (Table 2, p. 14). The above make uncertainty a major factor which must be accounted for in wood procurement decision-making. The only way to reduce the effect of uncertainty is to employ inventories: i.e. standing, roadside, intermediate and millyard. As mentioned in section 221. (p. 18), the effect of running out of wood is much greater at large wood processing mills, than at small mills.

The problem of where or how large inventories must be to minimize wood procurement costs is not examined here. However, heuristic programming was used to determine the theoretical size of wood inventory required at roadside, in transit and at the millyard to ensure a mill does not run out of wood; assuming perfect knowledge of cutting and transport volumes throughout the year, and uniform consumption of wood at the mill. In the analysis, the years 1972 to 1983 were examined separately. It was assumed that a large integrated complex was in question and the total volume cut during the year was consumed equally each month. For bundle floating, it was assumed that the distribution of wood deliveries during June, July, August, September, October and November was 10, 30, 30, 15, 10 and 5 %, respectively. The monthly distribution for truck delivered wood depended on its share of delivered volume. The most uniform distribution for delivered wood was aimed for, while taking into account spring and fall break-up periods, possibility of delivering wood by water and trucks required to haul wood to dumping terminals. For 100 % truck transport the volume delivered throughout the year was uniform. The monthly industrial wood cutting statistics for all Finland were used for the distribution of monthly cuttings in each year. An algorithm was developed to solve the above problem. The algorithm first calculates inventory balances at roadside and at the mill according

to the above distributions. The monthly inventories are then adjusted to ensure no wood shortages would occur: i.e. starting and year-end inventories were required for each year. The average inventory level for the year was calculated from the monthly levels. The criterion for the minimum inventory was that the mill could not run out of wood. Railway transport was not accounted for since railway rolling stock should be used uniformly throughout the year due to the high capital investment in rolling stock and since its availability for delivering wood is similar to truck transport. The theoretical minimum inventories possible for each year with 0, 25, 40, 50, 66, 75 and 100 % of the annual wood requirement delivered by bundle floating are presented in Fig. 20. It must be remembered that in the analysis we are dealing only with the inventory after extraction and the transport methods available are used in harmony so that the deficiencies of each method are supplemented by the others.

The average theoretical minimum inventory possible was a 0.81 month wood supply with 100 % truck transport. The maximum and minimum values for 100 % truck transport were 1.17 and 0.54 months, respectively. Wood supply in this sense means wood at roadside, in transit to the mill and at the mill. Eskelinen and Peltonen (1977) state that the optimum size of roadside and millyard inventories would be 0.48 and 0.12 months wood supply, respectively. These values correspond to only the minimum inventories obtained with 100 % truck transport during 1972 to 1983, and assuming perfect certainty in wood supply and requirements. If we also account for uncertainty in wood procurement and if no wood shortage was to be allowed during the above period, the average inventory when using truck transport should have been at least a 1.17 month wood supply. For 100 % bundle floating the average, maximum and minimum values were 7.15, 7.30 and 6.92 months wood supply, respectively. There is a 6.1 month inventory level difference between using 0 and 100 % bundle floating. If an approximate average cost for wood of 200 FIM/m³ and an interest rate of 16 %/a are used, the resulting interest cost difference is 15.67 FIM/m³. Similar calculations for the remaining shares of bundle floating give the following results:

-25 % share - interest cost difference	= 0.50 FIM/m ³	(0.20 month)
-40 % share - "	= 1.69 "	(0.68 month)
-50 % share - "	= 2.86 "	(1.15 month)
-66 % share - "	= 6.51 "	(2.59 month)
-75 % share - "	= 8.95 "	(3.54 month)

Fig. 20 shows that the relationship between inventory level and share of bundle floating is not linear. Thus, for conceivable levels of bundle floating use, the effect of interest cost is much reduced. Since the share of bundle floating in the Saimaa area is about 35 to 38 % of delivered volume, we can calculate the average interest cost due solely to bundle floating to be about 1.40 FIM/m³. This assumes an average cost of wood in inventory of 200 FIM/m³ and an interest rate of 16 %/a.

In conclusion, the additional wood inventory required at roadside, in transit or at the millyard in the Saimaa area due solely to bundle floating, is approximately a 0.6 month wood supply. Although interest is not added to the costs calculated in the study, an average additional interest cost of 1.40 FIM/m³ for bundle floating can be added to its cost when comparing it to the other methods, if desired. The theoretical interest costs which would accumulate after extraction, for both land and water delivered wood, can be calculated from Fig. 20. Also, if actual wood assortment values are available to the reader, the above can be used to determine the actual interest costs by wood assortments due solely to bundle floating. The above does not take

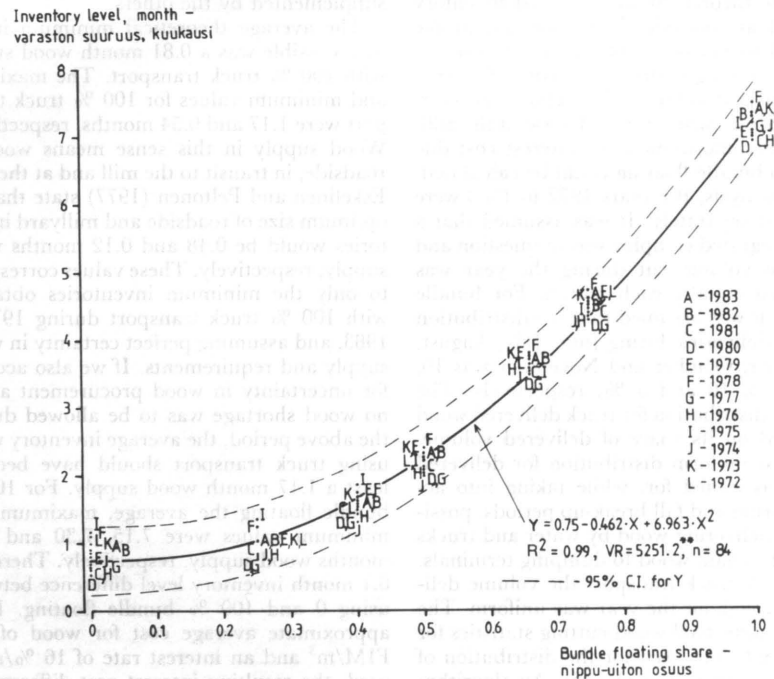


Fig. 20. Theoretical minimum inventories required to ensure no wood shortage occurs at the mill for various shares of bundle floating and truck transport delivered wood.

Kuva 20. Teoreettisen minimivaraston riippuvuus nippu-uiton ja autokuljetuksen kuljetusosuuksista.

into account variation between years, which would result in larger inventories. Larger inventories due to other factors would in turn reduce the additional interest cost due solely to bundle floating. Although no cost information is available, when wood inventories are required the difference in wood holding costs in favour of bundle floating would seem to outweigh any interest cost due solely to bundle floating; especially with softwood sawlogs and pine pulpwood. This requires further study however.

53. Terminal dirichlet tessellations

To examine the theoretical service areas for railway and bundle floating terminals in the

Saimaa area, dirichlet tessellations were made for all railway terminals available (n = 99), railway stations with stationary cranes (n = 21) and bundle floating terminals in use (n = 86). Railway terminals were included irrespective of whether they were in the Saimaa area or not. However, dirichlet pavements in the area were assigned to only 98 of the terminals available. Although there were 88 bundle floating terminals actually used during 1980 to 1982, terminals in use refers to terminals in continuous use. For this reason Partakoski (126, 36) was not included since it was only used once during the period, and Tappuvirta (84, 51) was no longer in use after 1981. The dirichlet tessellations are presented in Fig. 21, 22 and 23. Since grid cells were assigned in the tessellations, the borders between areas are "step-like" and not straight

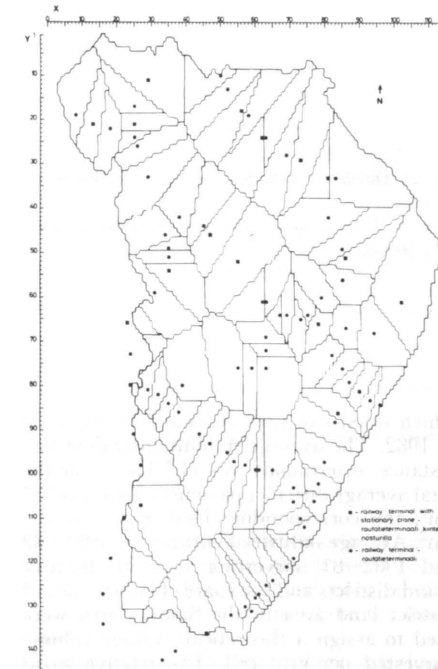


Fig. 21. Dirichlet tessellation for all railway terminals available.

Kuva 21. Käytettävissä olevien rautatieasemien teoreettiset vaikutusalueet.

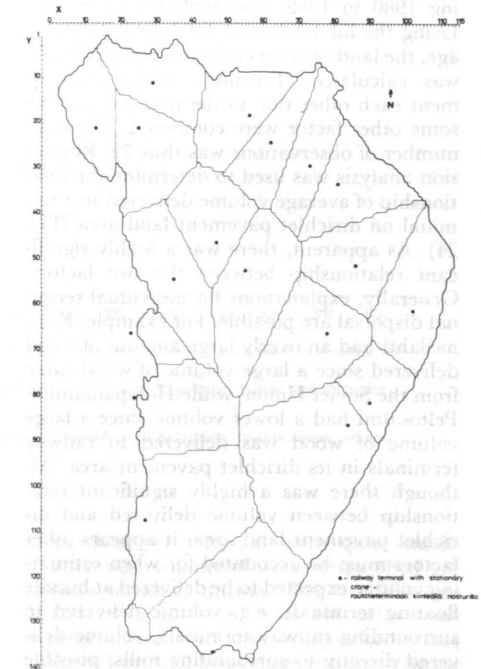


Fig. 22. Dirichlet tessellation for railway terminals with stationary cranes.

Kuva 22. Kiinteällä nosturilla varustettujen rautatieasemien teoreettiset vaikutusalueet.

lines. Also, only 82 of the railway terminals were actually used for wood transport in the area. For the bundle floating terminals the average minimum straight-line distance was 17.3 km and the total average dirichlet pavement area was 650 km². For railway terminals the corresponding values were 16.8 km and 571 km², and 29.9 km and 2 693 km² for all railway terminals available and terminals with stationary cranes, respectively.

From Fig. 22 it appears that the best coverage by the railway terminals with stationary cranes was in the northern part of the area. When all railway terminals are included the coverage efficiency is reduced due to narrowing of the theoretical service areas (Fig. 21).

To determine if there was any relationship between dirichlet pavement land area and volume delivered to a bundle floating terminal, a new dirichlet tessellation was made. All terminals to which wood was delivered during 1980 to 1982 were included (n = 88). Using the information matrix for lake coverage, the land area for each dirichlet pavement was calculated. Terminals which complement each other due to the road network or some other factor were combined. The total number of observations was thus 72. Regression analysis was used to determine the relationship of average volume delivered to a terminal on dirichlet pavement land area (Fig. 24). As apparent, there was a highly significant relationship between the two factors. Generally, explanations for individual terminal dispersal are possible. For example, Kannaslahti had an overly large amount of wood delivered since a large volume of wood came from the Soviet Union, while Holopanlahti + Peltosalmi had a lower volume since a large volume of wood was delivered to railway terminals in its dirichlet pavement area. Although there was a highly significant relationship between volume delivered and dirichlet pavement land area, it appears other factors must be accounted for when estimating volume expected to be delivered at bundle floating terminals: e.g. volume delivered to surrounding railway terminals, volume delivered directly to surrounding mills, possible external sources of wood and surrounding stand make-up.

A dirichlet tessellation was formed from the union of the 82 railway terminals actually used and the 88 bundle floating terminals at

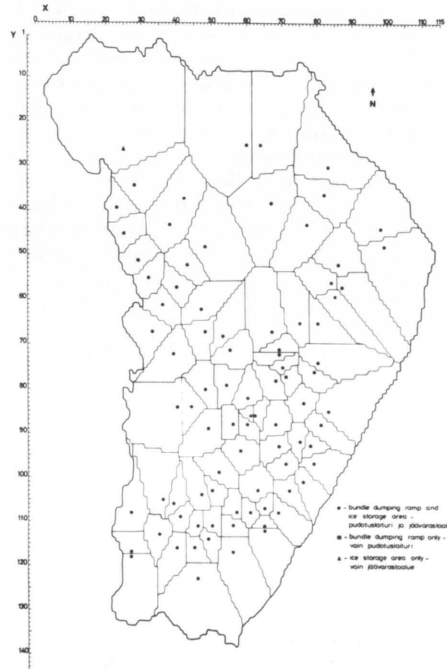


Fig. 23. Dirichlet tessellation for bundle floating terminals in use.

Kuva 23. Käytössä olevien vesikuljetusterminaalien teoreettiset vaikutusalueet.

which wood had been delivered during 1980 to 1982. The average minimum straight-line distance to terminals was 11.5 km, while the total average dirichlet pavement area was 333 km²; the corresponding land area was 264 km². Average industrial cuttings for 1981–82 and 1982–83 harvesting years by forestry board districts and the share of forestry board district land area in the Saimaa area were used to assign a theoretical average volume harvested per grid cell. The relative wood drainage area was determined for each terminal by first obtaining the average volume dispatched during 1980 to 1982 from its own dirichlet pavement. If its own pavement did not supply a sufficient volume, the balance

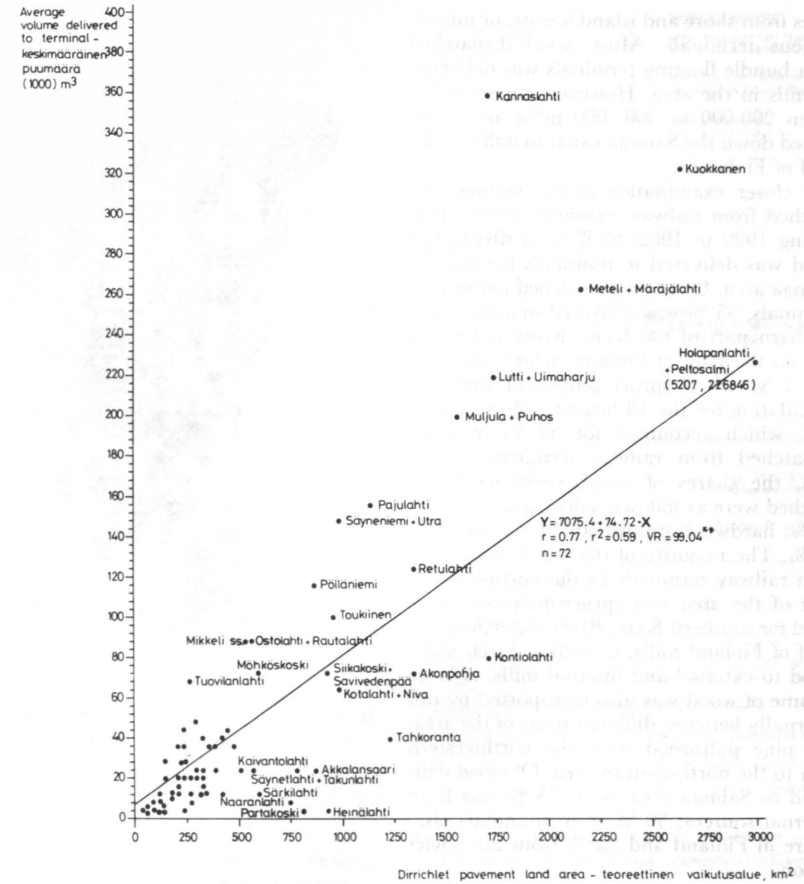


Fig. 24. Relationship between average volume delivered to bundle floating terminal and dirichlet pavement land area.

Kuva 24. Vesikuljetusterminaalin toimitetun keskimääräisen puumäärän ja teoreettisen vaikutusalueen välinen riippuvuus.

was obtained from unassigned cells in neighbouring dirichlet pavements. It must be remembered that Fig. 25 shows only relative areas which have no link to where the wood came from in reality.

Closer examination of Fig. 25 reveals that a large share of the wood in the north-western part of the area was dispatched from railway terminals, while in the north-eastern part most wood was dispatched from bundle floating terminals. In the southern half, volumes

dispatched per terminal were quite small. The average volume of wood dispatched per railway terminal during 1980 to 1982 was 25 025 m³/a (s = +/- 25 448 m³/a); the average total volume dispatched was 2 052 015 m³/a. The average volume of wood dispatched per bundle floating terminal during 1980 to 1982 was 43 948 m³/a (s = +/- 66 200 m³/a); the average total volume dispatched was 3 867 446 m³/a. The values for bundle floating terminals do not include vol-

umes from shore and island forests, or miscellaneous terminals. Most wood dispatched from bundle floating terminals was delivered to mills in the area. However, currently between 200 000 to 300 000 m³/a are transported down the Saimaa canal to mills on the Gulf of Finland.

A closer examination of the volume dispatched from railway terminals reveals that during 1980 to 1982, 63.8 % of dispatched wood was delivered to terminals beyond the Saimaa area. Of wood dispatched to external terminals, 55 % was delivered to mills in the southern part of the Kymi River watershed and on the Gulf of Finland; which consume over 2 M(m³) of spruce pulpwood annually. Calculating for the 18 largest railway terminals, which accounted for 59 % of wood dispatched from railway terminals in the area, the shares of wood assortments dispatched were as follows: softwood pulpwood, 67 %; hardwood pulpwood, 14 %; and logs, 19 %. The majority of the wood dispatched from railway terminals in the north-western part of the area was spruce pulpwood destined for southern Kymi River watershed and Gulf of Finland mills, as well as birch pulpwood to external and internal mills. A large volume of wood was also transported by rail internally between different parts of the area; e.g. pine pulpwood from the northwestern area to the north-eastern area. Of wood delivered to Saimaa area mills, 55 % was from external sources; 30 % from terminals elsewhere in Finland and 25 % from the Soviet Union.

The above analysis shows that railway transport was used to transport wood to destinations beyond the Saimaa area, to mills in other parts of the area where water transport was not possible and for transporting poorly floating wood (e.g. birch pulpwood). Railway transport was also used to a greater extent to transport wood procured from beyond the area to mills in the area, than for internal transport of wood. Bundle floating on the other hand was used to transport wood from the area itself, as well as wood trucked in from surrounding watersheds and the Soviet Union, to internal destinations. When taking the Saimaa area by itself it appears that bundle floating and railway transport are used in their proper niches.

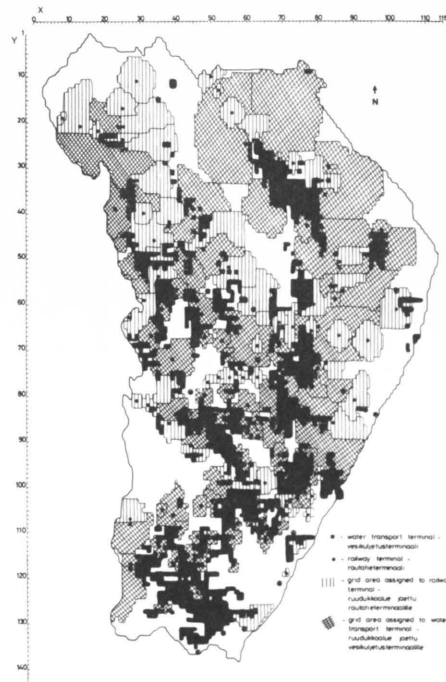


Fig. 25. Grid cells assigned to terminals according to average volume dispatched, dirichlet pavement and average industrial cuttings for forestry board districts.

