A Game Theoretic Simulation Model for Quality Oriented Timber Supply to Sawmills

Tiina Tolvanen-Sikanen, Lauri Sikanen and Pertti Harstela

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The first aim of this study was to develop a simulation model describing the flow of different timber qualities to different firms. The second aim was to study preliminarily the factors which affect timber distributions. In addition, we tested the hypothesis that in a small sawmill firm the traditional way of organizing timber procurement does not direct effectively good quality logs to the special production. The game theoretic approaching and the principles of Monte-Carlo simulation were applied in developing of the simulation model. The most important factors of the model were tried to find for further studies with sensitive analyses. Empirical validation brought forth promising results in the area of one municipality. The buyer's awareness of a marked stand, the seller's willingness to sell a marked stand, the buyer's ability to pay for wood and the proportion of first quality pine logs in a marked stand affected the distribution of pine logs. The results also supported the hypothesis that the traditional system, in which sawmills or their own forest department procure themselves all timber needed, is not the most effective way to direct enough good quality timber to the special production.

Keywords timber, supply, quality, simulation, probability.
Authors' address Faculty of Forestry, University of Joensuu, P.O.Box 111, FIN-80101 Joensuu, Finland **Fax** to *Sikanen* +358 73 151 3590 **E-mail** sikanen@joyl.joensuu.fi
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1 Introduction

Different branches of science examine timber procurement in different ways. It may be considered to be an economic activity and it can be studied by using the methods from the field of economics. Price formation, for example, has been scrutinized with demand and supply as the basis (Palo 1964). On the other hand, procurement is a logistics system and an operation which can be planned, implemented and controlled. It can also be studied by the means of available to forest technology and especially by applying operations research. In this study, an attempt is

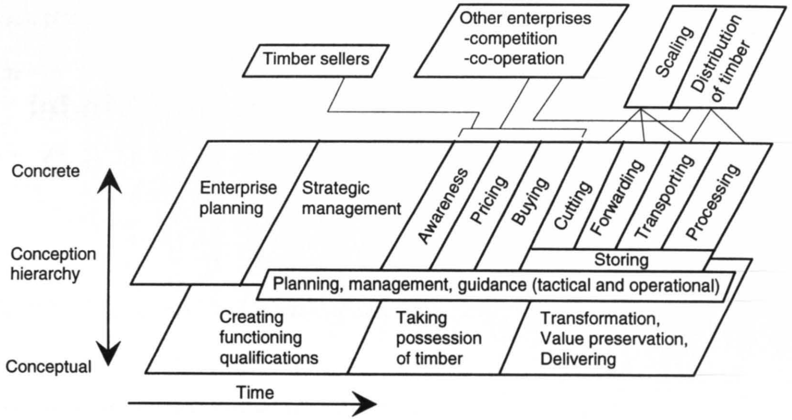

Fig. 1. Purchasing-based timber procurement at the enterprise level.

made to describe procurement as a logistics system and operation.

According to one definition "the mission of logistics is to get the right goods or services to the right place, at the right time, and in the desired condition, while making the greatest contribution to the firm" (Ballou 1992). This definition includes the concept of maximization of the ratio of output to input from the viewpoint of the whole and the optimization of the quality of raw material as part of the whole. In the forest industry during the past few years, the quality of wood especially has been observed to be an important element of profitability (Usenius et al. 1987, Hakala 1992, Kalliola et al. 1992).

From the viewpoint of operations research and logistics, the study of timber procurement is divided to conception hierarchy according to Fig. 1. This conception hierarchy forms the frame for this study. To date, only a few researchers have concerned themselves with alternatives in the organization of timber procurement. However, the effect of cooperation on procurement costs has been studied (Sääksjärvi 1976, Peltonen and Vesikallio 1979). According to Peltonen and Vesikallio (1979), these costs can be reduced by the efficient exploitation of human and other resources. Sääksjärvi (1976) and Soismaa (1988) have studied the organization of timber procurement by using the game theory. The different ways of organizing timber procurement were not examined in their studies and the purchasing mechanism was not analyzed in details. Sääksjärvi (1976) concluded that the overlapping of procurement areas and the ratio between planned procurement amounts and sustainable cutting volumes affected the price of timber in the study area. The division of utility is problem when joint procurement organizations serve several forest enterprises. In addition, it is difficult to model. Keipi's (1978a) study about transfer pricing for log allocation in a decentralized forest products firm is closely connected to this.

Furthermore, the implementation of a "mercantile exchange of roundwood" and its effect on the logistics services of the timber market have been theoretically scrutinized in the form of a timber procurement organization model (Kallio and Salo 1992, Vepsäläinen and Kuula 1992). According to Vepsäläinen and Kuula (1992) the timber market could be rationalized and made more efficient and more flexible with the help of the modern data processing technology and the implementation of a mercantile exchange of roundwood. On the other hand, the products and services for sale should also be standardized. This means problems in the trade of marked stands. The trade of harvested timber on such an exchange may lead to lengthy storage periods and losses in quality. There is not a comprehensive study of the alternatives in the organization of the timber trade and of the distribution of the timber in different qualities to the different purposes.

The planning and implementing of timber procurement have been studied by the means of operational analysis (Keipi 1978b, Mikkonen 1983, Dykstra 1984, Pulkki 1984). Planning models of practical work have also been developed (e.g. Kanerva 1976, Peltonen and Vesikallio 1979). Recent applications of geographic information systems (GIS) (e.g. Pulkki 1984, Kokkola 1993), of the principle of just-on-time (JOT) and the development of modern decision support systems (DSS) have been reported (Imponen 1990, Kaila and Saarenmaa 1990). These studies illustrate the planning of timber procurement in firms. Models of the timber procurement are still imperfect when describing the distribution of timber of different qualities to different firms and in such a way to the optimum place of production.

