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An Evaluation of Aspen Utilization in Alberta

by

Ⓒ Mark S. Koepke

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled An Evaluation of Aspen Utilization in Alberta submitted by Mark S. Koepke in partial fulfilment of the requirements for the degree of Master of Science in Forest Operations.

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ABSTRACT

The forest resource in Alberta contains 680 million cubic metres of deciduous merchantable timber. The timber is commonly called aspen and includes trembling aspen (*Popu tremuloides*, Michx.) and balsam poplar (*Populus balsam* L.). Although the net annual allowable cut for aspen million cubic metres, only 1% of this amount is util every year. This study evaluated optimal utilization Alberta's untapped aspen resource.

A model using linear programming was developed analyze utilization alternatives for aspen on the Slave Lake Forest. The model included harvesting, hauling and e[illegible] manufacturing options. Potential products were factory and construction lumber, pulp, particleboard, waferboard and plywood. The most profitable solution was an integrated complex of mills using a sawmill, a particleboard mill, a waferboard mill and a plywood mill.

The sensitivity of the model's optimal solution to change was also analyzed. The necessity for an integrated system of mills to utilize aspen was proven through variation of tree size class volumes and product prices. Aspen can also be utilized profitably when a pulp mill is substituted for the particleboard mill in the optimal solution. However, the substitution reduced the net profit by 75%. Critical operating costs and product prices were determined for various mills and products.

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"I can do all things through Christ Which strengthenth me."

Phil. 4: 13

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LIST OF ABBREVIATIONS

A --acre

admt --air dry metric ton(90% fibre, 10% moisture)

BDU --bone dry unit(5.664 m^3 or 200 ft^3 of oven dry chips)

cd --cord

cm --centimeter

DBH --diameter at breast height(1.4 m or 4.5 ft)

fbm --board foot

ft --foot

ft^3 --cubic feet

ha --hectare

in --inch

kg/m^3 --kilograms per cubic metre

lbs/ft^3--pounds per cubic foot

m --metre

m^3 --cubic metres

mm --millimeters

Mfbm --one thousand board feet

MMfbm --one million board feet

MMsf --one million square feet

Msf --one thousand square feet

odt --oven dry ton

1. STATEMENT OF THE PROBLEM

The aspen tree(genus *Populus*) is known by numerous names such as poplar, popple and asp. Some people think aspen is a diamond in the rough, while others call it junk or a weed. Many people burn it or curse it, but some simply love it. A few have successfully made a profit with aspen. Others have failed dismally. Researchers have evaluated this tree extensively; yet, with all this notoriety, the aspen resource in Alberta is vastly underutilized and needs development.

1.1 The Scope of the Aspen Problem

The forest resource in Alberta contains over 1.6 billion cubic metres of merchantable timber. Deciduous species make up about 40% of this figure, or 680 MMm^3 (McDonald 1979).The deciduous species include approximately 80% trembling aspen(*Populus tremuloides* Michx.), 20% balsam poplar(*Populus basamifera* L.) and a small amount of white birch(*Betula papyrifera* Marsh.)(Jackson 1974; McDonald 1979). Presently the net annual allowable cut for deciduous timber is approximately 11.7 MMm^3 as compared to 14.3 MMm^3 for conifers(Fregren 1979). The actual amount of the deciduous species harvested is estimated at only 1% of the annual allowable cut(Neilson 1975). These statistics show that Alberta aspen[1] is an underutilized resource of wood fibre.

Aspen utilization in Alberta has been studied for many years. Extensive research has been conducted on aspen's characteristics with respect to lumber recovery, pulping potential, veneer applicability, use in composite panels and for energy production. In addition, market studies have been conducted for numerous aspen products. The Alberta Government has tried to stimulate use of aspen by setting minimal stumpage prices and by giving other economic incentives to potential operations. With the exception of a waferboard mill in Slave Lake, a planned pulp mill in Fox Creek and other minor uses, few successful ventures into aspen utilization have emerged.

1.2 The Method of Analyzing the Problem

Many analysts agree that the latent potential of aspen will not be tapped until the resource becomes economically viable (Neilsen 1975; Toovey 1979; Fregren 1979; Kennedy 1979; Wengert 1976). The problem is one of discerning which combinations of alternatives in harvesting, processing and marketing will produce a feasible and profitable solution. This kind of problem can be solved using operations research.

---

[1] The term aspen will include both trembling aspen and balsam poplar, unless otherwise specified.

Operations research is the analysis, usually mathematical, of an operation or process to determine its purpose and maximum efficiency(Barnhart 1974). The analysis can either be dynamic or deterministic. Dynamic programming is a multi-staged procedure where the solution for an individual stage depends upon answers found in the preceding stage. The deterministic model evaluates a problem with known or constant parameters such as price, cost and technology. One deterministic modelling technique is linear programming. This technique evaluates a broad spectrum of variables according to stated constraints, yielding an optimum solution to the problem.