Kuva 25. Ruudut on jaettu kaukokuljetusterminaaleille seuraavien perusteiden: terminaaleille toimitettu keskimääräinen puumäärä, teoreettinen vaikutusalue ja keskimääräiset markkinahakkuut (ainespuu) piirimetsälautakunnittain.

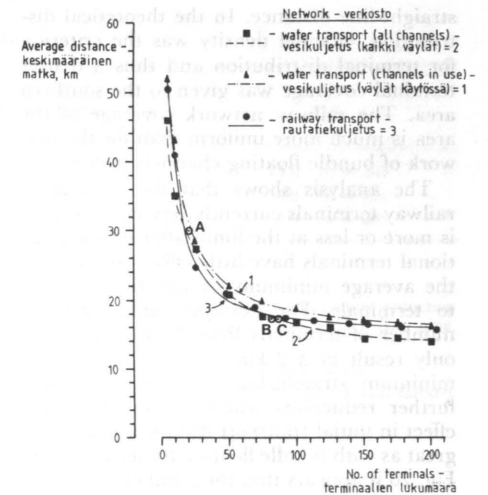
54. Terminal density vs average dirichlet pavement area

Raakapuun veteenpanokustannukset... (1981) states that if initial transport cost to dumping terminal, terminal construction costs and terminal maintenance costs are taken into account the minimum theoretical cost would occur if the volume dumped is 31 000 m³/a. However, wood turn-around time (i.e. amount of wood passing through the terminal per time period), raft gathering

costs and availability of suitable sites must also be taken into account. The purpose of this application of the spatial database – heuristic programming system, however, is to determine the relationship between terminal density and average minimum straight-line distance to both bundle floating and railway terminals. Since the densities of both water and railway transport terminals have been reduced in past years it is important to determine the effect of further reductions on the initial transport distance. Also, since the terminals are already in existence and Raakapuun veteenpanokustannukset... (1981) examined a situation where starting from construction of terminals, only the effect of terminal density on the minimum straight-line distance of initial transport was examined.

In the analysis various numbers of terminals were distributed over bundle floating channels currently in use, all bundle floating channels available and the railway network. The extent of coverage of the three networks analysed was determined using the information matrices for each network. Theoretical terminal coordinates were assigned according to the interval between route positions and the number of terminals desired. For example, if there are 500 grid cells containing a section of the network (i.e. route positions), route positions 50, 150, 250, 350 and 450 would be assigned as terminals. Following this procedure two sets of terminal locations for various numbers of terminals were generated along the bundle floating and railway transport networks. The first set was generated by assigning the terminal locations by rows from top to bottom, while the second set was assigned by columns from left to right. Average minimum straight-line distances for the various number of terminals for each transport network were then calculated and the minimum distance chosen from the two sets of data. Since the railway network extends beyond the Saimaa area, some terminals had no dirichlet pavement. These terminals were omitted from the calculations; thus the uneven gradation between the number of railway terminals and the extra observations. Regression analysis was used to determine the relationships within the three groups of data (Fig. 26).

From Fig. 26 we see that the regression equations fit their respective data very well:



- (1) $Y = 14.5 + 387.667/X - 1001.423/X^2$; $R = 0.9998$, $R^2 = 0.9996$, $VR = 8\ 002.4^{**}$, $n = 10$
 (2) $Y = 11.3 + 557.240/X - 4446.294/X^2 + 12637.658/X^3$; $R = 0.9997$, $R^2 = 0.9994$, $VR = 3358.6^{**}$, $n = 10$
 (3) $Y = 14.7 + 257.533/X + 480.623/X^2 - 4363.646/X^3$; $R = 0.9993$, $R^2 = 0.9986$, $VR = 1\ 666.5^{**}$, $n = 11$

- (A) railway terminals with stationary crane – kiinteänosturit rautatieterminaalit
 (B) railway terminals in use – käytössä olevat rautatieterminaalit
 (C) bundle floating terminals in use – käytössä olevat vesikuljetusterminaalit

Fig. 26. Relationship between the number of transport network terminals and the average minimum straight-line distance to terminals.

Kuva 26. Kuljetusverkon terminaalien lukumäärän ja keskimääräisen lyhimmän matkan (lennuntietä) välinen riippuvuus.

multiple coefficients of determination (R^2) were 0.9996, 0.9994 and 0.9986 for bundle floating channels in use, all bundle floating channels and railway network. The corresponding distances for dirichlet pavements for actual terminal locations are also shown on Fig. 26. Dirichlet pavement average distances for theoretical and actual railway terminal locations correspond quite well. Dirichlet pavement average distance for the actual bundle floating terminal distribution was slightly lower. This is due to the effect of terminal location on channels in the northern part having much more effect on minimum

straight-line distance. In the theoretical distribution, channel density was the criterion for terminal distribution and thus a denser terminal coverage was given to the southern area. The railway network coverage of the area is much more uniform than for the network of bundle floating channels in use.

The analysis shows that the number of railway terminals currently servicing the area is more or less at the limit, after which additional terminals have little effect on reducing the average minimum straight-line distance to terminals. For example, increasing the number of terminals from 82 to 200 would only result in a 2 km reduction in average minimum straight-line distance. Also, any further reductions will have an increasing effect in initial transport distance, but not as great as with bundle floating terminals. From Fig. 26 it appears that the number of railway terminals could be reduced to about 70 to 80, without too much effect on initial transport distance. However, if any terminals are to be abandoned, a detailed analysis is required to determine local effects.

If only the bundle floating channels in current use are accounted for and the average minimum straight-line distance to terminals is the decision criterion, the actual number of bundle floating terminals available ($n = 87$, includes Partakoski) is close to the optimum level. In past years a large number of terminals have been abandoned or are used on a sporadic basis; in the search for bundle floating terminals a total of 208 different terminal locations were found. It appears that the major benefit from new terminals would be if they were located on channels not in current use (e.g. Syväri and Juojärvi channels) or in the northern part of the area. For example, the difference between whether Holopaniemi (21, 24) in the northern part of the area is included or not on average minimum straight-line distance for the area is 0.7 km. Referring to the above, any further reductions in the number of bundle floating terminals requires careful scrutiny due to the exponential increase in average minimum straight-line distance to terminals and local effects.

The above theoretical evaluation omitted the effect of road locations and other physical obstacles (e.g. lakes or rivers) which would hinder the straight-line movement of wood to terminals. Situations such as these would

have to be analysed and solved as single problems. The above recommendations refer to the area as a whole; to help the formulation of a general policy for bundle floating and railway transport terminal density in the Saimaa area. Bundle floating and railway transport networks were examined separately, and thus the integrated use of all transport terminals was not examined. Cost information was not included either. However, in spite of the above shortcomings, it is felt that the above analysis reflects "good" solutions, which are quite close to the optimum.

To obtain a view of dirichlet tessellation information when both bundle floating and railway terminals are used in conjunction, a union of both sets of terminal data was formed. The total number of operational terminals was 185; includes 86 dumping terminals and 99 railway terminals. The average minimum straight-line distance for the Saimaa area was 11.4 km. When compared to bundle floating terminals (17.3 km) and railway terminals alone (16.8 km) it appears that the integrated use of all transport methods would seem worthwhile, especially where terminal densities are low.

The dirichlet pavement information also varies between different parts of the area. This is especially true in regard to the water transport network, where the network does not extend to the northern boundary of the area. To determine the above relationships the area was divided into three zones: zone 1 – grid cell rows 1 to 48; zone 2 – grid cell rows 49 to 96; and zone 3 – grid cell rows 97 to 144. The average minimum straight-line distances to terminals in each zone were calculated for available railway terminals, bundle floating terminals (in use), and a union of bundle floating and railway terminals (Table 8).

From Table 8 it is apparent that zone 1 (northern area) has the longest distance to terminals when dealing with bundle floating terminals, while there is little difference between zones 2 and 3. With railway terminals the longest distance is in zone 3, while zone 2 has the shortest. The minimum average straight-line distance to bundle floating terminals in use in the northern zone is almost double that in the central and southern zones. Therefore, any reduction in floating terminal density would have its most severe impact in the northern zone. The high density present

Table 8. Zonal average minimum straight-line distances.
Taulukko 8. Lyhimmät keskimääräiset alueittaiset matkat linnuntietä.

Zone alue	(A)	(B)	(C)
	Available railway terminals käytettävissä olevat rautatietermiinaalit, km	Bundle floating terminals in use käytössä olevat vesikuljetustermiinaalit, km	A+B, km
1	17.8 (n = 24)	25.2 (n = 14)	15.6 (n = 38)
2	15.1 (n = 44)	13.6 (n = 43)	8.8 (n = 87)
3	18.2 (n = 31)	13.2 (n = 29)	8.9 (n = 60)

in the central and southern zones is necessary due to high lake coverage and thus initial transport difficulties. However, it appears that the number of terminals in the central zone can be reduced with little effect on initial transport distance (Fig. 23, p. 54). From Fig. 21 (p. 53) and Table 8, it appears that the number of railway terminals in zones 2 and 3 is excessive. In practice only 82 of the terminals are in use, with 23 in zone 1, 39 in zone 2 and 20 in zone 3. General information for the 82 railway terminal dirichlet tessellation are as follows: average minimum straight-line distance, 17.3 km; average dirichlet pavement area, 690 km²; and average dirichlet pavement land area, 548 km². The reduction of 17 terminals only increased the average minimum straight-line distance by 0.5 km. Careful scrutiny is required when abandoning terminals. Although the total average may change little, there may be a large local effect. However, further terminal reductions in zone 2 would have the least effect on increasing the average minimum straight-line distance to railway terminals.

55. Wood processing centre/point dirichlet tessellations

Separate dirichlet tessellations were formed for wood processing centres/points consuming pine logs, spruce logs, hardwood logs, pine pulpwood, spruce pulpwood and hardwood pulpwood. Volumes consumed by wood assortment at the above centres/points during a good year were used when assigning grid cells. When calculating the volume available for assignment the following data for forestry board districts from Kuusela (1978), Kuusela and Salminen (1983) and Yearbook of Forest Statistics (1983) were employed:

- 1) allowable drain after nature conservation reduction by forestry board districts and species (i.e. pine, spruce and hardwood)
- 2) forest residues by forestry board districts
- 3) log/pulpwood compositions by species and forestry board districts
- 4) forestry board district land area

The land area of each forestry board district in the Saimaa area was determined and its percentage of total forestry board district land area calculated. The allowable drain (minus forest residues) for the part of the forestry board district in the Saimaa area was simply the total allowable drain times share of land area in the Saimaa area. The number of land area grid cells for each forestry board district in the area were determined. The volumes available by wood assortments were distributed evenly between the available grid cells. Although the above use of average statistics for forestry board districts to estimate volumes per grid cell available is not statistically sound, it was necessary due to the lack of detailed information for the smaller areas involved (i.e. municipalities or grid cells). Salminen (1981) gives a cartographic presentation of forest resources in Finland for 1971 to 1975. However, in this analysis no additional benefit would have been obtained with its use.

The volume requirement for each wood processing centre/point was first obtained from land grid cells in its own dirichlet pavement. If additional volume was required, unassigned land grid cells from neighbouring dirichlet pavements were then assigned. The order in which wood processing centres/points were handled was from north to south and west to east. Wood processing centre/point theoretical wood procurement areas for southern Saimaa area mills were combined

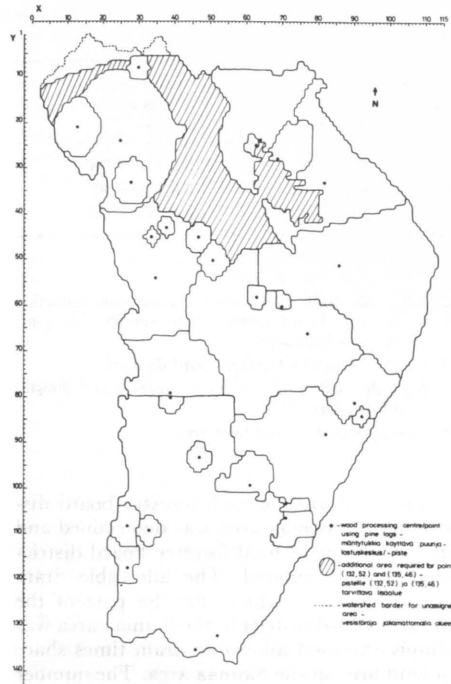


Fig. 27. Theoretical wood procurement areas for wood processing centres/points using pine logs.

Kuva 27. Mäntyttukia käyttävien puunjalostuslaitosten ja -laitosryhmien teoreettiset puunhankinta-alueet.

when their areas overlapped. Theoretical wood procurement areas for wood processing centres/points consuming pine logs, spruce logs, hardwood logs, pine pulpwood, spruce pulpwood and hardwood pulpwood are presented in Fig. 27, 28, 29, 30, 31 and 32. The assignments assume that all wood available is harvested and used by industry, and there is no wood import into the area.

Average data for the theoretical wood procurement areas is as follows:

- 1) pine logs – average land area, 1 451 km²
– average straight-line distance, 64 km
– 98.4 % of available grid cells assigned
- 2) spruce logs – average land area, 1 358 km²
– average straight-line distance, 58 km
– 80.2 % of available grid cells assigned

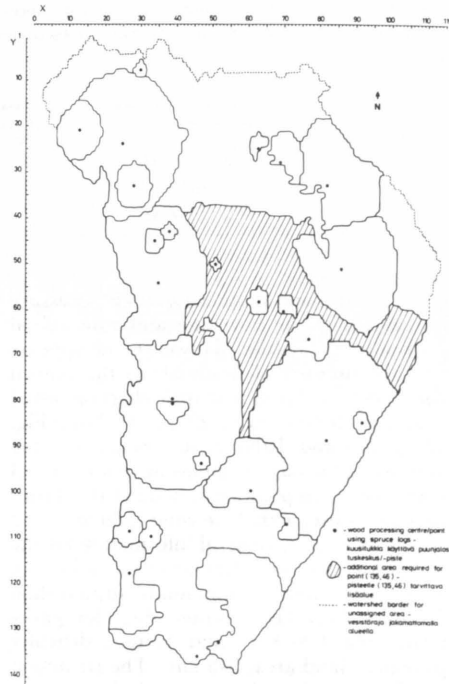


Fig. 28. Theoretical wood procurement areas for wood processing centres/points using spruce logs.

Kuva 28. Kuusittukia käyttävien puunjalostuslaitosten ja -laitosryhmien teoreettiset puunhankinta-alueet.

- 3) hardwood logs – average land area, 2 812 km²
– average straight-line distance, 103 km
– 86.2 % of available grid cells assigned
- 4) pine pulpwood – average land area, 9 134 km²
– average straight-line distance, 154 km
– 100.0 % of available grid cells assigned
- 5) spruce pulpwood – average land area, 2 215 km²
– average straight-line distance, 36 km
– 34.0 % of available grid cells assigned
- 6) hardwood pulpwood – average land area, 6 823 km²
– average straight-line distance, 117 km
– 89.6 % of available grid cells assigned

Fig. 27 shows that the majority of the theoretical wood procurement areas are quite small. If the mills in the southern part of the area at (132, 52) and (135, 46) are not included, the average straight-line distance would be 27 km. For the mills at (132, 52) and (135, 46) the average straight-line distance is 150 km. Thus, if all pine logs available for harvesting are cut for industrial consumption and if there is perfect cooperation between mills so that all logs are delivered to the closest mill, truck transport could be resorted to in all cases, with the exception of the mills at (132, 52) and (135, 46). For mills in the southern part of the area water and/or railway transport would be required also. The above would assume the equal distribution of benefits gained from reduced transport costs. Also, during a good year almost all pine

logs available would be required from the area if external sources are not available and the annual allowable drain was used fully for industrial purposes.

Fig. 28 shows the situation with spruce logs is similar to that with pine logs. If mills at (132, 52) and (135, 46) are again excluded the average straight-line distance is 24 km. The straight-line distance to the two grid cells is 136 km. The same conclusions can be made as above. There appears to be a small surplus of spruce logs in the area, even during a good year.

For hardwood logs (Fig. 29) we again have a situation similar to pine logs, except that the mills in the southern part are at (117, 27) and (135, 46). The average straight-line distance to these mills is 224.9 km, while for the remaining mills it is 30.8 km. It appears that

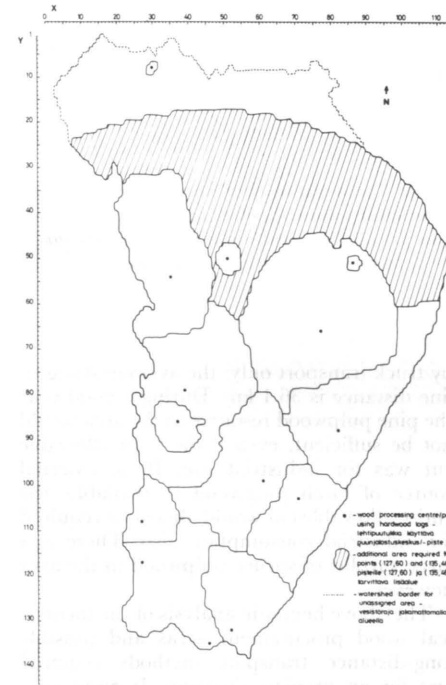


Fig. 29. Theoretical wood procurement areas for wood processing centres/points using hardwood logs.

Kuva 29. Lehtipuitukia käyttävien puunjalostuslaitosten ja -laitosryhmien teoreettiset puunhankinta-alueet.

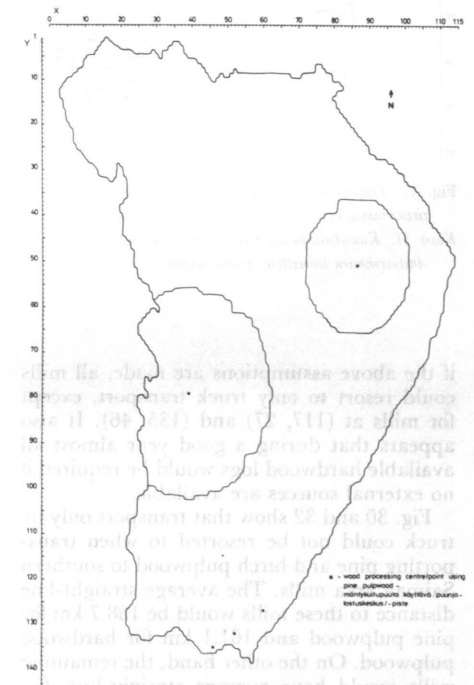


Fig. 30. Theoretical wood procurement areas for wood processing centres/points using pine pulpwood.

Kuva 30. Mäntykuitupuuta käyttävien puunjalostuslaitosten ja -laitosryhmien teoreettiset puunhankinta-alueet.

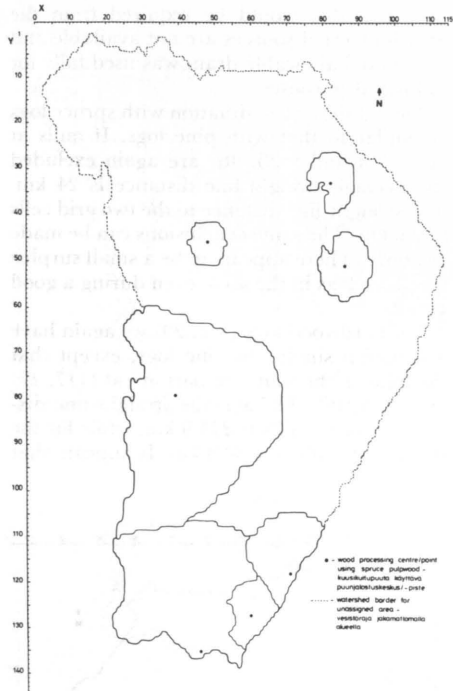


Fig. 31. Theoretical wood procurement areas for wood processing centres/points using spruce pulpwood.