Because small and medium-sized enterprises seem to concentrate on the special and customized production while large sawmills concentrate on the standard products, the distribution of the raw material that maximizes the profit/cost ratio is an important economic issue. Special and customized production may have a significant role in the development of the mechanical forest industry and in increasing export revenues. It can also be a way to improve the degree of utilization of the timber resource.

In Finland large firms procure all kinds of logs and distribute the raw material to their own sawmills. They have also agreements to procure timber for some small sawmills which may produce special products. So, large firms can utilize all quality classes of logs. Often they, however, have not special production and they may use very good quality logs also for bulk production. The traditional timber procurement of small firms is that their own forest department procures almost all the timber needed. Because they do not need normally low quality sawlogs or pulpwood they try to sell or change such a rawmaterial with other firms. Nowadays some small sawmills may procure timber together by a shared forest department or by working as a network. Besides, some independent middlemen procure timber for some small firms. Redsven's (1990) study concerned itself with a model in which the forest department of a large firm procured timber for small sawmills. The problems encountered with the model were that the sawmills were unable to influence adequately the quality of incoming timber and the delivery schedules were not exact enough. There exist also some doubts towards middlemen and networks. Therefore, quite many small firms still procure timber by themselves.

The aim of this study is to develop a preliminary model describing the flow of timber qualities from marked stands to the firms, which have special demands and non-special demands for the quality of raw material. An attempt is made to find the most critical points for further studies; e.g. profit/cost analysis. Another aim is to test the hypothesis that the traditional own procurement of a small sawmill does not direct good enough qualities of logs for a special production.

2 Material and Methods

Timber procurement includes many hierarchic and simultaneous operations and planning and management functions so that the whole system is complicated with many influencing factors. To describe the system of timber procurement it is important to construct the timber procurement as a whole and to find all aspects influencing it. Uncertainty and randomness are typical features for particular elements in timber procurement e.g. seller's willingness to sell, buyer's awareness of marked stands and competition for marked stands. Thus simulation is suitable approach in this kind of model construction (e.g. Render and Stair 1992).

The model was built by breaking down timber procurement into a set of components following each other chronologically. The components were linked together by a master flow diagram, and the operating rules were then determined (Hillier and Lieberman 1974). This was followed by the construction of a hierarchic structure for the model with the aggregation.

The game theoretic approaching was applied in the modelling of timber purchasing, because purchasing of timber is like a game between

Table 1. Main products, production volumes per year and the consumed raw material for the small enterprises included in the study.

Enterprise	Products	Volume m³/a	Raw material
A	Window blank	3000	Pine logs, I
	Baulk blank	1580	Pine logs, II & III
	Normal sawn timber	1000	Pine logs, II & III
	By-products of window blank	750	Pine log, I
B	Normal planed timber	285	Pine logs, I & II
		45	Spruce log
		25	Birch log
	Normal sawn timber	205	Pine logs, II & III
		10	Spruce logs
C	Poles	17 300	Special pine logs (pine logs I & II)

several sellers and buyers. Especially when trading is done with closed offers, it is like a simultaneous game. Players try to achieve a so-called Bertrand equilibrium. Their aim is to maximize their own utility assuming that all other buyers are doing the same (Varian 1990). In timber trade this means that every buyer tries to set the price offer so that he will get the marked stand he wants. At the same time he tries to exceed the offer of competitor as little as possible. All of the money paid more than the offer of the competitors is the disadvantage for the buyer.

The model was tested by gathering data of wood flows from within a rural municipality in North-Carelia, eastern Finland. There were 95 marked stands in which the total amount of timber was 54 946 m³ (pine log 12 395 m³, pine pulp wood 8986 m³, spruce log 12 919 m³, spruce pulp wood 11 615 m³, birch+other log 3169 m³, birch+other pulp wood 5862 m³). In the area of the municipality six timber buyers were operating, three big companies and three small enterprises. The big companies utilized large quantities of nearly all kinds of wood assortments while the municipality in question plays only minor role in the companies' total wood procurement. The big companies bought altogether about 80 % of the wood of the municipality in 1991. Each of the big companies bought both logs and pulp wood of pine, spruce and birch in the municipality. The small enterprises consisted of two sawmills and one enterprise specializing in poles. Their products, product volumes and raw material for the products are presented in Table 1.

3 Implementation of the Model

3.1 Outline

The model follows the buyer's choices of marked stands offered for sale and the buyer's attempts to buy them until his procurement goal is reached. The model is mainly constructed of yes/no options and the probabilities of the events. The possibilities are determined by functions and the generation of random numbers (so-called "Monte Carlo method"). Because of the Monte Carlo method used, quite many of the simulations had to be done with the same input before relevant results could be achieved.

The parts of the hierarchic structure of the model are: 1) coming of a marked stand to the awareness of the buyer, 2) purchasing decision and purchasing competition, 3) the price strategy of closed offers, 4) timber quantities in different timber assortments and quality classes and 5) the independent middleman's selling game (Fig. 2). The model is illustrated in the form of a segment scheme in Figs. 3–8. It lacks the mercantile exchange of roundwood -alternative of the model, but this can be inserted later. A simulation model of the mercantile exchange of roundwood has been proposed by Kallio and Salo (1992). The structure of the segment scheme and its functions will be explained in the following subsections.

The functions were determined theoretically and their empirical validation and estimation of parameters will be a further task. Again, relevant coefficients are out of scope of this study. The aim is to study the whole range of values of variables by sensitivity analyses and by this mean to indicate the most important variables for the further studies.