Linear programming has been used extensively in forestry. Some of the areas in which this technique has proven useful include forest management policies(Navon 1967; Jack 1967; Kidd, Thompson and Hoepner 1966; Forsten and Stewart 1970; Manning 1971; Leak 1964), harvesting and planning(Boughton 1967; Wardle 1966), minimizing wood procurement schedules(Thompson, Tilghman, Hoepner and Richards 1968), optimizing sawmill and plywood production(Szabo 1967; Ramsing 1968) and machine loading(Penick 1968; Little and Wooten 1972). Pearse and Sydneysmith(1966) and Sitter(1969) used linear programming on a broader scale. Rather than concentrating on one specific area, they applied the technique to optimize log allocation among different types of mills making various types of products. In this research, linear programming was used in the same broad sense to evaluate the aspen utilization problem in Alberta.

1.3 The Objective of the Analysis

The objective of this analysis was to determine the optimal utilization of Alberta's aspen resource using a linear programming model. The application of linear programming to this type of problem is not new. The uniqueness of this analysis is that:

1. the focus will be specifically on the Alberta aspen situation,
2. the analysis will cover numerous activities and options from the standing tree to the market place, and
3. the model will provide a perspective on potentially profitable industry development.

The results of the analysis will describe what changes are required before aspen can compete more effectively with other wood species.

2. BACKGROUND ON ASPEN

A broad overview of the characteristics of aspen and its uses is needed in considering optimum utilization. The background will include dicussion of the resource, wood quality, harvesting techniques and products.

2.1 Characteristics of the Resource

As was mentioned in the first chapter, about 680 MMm^3 of aspen timber are available for utilization in Alberta. This aspen is located on a wide variety of sites throughout the Province, but it grows best in the boreal forest regions in central and northern Alberta(Jackson 1974). Aspen is a seral species on many sites and is eventually replaced by the coniferous forest type. In some locations, relatively stable stands of aspen can be considered *de facto* climax, because there is no forseeable replacement by conifers(Mueggler 1976).

Aspen is of a clonal habit. In one study(Barnes 1975), leaf, bud and twig characteristics were evaluated from over 1200 clones ranging from British Columbia to Colorado. Multivariate analysis revealed twenty-four population groups. Other findings show clonal variability in growth, colouration, susceptibility to disease and suckering ability(Barnes 1966; Barnes 1969; Wall 1971). Forest management of aspen is also affected by clonal characteristics. The suckering ability of the clones causes rapid restocking of a site after a disturbance. This is a detrimental characteristic if the management objective is to change cover type. The variablility of clones plus the difficulty of growing aspen from seed makes aspen tree improvement a difficult task(Higginbotham 1981).

The aspen resource is valuable for its aesthetic characteristics, firebreak ability and watershed control (Wengert 1976). It provides food and shelter for both wild and domesticated animals. Aspen reaches maturity in 60-80 years. The species also regenerates quickly after disturbance because of its suckering ability(Schier 1976).

The high incidence of decay fungi within stands is one of the major problems in utilizing the aspen resource. Table 1 shows the percentage decay around the Lesser Slave Lake region of Alberta. Although these studies show balsam poplar stands contain only 4-7% decay, the trembling aspen figures vary from 6.2 to 42.3% decay. This variability and high percentage of decay must be taken into account when developing any method of utilization.

A number of investigators feel that a major obstacle to the utilization of aspen is inaccurate resource data(Neilson 1975; Brese and Associates 1977; Keays, Hatton, Bailey and Neilson 1974; Toovey 1979; Fregren 1979). The Alberta Forest Service(1971) has the most complete inventory statistics. The data contained in this inventory were obtained primarily from aerial photographs dating from the early 1950's to the early 1960's. Companies may be very reluctant to make large

TABLE 1

PERCENT DECAY OF ASPEN IN LESSER SLAVE LAKE REGION

Age of Trees (*years*)	Paul and Etheridge, 1958		Bailey and Dobie, 1977		McDonald, 1979	
	TA	BP	TA	BP	TA	BP
30	11.8	2.9	6.2	6.2	...	...
40	13.5	8.7	6.2	6.2	...	...
50	30.2	8.2	6.2	6.2	...	...
60	40.0	7.4	8.4	5.0	10–15	...
70	42.3	8.4	8.4	5.0	10–15	...
80	39.6	10.1	8.4	5.0	25–30	...
90	36.0	11.4	12.2	5.5	25–30	...
100	33.1	13.4	12.2	5.5	...	...
110	30.2	15.2	12.2	5.5	...	...

Source: Paul, G. and D.E. Etheridge. 1958. Decay of aspen(*Populus tremuloides* Michx.) and balsam poplar (*Populus balsamiferia* L.) in the Lesser Slave Lake Region in Alberta. Joint Interim Rep., Gov. of Alta., Dep. Lands For., Can. Dept. Ag., For. Biol. Div., Calgary and Edmonton, Alta. pp. 12-13.

Source: Bailey, G.R. and J. Dobie. 1977. Alberta poplars—tree and log quality. Envirn. Can., West. For. Prod. Lab., Inf. Rep. VP-X-155, Vancouver, B.C. p. 4.