Kuva 31. Kuusikuutupuuta käyttävien puunjalostuslaitosten ja -laitosryhmien teoreettiset puunhankinta-alueet.

if the above assumptions are made, all mills could resort to only truck transport, except for mills at (117, 27) and (135, 46). It also appears that during a good year almost all available hardwood logs would be required if no external sources are available.

Fig. 30 and 32 show that transport only by truck could not be resorted to when transporting pine and birch pulpwood to southern Saimaa area mills. The average straight-line distance to these mills would be 188.7 km for pine pulpwood and 161.1 km for hardwood pulpwood. On the other hand, the remaining mills would have average straight-line distances of 32.0 km and 30.0 km for pine and hardwood pulpwood, respectively. They, could be supplied by truck transport only. Spruce pulpwood (Fig. 31) could be supplied

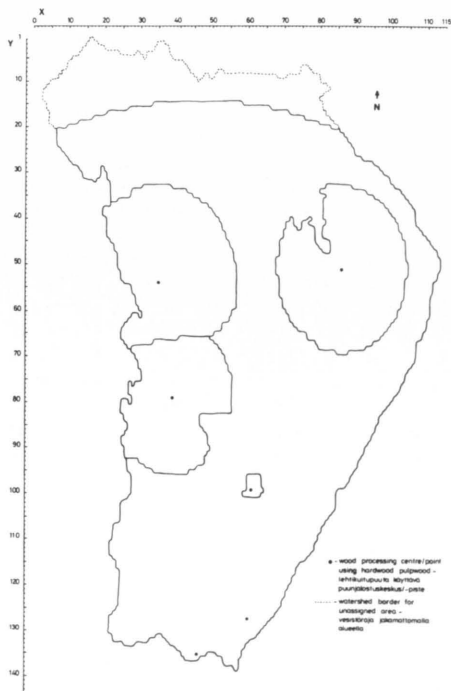


Fig. 32. Theoretical wood procurement areas for wood processing centres/points using hardwood pulpwood.

Kuva 32. Lehtikuutupuuta käyttävien puunjalostuslaitosten ja -laitosryhmien teoreettiset puunhankinta-alueet.

by truck transport only; the average straight-line distance is 36.1 km. During a good year the pine pulpwood resource in the area would not be sufficient, even if the total allowable cut was for industrial use. If no external source of birch pulpwood is available, the entire allowable cut would almost be required for industrial consumption also. There is a large surplus of spruce pulpwood in the area however.

The above heuristic analysis of the theoretical wood procurement areas and possible long-distance transport methods required was for an utopian situation. It employs a number of simplifications of the wood procurement environment in the area. It must be remembered that the only priorities in wood assignment were straight-line distance, wood

consumption and estimated wood availability. Also, the objective in the analysis was minimal long-distance transport cost. As will become apparent in section 57., water transport allows transport from the northern part of the area to southern mills to be economically feasible. Due to this, all unassigned wood was given last to the mills in the southern part when filling wood requirements in excess of dirichlet pavement supply. Also, a large part of wood consumed in the area is at mills in the southern part: e.g. Imatra, Joutseno, Lappeenranta and Ristiina account for 48 % of industrial wood consumption in the area during a good year. Thus, mills at these centres/points use far in excess of what is available in their dirichlet pavements.

Keeping the above in mind the following conclusions were made. Even if there was perfect cooperation between mills, and wood purchasers and sellers, the use of water and railway transport would be required for long-distance transport to mills in the southern part of the area consuming pine logs, spruce logs, hardwood logs, pine pulpwood and hardwood pulpwood. Also, to fill any wood shortages water and railway transport would be required in the transport of wood from external sources. The large surplus of spruce pulpwood on the other hand, should be transported to external destinations by railway and/or water transport if long-distance transport costs are to be kept at a minimum. Mills in the southern part of the area will not be able to rely solely on truck transport in any situation if they are to remain economically viable.

56. Stumpage vs terminal, mill and north/south proximity

Although regional stumpage rates negotiated between wood buyers' and sellers' organizations prevail in the area, an analysis was made of whether there were any relationships between the average stumpage for wood assortments, and proximity of bundle floating and railway terminals and mills using the particular wood assortment. Fig. 33 shows the cities and municipalities in the area, along with bundle floating and railway terminals.

Appendix B (p. 88) presents a list of the city and municipality names. However, in the following, both cities and municipalities will be referred to as municipalities. The following information was determined for each municipality (n = 81) by employing the spatial database - heuristic programming system:

- 1) average straight-line distance in municipality to closest mill using the wood assortment type
- 2) average straight-line distance in municipality to closest railway terminal
- 3) average straight-line distance in municipality to closest bundle floating terminal
- 4) coordinates of municipality centre-points (Y axis coordinate was used to define north/south position in the area)

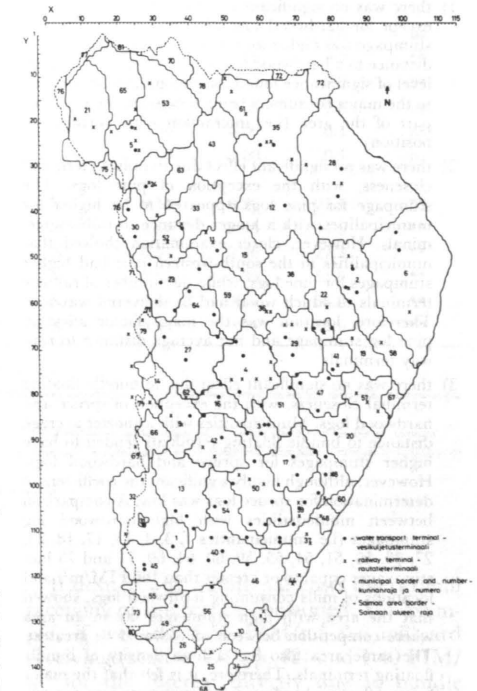


Fig. 33. Municipalities, and bundle floating and railway terminal locations in the Saimaa area. See Appendix B (p. 88) for names of municipalities.

Kuva 33. Saimaan alueen kunnat sekä vesikuljetus- ja rautatietermiinit. Kuntien nimet ovat liitteessä B (s. 88).

Regression analysis was used to determine if any correlation existed between the above variables and the average municipality stumpage rates for wood assortments given by Rauskala (1984). The results are presented in Table 9. Although the results are not presented, multiple regression was also used to determine if there were any interactions between the independent variables. One interaction was found: i.e. average pine pulpwood stumpage on distance to pine pulpwood using mill and north/south position. This was due to the major concentration of pine pulpwood using mills in the southern part of the area.

The following conclusions can be made about the effect of the four variables studied on average stumpages for wood assortments in the area:

- 1) there was no significant effect due to mill closeness, except for hardwood logs and pine pulpwood. The stumpage was higher for municipalities with a shorter distance to a hardwood log consuming mill. The high level of significance found for pine pulpwood was due to the major consumers being located in the southern part of the area (i.e. interaction with north/south position)
- 2) there was no significant effect due to railway terminal closeness, with the exception of pine logs. The stumpage for pine logs appeared to be higher for municipalities with a longer distance to railway terminals. However, closer examination showed that municipalities in the south-western part had higher stumpages for pine logs, while the number of railway terminals to which wood had been delivered was low. Therefore, location was the major factor affecting pine log stumpage and not average distance to railway terminals
- 3) there was no significant effect due to bundle floating terminal closeness, with the exception of spruce and hardwood logs. Municipalities with a shorter average distance to bundle floating terminals tended to have higher stumpages for spruce and hardwood logs. However, although highly significant the coefficient of determination for spruce logs was low. A comparison between municipalities with high hardwood log stumpages (i.e. municipalities 1, 3, 4, 13, 17, 18, 23, 27, 39, 50, 51, 54, 55, 59, 60, 64, 69, 71 and 73 had stumpages equal to or greater than 160 FIM/m³) and locations of mills consuming hardwood logs, showed that the area with high stumpages lay in an area where competition between mills would be greatest. The same area also has a high density of bundle floating terminals. Therefore, it is felt that the major factor affecting hardwood log stumpage was not terminal proximity but competition between the mills
- 4) the north/south position of a municipality was the most important variable affecting stumpage for all wood assortments. As you move north the stumpage decreases for all wood assortments

57. Transport method competitiveness

BASDATSERCH was used to analyse the competitiveness of the transport methods available for wood transport to a mill in the southern part of the area. The wood transported was 3 m (half-dry) softwood pulpwood. The truck-trailer unit employed was a 4 axle truck with two axle trailer. The loading site class was 2. Three wire ropes with lock bindings were used in bundle floating. A total of 375 points were distributed throughout the area at an interval of 12.5 km. If an assigned grid cell was not serviced by a road an adjacent grid cell was chosen. The transport costs for all methods were calculated using BASDATSERCH.

Delivery to one mill was chosen to keep the data homogeneous. As apparent from section 55. (p. 62), the concentration of pine pulpwood consumption in the southern part of the area requires wood procurement essentially throughout the entire area. Also, since the mills in the southern part of the area are quite close, it was assumed that the information from one mill would also be applicable to neighbouring mills. In practice the majority of transport involving exceptionally long distances is to southern Saimaa area mills.

Fig. 34 presents the costs by road and railway transport and bundle floating as a function of the straight-line distance between the source grid cell and mill. The costs do not include mill receiving or interest costs.

The larger dispersions for railway transport and bundle floating are due to the cost of initial transport to a terminal. Thus, if a terminal is close to the source, the cost is near the lower limit of the 95 % C.I. for Y. From Fig. 34 we can make the following conclusions about long-distance transport of 3 m (half-dry) softwood pulpwood to southern Saimaa area mills (costs of mill receiving and wood holding not included):

- 1) on the average bundle floating is cheaper than road transport for straight-line distances greater than 48 km
- 2) when the initial transport distance to a terminal is short (i.e. less than 5 km) bundle floating begins to be competitive with truck transport at straight-line distances slightly less than 20 km
- 3) on the average railway transport is cheaper than road transport for straight-line distances greater than 125 km

Table 9. Regression results for regression of average municipality stumpage on various long-distance transport variables (n = 81).

Taulukko 9. Kuntien keskimääräisten kantohintojen riippuvuus eräistä kaukokuljetusmuuttujista regressioanalyysin mukaan (n = 81).

Wood assortment <i>puutavaralaji</i>		Variable <i>muuttuja</i>				Regression information <i>lunnuksiluvut</i>			
		X1	X2	X3	X4	r	r ²	VR	F
Pine log	- MäT	X				0.01	0.00	0.0	ns
Spruce log	- KuT	X				-0.11	0.01	1.0	ns
Hardwood log	- LeT	X				-0.41	0.16	15.9	**
Pine pulpwood	- MäK	X				-0.40	0.16	14.9	**
Spruce pulpwood	- KuK	X				-0.11	0.01	0.9	ns
Hardwood pulpwood	- LeK	X				-0.15	0.02	1.7	ns
Pine log	- MäT		X			0.27	0.08	6.5	**
Spruce log	- KuT		X			0.11	0.01	0.9	ns
Hardwood log	- LeT		X			-0.08	0.01	0.5	ns
Pine pulpwood	- MäK		X			0.08	0.01	0.5	ns
Spruce pulpwood	- KuK		X			0.15	0.02	1.8	ns
Hardwood pulpwood	- LeK		X			0.15	0.02	1.8	ns
Pine log	- MäT			X		-0.21	0.04	3.8	ns
Spruce log	- KuT			X		-0.32	0.10	9.2	**
Hardwood log	- LeT			X		-0.66	0.43	60.2	**
Pine pulpwood	- MäK			X		-0.09	0.01	0.6	ns
Spruce pulpwood	- KuK			X		0.04	0.00	0.1	ns
Hardwood pulpwood	- LeK			X		0.03	0.00	0.1	ns
Pine log	- MäT				X	0.51	0.26	27.5	**
Spruce log	- KuT				X	0.60	0.36	44.6	**
Hardwood log	- LeT				X	0.51	0.26	27.3	**
Pine pulpwood	- MäK				X	0.62	0.39	51.0	**
Spruce pulpwood	- KuK				X	0.68	0.46	68.2	**
Hardwood pulpwood	- LeK				X	0.49	0.24	24.6	**

X1 - average straight-line distance in municipality to closest mill using the wood assortment - keskimääräinen matka linuntietä lähimpään puutavaralajia käyttävään laitokseen eri kunnissa

X2 - average straight-line distance in municipality to closest railway terminal - keskimääräinen matka linuntietä lähimpään rautatietermiinalliin eri kunnissa

X3 - average straight-line distance in municipality to closest bundle floating terminal - keskimääräinen matka linuntietä lähimpään vesikuljetustermiinalliin eri kunnissa

X4 - Y axis grid coordinate of municipality centre - kunnan keskipisteen Y-koordinaatti

- 4) on the average railway transport is never competitive with bundle floating
- 5) the upper limit of the bundle floating 95 % C.I. for Y intersects the lower limit of the truck transport 95 % C.I. for Y at 160 km (i.e. in all cases bundle floating can be said to be cheaper than truck transport after this point irrespective of initial transport distance)
- 6) the lower and upper limits of railway transport and bundle floating 95 % C.I. for Y do not intersect (i.e. if we have an exceptionally long distance to a bundle floating terminal and a short distance to a railway terminal, railway transport is competitive in all cases; however, this never occurs in practice in the area)

If desired any additional costs due to mill receiving or interest can be added. For example, if we add 1.50 FIM/m³ for millyard receiving (section 432., p. 42) and 1.40 FIM/m³ for the interest directly due to bundle floating (section 52., p. 52) to the cost of bundle floating, the average straight-line distance after which bundle floating is cheaper than truck transport is 67 km.

All transport data for the 375 points were

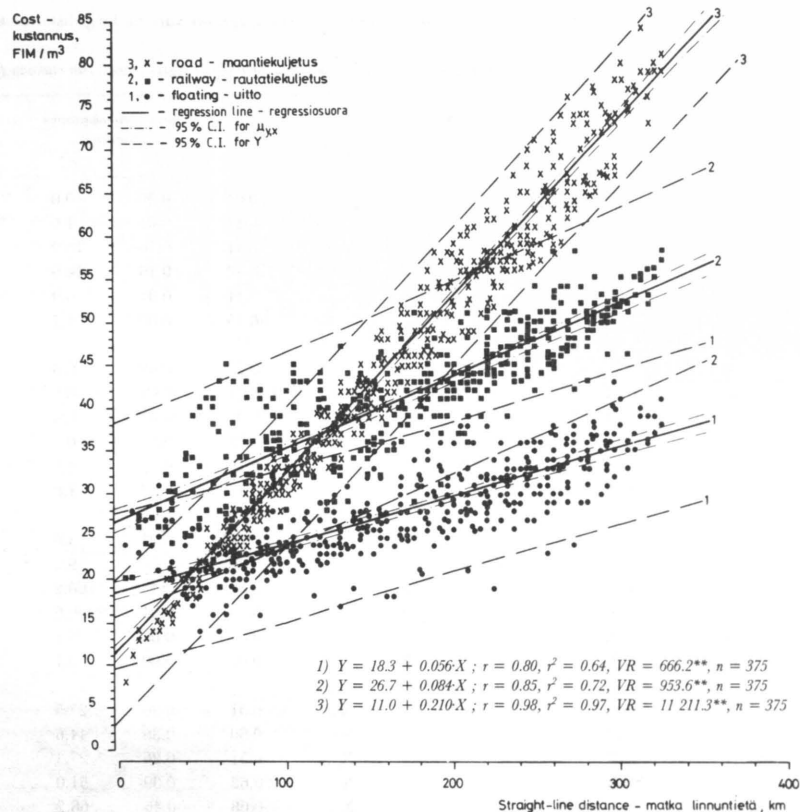


Fig. 34. Total transport cost as a function of straight-line distance to a southern Saimaa area mill (3 m half-dry softwood pulpwood).

Kuva 34. Puolikuivan havukuitupuun (3 m) kaukokuljetuskustannukset Etelä-Saimaan alueella olevalle tehtaalte.

analysed and the following average statistics obtained:

- average straight-line distance to mill - 171.6 km
- average road distance to mill - 230.7 km
- average distance to railway terminal - 25.7 km
- average distance from railway terminal to mill - 233.6 km
- average total railway transport distance - 259.3 km
- average distance to bundle floating terminal - 24.7 km
- average distance from bundle floating terminal to mill - 276.9 km
- average total bundle floating distance to mill - 301.6 km

The ratios between average straight-line distance and average total transport distances for the three methods are:

- straight-line	- 1.00
- road	- 1.34
- railway	- 1.51
- bundle floating	- 1.76

The functional relation for straight-line distance to mill (X) and actual road distance to the mill (Y):

$$Y = -4.8 + 1.372X; r = 0.98, r^2 = 0.97, VR = 11\,221.7^{**}$$

The functional relation for straight-line distance to the mill and road distance to a railway terminal (Y):

$$Y = 26.8 - 0.006X; r = 0.03, r^2 = 0.00, VR = 0.3^{**}$$

- no correlation
- average distance to railway terminal for area is 25.7 km

The functional relation for straight-line distance to the mill (X) and actual railway distance to the mill (Y):

$$Y = 6.5 + 1.323X; r = 0.93, r^2 = 0.88, VR = 2\,714.8^{**}$$

The functional relation for straight-line distance to mill (X) and total railway transport distance to mill (Y):

$$Y = 33.3 + 1.317X; r = 0.94, r^2 = 0.88, VR = 2\,714.8^{**}$$

The functional relation for straight-line distance to mill (X) and road distance to floating terminal (Y):

$$Y = 9.7 + 0.087X; r = 0.40, r^2 = 0.16, VR = 70.3^{**}$$

- for southern Saimaa area mills the distance to a dumping terminal increases with increasing distance from mill
- average road distance to the closest bundle floating terminal for the area is 24.7 km

The functional relation for straight-line distance to mill (X) and actual bundle floating distance (Y):

$$Y = 47.8 + 1.340X; r = 0.94, r^2 = 0.89, VR = 3\,019.6^{**}$$

The functional relation for straight-line distance to mill (X) and total bundle floating distance (Y):

$$Y = 56.7 + 1.427X; r = 0.96, r^2 = 0.91, VR = 3\,995.8^{**}$$

From the above we see that from any given point bundle floating has the longest average distance, followed by railway transport. As apparent from the above the only way to compare transport methods is with the use of straight-line distance.

The information gained from the BASDATSERCH analysis and the cost subroutines described in section 432. were used to develop cost functions for the other roundwood assortments. In the pulpwood assortments the only length class included was 3 m. For bundle floating only the cost of initial transport to the terminal was adjusted according to wood assortment. The cost for the actual bundle floating from the terminal to the mill was the same for all assortments. For road and railway transport, the cost differences by wood

assortments from the forest to the mill were obtained from the cost subroutines. Fig. 35 shows the average transport costs by straight-line distance for all roundwood assortments. The linear relationships for all assortments allows easy comparisons for cost competitiveness. Also, the conclusions made for 3 m (half-dry) pulpwood are very similar when making comparisons between methods for other assortments; as long as the same assortment is in question for all methods. From Fig. 35 we also see that 3 m (half-dry) softwood pulpwood (assortment 2) is the most economical wood assortment to transport by truck and its economicalness becomes more apparent over longer distances. Examination of Fig. 35 shows that the average break-even distances for truck transport and railway transport, for assortments other than 3 m (half-dry) pulpwood are at shorter distances. Also, one of the ideas in the use of truck transport is direct transport of fresh wood to the mill and thus minimization of inventories and wood deterioration. The transport of fresh wood clearly results in higher transport costs; especially for truck transport. Thus, the competitiveness between the methods outlined above and based on the BASDATSERCH analysis results for 3 m (half-dry) pulpwood is in no way discriminatory against truck transport.