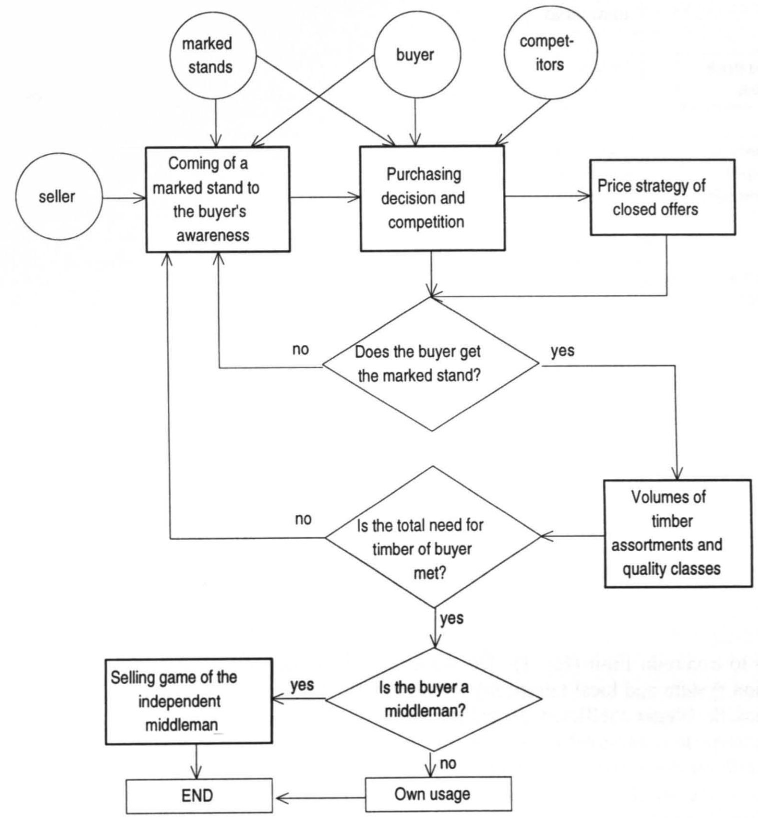

Fig. 2. Five main parts of the model and their interactions.

3.2 Coming of a Marked Stand to the Buyer's Awareness

Marked stands are selected from the register to the process according to quality and in order of superiority (Fig. 3). The concept "the probability of the buyer's awareness" (P_t) describes whether or not an enterprise becomes aware of a marked stand. The probability of buyer's awareness was assumed to depend on the distance between a marked stand and the enterprise, the buyer's enterprise type, and the seller type. When the stand is near the enterprise, the distance has only a slight influence. When the distance increases, the probability decreases with ever increasing

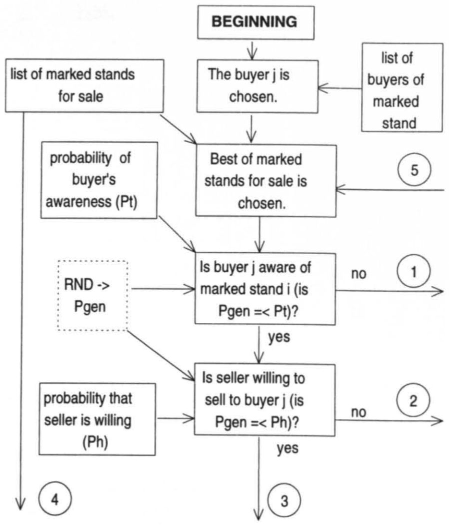

Fig. 3. Coming of a marked stand to the buyer's awareness.

speed up to a certain limit (Eq. 1). The better information system and local familiarity the enterprise has, the bigger coefficient describing the buyer's enterprise is assumed to be. The coefficient describing the seller has different values according to the publicity of the marked stand information. The values of the coefficients used in testing of the model are presented in Table 2.

$$P_t = \exp\left(-\left(\frac{s}{\beta}\right)^{\gamma}\right) \cdot y \cdot m \qquad (1)$$

in which

s = distance between the marked stand and the sawmill, km

ß,γ = constants definable by empirical tests

y = coefficient describing the buyer's enterprise, $0 \leq y \leq 1$

m = coefficient describing the seller, 0 m 1

P_{gen} is a uniformly distributed random number given by random number generator; $0 \leq P_{gen} \leq 1$. If P_{gen} is smaller or equal to the probability of the event, the event comes true in the simulation.

Table 2. Educated guess values of the coefficients used in the basic simulation (A, B and C are small enterprises, D, E and F are big companies).

Coefficient		Value
y, when enterprise is	A	0.95
	B	0.90
	C	0.90
	D	0.55
	E	0.55
	F	0.55
m, when publicity[1] is	H	0.98
	S	0.93
	I	0.50
	N	0
ß		100
γ		2.5
d		1
E		0.8–1.2
ζ		1.1
u		0.8–1.3

[1] Publicity of the marked stand information is presented in the marking report of the marked stand by letters:
H = information about marked stand may be given to all buyers
S = information to be given if buyer asks for it
I = information given only to selected buyers
N = no information to be given

The probability that the seller is willing to sell a marked stand to the buyer in question (P_h) is described by Equation 2. In addition of buyer's enterprise type and the seller types, the seller's traditional manner of selling timber affect this probability. The sellers usually want to maintain old seller-buyer relationships (Matti Saramäki, North-Carelian Regional Union of Forest Management Associations, pers. comm. July 9, 1992). Therefore the value of coefficient describing traditional manner is near to one in the situations, where a seller and a buyer have old business relations.