Fig. 36, 37, 38 and 39 were derived from further analysis of the transport information for the area. Fig. 36 presents the policy which would yield minimum long-distance transport cost to the mill in question, assuming no additional wood receiving or interest costs. In Fig. 36 wood is transported via the terminal/method giving the lowest transport cost. In no case was wood transported via a railway terminal. All wood was transported by bundle floating or directly by truck to the mill. Ten additional bundle floating terminals which are no longer in use were included in BASDATSERCH to determine if they had been unwisely abandoned. Only two of the terminals (both on Lake Höytiäinen) had wood routed to them. Wood was transported directly past terminals on Juojärvi and Syväri channels. Also, the Meteli bundle floating terminal was uneconomical to use. Fig. 37, 38 and 39 present cost isogram maps for bundle floating, and truck and railway transport,

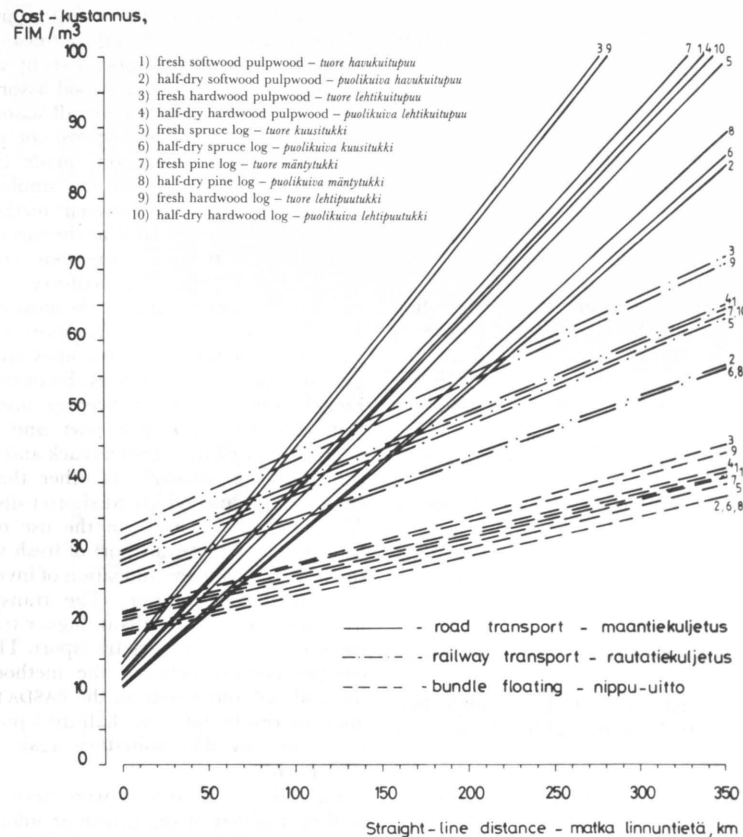


Fig. 35. Average total transport costs by straight-line distance for roundwood assortments.
Kuva 35. Keskimääräiset kaukokuljetuskustannukset puutavaralajeittain.

respectively. In Fig. 37 and 38 the lower localized costs are due to terminal closeness. Not all terminals are indicated since the iso-grams are based on the 375 points dispersed throughout the area. By comparing the figures, the cost competitiveness of the methods when transporting wood to mills in the southern part of the area is apparent.

After examination of the data and the transport environment in the area, it was felt that the above relationships between straight-line distance and total transport cost could be applied to the entire area. However, to test the above assumption five other wood processing centres/points were chosen for further

examination (i.e. Kuopio (54, 35), Joensuu (66, 67), Varkaus (79, 39), Puhos (88, 82) and Ristiina (117, 27)). For each centre/point, nine sources were chosen randomly from areas where transport by all three methods was possible to the point in question and transport costs were calculated (i.e. 45 points in total). This data was compared to the data obtained earlier. The test sample was slightly larger than 10 % of the sample for the single regression (i.e. pooled data). Analysis of covariance was used to determine if any differences existed between the basic and test data. The analysis of covariance results are presented in Appendix C (p. 88). The analy-

sis showed that there were no significant differences between data from the first group (i.e. to the southern Saimaa area mill) and the second group (i.e. to 5 other mills). Both slope and y-intercept differences were insignificant in both groups of data for road and railway transport, and bundle floating costs. It was concluded that the cost equations/relationships presented above can be applied to the entire area.

The BASDATSERCH results for the 375 points were employed to calculate the average costs for initial transport to a dumping terminal, actual bundle floating and total distance. The average costs were 14.64, 13.34 and 27.98 FIM/m³ for initial transport, actual bundle floating and total, respectively. From the costs employed in the cost sub-routines and a 5.00 FIM/m³ wood receiving cost, the following average bundle floating cost distribution can be calculated for the area when transporting wood to southern Saimaa area mills:

- actual initial truck transport cost (excludes dumping and binding work costs)	- 43 %
- interface cost (dumping, binding work and actual binding, terminal maintenance, forming dumping stores on ice and raft formation costs)	- 17 %
- actual bundle towing cost	- 25 %
- mill receiving cost	- 15 %

Calculating for the average initial transport distance (24.7 km) and actual average towing distance (276.9 km) we see that about 75 % of the cost occurred over about 8 % of the total distance. Thus, rationalization of bundle floating should be focused on the initial transport to terminals, and the interface between truck transport and actual bundle towing. Mill receiving also has an important role on the final cost of bundle floating. With decreasing average towing distance the importance of actual bundle towing cost would decrease further.

58. Cost-benefit analysis

The spatial database - heuristic programming system was employed to analyse the cost savings which would accrue with the construction of a new bundle floating termi-

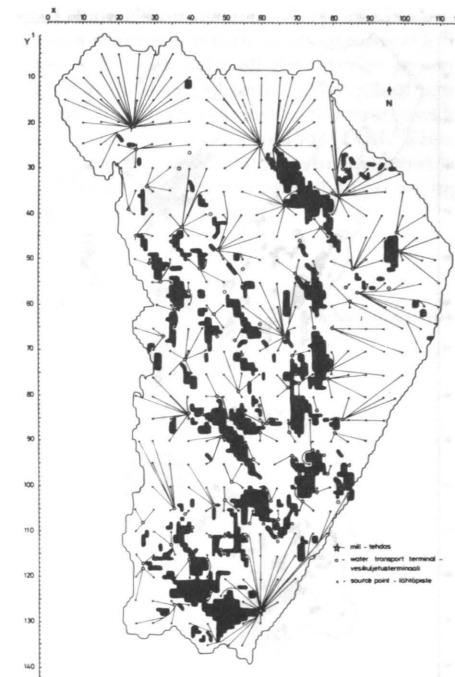


Fig. 36. Wood flows giving lowest long-distance transport cost to a southern Saimaa area mill.

Kuva 36. Puun kaukokuljetuksen minimikustannusratkaisu Etelä-Saimaan alueella olevalle tehtaalte.

nal. During 1980 to 1982 an average of 184 287 m³/a was delivered to the Peltosalmi terminal (26, 26). The new terminal examined was to be located at Runni (21, 18). Since the area from which wood is delivered to Peltosalmi was not known, it was assumed that wood was delivered uniformly from the area giving lowest transport cost for Holopanihahti and Peltosalmi (Fig. 36). The area for Holopanihahti had to be included since it is available only during winter, while Peltosalmi is only available during summer. Only summer delivery was examined. Thirty-nine sources were distributed uniformly in the above area and BASDATSERCH was used to calculate the average transport cost to a mill at (79, 39) when only Peltosalmi was

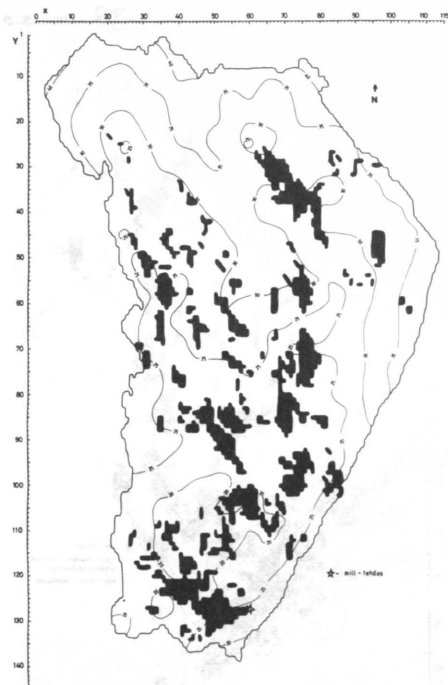


Fig. 37. Isogram map for total bundle floating cost to a southern Saimaa area mill. Costs are FIM/m³.

Kuva 37. Nippu-uiton kokonaiskustannusten isogrammikartta Etelä-Saimaan alueella olevalle tehtaalle. Kustannukset ovat FIM/m³.

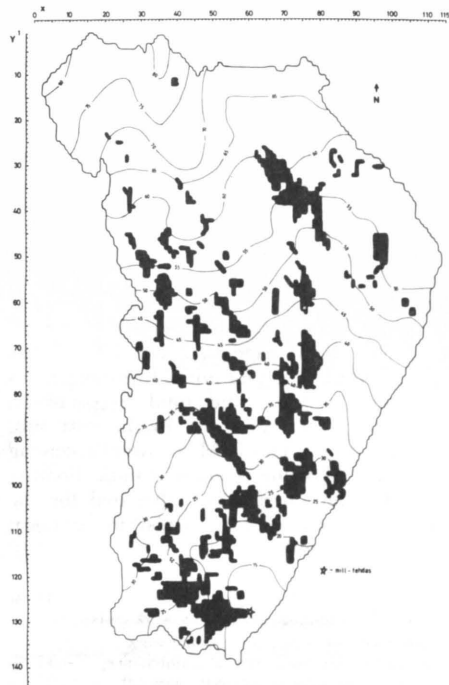


Fig. 38. Isogram map for road transport cost to a southern Saimaa area mill. Costs are FIM/m³.

Kuva 38. Maantiekuljetuskustannusten isogrammikartta Etelä-Saimaan alueella olevalle tehtaalle. Kustannukset ovat FIM/m³.

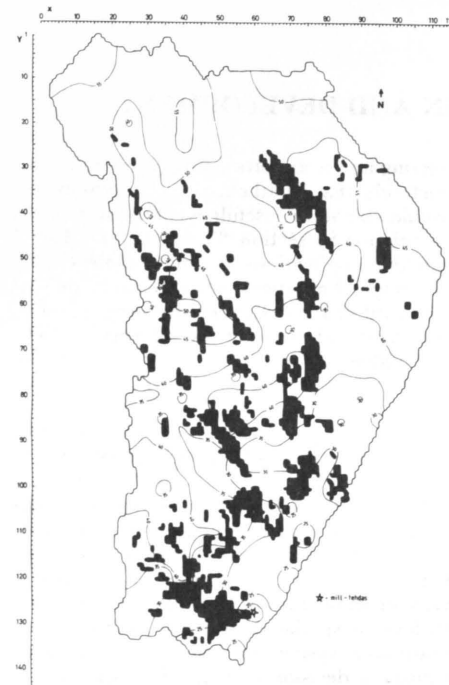


Fig. 39. Isogram map for railway transport cost to a southern Saimaa area mill. Costs are FIM/m³.

Kuva 39. Rautatiekuljetuksen kokonaiskustannusten isogrammikartta Etelä-Saimaan alueella olevalle tehtaalle. Kustannukset ovat FIM/m³.

available, and when Runni and Peltosalmi were both available. The average transport cost for the area when only Peltosalmi was available was 30.16 FIM/m³. When both Peltosalmi and Runni were available the average cost was 28.87 FIM/m³. The average costs for railway and road transport from the area were 42.15 FIM/m³ and 44.11 FIM/m³, respectively. The average cost saving for wood delivered during summer to a bundle floating terminal in the area would be 1.30 FIM/m³ if Runni was in use: i.e. about 239 000 FIM/a.

The above assumed that the bundle floating channel cost to Runni was the same as to Holopnlahti and the total maintenance costs

for both Runni and Peltosalmi would not be larger than for Peltosalmi alone: i.e. maintenance costs at Peltosalmi would reduce in relation to volume transferred to Runni. Although the above costs were for 3 m (half-dry) softwood pulpwood the same cost differences were assumed between all assortments floated (Fig. 35). Wood was also assumed to be delivered uniformly from the area in question.

In a cost-benefit analysis the above value would be compared to the cost of improving the channel to the terminal, as well as construction of the terminal itself. For example, if the investment in building the new terminal

and channel improvements is required to produce a minimum return on investment of 6 % over a 20 year write-off period, the present value of the series of terminable annual payments¹ (i.e. annual savings in our case) would be approximately 2.74 million FIM. Thus, the maximum allowable investment would be 2.74 million FIM; assuming the cost saving per year does not change.

¹ Present value of a series of terminable annual payments:

$$V_0 = \frac{a \cdot ((1 + i)^n - 1)}{i \cdot (1 + i)^n}$$

where V_0 is present value
 a is terminable annual payment
 n is number of years
 i is interest per annum

6. FURTHER APPLICATION AND DEVELOPMENT

61. Improvements possible

A system such as the spatial database – heuristic programming system developed during this study is never complete. Information must always be updated. New applications of the system would require the development of new data manipulation algorithms. Some new information type may be beneficial to the system and thus added. Making the system applicable for use by many people would require extensive modification of the programs for user orientation, as well as instruction in use of the system. Better display of information and linkage to a digital plotter would be beneficial. A reclassification of lake locations is required and a finer classification of the road network would be beneficial. A finer classification of roads would make road route searches simpler: e.g. at present all private roads are class 6. The search algorithms can be made more efficient and developed further to reduce CPU time requirements. A learning function could be added to store routes already found. Cost functions could be developed and added to the system. If the system of this type is developed for widespread use DBMS features must be incorporated into its design. Continuous development of the system would be a must. However, the most beneficial improvement of the system would be to extend its coverage to include all Finland.

62. Other transport information possible

The examples given in section 5. only outline some of the possible applications of the system. More extensive analysis of the examples presented is also possible. As more information becomes available through analysis it is incorporated into the spatial database and the method becomes more powerful. In addition, combining the information obtained with other available information (e.g. har-

vesting and wood processing costs) and other methods (e.g. mathematical programming) would extend the usefulness of the system. As mentioned in section 33. (p. 29) the list of possible applications is almost endless, with the major limitations being the imagination and skill of the designers and programmers, accuracy and scope of the information, and the budget of the system.

63. Application to field operations

With increased use of computers at the field level a system similar to the one presented in this thesis would appear to be beneficial. Also, if a firm decides to purchase a GIS for its operations, it could easily be used to form a spatial database – heuristic programming system for use in long-distance transport decision-making. Similarly, many of the features described in this thesis may already be included in the GIS, while any lacking features could be added.

With the use of a spatial database – heuristic programming system, information for use in tactical planning can be readily obtained. The proper terminals for wood deliveries, as well as the competitiveness of the choices available are clearly delineated. Terminals available, wood requirements, wood sources available, etc., could all be included in the system and easily obtained when making decisions. A system of this type could also be used as a standard to compare the efficiency of the field operations. If the system is updated daily, for example with wood purchase locations, roadside inventory locations, terminal inventories, etc., all managers could access the system to view the current wood procurement situation. The spatial delineation of the above data is more meaningful than a list of tables. The ready access and clear visual display of information would make decision-making in long-distance transport, as well as in all wood procurement, more accurate and easier.

64. Limitations

The greatest limitation in the development of a system as outlined in this thesis is the extensive work required in data acquisition and recording for storage in a computer. The volume of information required precludes the use of micro-computers. There is extensive programming involved and a person would be required solely to run the system and for further development. Also, considerable work would be required to gather new information as it becomes available and for updating the spatial database. If a decision is made to purchase a GIS an entire new department would be required and specialized personnel obtained.

No cost information was recorded for the development of the spatial database – heuristic programming system described in this thesis. However, if a complex forestry plan-

ning tool is needed to deal with data ranging from forest inventory to harvesting and transport, then a GIS may be the best system to employ. The spatial database – heuristic programming system dealt with in this thesis, was designed only for problems relating to long-distance transport of wood. Its use in the field would also assume a computer of sufficient size is available: i.e. at least a minicomputer.

Due to the sheer volume of information stored in the system, data errors may still exist. When employing the system it is important to monitor the results. Also, when employing the system the criteria used in analysis must be kept in mind when making conclusions: e.g. with dirichlet pavements the criterion is straight-line distance. The system is intend for use as an aid in decision-making and not for making decisions.

7. CONCLUSIONS

The spatial database – heuristic programming system developed in this study proved to be applicable for aiding long-distance transport decision-making in an ever-changing and complex environment. To remain applicable in a dynamic environment continuous updating of the spatial database is required. By employing a spatial database and heuristic programming the major limitations are the imagination and skill of the user, the accuracy and scope of the information contained in the system and the budget. The differences between the road, railway and water transport route search algorithms and manually determined routes and minimum distances were insignificant. It also appears that the road route search algorithm gives distances closer to reality than manually measured map distances. The analyses of the spatial arrangements between points of supply and demand are beneficial in wood procurement planning. A spatial database – heuristic programming system is applicable in solving, the following types of problems:

- 1) wood procurement and transport environment examination
- 2) wood procurement planning and coordination
- 3) examination of wood supply and demand variations
- 4) transport routing
- 5) theoretical service areas for terminals
- 6) facilities location problems
- 7) theoretical wood procurement areas
- 8) cost-benefit analyses
- 9) wood procurement/transport efficiency control
- 10) channel competitiveness
- 11) visual display of spatial information

The spatial database – heuristic programming system was used to achieve the other aim of the study, which was to study the competitiveness and search for possible areas for rationalization of the water transport system in the Saimaa area in particular, and long-distance transport in general. The following conclusions can be made for the problems analysed in section 5.:

- 1) when dealing with the total average inventory at roadside, in transit and at the millyard in the Saimaa area, the inventory required due solely to the seasonal nature of bundle floating is approximately a 0.6 month wood supply. This results in an interest cost due solely to bundle floating of 1.40 FIM/m³ at an interest rate of 16 %/a and average wood cost of 200 FIM/m³
- 2) the number of railway terminals could be reduced to 70 to 80, with possible reductions occurring in the central zone of the area
- 3) the total number of bundle floating terminals is near the optimum but adjustment of terminal locations would reduce the average minimum straight-line distance
- 4) the most impact of floating terminal increases/reductions would be in the northern zone of the area
- 5) the least impact of floating terminal increases/reductions would be in the central zone
- 6) the largest use of railway transport is in the north-western part of the area, while bundle floating is most extensively used in the north-eastern part
- 7) 64 % of wood dispatched from railway terminals in the area was delivered to mills beyond the area, while 55 % of the wood delivered by railway to mills in the area was from external sources
- 8) the majority (55 %) of wood dispatched from railway terminals with external destinations was transported to mills in the southern part of the Kymi River watershed and on the coast of the Gulf of Finland
- 9) softwood pulpwood was the major wood assortment transported by railway
- 10) railway and water transport are used in their proper transport niches in the area, with railway transport employed for poor floating species, wood to external destinations, wood from external destinations, and transport between areas where bundle floating is not possible
- 11) no matter how wood transport is optimized in the area, the mills in the southern part of the area will require the use of railway and/or water transport for pine logs, spruce logs, hardwood logs, pine pulpwood and hardwood pulpwood if they are to remain competitive; these mills account for almost 50 % of industrial wood consumption in the area
- 12) there appears to be a surplus of spruce pulpwood in the area and a shortage of pine pulpwood
- 13) the major factor affecting stumpage in the area is north/south position; i.e. stumpage decreases with northerly position
- 14) relative closeness to a mill was only significant for birch log stumpage; i.e. higher stumpage with decreasing distance to mill
- 15) position in regard to railway and bundle floating terminal, or mill had no effect on stumpage for pine

logs, pine pulpwood, spruce pulpwood and hardwood pulpwood. Closeness to a dumping terminal had a small effect on increasing spruce log stumpage

- 16) for the area on the average, total road, railway and water transport distances are 1.34, 1.51 and 1.76 times the straight-line distance from the source to destination, respectively
- 17) on the average bundle floating is cheaper than road transport for straight-line distances greater than 48 km for all floatable wood assortments
- 18) when the initial transport distance to a terminal is short (i.e. less than 5 km) bundle floating begins to be competitive with truck transport at straight-line distances of slightly less than 20 km
- 19) on the average railway transport is cheaper than road transport for straight-line distances greater than 125 km

- 20) on the average railway transport is never competitive with bundle floating
- 21) in all cases bundle floating can be said to be cheaper than truck transport after a straight-line distance of 160 km irrespective of initial transport distance
- 22) if an additional cost of 1.50 FIM/m³ for millyard receiving, as well as the cost of interest directly due to bundle floating, are added to the costs of bundle floating, the average straight-line distance after which bundle floating is cheaper than truck transport is 67 km
- 23) in rationalization of bundle floating most attention should be focused on initial transport to terminals, the interface between road transport and actual bundle towing, and mill receiving

8. SUMMARY

The study deals with long-distance transport of wood in the Saimaa area of Finland. Long-distance transport was limited to cover the transport of wood raw material from the forest, at roadside, to its place of utilization. It also includes extended primary transport. Due to the complex nature of the long-distance transport environment in the area, decision-making in long-distance transport is difficult. Thus, the major objective of the study was to develop a method which could be used in solving transport problems and in formulating transport policies in an ever-changing and complex environment. The other objective was to study the competitiveness and search for possible areas for rationalization of water transport in particular, and long-distance transport in general.