$$P_h = m \cdot y \cdot d \qquad (2)$$

in which

m = coefficient describing the seller, 0 m 1

y = coefficient describing the buyer's enterprise, $0 \leq y \leq 1$

d = coefficient describing the seller's traditional manner of selling timber, $0 \leq d \leq 1$

3.3 Purchasing Decision and Competition

The buyer's ability to pay for timber (R_{ij}) is described by the difference between the revenue from sales of the products and the costs of production and timber procurement. Equation 3 describes the ability to pay during a long period. Therefore it is a rather rough estimation.

$$R_{ij} = \sum_{a=1}^{n_a}\sum_{l=1}^{n_l}\left[V_{ali}\cdot\left(D_{al} - CM_{al} + DB_{al}\right)\right] - \sum_{a=1}^{n_a}\sum_{l=1}^{n_l}\left[V_{ali}\cdot\left(s\cdot CT + CL + CO + CC\right)\right] \qquad (3)$$

in which

V_{ali} = quantity of the timber assortment a in quality class l in marked stand i, m^3

D_{al} = revenue from sales of products made of timber assortment a (quality class l), FIM/m^3 of roundwood

CM_{al} = production costs of products made of timber assortment a (quality l) without roundwood cost, FIM/m^3 of roundwood

DB_{al} = revenue from sales of by-products made of timber assortment a (quality l), FIM/m^3 of roundwood

s = distance between a marked stand and buyer's enterprise, km

CT = long-distance transport cost, FIM/m^3/km

CL = logging cost, FIM/m^3

CO = overhead cost, FIM/m^3

CC = buyer's capital cost, FIM/m^3

a = timber assortment

l = quality class

n_a = number of timber assortments in marked stand i

n_l = number of quality classes in marked stand i

i = marked stand

j = buyer

The competing buyers' abilities to pay for timber (R_{ik}) are calculated in the same way. The buyer's purchasing power in the marked stand for cutting O_{ij} is calculated by Equation 4.

$$O_{ij} = \frac{\left(R_{ij} - R_{ik}\right)}{\sum_{a=1}^{n_a}\sum_{l=1}^{n_l} V_{ali}} \qquad (4)$$

In the selling situation with open offers, the buyer does not need to pay a price equal to his ability to pay for timber. He needs only to pay the price which is slightly more than his foremost competitor's ability to pay for the same timber. When the buyer operates rationally, he tries to maximize his gain. In the purchasing situation, the buyer usually has alternative marked stands to choose between. If the buyer is aware of and seller is willing to sell alternative stands, the buyer will compare his purchasing power with respect to all these stands. The buyer tries to buy the marked stand for which his purchasing power is biggest (Fig. 4).

3.4 Price Strategy of Closed Offers

The game theory pattern of thinking has been used in this part system (Fig. 5). When a marked stand is sold on the basis of closed offers, the choice of price strategy follows the structure of a simultaneous game (Varian 1990). The buyers set their purchasing prices according to the so-called Bertrand equilibrium theory (see Chapter 2).

The price strategy in this model is operated by calculating the coefficient (S_j) by means of Equation 5. Usually buyers prefer the marked stands nearby their mills, because the costs of transportation are lower. Therefore the offered price of the nearby marked stand is higher. In addition, the buyer tries to find out profits of products which can be made of timber from the marked stand. As a result of that the buyer has his profit expectation. If the profit expectation is low, the offered price will be low too. According to Sääksjärvi (1976) the more buyers are operating in the same area, the harder the competition is. The variable ζ^{nb} describes the effect of the number of buyers on the hardness of the competition. If there is not timber in the buyer's store and the buyer has already many orders for products, the urgency of need for timber will be high. The values of the coefficients used in testing of the model are presented in Table 2.

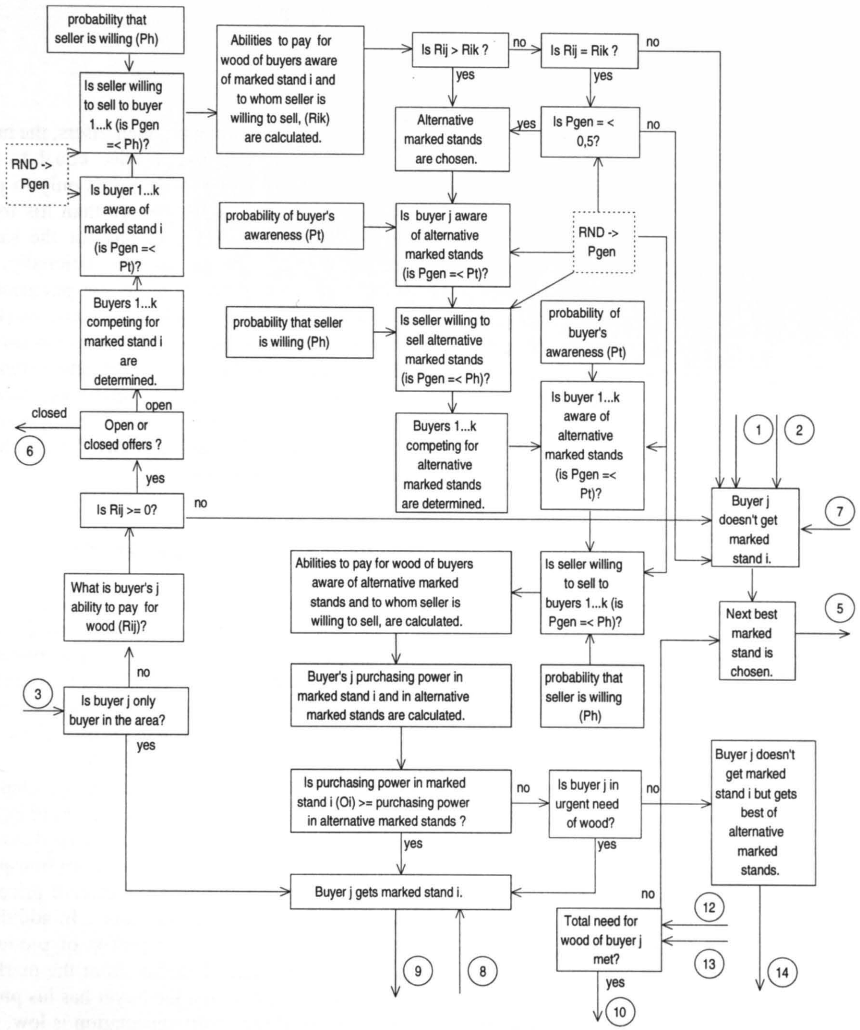

Fig. 4. Purchasing decision and competition.

$$S_j = \exp\left(-\left(\frac{s}{\beta}\right)^{\gamma}\right) \cdot E \cdot \zeta^{nb} \cdot g \cdot u \tag{5}$$

in which

S_j = coefficient of price strategy

s = dist. between marked stand and sawmill, km

β, γ = constants definable by empirical tests

E = coefficient describing the buyer's profit expectation

nb = number of buyers in the area

ζ = constant definable by empirical tests (1.1)

g = coefficient of purchasing goal = buyer's purchasing goal in area (m^3) / allowable cut (m^3)

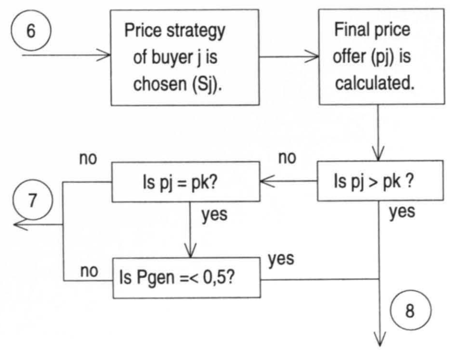

Fig. 5. Price strategy of closed offers.

u = coefficient describing urgency of need for timber

The price offer of the buyer in question is obtained by multiplying the average purchasing price ($\bar{p}$) by the coefficient of the price strategy (Eq. 6). The buyer's final price offer (p_j) is:

$$p_j = \bar{p} \cdot S_j, \quad \text{if } R_{ij} \geq p_j \tag{6}$$

The buyer (j) wins the price competition, if:

$$p_j > p_k \tag{7}$$

in which

p_k = price offer of foremost competitor

3.5 Volumes of Timber Assortments and Quality Classes

The volumes of timber in a marked stand are usually estimated visually. The average error of such estimates can be considerable; the visual appraisal of most stand parameters has been observed to result in average errors of about 20 % (Poso 1982). The average error in the proportions of timber assortments may be of the same order. This is why the model's actual quantities of the timber assortments falling into different quality classes in the marked stand are calculated by Equation 8.

$$V_{al} = V_a \cdot r_{al} \cdot (1 \pm e) \tag{8}$$

in which

V_{al} = actual quantity of timber assortment a in quality class l in marked stand i, m^3

V_a = quantity of timber assortment a according to cutting plan, m^3

r_{al} = proportion of quality l in V_a, $0 \leq r_{al} \leq 1$

e = estimating error in the proportions of quality classes, $0 \leq e \leq 1$

Equation 8 is inserted into the model as shown in Fig. 6.

If buyer j exchanges timber with other enterprises, part of the model described in Fig. 7 can be joined to the model. The buyer gives away surplus timber assortments and qualities. The quantity of timber given away (VA_{al}) is equal to the quantity of the timber assortment in the buy-

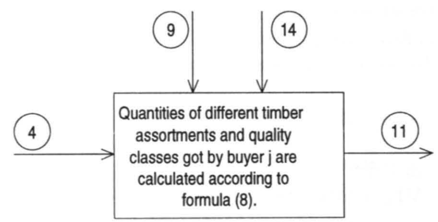

Fig. 6. Calculation procedure for timber quantities of different assortments and quality classes inserted into the model.

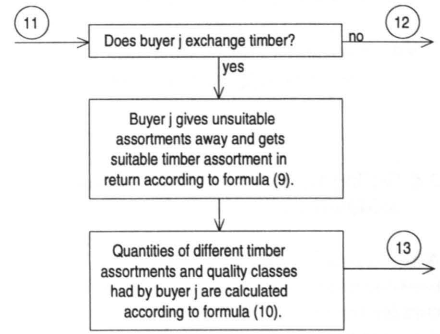

Fig. 7. Flow of timber when exchanging timber.

er's store minus the quantity needed of this assortment. In return, the buyer receives timber of an assortment of which he needs most of all (difference between quantity of timber assortment needed and quantity of this assortment in the buyer's store is biggest). The quantity of the timber assortment received (VG_{al}) is calculated by Equation 9.

$$VG_{al} = \sum_{a=1}^{n_{ag}} \sum_{l=1}^{n_{lg}} (VA_{al} \cdot B) \quad (9)$$

in which
a = timber assortment
l = quality class
n_{ag} = number of timber assortments given away
n_{lg} = number of quality classes given away
B = price ratio between the timber assortment given away and got in return

The quantities of different timber assortments and quality classes possessed by buyer j after exchanging are calculated according to Equation 10.