Bundle floating was the only water transport method studied. Truck and tractor transport were included in road transport. Bundle floating and railway transport also included initial transport to terminals and terminal operations. The area is well serviced by all three transport systems. The total length of waterway channels in the area was 3 233 km and 88 terminals were used during 1980 to 1982. The length of railway servicing the area was about 1 400 km and 82 terminals were used during 1980 to 1982. The density of the road network was estimated to be about 23 m/ha. The annual industrial wood requirement (roundwood and forest chips) during a good year was about 13 M(m³) and 37 wood processing centres/points were demarcated. The total area was 56 075 km².

The shares of wood delivered to mills during 1981 and 1982 were 49.5, 36.5 and 14.0 %, for truck, water and railway transport, respectively. The smallest variation between annual volumes delivered to mills in the area was with water transport (i.e. CV was 0.07), while truck and railway transport had the highest variation between years (i.e. CV were 0.30 and 0.29, respectively). From 1972 to 1982 the rates of direct transport cost increase in Finland for tractor, truck, water and railway transport were 18.2, 10.9, 11.6 and 11.5

%/a, respectively. Although truck transport should be more susceptible to inflationary pressures than water or railway transport, rationalization has been able to keep its cost better in line. The use of tractors for delivery to the mill was insignificant. When use of a truck trailer-unit was possible and the loading site class was (2), extended primary transport by tractor was only competitive for distances up to 4.5 to 8 km (1983 costs), depending on the wood assortment and destination in question.

When choosing the most appropriate transport policy, a firm should strive to achieve the best overall economic result over the long-term. When choosing between transport policies both business economic and national economic factors must be accounted for. The major business economic factors are: 1) availability of wood for purchasing; 2) harvesting schedule (i.e. availability of wood at roadside); 3) harvesting methods in use and costs; 4) direct transport costs; 5) time required for transport from forest to mill; 6) technical factors as to method availability and effect on wood quality; 7) holding costs; 8) transport method dependability and service; and 9) wood demand at the mill. The major national economic factors are: 1) productivity of resources (e.g. labour, energy and capital); 2) environmental effect; 3) domestic ratio; 4) dependability and applicability in crises; 5) net cost to the State after accounting for establishment, maintenance and operational costs and revenue directly related to the transport methods; and 6) accident risk.

Operations research (OR), database management systems (DBMS) and geographic information systems (GIS) were reviewed to determine their applicability as aids in long-distance transport decision-making. It was found that OR methods or DBMS by themselves, were not applicable to the problem on hand. Their major deficiency was that they do not account for spatiality of data. GIS with specially developed software would appear to be applicable, but the investment required for just solving long-distance trans-

port problems would be unjustified. If a GIS is employed by a firm for forest management planning, then the starting point is different and the type of system developed in this study could be easily formed and added to it or used independently.

A spatial database – heuristic programming system was developed to aid the examination of the transport situation in the study area. The method for spatial delineation of data was the grid method since more emphasis was placed on data manipulation, than graphical resolution. The polygon method would be the most appropriate if high graphical resolution is required. To be more versatile, most modern GIS employ both methods. The uniform coordinate system was used to form the grid covering the area. The interval between grid lines was 2.5 km (i.e. each grid cell covered an area of 6.25 km²). All information relating to long-distance transport was obtained and stored by grid cell coordinates. The major information groups were: 1) roads, 2) railway system, 3) water transport system, 4) watersheds, 5) water coverage, 6) mills, 7) forestry board districts and 8) municipalities. Descriptive information for the area was gathered and stored in information catalogues: i.e. annual allowable drain by wood assortments and forestry board districts, wood volumes dispatched from terminals, industrial cuttings, wood consumption at mills, wood delivered to mills, channel costs, payment rates, stumpages by municipalities, and terminal and transfer facility names and descriptions. Information matrices were formed to represent special features for use in data manipulation or output. The above form the spatial database.

Due to the large number of transport choices available, heuristic search algorithms were developed. When major transport arteries are examined, there are two transport network configurations possible: i.e. branching and interconnected loop configurations. The road and railway networks had interconnected loop configurations, while the waterway network had a branching configuration. For this reason the complexity of the route search algorithms between the methods differed. By stating the coordinates of the source and destination, the search algorithm determines a "good" route between the two points.

In all cases it can be said the best railway and water transport routes are found. Due to the very complex nature of the road network, the route found may not always be the best one possible. However, it can be held to be always very close to it. Analysis of variance showed that there were no significant differences between route search algorithm and manually measured minimum distances for all transport methods. Cost subroutines were developed to employ the information gained from the route search algorithms to determine actual transport costs. The route search algorithms and cost subroutines were combined to form BASDATSERCH. The operation of BASDATSERCH is as follows:

- 1) the grid coordinates of the source and destination are fed into the program
- 2) the type of wood assortment to be transported, as well as the loading site class are entered
- 3) the program then checks that both the source and destination are serviced by a road; if not the run is stopped and a message given that no transport is possible. The program does not account for the logging of shore and island forests where water transport is the only possible transport mode
- 4) the program determines whether the destination is serviced by a railway and/or water transport channel. If access to the destination by one or both methods is not possible, the route search for the method(s) in question is not initiated. Similarly, the search by either method is only activated if a transportable wood assortment is in question
- 5) if wood can be delivered by bundle floating then the program will determine the five closest bundle floating terminals based on straight-line distance. The program has the capacity for ten terminals but it was found that five was sufficient
- 6) road routes and distances are determined between the source and five terminals, and the cost of initial transport to each terminal calculated for both truck and tractor transport. If the distance exceeds 40.0 km no tractor transport cost is calculated
- 7) bundle floating routes are then determined between the five terminals and the destination, and the direct cost of bundle floating from each terminal calculated
- 8) total bundle floating costs to the destination are calculated via all five terminals using tractor and truck transport
- 9) all information obtained above is outputted. The dumping terminal class is also printed to give the decision-maker knowledge about terminal availability for dumping (i.e. 1 – summer use, 2 – winter use, 3 – all year). Ten terminals which are no longer in use were included in the list of available dumping terminals to determine if they had been justifiably abandoned and are referred to by class 4
- 10) steps 5) through 9) are repeated for railway transport. In addition, the type of railway terminal (i.e. stationary crane or not) has to be examined when

- calculating the cost of initial transport to the terminal
- 11) the road route connecting the source and destination is determined, and the truck and tractor costs calculated and outputed

BASDATSERCH only presents information for the decision-maker to employ in choosing the best long-distance transport method and if applicable, the best terminal via which wood should be transported. While BASDATSERCH can be used in determining the competitiveness between methods, other heuristic programming techniques can be used to gain further information about the transport environment. For example, dirichlet tessellations can be used to determine interface/fringe areas where detailed attention can be focused, to determine theoretical spheres of influence based on shortest straight-line distance or to demarcate an area. There are no standard heuristic programming techniques available and each application must be tailor fit to the problem. The possible uses of a system of this type is almost endless, with the major limitations being the imagination and skill of the designers and programmers, accuracy and scope of the information contained, and the budget.

The greatest limitation in the development of a system as outlined, is the extensive work required in data acquisition and recording for storage in a computer. The volume of information required precludes the use of microcomputers. There is extensive programming involved and a person would be required solely to run the system and for further development. Also, considerable work would be required to gather new information as it becomes available and for updating the spatial database. To remain applicable in a dynamic environment continuous updating of the spatial database is required.

The spatial database – heuristic programming system was used to study the competitiveness and search for possible areas of rationalization of water transport in particular and long-distance transport in general. The system was applied to solving the following problems: wood procurement variation, terminal theoretical service areas, terminal distance vs average straight-line distance to terminals, wood processing centre/point theoretical wood procurement areas, stumpage vs terminal, mill and north/south prox-

imity, transport method competitiveness and cost-benefit analysis. The following conclusions can be made from the results obtained in the examinations:

- 1) when dealing with total average inventory required at roadside, in transit and at the millyard in the Saimaa area (to ensure no wood shortages at the mill), the average inventory required due solely to the seasonal nature of bundle floating is approximately a 0.6 month wood supply. This results in an interest cost due solely to bundle floating of 1.40 FIM/m³ at an interest rate of 16 %/a and average wood cost of 200 FIM/m³
- 2) the number of railway terminals could be reduced to 70 to 80, with possible reductions occurring in the central zone of the area
- 3) the total number of bundle floating terminals is near the optimum but adjustment of terminal locations would reduce the average minimum straight-line distance
- 4) the most impact of floating terminal increases/reductions would be in the northern zone of the area
- 5) the least impact of floating terminal increases/reductions would be in the central zone
- 6) the largest use of railway transport is in the north-western part of the area, while bundle floating is most extensively used in the north-eastern part
- 7) 64 % of wood dispatched from railway terminals in the area was delivered to mills beyond the area, while 55 % of the wood delivered by railway to mills in the area was from external sources
- 8) the majority (55 %) of railway dispatched wood with external destinations was transported to mills in the southern part of the Kymi River watershed and on the coast of the Gulf of Finland
- 9) softwood pulpwood was the major wood assortment transported by railway
- 10) railway and water transport are used in their proper transport niches in the area, with railway transport employed for poor floating species, wood to external destinations, wood from external destinations, and transport between watershed areas where bundle floating is not possible
- 11) no matter how wood transport is optimized in the area, the mills in the southern part of the area will require the use of railway and/or water transport for pine logs, spruce logs, hardwood logs, pine pulpwood and hardwood pulpwood if they are to remain competitive; these mills account for almost 50 % of industrial wood consumption in the area
- 12) there appears to be a surplus of spruce pulpwood in the area and a shortage of pine pulpwood
- 13) the major factor affecting stumpage in the area is north/south position; i.e. stumpage decreases with northerly position
- 14) relative closeness to a mill was only significant for birch log stumpage; i.e. higher stumpage with decreasing distance to mill
- 15) position in regard to railway and bundle floating terminal, or mill had no effect on stumpage for pine logs, pine pulpwood, spruce pulpwood and hardwood pulpwood. Closeness to a dumping terminal had a small effect on increasing spruce log stumpage

- 16) for the area on the average, total road, railway and water transport distances are 1.34, 1.51 and 1.76 times the straight-line distance from the source to destination, respectively
- 17) on the average bundle floating is cheaper than road transport for straight-line distances greater than 48 km for all floatable wood assortments
- 18) when the initial transport distance to a terminal is short (i.e. less than 5 km) bundle floating begins to be competitive with truck transport at straight-line distances of slightly less than 20 km
- 19) on the average railway transport is cheaper than road transport for straight-line distances greater than 125 km
- 20) on the average railway transport is never competitive with bundle floating
- 21) in all cases bundle floating can be said to be cheaper than truck transport after a straight-line distance of 160 km irrespective of initial transport distance
- 22) if an additional cost of 1.50 FIM/m³ for millyard receiving, as well as the cost of interest directly due to bundle floating, are added to the cost of bundle floating, the average straight-line distance after which bundle floating is cheaper than truck transport is 67 km
- 23) in rationalization of bundle floating most attention should be focused on initial transport to terminals, the interface between road transport and actual bundle towing, and mill receiving

With the use of a spatial database – heuristic programming system, information for use in tactical planning can also be readily obtained. The proper terminals for wood deliveries, as well as the competitiveness of the choices available are clearly delineated. Terminals available, wood requirements, wood sources available, etc., could all be included in the system and easily obtained when making decisions. A system of this type could also be used as a standard to compare the efficiency of the field operations. If the system is

updated daily, for example with wood purchase locations, roadside inventory locations, terminal inventories, etc., all managers could access the system to view the current wood procurement situation. The competitiveness of different channels can also be examined, as well as facilities location problems. The spatial delineation of the above data is more meaningful than a list of tables. The ready access and clear visual display of information would make decision-making in long-distance transport, as well as in all wood procurement, more accurate and easier.

The spatial database – heuristic programming system developed in this study proved to be applicable for aiding long-distance transport decision-making in an ever-changing and complex environment. The examples listed above only outline some of the possible applications of the system. Also, as more information becomes available through analysis it can be incorporated into the spatial database. In this way the system would become more powerful. In addition, combining the information obtained with other available information (e.g. harvesting and wood processing costs) and methods (e.g. mathematical programming) would extend the usefulness of the system. With increased use of computers at the field level a system similar to the one presented in this thesis would seem to be a powerful aid in long-distance transport decision-making. It must be remembered that the spatial database – heuristic programming system described, is an aid to be used in decision-making and is not a source of ready answers.