$$VT_{al} = VH_{al} + V_{al} + VG_{al} - VA_{al} \quad (10)$$

in which
VT_{al} = total quantity of timber assortment a, quality l, possessed by buyer j, m^3
VH_{al} = quantity of timber assortment a, quality l, in buyer j's store before timber exchange, m^3
V_{al} = actual quantity of timber assortment a, quality l, in marked stand i, m^3
VG_{al} = quantity of timber assortment a, quality l, received by buyer j in timber exchange, m^3
VA_{al} = quantity of timber assortment a, quality l, given away by buyer j in timber exchange, m^3

3.6 Selling Game of the Independent Middleman

A middleman in the timber trade can be a timber-processing enterprise that sells the timber unsuitable for itself to other enterprises or it can be an enterprise which only acts as an agent for the timber it procures. The timber procured by an independent middleman is competed for by buyers to whom the seller is willing to sell the timber (Fig. 8). The probability that an independent middleman is willing to sell timber to the buyer (P^*_h) is described by Equation 11. In addition of the buyer type, the intensity of competition between enterprises affect the probability. The more similar the products of competitive enterprises are and the more same the market areas of them are the bigger intensity of competition is.

$$P^*_h = y \cdot v \quad (11)$$

in which
y = coefficient describing buyer's enterprise, $0 \le y \le 1$
v = coefficient describing intensity of competition between the enterprises, $0 \le v \le 1$

The timber is got by the buyer enterprise whose ability to pay for the timber is the best. The middleman, however, sets the minimum price for the timber; i.e. the price that covers his timber procurement costs. The buyer enterprise cannot get more timber from the middleman than there is in the middleman's store of timber. Furthermore, because of sorting mistakes, the timber assortments and quality classes may be other than those wanted in the timber offered by the middleman. The buyer gets his timber according to Equation 12.

$$V = VT^*_{al} + VI \quad (12)$$

in which
V = total quantity of timber got by buyer's enterprise, m^3
VI = quantity of the incorrectly sorted timber, m^3
VT^*_{al} = quantity of timber assortment a, quality l, got by buyer's enterprise, m^3
1) $VT^*_{al} = VW_{al} \cdot r$, if $VW_{al} \quad VM_{al}$
2) $VT^*_{al} = VM_{al} \cdot r$, if $VW_{al} > VM_{al}$
where
VW_{al} = quantity of timber assortment a, quality l, wanted by buyer's enterprise, m^3
VM_{al} = supposed quantity of timber assortment a, quality l, in middleman's store, m^3
r = proportion of correctly sorted timber, $0 \le r \le 1$

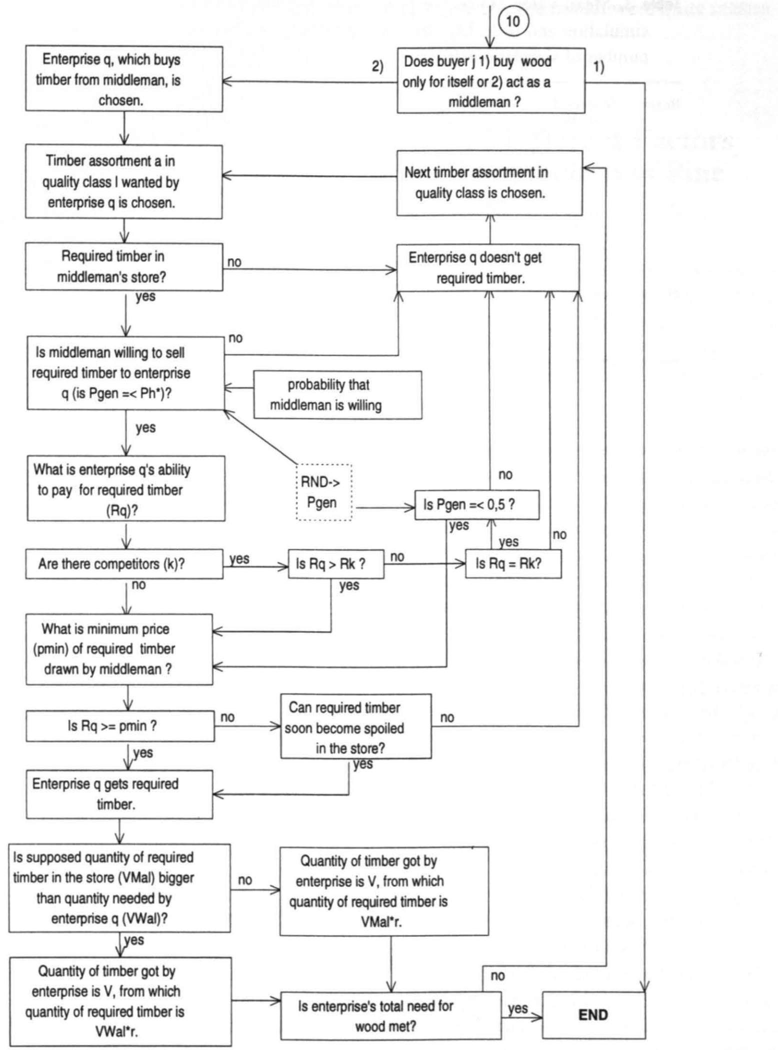

Fig. 8. Selling game of the independent middleman.

4 Evaluation of the Model

Firstly, the model was tested to see that it works mechanically. In the second stage of testing, the model was used to experiment with material collected in a rural municipality in North Carelia, eastern Finland. The results of the model were compared with the actual distribution of pine logs to quality classes procured from the municipality by the buyer enterprise. In the so-called

Table 3. Mean value (x) of the proportions by quality class of pine logs in the basic simulation and in reality, the standard deviation (s) in the basic simulation and the number of simulations (n).

Buyer	Statistical variable	Quality class: I quality, Basic simulation	I quality, Reality	II quality, Basic simulation	II quality, Reality	III quality, Basic simulation	III quality, Reality
A	x, %	30.1	35–45	52.4	35–45	17.5	10–20
	s, %	2.5		2.0		2.7	
	n	35		35		35	
B	x, %	22.1	25	52.6	45	25.2	30
	s, %	1.3		1.6		0.3	
	n	24		24		24	

basic simulation real values of the parameters were used when they were known (e.g. distance between marked stands and mills, revenues, costs, number of buyers in the area, buyer's purchasing goal). Otherwise the educated guesses were used.

The information about location, timber assortment quantities and the size of timber in the marked stands offered for sale in 1991 was got from the register of the local forest management association. Because the information did not include the distribution of the logs into quality classes, these were calculated on the basis of the results of the 7th national forest inventory (NFI). In the 7th NFI the results of quality class proportions were presented by breast height diameter, dbh. The averages of them for pine were 22.1 % (first/best quality class), 53.9 % (second quality class) and 24.0 % (third quality class) (Tomppo 1992). Quality was assumed to be normally distributed and the standard deviation was calculated to be 6 if the average dbh of the marked stand was known and 7 if the dbh was not known. The quality class proportions were calculated using a formula of normally distributed random numbers. Normally distributed random number z was calculated using two uniformly distributed random numbers x_1 and x_2 and Equation 13.

$$z = \cos(2\pi x_2) \cdot \sqrt{-2 \cdot \ln(x_1)} \tag{13}$$

The empirical measurement of quality classes in the timber flow of one municipality would be a huge task. Therefore the quality class proportions were calculated using functions mentioned before. The further development of the model will be based on validiation of single model units. This kind of total validiation, however, is an important support for the evaluation of the model.

Using Equation 14 it was possible to calculate the proportions for quality classes I and II in the marked stands.

$$q = \mu + \delta \cdot z \tag{14}$$

in which

q = $N(\mu,\delta)$ distributed quality class proportion in marked stand, %

μ = expected value of quality class proportion in dbh class, %

δ = standard deviation of q

z = $N(0,1)$ distributed random number using Equation 13

The proportion of quality class III was calculated by means of Equation 15:

$$\text{III-quality} = 100\% - (\text{I-quality,\%} + \text{II-quality,\%}) \tag{15}$$

Three small and three large buyers of timber operated in the study area. The managers of these enterprises were interviewed in order to know how much timber they bought in 1991 from the forestry association's area. In addition, they were

asked about the quality distribution of the timber bought, the ratio of utilization, annual production quantities, the overhead costs of timber procurement, revenue from sales of products, and the capital costs of the enterprise. This information was needed for calculating the enterprises' ability to pay for timber.

In the testing of the model, the required timber for the two buyer enterprises was procured through 35 simulations (basic simulation). The values of coefficients used in the basic simulation are presented in Table 2. These coefficients are so called educated guesses but, for example, the coefficients describing the buyer's enterprise type and the type of seller are based on the comments of experts from buyer organizations and forest management associations.

The statistical variables were calculated from the simulations (Table 3). The actual amount of pine logs of I quality class obtained by enterprise A was 50–60 %. It was estimated that 15 % of the total amount was achieved by exchanging logs with other enterprises and this is why the proportion of I quality class got directly from marked stands for enterprise A was 35–45 %.

Buyer A got pine logs of I quality a little less and pine logs of II quality a little more than in reality. Buyer B experienced the biggest differences between the model and reality in the quantity of pine logs of II and III quality. As a whole, the results given by the model were quite reasonable.

5 Effects of Different Factors on the Distribution of Pine Log Quality

After the testing, sensitivity analyses of the model were made. The effects of the probability of the buyer's awareness, the probability of the seller's willingness to sell, the buyer's ability to pay for wood, and quality class distribution of sawtimber in the marked stands on the distribution of pine log quality were studied.

The probability of the buyer's awareness affected the distribution of quality of pine logs obtained by the buyer. The bigger the probability of the buyer's awareness was, the better raw material the buyer got up to the relative probability of 80 %. Relative probability of 100 % means probability during the base simulation in the enterprise. The variation in probability affected most of all the quantities of pine logs of I and III quality (Figs. 9 and 10). The quantity of logs of II quality remained almost unchanged although the probability changed.

The probability that the seller is willing to sell

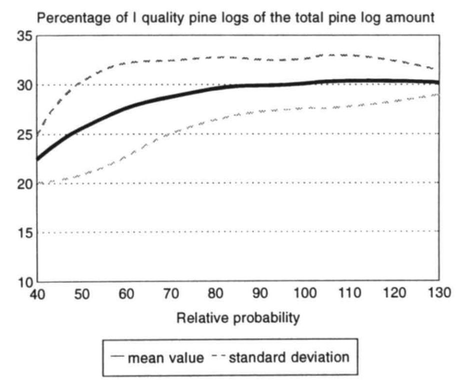

Fig. 9. Effect of "the probability of buyer's awareness" on the proportion of I quality pine logs got by buyer, % (basic simulation = 100).

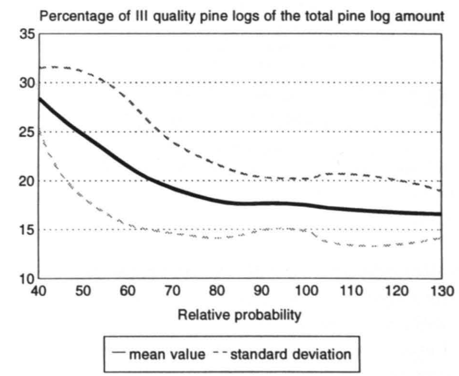

Fig. 10. Effect of "the probability of buyer's awareness" on the proportion of III quality pine logs got by buyer, % (basic simulation = 100).