LITERATURE CITED

- Aarne, M. 1981. Markkinapuun alueittaiset hankintamäärät ja kulkuvirrat 1979 (Summary: Removal and flows of commercial roundwood in Finland in 1979 by districts). *Folia For.* 484. 37 pp.
- Årvidsson, A., Johansson, J., Nilsson, S. & Öberg, S. 1978. Tjällossningens inverkan på skogsbrukets virketransporter (Summary: The importance of the spring thaw on the transport of wood within forestry). *Sveriges lantbruksuniversitet, Inst. för skogsteknik, Rapport* 123. 57 pp.
- Bare, B. B. 1978. Natural resource management information systems: their role in today's decision environment. *Proceedings of the Workshop Integrated Inventories of Renewable Natural Resources*, Jan. 8-12, Tuscon, Arizona. U.S.D.A., For. Serv., Gen. Tech. Rep. RM-55. 350-353.
- Beman, L. E. 1978. Computer assisted resource management. *Proceedings of the Workshop Integrated Inventories of Renewable Natural Resources*, Jan. 8-12, Tuscon, Arizona. U.S.D.A., For. Serv., Gen. Tech. Rep. RM-55. 375-380.
- Bloomberg, W. J., Hunt, D. & Wallis, G. W. 1976. A data bank system for forest tree disease and growth plots in British Columbia. *Can. For. Serv., Pacific Res. Cen., Rep. BC-X-143*. 26 pp.
- Bonner, G. M. 1983. Computers, mapping and national forestry statistics. *Can. For. Ind.* 103(6): 18-20.
- Boss, D. E. 1984. Preliminary report on a cartographic modeling approach to classification of budworm-impacted spruce-fir stands according to risk of fiber loss. *Poster paper, Forest Land Classification Symposium, Univ. of Wisconsin, Madison, Mar. 19-20*. 9 pp.
- Chorafas, D. N. 1965. *Systems and simulation*. Academic Press, New York. 503 pp.
- Corcoran, T. & Heij, W. 1982. Continuity in simulation model implementation - a progress report. *Proceedings of IUFRO S3.04.01, XVII World Congress, Kyoto, Japan, Sept. 6-17, 1981*. Univ. of Maine, Misc. Rep. 264. 147 pp.
- Craig, D. & Corcoran, T. 1982. Applications and other citations involving GPSS. *Univ. of Maine, School of Forest Resources, Tech. Notes* 83. 14 pp.
- Dehlén, R., Liljebald, H. & Nilsson, S. 1983. Optiflow - Beskrivning av ett system för regionala analyser av flöde samt utnyttjande av skogsråvaror - och en tillämpning (Summary: Description of a system for regional analyses of flow and utilization of forest raw materials - and one method of application). *Sveriges Lantbruksuniversitet, Institutioner för skogsteknik, Rep.* 153. 74 pp.
- de Steiguer, J. E. & Giles, R. H. 1981. Introduction to computerized land-information systems. *J. of For.* 79(11): 734-737.
- Dykstra, D. P. 1976. Timber harvesting layout by mathematical and heuristic programming. Ph.D. thesis, Oregon State University. *Univ. Microfilms International, Ann Arbor, Michigan*. 299 pp.
- 1984. Mathematical programming for natural resource management. McGraw-Hill Book Co., New York. 318 pp.
- & Riggs, J. L. 1977. An application of facilities location theory to the design of forest harvesting areas. *AIIE Transactions* 9(3): 270-277.
- Einola, J. 1968. Raakapuuvastaston suunnittelusta ja tarkkailusta (Summary: On the planning and control of raw wood inventories). *Silva Fenn.* 2(2): 81-125.
- Erdle, T. A., Arp, P. A. & Meng, C. H. 1982. Optimizing pulpwood inventories at roadsides, millyards and concentration yards: a case study. *Proceedings of IUFRO S3.04.01, XVII World Congress, Kyoto, Japan, Sept. 6-17, 1981*. Univ. of Maine, Misc. Rep. 264. 40-51.
- & Jordan, G. 1984. Computer-based mapping in forestry: a view from New Brunswick. *Can. For. Ind.* 104(4): 38-46.
- Eskelinen, A. 1984. Kaukokuljetuksen vaihtoehtolaskentajärjestelmä. *Metsätehon katsaus* 3. 4 pp.
- , Hägblom, R. & Peltonen, J. 1984. Osapuuna- ja metsähakkeenahankinnan kustannuskilpailukyky: yritysmallitarkastelu (Summary: A model for optimizing the use of wood raw material). *Metsätehon tiedotus* 389. 31 pp.
- , Keltikangas, M., Peltonen, J. & Vesikallio, H. 1981. Hakkuiden suunnittelumenetelmä suur- metsäalueille (Summary: Planning method for cuttings in large-sized forest holdings). *Metsätehon tiedotus* 368. 15 pp.
- & Peltonen, J. 1977. Puunhankinnan suunnittelumalleilla suoritettava raakapuuvastaston koon optimointi (Summary: Optimization of the size of roundwood storages performed by logging planning models). *Metsätehon tiedotus* 343. 29 pp.
- & Peltonen, J. 1980. Suunnittelusysteemi puunkorjuun menetelmävalintaan. *Metsätehon katsaus* 16. 4 pp.
- & Peltonen, J. 1982. Puunkorjuun vaihtoehtolaskentajärjestelmä puunhankinnan suunnittelussa. *Metsätehon katsaus* 20. 4 pp.
- Fontaine, S. 1983. Computers: the industries best tool for solving a crisis in the mill. *Can. For. Ind.* 103(12): 6-8.
- Frost, R.A. 1984. *Database management systems*. Grenada Publishing Ltd., London. 265 pp.
- Galbraith, J. E. & Meng, C. H. 1981. Simulating optimum inventory of harvested wood. *J. of For.* 79(5): 292-295.
- Garbini, J. L., Lembersky, M. R., Chi, U. H. & Hehnen, M. T. 1984. Merchandizer design using simulation with graphical animation. *For. Prod. J.* 34(4): 61-69.
- Gass, S. I. 1983. Decision-making models: validation, assessment, and related issues for policy analysis. *Oper. Res.* 31(4): 603-631.
- Gill, P. E., Murray, W. & Wright, M. H. 1982. *Practical optimization*. Academic Press, London. 401 pp.
- Gillam, D. S. 1969. CIP puts computers to work in woodlands. *Can. For. Ind.* 89(3): 42-43.
- Glew, D. R., Hegyi, F. & Honer, T. G. 1976. Data base requirements for growth models in computer assisted resource planning systems in British Columbia. *Proceedings of Div. IV, XVI IUFRO World Congress, June 6 - July 2, Oslo, Norway*: 74-85.
- Goulet, D. V. 1979. Tree-to-mill forest harvesting simulation models: where are we? *For. Prod. J.* 29(10): 50-55.
- , IFF, R. H. & Sirois, D. L. 1980. Five forest harvesting simulation models. *For. Prod. J.* 30(7): 17-20.
- Haarala, R. 1973. The effect of terrain on the output in forest transportation of timber (Seloste: Maaston vaikutus puutavaran metsäkuljetustuotokseen). *Acta For. Fenn.* 128. 43 pp.
- Hakkarainen, A. E. 1978. Mitä on puunkorjuun rationalisointi? *Metsätehon katsaus* 11. 4 pp.
- Heikkerö, T. 1979. Economics of water transport and its impact on other transport alternatives. *Proceedings of IUFRO S3.01-04, Symposium on Water Transport of Wood, Univ. of Helsinki, Dept. of Logging and Utilization of Forest Products, Res. Notes* 40: 133-162.
- Henriksen, J. O. 1983. The integrated simulation environment (simulation software of the 1990's). *Oper. Res.* 31(6): 1053-1073.
- Himanen, K. 1981. Logistiikan perusteet. *Helsingin teknillinen korkeakoulu, Rep.* 52. 174 pp.
- Hokans, R. H. 1983. Evaluating spatial feasibility of harvest schedules with simulated stand-selection decisions. *J. of For.* 81(9): 601-603.
- Huttunen, T. 1983. Suomen puunkäyttö, poistuma ja metsätase 1981-83 (Summary: Wood consumption, total drain and forest balance in Finland, 1981-83). *Folia For.* 565. 46 pp.
- Integrated inventories. . . 1978. *Integrated inventories of renewable natural resources. Proceedings of workshop, Tuscon, Arizona, Jan. 8-12. U.S.D.A., For. Serv., Gen. Tech. Rep. RM-55*. 482 pp.
- Kanerva, A. 1976. Operaatioanalyysimenetelmien käyttö kaukokuljetusten ja tehdasvastaanoton ohjelmoinnissa. *Insinöörijärjestöjen koulutuskeskus, mimeograph* 103 - 76 IX. 8 pp.
- Karttaprojekti. 1962. *Karttaprojekti. Kustannusosakeyhtiö Otava, Encyclopedia Fennica* 4: 530-531.
- Keipi, K. 1978. Approaches for functionally decentralized wood procurement planning in a forest products firm (Seloste: Menetelmiä metsäteollisuusyrityksen toimintojen mukaisesti hajautettua puunhankinnan suunnittelua varten). *Commun. Inst. For. Fenn.* 93(3): 1-116.
- Kilkki, P. & Siitonen, M. 1976. Principles of a forest information system. *Proceedings of Div. IV, XVI IUFRO World Congress, Oslo, Norway, June 20 - July 2*: 154-163.
- Kuusela, K. 1978. Suomen metsävarat ja metsien omistus 1971-1976 (Summary: Forest resources and ownership in Finland 1971-1976). *Commun. Inst. For. Fenn.* 93(6): 1-107.
- & Salminen, S. 1983. Metsävarat Etelä-Suomen kuuden pohjoisimman piirimetsälautakunnan alueella 1979-1982 sekä koko Etelä-Suomessa 1977-82 (Summary: Forest resources in the six northernmost forestry board districts of South Finland, 1979-1982, and in the whole of South Finland, 1977-82). *Folia For.* 568. 79 pp.
- Kärkkäinen, M. 1973. On the properties of tree wounds due to timber transportation in thinnings (Seloste: Harvennuspuutavaran kuljetuksen aiheuttamien puustovaurioiden ominaisuuksista). *University of Helsinki, Dept. of Logging and Utilization of Forest Products, Res. Notes* 22. 174 pp.
- Laajalahti, T. & Pennanen, O. 1983. *Metsäteollisuuden raaka- ja jätetuun kaukokuljetukset vuonna 1982. Metsäteho mimeograph*. 8 pp.
- Lallukka, H. H. 1983. Puutavaran hinnan määrittäminen. *Tapion Taskukirja, 19th edition, Kirjayhtymä, Helsinki*: 420-428.
- Law, A. M. 1983. Statistical analysis of simulation output data. *Oper. Res.* 31(6): 983-1029.
- LeDoux, C. B. & Butler, D. A. 1982. Prebunching? Results from simulation. *J. of For.* 80(2): 79-83.
- Lehnhausen, H. & Lohmann, H. 1981. A conceptual approach to simulation of a forest working process. *Forest Operations Analysis - techniques in planning and control, IUFRO S3.04.01 report*: 10A1-10A22.
- Lussier, L. J. 1972. Reduction of wood costs through increased use of management techniques. *Pulp and Paper Mag. Can.* 73(3): 70-74.
- Lönnberg, B. 1983. The effect of water transport of wood on wood quality. *Proceedings of the Seminar on Water Transport of Wood, May 31 - June 18, 1982. National Board of Vocational Education, Forestry Training Programme for Developing Countries, Helsinki, Finland*: 223-226.
- Macklin, C. & Manning, G. H. 1978. FORSTAT - economic data base at Pacific Forest Research Centre. *Can. For. Serv., Pacific For. Res. Cen., Rep. BC-X-179*. 15 pp.
- Map reading. 1960. *Map reading. Dept. of the Army Field Manual FM 21-26, U.S. Government Printing Office, Washington*. 222 pp.
- Marble, D. F. & Peuquet, D. J. ed. 1983. *Geographic information systems and remote sensing: chapter 22. Manual of Remote Sensing, 2nd edition, American Society of Remote Sensing, The Sheridan Press*: 923-958.
- Martin, A. J. & Sendak, P. E. 1973. Operations research in forestry: a bibliography. U.S.D.A., For. Serv., Gen. Tech. Rep. NE-8. 90 pp.
- Masse, R. F. 1983. Comprehensive forest planning and management system: a cooperative experience. *J. of For.* 81(11): 718-720.
- Mikkonen, E. 1983. Eräiden matemaattisten ohjelmoinnin menetelmien käyttö puun korjuun ja kuljetuksen sekä tehdaskäsitelyn menetelmävalinnan apuvälineenä (Summary: The usefulness of some techniques of the mathematical programming as a tool for the choice of timber harvesting system). *Acta For. Fenn.* 183. 110 pp.
- 1984. Puutavaran ajo traktorilla välivarastosta (Summary: Haulage of timber by tractor from intermediate landing). *Metsätehon tiedotus* 384. 16 pp.
- Newnham, R. M. 1973. Process control in forest harvesting. *For. Chron.* 49(1): 35-40.

- 1975a. LOGPLAN – a model for planning logging operations. Dept. of the Environment, Can. For. Serv., Inf. Rep. FMR-X-77. 59 pp.
- 1975b. A FORTRAN program for LOGPLAN – a model for planning logging operations. Dept. of the Environment, Can. For. Serv., Inf. Rep. FMR-X-78. 77 pp.
- Nippu-uitomahdollisuudet . . . 1984. Nippu-uitomahdollisuudet Kemijoen vesistöalueella. Mimeograph, Kemi. 66 pp.
- Peltonen, J. & Vesikallio, H. 1979. Puunhankintakustannuksiin vaikuttavien tekijöiden kehittämisen kustannusvaikutukset (Summary: The effect of the development of factors that influence timber procurement costs). Metsätalon tiedotus 357. 35 pp.
- & Väisänen, U. 1972. Korjuun vuosisuunnitelma (Summary: One-year plan for logging). Metsätalon tiedotus 311. 23 pp.
- Pertovaara, H. 1982. Uitto- ja väylänrakennustekniikka. Lecture series booklet, Helsinki. 235 pp.
- Planning and control . . . 1982. Planning and control of forest operations. Proceedings of IUFRO S3.04.01, XVII World Congress, Kyoto, Japan, Sept. 6–17, 1981. Univ. of Maine, Misc. Rep. 264. 147 pp.
- Planning and decisionmaking . . . 1973. Planning and decisionmaking as applied to forest harvesting. Proceedings of symposium, School of Forestry, Sept. 11–12, 1972.
- Planning systems . . . 1973. Planning systems and control. Proceedings of IUFRO joint meeting of Div. 3 and 4, Freiburg, Oct. 1–5. 173 pp.
- Pulkki, R. & Aitolahhti, M. 1982. A mobile crusher for forest road construction (Seloste: Liikkuva moreeniinmurskain metsätien rakentamisessa). Commun. Inst. For. Fenn. 107. 30 pp.
- Putkisto, K. 1949. Vanerikoivujen kasamisesta II. Metsätalon tiedoituksia 28. 6 pp.
- Puutavaran autokuljetuksen . . . 1983. Puutavaran autokuljetuksen perusmaksut. Metsäalan Kuljetuksenantajat ja Suomen Kuorma-oliittito ry. Lahden Kirjapaino ja Sanomalehti Oy, Lahti. 45 pp.
- Puutavaran metsätraktorikuljetusmaksut . . . 1983. Puutavaran metsätraktorikuljetusmaksut Etelä-Suomessa: palkkausalueet 3–4. Metsäalan Kuljetuksenantajat ja Koneurakoitsijain Liitto ry. Lahden Kirjapaino ja Sanomalehti Oy, Lahti. 33 pp.
- Puutavaran uiton . . . 1980. Puutavaran uiton kehittäminen. Uiton kehittämissyhmä, Mimeograph, Helsinki. 43 pp.
- Raakapuun veteenpanokustannukset . . . 1981. Raakapuun veteenpanokustannukset eri kokoisilla pudotuspaikoilla. Valtion teknillinen tutkimuskeskus, Tie- ja liikennelaboratorio, Tutkimus- selustus 279. 53 pp.
- Rauskala, R. 1984. Kunnittaiset kantohinnat ja puukuutiometrin bruttoarvot hakkuuvuonna 1982/83. Metsäntutkimuslaitoksen tiedonantoja 128. 38 pp.
- Road and waterway . . . 1983. Road and waterway construction. Official Statistics of Finland XIX:98. 71 pp.
- Roitto, W. E. 1954. Eräitä näkökohtia Saimaan vesistöalueen puutavaran kaukokuljetuksen kehittämismahdollisuuksista (Referat: Einige Gesichtspunkte zu den Entwicklungsmöglichkeiten der Fernverfrachtung von Holzware aus dem Gewässergebiet des Saimasees). Acta For. Fenn. 61(3): 1–19.

- Roitto, Y. 1958. Raakapuun kaukokuljetus Saimaan vesistöissä: liikennetaloudellinen tutkimus (Referat: der Rohholz-Ferntransport im Gewässergebiet des Saimaa in Ost-Finnland. Verkehrswirtschaftliche Untersuchung). Acta For. Fenn. 67(3): 1–116.
- 1963. Suomen sisävesien aluskanta: puutavaraliikenteen aluksia koskeva selvittely (Summary: Finnish inland waterway fleet: an analysis with special reference to wood transporting vessels). Silva Fenn. 113 (4): 1–80.
- 1975. Raakapuukuljetusten optimointi (Summary: Optimization of roundwood transport). Silva Fenn. 9(1): 74–87.
- 1976. The economic transport unit size in roundwood towing on Lake Iso-Saimaa (in eastern Finland) (Tiivistelmä: taloudellinen kuljetusyksikkö Ison-Saimaan nippulauttahinauksessa). Acta For. Fenn. 153. 30 pp.
- Rose, D. W., Ek, A. R., Hoganson, H. M. & Aube, P. 1984. A spatial regional timber supply model for industrial expansion. For. Prod. J. 34(1): 21–27.
- Ruutujärjestelmätoimikunta. 1970. Suositus ruutujärjestelmän käyttämisestä biologian eri aloilla havaintopaikkojen ilmoittamisessa. Silva Fenn. 4(3): 230–231.
- Saarilahti, M. 1982. Tutkimuksia radioaaltojen soveltuvuudesta turvemaiden kulkukelpoisuuden arvioimiseen (Summary: Studies on the possibilities of using radar techniques in detecting the trafficability of peatlands). Acta For. Fenn. 176. 105 pp.
- Salminen, J. 1983. Metsäkuljetusmenetelmien vertailu. Metsätalon katsaus 5. 4 pp.
- Salminen, S. 1981. Vuosien 1971–75 valtakunnallisia metsävaratietoja karttamuodossa (Summary: A cartographic presentation of forest resources in Finland 1971–75). Folia For. 483. 42 pp.
- Savolainen, R. & Vesikallio, H. 1974. Raakapuun kaukokuljetusmuotojen käytön edullisuus vuonna 1973 ja sen kehitys vuosina 1974–1983 (Summary: The costs of the forms of long-distance transport of roundwood in Finland in 1973 and their development in 1974–1983). Metsätalon tiedotus 328. 40 pp.
- Schultz, R. L. & Slevin, D. P. 1975. Implementing operations research/management science. American Elsevier Publishing Co. Ltd., London. 334 pp.
- Seppälä, R. 1971. Simulation of timber-harvesting systems (Seloste: Puunkorjuuketjujen simulointi). Folia For. 125. 36 pp.
- Seppänen, O. 1937. Saimaan vesistön uittoväylät ja uittojen organisaatio niissä. Acta For. Fenn. 46. 168 pp.
- Seuna, P. 1971. Suomen vesistöalueet: ehdotus vesistöalueiden yleisjaoksi ja vesistötunnukseksi. Vesihallitus – National Board of Waters, Rep. 10. 53 pp.
- Simula, M. 1983. Productivity differentials in the Finnish forest industries (Seloste: Tuottavuuden vaihtelu Suomen metsäteollisuudessa). Acta For. Fenn. 180. 67 pp.

- Simulation techniques . . . 1978. Simulation techniques in forest operational planning and control. Proceedings of IUFRO S3.04.01, Workshop/Symposium, Wageningen, the Netherlands, Oct. 3–6. 310 pp.
- Some words on . . . 1969. Some words on computers in general and in forest uses. Can. For. Ind. 89(4): 49–50.
- Steele, R. G. D. & Torrie, J. H. 1960. Principles and procedures of statistics. McGraw-Hill Book Co. Inc., New York. 481 pp.
- Stolpe, N. 1954. Uitto, sen organisaatiota ja tulevaisuutta koskevia näkemyksiä (Referat: Flösserei, Ansichten über ihre Organisation und Zukunft). Acta For. Fenn. 61(5): 1–12.
- Sääksjärvi, M. 1976. Eräs puunhankinnan yhteistyömalli: hyödyn jakaminen peliteoreettisena ongelmana. Lappeenrannan teknillinen korkeakoulu, tieteellisiä julkaisuja 4. 120 pp.
- Taha, H. A. 1982. Operations research: an introduction. Macmillan Publishing Co. Inc., New York. 848 pp.
- TAKU-tavarankuljetusmallin . . . 1976. TAKU-tavarankuljetusmallin yleiskuvaus. Valtion Tietokonekeskus, Espoo, mimeograph. 6 pp.
- Talkamo, T. 1983. VR:n raakapuukuljetukset lisääntymässä? Rautatieliikenne 11: 16–17.
- Tariffitaulukot . . . 1983. Tariffitaulukot: 1.7.1983. Valtionrautatiet, Helsinki. 370 pp.
- Tavarankuljetusmallin . . . 1974. Tavarankuljetusmallin "TAKU" ATK-systeemi. Valtion Tietokonekeskus, Espoo, Ohjelmasseloste. 41 pp.
- Tehotoimilla . . . 1983. Tehotoimilla lisää leimikoita. Maataloustuottaja 2–3. p. 18.
- The proceedings of . . . 1983. The proceedings of the 1983 summer computer simulation conference, July 11–13, Vancouver, B. C., Canada. North-Holland Publishing Co., Amsterdam, the Netherlands. 1131 pp.
- Thompson, E. F. & Haynes, R. W. 1971. A linear programming-probabilistic approach to decision-making under uncertainty. For. Sci. 17(2): 224–229.
- Thornburn, G., Magar, K. M. & Nagle, G. S. 1973. An information system for rural land-use planning. Can. For. Serv., Pacific For. Res. Cen., Rep. BC-X-75. 91 pp.
- Tolonen, A. 1983. Kokeita uittopuun laadun säilyttä-

- seksi. Metsäteknologian pro gradu -tutkielma, Helsingin yliopisto. 61 pp.
- Tyre, G. L. & Srepetis, G. D. 1978. Systems for roundwood inventory and control of veneer, sawtimber and pulpwood volumes. For. Prod. J. 28(1): 40–41.
- Uiton ongelmat ja . . . 1981. Uiton ongelmat ja kehittämismahdollisuudet: yhteenvedo asiantuntijahaastattelusta. Valtion teknillinen tutkimuskeskus, Tie- ja liikennelaboratorio, Tutkimus- selustus 237. 18 pp.
- Univac 1100/60 . . . 1982. Univac 1100/60 käytön opas. Valtion Tietokonekeskus, Otaniemi.
- van Roessel, J. W. 1978. Simulating operational conditions with Timber-Pak. Proceedings of IUFRO S3.04.01, Simulating Techniques in Forest Operational Planning and Control, Wageningen, the Netherlands, Oct. 3–6: 146–160.
- Vesikallio, H. 1979. Water transport from a wood quality point-of-view. Proceedings of IUFRO S3. 01–04, Symposium on Water Transport of Wood, Univ. of Helsinki, Dept. of Logging and Utilization of Forest Products, Res. Notes 40: 123–130.
- 1981. Metsäteollisuusyritysten puunhankinta muuttuvassa yhteiskunnassa (Summary: The timber procurement of forest industry companies in the changing society). Metsätalon tiedotus 371. 62 pp.
- & Salminen, J. 1978. Raakapuun uiton kelpailukyky. Suomen Itsenäisyyden Juhlavuoden 1967 Rahasto, Sarja B, 47. 69 pp.
- Väylätilasto . . . 1979. Väylätilasto 1979. Tie- ja vesirakennushallitus, vesitieosasto, tutkimustoimisto. 33 pp.
- Wardle, P. A. (ed.) 1971. Operational research and the managerial economics of forestry. Proceedings of IUFRO working group, Forest Commission Res. Station, Alice Holt Lodge, Sept 1970. Forest Commission Bull. 44. 140 pp.
- Wiiala, A. 1962. Yksityiset tiet. Vammalan Kirjapaino Oy, Vammala. 243 pp.
- Yearbook of Forest Statistics. 1974a, 1974b, 1976, 1977, 1978, 1979, 1980, 1981, 1982, 1983, 1984. Yearbook of forest statistics. Official Statistics of Finland XVII A:14, Folia For. 195, 225, 255, 295, 345, 375, 430, 460, 510, 550, 590.