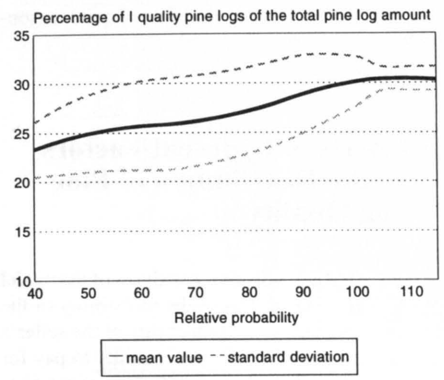

Fig. 11. Effect of "the probability that the seller is willing to sell" on the proportion of I quality pine logs got by buyer, % (basic simulation = 100).

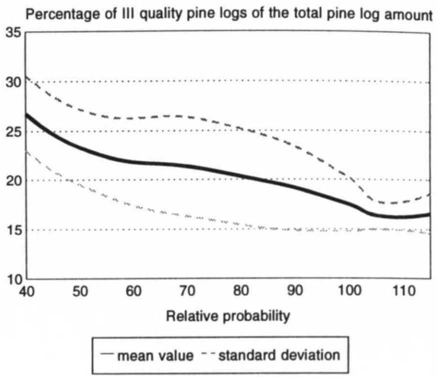

Fig. 12. Effect of "the probability that the seller is willing to sell" on the proportion of III quality pine logs got by buyer, % (basic simulation = 100).

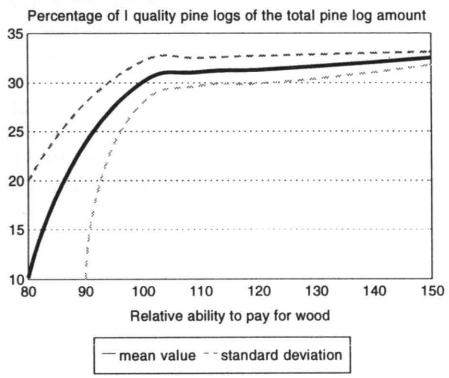

Fig. 13. Effect of "the buyer's ability to pay for wood" on the proportion of I quality pine logs got by buyer, % (basic simulation = 100).

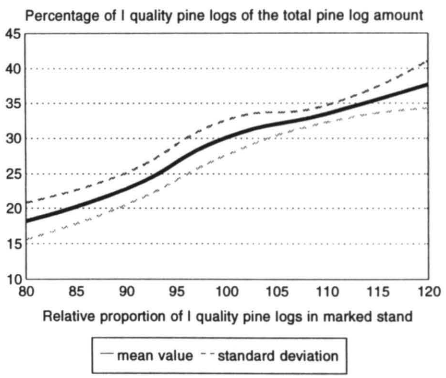

Fig. 14. Effect of "the proportion of I quality pine logs in the marked stand" on the proportion of I quality pine logs got by buyer, % (basic simulation = 100).

affected almost as strongly as the probability of the buyer's awareness (Figs. 11 and 12). Noteworthy is the point that making probabilities bigger has less significance than making them smaller.

The buyer's ability to pay for wood and the changes in the quality class distribution of sawtimber in the marked stands had the strongest effect on the distribution of pine logs got by the buyer in terms of quality classes. If the buyer's ability to pay for wood decreased 5 % from the value in the basic simulation, the quantity of the pine logs of I quality got by the buyer decreased 7 % (Fig. 13). Changes in the proportions of quality classes in the marked stands affected rather linearly the quality distribution of the raw

material got by the buyer (Fig. 14).

The effect of the timber exchanging by enterprises on the distribution of pine log quality was also analyzed using the model. If the enterprise was able to exchange the timber unsuitable for its own use, the quality of timber got by it improved. Enterprise A, for example, got 30.1 % of I quality pine logs in the basic simulation, but in simulation with timber exchange the corresponding figure for I quality logs was 56.2 %. The proportion of II quality pine logs decreased from 52.4 % to 32.6 % and III quality logs from 17.5 % to 11.2 %.

6 Conclusions

The first tests with the model indicated that the distribution of different qualities of pine saw logs supplied to sawmills was reasonably described. Additional testing is, however, required. This will be done following further development on the model. Especially empirical estimation and validation of the functions are necessary.

The analyses of timber exchanging with the model supported the hypothesis that traditional timber procurement of a small sawmill can be improved. For example, the good qualities of timber can be directed to the special production better with timber exchanging. One of the main reasons for the weakness of the traditional timber procurement may be that entire marked stands are offered for sale instead of parcels of timber assortments.

According to sensitivity analyses carried out, decreasing awareness of marked stands by the buyer and the buyer's ability to pay affected significantly the quality distribution of pine saw logs. On the other hand, increasing these variables from the level of the basic simulation does not have the same effect. This may be due to the high level of probabilities in the basic simulation and the small number of marked stands that can be controlled with the model.

The willingness of the seller to sell timber to the buyer in question also affected the distribution of quality of pine saw logs. This indicates the importance of established business relationships.

The factors mentioned before seem to be important variables in the model describing the distribution of timber. Therefore, empirical studies may be directed at the analyses of their influences. On the other hand, this study did not explore the effects of enterprise networks, procurement agreements between small and large firms, or arrangements of the mercantile exchange of roundwood, on the procurement of the appropriate timber quality. These should be inserted into the model when developing it further.

Acknowledgements

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