Total of 123 references

TIIVISTELMÄ

SIJAINITITIE TOKANTA – HEURISTINEN OHJELMOINTI JÄRJESTELMÄ PUUTAVARAN KAUKOKULJETUKSEN PÄÄTÖKSENTEOSSA

Tutkimuksessa käsitellään puutavaran kaukokuljetusta Saimaan alueella. Tutkimus rajattiin puutavaran kuljetukseen metsästä (tienvarresta) käyttöpaikalle ja se sisältää myös jatkettua lähikuljetuksen. Sopivan kuljetustavan löytäminen ei ole helppoa, koska ongelmakenttä on monimutkainen ja päätöksenteossa käytettävissä apuvälineissä on puutteita. Tutkimuksen päätavoitteeksi tuli etsiä tähän ongelmaan parannuksia. Sen aikana kehitettiin sijaintitietokannan ja heuristisen ohjelmoinnin avulla toimiva järjestelmä, joka soveltuu käytettävissä kaukokuljetusta koskevassa päätöksenteossa. Toinen tutkimuksen tavoitteista oli tutkia kehitetyn menetelmän avulla vesikuljetuksen kilpailukykyä ja erilaisia rationaalisointimahdollisuuksia. Maantie- ja rautatiekuljetus otettiin myös huomioon.

Nippu-uitto oli ainoa tutkittu vesikuljetusmenetelmä. Maantiekuljetukseen sisältyy sekä autokuljetus että jatkettu lähikuljetus traktorilla. Alkukuljetus terminaaleille ja terminaaleilla tapahtuvat toiminnot sisältyvät nippu-uittoon ja rautatiekuljetukseen. Kaikki nämä kuljetusmenetelmät palvelevat aluetta hyvin. Vesiväylien pituus alueella on 3 233 km ja vuosina 1980–1982 puuta toimitettiin 88 vesikuljetusterminaalille. Rautateitä alueella oli noin 1 400 km ja puuta toimitettiin 82 rautatieterminaalille samoina vuosina. Tieverkoston tiheydeksi alueella arvioitiin 23 m/ha. Saimaan alueella oli 37 eri puunjalostuslaitosta tai -laitosryhmää. Koko alueen pinta-ala oli 56 075 km². Alueen puunjalostusteollisuuden ainespuun tarve hyvänä vuonna on noin 13 M(m³).

Tehtaalle toimitettujen puumäärien osuudet auto-, vesi- ja rautatiekuljetuksessa olivat 49,5, 36,5 ja 14,0 %. Pienin vuotuinen vaihtelu on ollut vesikuljetuksessa, auto- ja rautatiekuljetuksessa vaihtelu oli suurin. Keskimääräiset välittömät kuljetuskustannukset Suomessa ovat traktori-, auto-, vesi- ja rautatiekuljetuksissa nousevat 18,2, 10,9, 11,6 ja 11,5 %/a. Vaikka autokuljetus yleensä on inflaatioherkin, todettiin, että sen rationaalisoinnilla on pystytty pitämään kustannusten nousu paremmin hallinnassa kuin muilla kuljetusmenetelmillä. Traktoreilla tehtaalle toimitetulla puumäärällä ei ollut alueella mitään merkitystä. Kun kuljetusta voidaan suorittaa ajoneuvoyhdistelmällä ja kun kuormauspaikka-alue on 2, oli jatkettu lähikuljetus traktorilla tavaralajista riippuen kilpailukykyinen 4,5–8 km saakka.

Kun puutavara-yhtiö valitsee itselleen sopivaa kulje-

tuspolitiikkaa, tavoitteena pitäisi olla yhtiön paras mahdollinen kokonaistaloudellinen tulos. Tarkasteltaessa eri kuljetusmenetelmiä olisi otettava huomioon paitsi liike-, myös kansantaloudelliset näkökulmat. Tärkeimmät liikeluokalliset tekijät ovat: 1) puun oston kausivaihtelut, 2) puunkorjuun kausivaihtelut, 3) käytetyt korjuumenetelmät, 4) välittömät kaukokuljetuskustannukset, 5) aika- ja viive puutavaran kuljetuksessa, 6) tekniset tekijät (esim. menetelmän käyttömahdollisuudet ja suoranainen vaikutus puutavaran laatuun), 7) varaston lyhytputokustannukset, 8) kuljetusmenetelmän varmuus ja palvelukyky ja 9) tehtaan puuntarve. Tärkeimmät kansantaloudelliset tekijät ovat: 1) työvoiman, pääoman ja energian tehokas käyttö, 2) ympäristöön aiheutuvat haitat, 3) menetelmien kotimaisuusaste, 4) toimivuus häiriö- ja kriisitilanteissa, 5) kuljetusmenetelmistä julkiselle vallalle aiheutuvat nettokustannukset (kuljetusväylien ja terminaalien rakentamis-, hoito- ja toimintakulut vastaan suoraanaiset tulot) ja 6) onnettomuusriski.

Operaatiotutkimuksen, tietokannan hallintojärjestelmien ja sijaintitietojärjestelmien soveltuvuutta kaukokuljetusta koskevaan päätöksentekoon tarkasteltiin. Ongelman suuruuden ja monimutkaisuuden vuoksi operaatiotutkimus ja tietokannan hallintojärjestelmät eivät sellaisenaan sopeutuneet alueella päätöksentekoon apuvälineiksi. Niiden suurin puute oli se, etteivät ne ota huomioon tietojen maantieteellistä sijaintia. Sijaintitietojärjestelmää, johon on liitetty sopivat ohjelmistot, voitaisiin käyttää, mutta menetelmä vaatii niin suuria pääomia, ettei sitä kannata käyttää vain kaukokuljetusta koskevassa päätöksenteossa. Jos metsäalan organisaatiolla on jo käytettävissään sijaintitietojärjestelmä metsätalouden suunnittelussa, tilanne on luonnollisesti toinen. Silloin seuraavassa esitetyt päätöksentekoon apuväline voidaan helposti muodostaa sijaintitietojärjestelmän avulla. Se voidaan lisätä osana sijaintitietojärjestelmään tai sitä voidaan käyttää erikseen.

Tutkimuksessa kehitettiin sijaintitietokanta – heuristinen ohjelmointijärjestelmä, jota käytettiin alueen kaukokuljetuksen tarkastelussa. Sijaintitiedot järjestettiin ruudukkomenetelmällä. Se sopi hyvin tietojen käsittelyyn ja oli halvempi ja helpokäyttöisempi kuin muut menetelmät. Jos vaaditaan tarkkaa graafista tulostusta, näin polygonimenetelmä on sopivin. Monipuolisuuden saavuttamiseksi nykyaikaiset sijaintitietojärjestelmät käyttä-

vät molempia menetelmiä. Ruudukon muodostamisessa käytettiin yhtenäiskoordinaatistoa. Ruutujen sivut olivat 2,5 km pitkiä eli koko ruudun ala oli 6,25 km². Kaikki kaukokuljetusta koskevat tiedot kerättiin ja tallennettiin ruutujen koordinaattien avulla. Pääasialliset tietoryhmät olivat: 1) tiet, 2) rautatiesysteemi, 3) vesikuljetussysteemi, 4) vesistöt, 5) järvisyys, 6) puunjalostuslaitokset, 7) piirimetsälautakunnat ja 8) kunnat. Alueelta hankittiin ja tallennettiin tietoluetteloihin myös deskriptiivistä informaatiota, esim. hakkuupoistuma, terminaaleille toimitetut puumäärät, markkinahakkuut, jalostuslaitosten ainespuun käyttö, väylien kustannukset, maksutalukkotiedot, kuntien kantohinnat ja terminaaleja kuvaavia tietoja. Mainittujen tietojen avulla muodostettiin informaatiomatriisit. Ne ovat tietokone muistissa yksittäisten karttojen kaltaisia ja jokainen matriisi sisältää yhden tietolajin. Informaatiomatriiseja käytettiin tietojen käsittelyssä tai tulostuksessa. Kaikki yllä luetellut tiedot sisältyvät sijaintitietokantaan.

Heuristisia kuljetusreitin etsimisalgoritmeja kehitettiin siten, että ne olivat apuna sijaintitietojen hyväksikäytössä. Kun valtaväylät tarkistettiin, saatiin kaksi erityyppistä muotoa: yhdistetty rengasmuoto ja haarautuva muoto. Alueen tie- ja rautatieverkostot ovat yhdistettyjä rengasmuotoisia kun taas vesiväylillä on haarautuva muoto. Reitin etsimisalgoritmin monimutkaisuusaste riippuu kuljetusmenetelmän verkoston monimutkaisuudesta ja muodosta. Kun alku- ja päätepuisteiden koordinaatit syötetään tietokoneeseen, reitin etsimisalgoritmi löytää ”hyvän” reitin pisteiden välillä. Algoritmeilla löydetty rautatie- ja vesikuljetusreitit ovat myös parhaat mahdolliset reitit. Maantieverkoston monimutkaisuuden vuoksi maantiereitin etsimisalgoritmi löytää aina reitin, joka on ”melkein” paras ja suurimmassa osassa tapauksia parhaan mahdollisen reitin. Varianssianalyysin avulla todettiin, ettei käsin lasketun lyhimmän reitin ja tietokoneella laskettujen reittien välillä ollut mitään merkittävää eroa. Tutkimuksen kuudessa kehitettiin myös kustannusalihojelmia, joiden avulla kustannusten laskemisessa voitiin käyttää hyväksi reitin etsimisalgoritmiin saatuja tietoja. Pääohjelmalle annettiin nimi BASDATSERCH ja se yhdistää yllä mainitut osat keskenään. BASDATSERCH:in toimintaperiaate on seuraava:

- 1) alku- ja päätepuisteiden koordinaatit syötetään tietokoneeseen
- 2) puutavara-laji syötetään tietokoneeseen
- 3) ohjelma tarkistaa, että sekä alku- että päätepuisteille on olemassa tieyhteys. Jos yhteyttä ei ole, ohjelma tulostaa viestin ja loppuu
- 4) ohjelma tarkistaa, onko päätepuisteelle rautatie- tai vesikuljetusväyläyhteys
- 5) jos vesikuljetus on mahdollinen, ohjelma etsii viisi lähintä vesikuljetusterminaalial

- 6) tieyhteys ja matkat alkupuisteesta kaikkiin terminaaleihin selvitetään ja alkukuljetuskustannukset lasketaan. Alkukuljetusvaihtoehdot ovat kuljetus autolla ja jatkettuna lähikuljetuksena traktorilla
- 7) vesikuljetusväylät ja uittokustannukset terminaaleista päätepuisteeseen määritellään
- 8) kokonaisvesikuljetuskustannukset alkupuisteesta päätepuisteelle lasketaan jokaisen terminaalin osalta erikseen
- 9) kaikki tiedot tulostetaan
- 10) vaiheet 5–9 toistetaan rautatiekuljetusta koskevin tiedoin
- 11) maantiereitti alku- ja päätepuisteiden välillä selvitetään ja kustannukset määritellään autolla sekä jatkettuna lähikuljetuksen traktorilla. Tiedot tulostetaan

BASDATSERCH tulostaa vain sellaisia tietoja, joita voidaan käyttää päätöksenteossa apuna, ei valmiita ratkaisuja. BASDATSERCH on yksi esimerkki sijaintitietokanta – heuristisesta ohjelmointijärjestelmästä, jossa vertaillaan eri kuljetusmenetelmien kilpailukykyä. Järjestelmää voidaan käyttää myös muiden ongelmien ratkaisemiseen. Voidaan esimerkiksi määritellä pisteen teoreettisen vaikutusalue lyhimpien matkojen avulla (matka linnuntietä). Tällöin voidaan paikallistaa ne alueet, joihin olisi kiinnitettävä huomiota. Sijaintitietokanta – heuristisen ohjelmointijärjestelmän käyttömahdollisuudet ovat laajat. Suurimmat rajoittavat tekijät ovat suunnittelijoiden ja ohjelmoijien kyky ja mielikuvitus, tietojen tarkkuus ja laajuus sekä järjestelmän budjetti.

Suurin vaikeus tällaisen järjestelmän kehittämisessä on tietojen hankinta ja niiden tallentaminen tietokoneen muistiin. Syötettävien tietojen määrä on niin suuri, etteivät mikrotietokoneet sovellu tehtävän suorittamiseen. Ohjelmointi vaatii niin paljon aikaa, että järjestelmän käyttöä ja kehittelyä varten tarvitaan ainakin yksi henkilö. Myös sijaintitietokannan pitäminen ajan tasalla vaatii paljon työtä. Toisaalta järjestelmälle uhrattu aika takaa sen käyttökelpoisuuden myös muuttuvissa olosuhteissa.

Sijaintitietokanta – heuristista ohjelmointijärjestelmää käyttämällä saavutettiin tutkimuksen toinen tavoite eli tutkittiin vesikuljetuksen kilpailukykyä ja rationaalisointimahdollisuuksia. Tarkastellut tekijät olivat: puunhankinnan vaihteluiden vaikutus kaukokuljetusmenetelmän valintaan, vesikuljetus- ja rautatieterminaalien teoreettiset vaikutusalueet, terminaalien tiheyden vaikutus keskimääräiseen matkaan (linnuntietä) vesikuljetus- ja rautatieterminaalille, puunjalostuslaitosten ja laitosryhmien teoreettiset puunhankinta-alueet, kantohinnat ja eri kuljetusmenetelmien välisen riippuvuus, kaukokuljetusmenetelmien kilpailukykyyn vaikuttaminen ja kustannus-hyötyanalyysi. Niiden perusteella voidaan tehdä seuraavat päätelmät:

- 1) Saimaan alueella nippu-uiton suoranainen vaikutus varastojen suuruuteen on noin 0.6 kuukauden puun tarve. Nippu-uiton aiheuttama suoranainen korkokustannus on noin 1.40 FIM/m³ laskettuna 16 %/a korolla ja keskimääräisellä puun arvolla 200 FIM/m³
- 2) rautatieterminaalin määrä voidaan vähentää 70–80 terminaaliin; alkumatkat pitenisivät vähiten, jos terminaalin lukumäärää vähennettäisiin Saimaan alueen keskiosassa
- 3) vesikuljetusterminaalien lukumäärä on suunnilleen optimissa, mutta eräiden terminaalin sijoituksen tarkistuksella voitaisiin alkukuljetusmatkoja lyhentää
- 4) suurin vaikutus alkukuljetusmatkaan olisi vesikuljetusterminaalien lisäämisellä/vähentämisellä alueen pohjoisosassa
- 5) pienin vaikutus alkukuljetusmatkaan olisi vesikuljetusterminaalien lisäämisellä/vähentämisellä alueen keskiosassa
- 6) rautatiekuljetuksia käytetään eniten alueen luoteisosassa, nippu-uittoa eniten koillisosassa
- 7) 64 % alueen rautatiekuljetuksen puumäärästä toimitettiin alueen ulkopuolelle ja 55 % tästä määrästä toimitettiin etelään Kymijoen vesistön ja Suomenlahden rannalla oleville tehtaille
- 8) 55 % alueen tehtaille rautateitse toimitetusta puumäärästä tuli alueen ulkopuolelta
- 9) rautateitse kuljetettiin eniten havukuitupuuta
- 10) rautatiekuljetusta ja nippu-uittoa käytetään oikeissa paikoissa puunkuljetuksessa. Rautatiekuljetusta käytettiin huonosti uivien puutavaraerien kuljetamisessa, puutavaran kuljetuksessa alueen ulkopuolelta alueen tehtaisiin, alueen puutavaran kuljetuksessa alueen ulkopuolelle oleville tehtaille ja kuljetuksessa sellaisten alueen osien välillä, missä nippu-uitto ei ole mahdollinen
- 11) puun kuljetuksen optimoinnista huolimatta tarvitaan rautatiekuljetusta ja/tai vesikuljetusta mäntytykin, kuusitykin, lehtipuutykin, mäntykuitupuun ja lehtikuitupuun kuljetuksissa Etelä-Saimaan alueella oleville tehtaille
- 12) alueella näyttää olevan kuusikuitupuun ylitarjontaa ja puutetta mäntykuitupuusta
- 13) merkitsevin tekijä kantohinnoissa oli kunnan etelä/pohjoissijainti (pohjoiseen mentäessä kaikkien puutavaraerien kantohinta laskee)
- 14) tehtaan läheinen sijainti vaikutti (korottavasti) vain lehtipuutykin kantohintaan
- 15) rautatie- tai vesikuljetusterminaalien läheinen sijainti ei juurikaan vaikuttanut kantohintaan. Vain vesikuljetusterminaalin läheisyysdella oli pieni positiivinen vaikutus kuusitykin kantohintaan
- 16) kokonaiskuljetusmatkat maantie-, rautatie- ja vesikuljetuksessa olivat suhteessa 1.34, 1.51 ja 1.76 linnuntietä mitattuun matkaan alku- ja päätepestaiden välillä

- 17) nippu-uitto on keskimäärin autokuljetusta halvempaa 48 km:n matkan (linnuntietä) jälkeen
- 18) kun alkukuljetusmatka vesikuljetusterminaalille on lyhyt (alle 5 km), alkaa nippu-uitto olla kilpailukykyinen autokuljetuksen kanssa 20 km:n matkan (linnuntietä) jälkeen
- 19) rautatiekuljetus on keskimäärin autokuljetusta halvempaa 125 km:n matkan (linnuntietä) jälkeen
- 20) rautatiekuljetus ei ole milloinkaan kilpailukykyinen nippu-uiton kanssa, kun kysymyksessä on uittettava puutavaraerä
- 21) kaikissa tapauksissa nippu-uitto on autokuljetusta halvempaa 160 km:n matkan (linnuntietä) jälkeen
- 22) jos tehtaan vastaanottokustannukset ovat uittossa 1.50 FIM/m³ kalliimpia ja korkokustannukset laskeetaan mukaan, nippu-uitto on keskimäärin autokuljetusta halvempaa 67 km:n matkan (linnuntietä) jälkeen
- 23) nippu-uittoa rationalisoitaessa pitäisi eniten huomiota kiinnittää alkukuljetukseen, terminaalin toimintoihin ja tehdasvastaanottoon

Sijaintitietokanta – heuristisen ohjelmointijärjestelmän avulla saadaan helposti informaatiota vuosisuunnittelua varten. Oikeat reitit terminaaleineen sekä eri menetelmien keskinäinen kilpailukyky pystytään määrittämään selvästi. Käytössä olevien terminaalin sijainnit, puutarve, puun paikallinen saatavuus yms. tiedot olisivat helposti käytettävissä kaukokuljetukseen päätöksenteossa. Tämän tyypistä järjestelmää voidaan myös käyttää standardina vertailtaessa käytännön kuljetuksen tehokkuutta. Jos järjestelmän päivitys olisi ajan tasalla, olisi päätöksentekijällä käteensä ulottuvilla hyödyllistä tietoa esim. puukaupoista ja tienvarsari- ja terminaaliavarausten sijainnista ja suuruuksista. Eri väylien kilpailukyky voidaan tarkistaa, samoin toimipaikkojen sijainnit. Tietojen esittäminen sijainnin avulla on hyödyllisempää kuin monen taulukon tulostus.

Tässä tutkimuksessa kehitetty sijaintitietokanta – heuristinen ohjelmointijärjestelmä on osoittautunut hyödylliseksi apuvälineeksi puutavaran kaukokuljetuksen päätöksenteossa. Edellä on mainittu vain muutamia esimerkkejä järjestelmän käyttökelpoisuudesta. Järjestelmän avulla saatua tietoa voidaan myös tallentaa järjestelmän sijaintitietokantaan, jolloin järjestelmästä tulee monipuolisempi. ATK:n käyttö lisääntyessä myös kentällä edellä selostettu järjestelmä voi olla hyödyllinen apuväline kaukokuljetuksen päätöksenteossa. Aina on kuitenkin muistettava, ettei järjestelmä anna valmiita ratkaisuja vaan ainoastaan päätöksentekoa helpottavaa tietoa.

APPENDIX A – Example of BASDATSERCH output Liite A – Esimerkki BASDATSERCH:in tulostuksesta

<pre> ***** * BASDAT SEARCH * ***** </pre>		<p>ACTUAL RAILWAY TRANSPORT DISTANCE:</p> <p>- 46, 47 TO 54, 35 - 66.8 KM - 44, 45 TO 54, 35 - 59.8 KM - 42, 38 TO 54, 35 - 40.2 KM - 49, 35 TO 54, 35 - 12.5 KM - 46, 34 TO 54, 35 - 23.1 KM</p>
<p>THE SOURCE COORDINATES ARE: 47, 45 THE DESTINATION COORDINATES ARE: 54, 35</p> <p>IS SOURCE 47, 45 SERVICED BY A ROAD? YES IS DESTINATION 54, 35 SERVICED BY A ROAD? YES</p> <p>IS DESTINATION 54, 35 SERVICED BY A BUNDLE FLOATING ROUTE? YES</p>		<p>ACTUAL RAILWAY TRANSPORT COST:</p> <p>- 46, 47 TO 54, 35 - 13.44 FIM - 44, 45 TO 54, 35 - 11.76 FIM - 42, 38 TO 54, 35 - 10.36 FIM - 49, 35 TO 54, 35 - 10.36 FIM - 46, 34 TO 54, 35 - 10.36 FIM</p>
<p>BASED ON STRAIGHT-LINE DISTANCE, THE CLOSEST 5 DUMPING TERMINALS ARE:</p> <p>- 48, 48 AKONPOHJA 3 7.9 KM - 52, 43 MELAVESI 3 13.5 KM - 40, 46 LASTUKOSKI 4 17.7 KM - 43, 38 PAJULAHTI 3 20.2 KM - 52, 55 LUIKONLAHTI 4 28.0 KM</p>		<p>ROAD DISTANCE - ALL HIGHWAY CLASSES: 57.7 KM ROAD DISTANCE - ALONG MAJOR HIGHWAYS: 56.7 KM</p> <p>TOTAL (ROAD + WATER) BUNDLE FLOATING TRANSPORT COSTS VIA 5 CLOSEST DUMPING TERMINALS:</p> <p>TRUCK:</p> <p>- 47, 45 TO 48, 48 TO 54, 35 - 20.24 FIM - 47, 45 TO 52, 43 TO 54, 35 - 20.68 FIM - 47, 45 TO 40, 46 TO 54, 35 - 28.13 FIM - 47, 45 TO 43, 38 TO 54, 35 - 21.26 FIM - 47, 45 TO 52, 55 TO 54, 35 - 37.84 FIM</p>
<p>ROAD DISTANCES FROM SOURCE TO DUMPING TERMINALS:</p> <p>- 48, 48 AKONPOHJA 3 15.0 KM - 52, 43 MELAVESI 3 23.5 KM - 40, 46 LASTUKOSKI 4 24.6 KM - 43, 38 PAJULAHTI 3 26.0 KM - 52, 55 LUIKONLAHTI 4 36.6 KM</p>		<p>TRACTOR:</p> <p>- 47, 45 TO 48, 48 TO 54, 35 - 34.43 FIM - 47, 45 TO 52, 43 TO 54, 35 - 47.13 FIM - 47, 45 TO 40, 46 TO 54, 35 - 55.89 FIM - 47, 45 TO 43, 38 TO 54, 35 - 51.02 FIM - 47, 45 TO 52, 55 TO 54, 35 - 82.92 FIM</p>
<p>TRUCK TRANSPORT COSTS FROM SOURCE TO DUMPING TERMINALS:</p> <p>- 48, 48 AKONPOHJA 3 13.15 FIM - 52, 43 MELAVESI 3 14.67 FIM - 40, 46 LASTUKOSKI 4 15.04 FIM - 43, 38 PAJULAHTI 3 15.41 FIM - 52, 55 LUIKONLAHTI 4 17.22 FIM</p>		<p>TOTAL (ROAD + RAILWAY) RAILWAY TRANSPORT COSTS VIA 5 CLOSEST RAILWAY TERMINALS:</p> <p>TRUCK:</p> <p>- 47, 45 TO 46, 47 TO 54, 35 - 24.93 FIM - 47, 45 TO 44, 45 TO 54, 35 - 25.91 FIM - 47, 45 TO 42, 38 TO 54, 35 - 28.98 FIM - 47, 45 TO 49, 35 TO 54, 35 - 32.74 FIM - 47, 45 TO 46, 34 TO 54, 35 - 31.25 FIM</p>
<p>TRACTOR TRANSPORT COSTS FROM SOURCE TO DUMPING TERMINALS:</p> <p>- 48, 48 AKONPOHJA 3 27.34 FIM - 52, 43 MELAVESI 3 41.13 FIM - 40, 46 LASTUKOSKI 4 42.80 FIM - 43, 38 PAJULAHTI 3 45.16 FIM - 52, 55 LUIKONLAHTI 4 62.30 FIM</p>		<p>TRACTOR:</p> <p>- 47, 45 TO 46, 47 TO 54, 35 - 27.24 FIM - 47, 45 TO 44, 45 TO 54, 35 - 25.56 FIM - 47, 45 TO 42, 38 TO 54, 35 - 58.14 FIM - 47, 45 TO 49, 35 TO 54, 35 - ***** FIM - 47, 45 TO 46, 34 TO 54, 35 - ***** FIM</p>
<p>ACTUAL BUNDLE FLOATING DISTANCE:</p> <p>- 48, 48 TO 54, 35 - 46.6 KM - 52, 43 TO 54, 35 - 40.6 KM - 40, 46 TO 54, 35 - 69.3 KM - 43, 38 TO 54, 35 - 34.1 KM - 52, 55 TO 54, 35 - 125.5 KM</p>		<p>TRUCK TRANSPORT COST - ALL HIGHWAY CLASSES: 20.17 FIM TRUCK TRANSPORT COST - ALONG MAJOR HIGHWAYS: 20.17 FIM</p> <p>TRACTOR TRANSPORT COST DIRECT TO MILL: ***** FIM</p>
<p>ACTUAL BUNDLE FLOATING COST:</p> <p>- 48, 48 TO 54, 35 - 7.09 FIM - 52, 43 TO 54, 35 - 6.01 FIM - 40, 46 TO 54, 35 - 13.09 FIM - 43, 38 TO 54, 35 - 5.85 FIM - 52, 55 TO 54, 35 - 20.62 FIM</p>		<p>IS DESTINATION 54, 35 SERVICED BY A RAILWAY LINE? YES</p> <p>BASED ON STRAIGHT-LINE DISTANCE THE CLOSEST 5 RAILWAY TERMINALS ARE:</p> <p>- 46, 47 JUANKOSKI JKI 5.6 KM - 44, 45 VUOTLAHTI VTL 7.5 KM - 42, 38 SANKIMAKI SKM 21.5 KM - 49, 35 TOIVALA TOI 48.1 KM - 46, 34 SIILINJARVI SIJ 27.6 KM</p>
<p>ROAD DISTANCES FROM SOURCE TO RAILWAY TERMINALS:</p> <p>- 46, 47 JUANKOSKI JKI 7.5 KM - 44, 45 VUOTLAHTI VTL 7.5 KM - 42, 38 SANKIMAKI SKM 28.5 KM - 49, 35 TOIVALA TOI 48.1 KM - 46, 34 SIILINJARVI SIJ 40.6 KM</p>		<p>TRUCK TRANSPORT COSTS FROM SOURCE TO RAILWAY TERMINALS:</p> <p>- 46, 47 JUANKOSKI JKI 11.50 FIM - 44, 45 VUOTLAHTI VTL 14.15 FIM - 42, 38 SANKIMAKI SKM 18.62 FIM - 49, 35 TOIVALA TOI 22.38 FIM - 46, 34 SIILINJARVI SIJ 20.89 FIM</p>
<p>TRACTOR TRANSPORT COSTS FROM SOURCE TO RAILWAY TERMINALS:</p> <p>- 46, 47 JUANKOSKI JKI 13.80 FIM - 44, 45 VUOTLAHTI VTL 13.80 FIM - 42, 38 SANKIMAKI SKM 47.78 FIM - 49, 35 TOIVALA TOI ***** FIM - 46, 34 SIILINJARVI SIJ ***** FIM</p>		

APPENDIX B – City (*) and municipality numbers and names
Liite B – Kaupunkien (*) ja kuntien numerot ja nimet

1. Anttola	21. Kiuruvesi	41. Pyhäselkä	61. Valtimo
2. Eno	22. Kontiolahti	42. Rantasalmi	62. Varkaus (*)
3. Enonkoski	23. Kuopio (*)	43. Rautavaara	63. Varpaisjärvi
4. Heinävesi	24. Lapinlahti	44. Rautjärvi	64. Vehmersalmi
5. Iisalmi (*)	25. Lappeenranta (*)	45. Ristiina	67. Värtsilä
6. Ilomantsi	26. Kemi	46. Ruokolahti	68. Ylämaa
7. Imatra (*)	27. Leppävirta	47. Rääkkylä	69. Haukivuori
8. Joensuu (*)	28. Lieksa (*)	48. Saari	70. Kajaani (*)
9. Joroinen	29. Liperi	49. Savitaipale	71. Karttula
10. Joutseno	30. Maaninka	50. Savonlinna (*)	72. Kuhmo
11. Juankoski	31. Mikkeli (*)	51. Savonranta	73. Mäntyharju
12. Juuka	32. Mikkeli	52. Siilinjärvi	74. Pieksämäki
13. Juva	33. Nilsä	53. Sonkajärvi	75. Pielavesi
14. Jäppilä	34. Nuijamaa	54. Sulkava	76. Pyhäjärvi
15. Kaavi	35. Nurmes (*)	55. Suomenniemi	77. Pyhäntä
16. Kangaslampi	36. Outokumpu (*)	56. Taipalsaari	78. Sotkamo
17. Kerimäki	37. Parikkala	57. Tohmajärvi	79. Suonenjoki (*)
18. Kesälahti	38. Polvijärvi	58. Tuupovaara	80. Valkeala
19. Kiihtelysvaara	39. Punkaharju	59. Tuusniemi	81. Vuolijoki
20. Kitee	40. Puumala	60. Uukuniemi	

APPENDIX C – Covariance analysis of transport cost relationships
Liite C – Kaukokuljetuskustannusten kovarianssianalyysi

1. Road transport cost

- 1) to southern Saimaa mill: $Y = 11.0 + 0.210 \cdot X$; $r^2 = 0.97$, $VR = 11\,211.3^{**}$, $n = 375$
 2) to 5 other mills: $Y = 12.3 + 0.204 \cdot X$; $r^2 = 0.97$, $VR = 1\,276.7^{**}$, $n = 45$
 3) pooled data: $Y = 11.2 + 0.209 \cdot X$; $r^2 = 0.97$, $VR = 13\,141.3^{**}$, $n = 420$

Group regression

line	group	df	Σx^2	Σxy	Σy^2	df	SS(E)	MS(E)
1	1	374	2529407	531037	115198	373	3709.1	9.944
2	2	44	247251	50399	10619	43	346.0	8.046
3	pooled residuals					416	4055.1	9.748
4	differences for testing common slope					1	8.4	8.4
5	common slope	418	2776658	581436	125817	417	4063.5	9.745
6	difference for testing common levels					1	13.7	13.7
7	single regression	419	2937873	613682	132260	418	4077.2	9.754

$$\text{test for common slope } F_{1,416} = \frac{8.4}{9.748} = 0.86^{ns}$$

$$\text{test for common y-intercept } F_{1,417} = \frac{13.7}{9.745} = 1.41^{ns}$$

2. Railway transport cost

- 1) to southern Saimaa mill: $Y = 26.7 + 0.084 \cdot X$; $r^2 = 0.72$, $VR = 953.6^{**}$, $n = 375$
 2) to 5 other mills: $Y = 24.8 + 0.095 \cdot X$; $r^2 = 0.67$, $VR = 86.5^{**}$, $n = 45$
 3) pooled data: $Y = 26.4 + 0.086 \cdot X$; $r^2 = 0.73$, $VR = 1\,105.8^{**}$, $n = 420$

Group regression

line	group	df	Σx^2	Σxy	Σy^2	df	SS(E)	MS(E)
1	1	374	2529407	213497	25069	373	7048.4	18.90
2	2	44	247251	23581	3367	43	1118.1	26.00
3	pooled residuals					416	8166.5	19.63
4	differences for testing common slope					1	27.2	27.2
5	common slope	418	2776658	237078	28436	417	8193.7	19.65
6	difference for testing common levels					1	18.7	18.7
7	single regression	419	2937873	252631	29937	418	8212.4	19.647

$$\text{test for common slope } F_{1,416} = \frac{27.2}{19.6} = 1.39^{ns}$$

$$\text{test for common y-intercept } F_{1,417} = \frac{18.7}{19.65} = 0.95^{ns}$$

3. Bundle floating cost

- 1) to southern Saimaa mill: $Y = 18.3 + 0.056 \cdot X$; $r^2 = 0.64$, $VR = 666.2^{**}$, $n = 375$
 2) to 5 other mills: $Y = 18.6 + 0.062 \cdot X$; $r^2 = 0.58$, $VR = 58.2^{**}$, $n = 45$
 3) pooled data: $Y = 18.5 + 0.056 \cdot X$; $r^2 = 0.64$, $VR = 736.8^{**}$, $n = 420$

Group regression

line	group	df	Σx^2	Σxy	Σy^2	df	SS(E)	MS(E)
1	1	374	2529407	141993	12434	373	4462.7	11.964
2	2	44	247251	15229	1630	43	692.1	16.096
3	pooled residuals					416	5154.8	12.391
4	differences for testing common slope					1	6.9	6.9
5	common slope	418	2776658	157222	14064	417	5161.7	12.378
6	difference for testing common levels					1	32.1	32.1
7	single regression	419	2937873	163999	14349	418	5193.8	12.425

$$\text{test for common slope } F_{1,416} = \frac{6.9}{12.391} = 0.56^{ns}$$

$$\text{test for common y-intercept } F_{1,417} = \frac{32.1}{12.378} = 2.59^{ns}$$

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- 168 Wuolijoki, E. 1981. Effects of simulated tractor vibration on the psychophysiological and mechanical functions of the driver: Comparison of some excitatory frequencies. Seloste: Traktorin simuloidun värinän vaikutukset kuljettajan psykofysiologisiin ja mekaanisiin toimintoihin: Eräiden herätetaajuuksien vertailu.
- 169 Chung, M.-S. 1981. Flowering characteristics of *Pinus sylvestris* L. with special emphasis on the reproductive adaptation to local temperature factor. Seloste: Männyn (*Pinus sylvestris* L.) kukkimisominaisuuksista, erityisesti kukkimisen sopeutumisesta paikalliseen lämpöilmastoon.
- 170 Savolainen, R. & Kellomäki, S. 1981. Metsän maisemallinen arvostus. Summary: Scenic value of forest landscape.
- 171 Thammincha, S. 1981. Climatic variation in radial growth of Scots pine and Norway spruce and its importance to growth estimation. Seloste: Männyn ja kuusen sädekasvun ilmastollinen vaihtelu ja sen merkitys kasvun arvioinnissa.
- 172 Westman, C. J. 1981. Fertility of surface peat in relation to the site type class and potential stand growth. Seloste: Pintaturpeen viljavuuden tunnuksat suhteessa kasvupaikkatyyppiin ja puuston kasvupotentiaaliin.
- 173 Chung, M.-S. 1981. Biochemical methods for determining population structure in *Pinus sylvestris* L. Seloste: Männyn (*Pinus sylvestris* L.) populaatiorakenteesta biokemiallisten tutkimusten valossa.
- 174 Kilkki, P. & Varmola, M. 1981. Taper curve models for Scots pine and their applications. Seloste: Männyn runkokäyrämalleja ja niiden sovellutuksia.
- 175 Leikola, M. 1981. Suomen metsätieteellisen julkaisutoiminnan rakenne ja määrällinen kehitys vv. 1909–1978. Summary: Structure and development of publishing activity in Finnish forest sciences in 1909–1978.
- 176 Saarilahti, M. 1982. Tutkimuksia radioaaltojen soveltuvuudesta turvemaiden kulkelpoisuuden arvioimiseen. Summary: Studies on the possibilities of using radar techniques in detecting the trafficability of peatlands.
- 177 Hari, P., Kellomäki, S., Mäkelä, A., Ilonen, P., Kanninen, M., Korpilahti, E. & Nygrén, M. 1982. Metsikön varhaiskehityksen dynamiikkaa. Summary: Dynamics of early development of tree stand.
- 178 Turakka, A., Luukkanen, O. & Bhumibhamon, S. 1982. Notes on *Pinus kesya* and *P. merkusii* and their natural regeneration in watershed areas of northern Thailand. Seloste: Havaintoja männyistä (*Pinus kesya* ja *P. merkusii*) ja mäntyjen luontaisesta uudistumisesta Pohjois-Thaimaan vedenjakaja-alueilla.
- 179 Nyssönen, A. & Ojansuu, R. 1982. Metsikön puutavaralajirakenteen, arvon ja arvokasvun arviointi. Summary: Assessment of timber assortments, value and value increment of tree stands.
- 180 Simula, M. 1983. Productivity differentials in the Finnish forest industry. Seloste: Tuotavuuden vaihtelu Suomen metsäteollisuudessa.
- 181 Pohtila, E. & Pohjola, T. 1983. Lehvästöröisyyden ajoitus kasvukauden aikana. Summary: The timing of foliage spraying during the growing season.
- 182 Kilkki, P. 1983. Sample trees in timber volume estimation. Seloste: Koeput puuston tilavuuden estimoinnissa.
- 183 Mikkonen, E. 1983. Eräiden matemaattisten ohjelmoinnin menetelmien käyttö puunkorjuun ja kuljetuksen sekä tehdaskäsittelyn menetelmävalinnan apuvälineenä. Abstract: The usefulness of some techniques of the mathematical programming as a tool for the choice of timber harvesting system.
- 184 Westman, C. J. 1983. Taimitarhamaiden fysikaalisia ja kemiallisia ominaisuuksia sekä niiden suhde orgaanisen aineen määrään. Summary: Physical and physico-chemical properties of forest tree nursery soils and their relation to the amount of organic matter.
- 185 Kauppi, P. 1984. Stress, strain, and injury: Scots pine transplants from lifting to acclimation on the planting site. Tiivistelmä: Metsänviljelytaimien vaurioituminen noston ja istutuksen välillä.
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- 189 Heliövaara, K. & Väisänen, R. 1984. Effects of modern forestry on northwestern European forest invertebrates: A synthesis. Seloste: Nykyaikaisen metsänkäsittelyn vaikutukset luoteiseurooppalaisen metsän selkärangattomiin: Synteesi.
- 190 Suomen Metsätieteellinen Seura 75 vuotta. The Society of Forestry in Finland – 75 years. 1984.

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