Source: McDonald, C.S. 1979. Status of the hardwood resources in Alberta. *In:* Utilization of Western Canadian Hardwoods Symp. Proc., ed. J.A. McDonald and M.N. Carroll. Forintek Can. Corp., Spec. Pub. No. SP-2, Vancouver, B.C. p. 25.

Note: TA—trembling aspen: BP—balsam poplar.

capital investments for aspen utilization with a poor and limited data base. In the next few years, the Alberta Forest Service will complete a new forest inventory which should provide new information on the aspen resource.

2.2 Characteristics of the Wood

Aspen is a fine-grained, light-weight hardwood. The wood is characterized by numerous small vessels scattered evenly throughout the fibres. Fibres make up 66% of the wood volume and are one-third to one-sixth of the length of fibres generally found in softwoods (Kennedy 1974). Annual rings are often not conspicuously defined due to the relative uniformity of the cells(Wengert 1975). The wood is white to light brown in colour. Discolouration is common in areas of bacterial wetwood[2] and incipient decay. Aspen has a slight characteristic odour when wet; it is odourless and tasteless when dry.

A major indicator of the strength of wood is its specific gravity. Aspen has low specific gravity which indicates low strength properties. Various specific gravity values for trembling aspen and balsam poplar given in the literature are found in Table 2. Wetwood in trembling aspen causes the specific gravity to be 0.03-0.04 units lower than for unaffected wood, while wetwood in balsam poplar has

---

[2] Wetwood and wet pockets are areas of high moisture content surrounded by wood of lower moisture content. They are caused by bacteria.

TABLE 2

SPECIFIC GRAVITY OF TREMBLING ASPEN AND BALSAM POPLAR

Species	Condition	Jessome, 1977	U.S. Forest Prod. Lab., 1974	Irwin and Dole, 1961	Erickson, 1972
trembling aspen	green	0.374	0.350	0.380	0.367
	air-dry	0.408	0.380	0.420*	0.455*
balsam poplar	green	0.372	0.310	0.370	...
	air-dry	0.415	0.340	0.420*	...

Source: Jessome, A.P. 1977. Strength and related properties of woods grown in Canada. Fisheries and Envirn. Can., East. For. Prod. Lab., For. Tech. Rep. 21, Ottawa, Ont. p. 32.

Source: U.S. Forest Products Laboratory. 1974. Wood handbook: wood as an engineering material. U.S.D.A., Ag. Handb. 72, rev., Washington, D.C. pp. 4-7, 4-8.

Source: Irwin, J.D. and J.A. Doyle. 1961. Properties and utilization of Canadian poplars. Can. Dep. Forest., For. Prod. Res. Br., Tech. Note 24. p. 22.

Source: Erickson, J.R. 1972. The moisture content and specific gravity of the bark and wood of northern pulpwood species. U.S.D.A., For. Ser. Res. Note NC-141. p. 3.

*Specific gravity using oven dry volume.

little effect(Kennedy 1974; Haygreen and Wang 1966). Kennedy(1968) reports in general, the the compression strength of trembling aspen is low when compared to species of similar specific gravity. He notes however, that bending strength of air-dried wood and the modules of elasticity in both green and air-dried specimens do not differ significantly from similar species. Wengert(1975) states that trembling aspen is also high in toughness. Volumetric shrinkage of aspen during drying ranges from 11.6-11.8%(Kennedy 1968). The large tangential to radial shrinkage ratio in trembling aspen can give rise to cupping and diamonding during the drying process. Tension wood and wet pockets further complicate uniform drying. Research by MacKay(1980) has proven that aspen can be dried efficiently and effectively despite these difficulties.

Other characteristics of aspen need to be considered. Nail-holding strength is low, but the uniform texture and short fibres allow the use of large nails without splitting the wood. Aspen does not dull tools quickly or require high power consumption when machining. Unless extra care is taken, though, the wood does not cut cleanly resulting in a fuzzy surface. The wood has excellent paint holding ability and provides a good surface for printing with ink. Aspen glues well but the wood is absorptive. Stain often appears blotchy when it is not applied carefully. Uniform preservative treatment of aspen is difficult because the tyloses in the heartwood and areas of wetwood resist penetration of the preservative.

2.3 Characteristics of Harvesting

Harvesting is a critical area when considering the economics of aspen utilization. At least two companies ceased operations primarily due to high harvesting costs(Koepke 1976). The harvesting technique most commonly used in aspen is manual felling with wheeled skidding. Trees are hauled as full-trees, tree-lengths or 2.54 m(100 in) bolts. Harvesting costs are high for a number of reasons, one major one being the large amount of decay within the stands. As was noted earlier, some older stands may be over 40% decayed. Ideally, all decayed material should be left in the bush but detecting decay is often difficult. Many trees have substantial decay without having visual indicators such as conks or scars Even with the presence of such external indicators, serious decay is not necessarily found(Bailey 1974). The time required to handle this decayed material significantly increases harvesting cost.

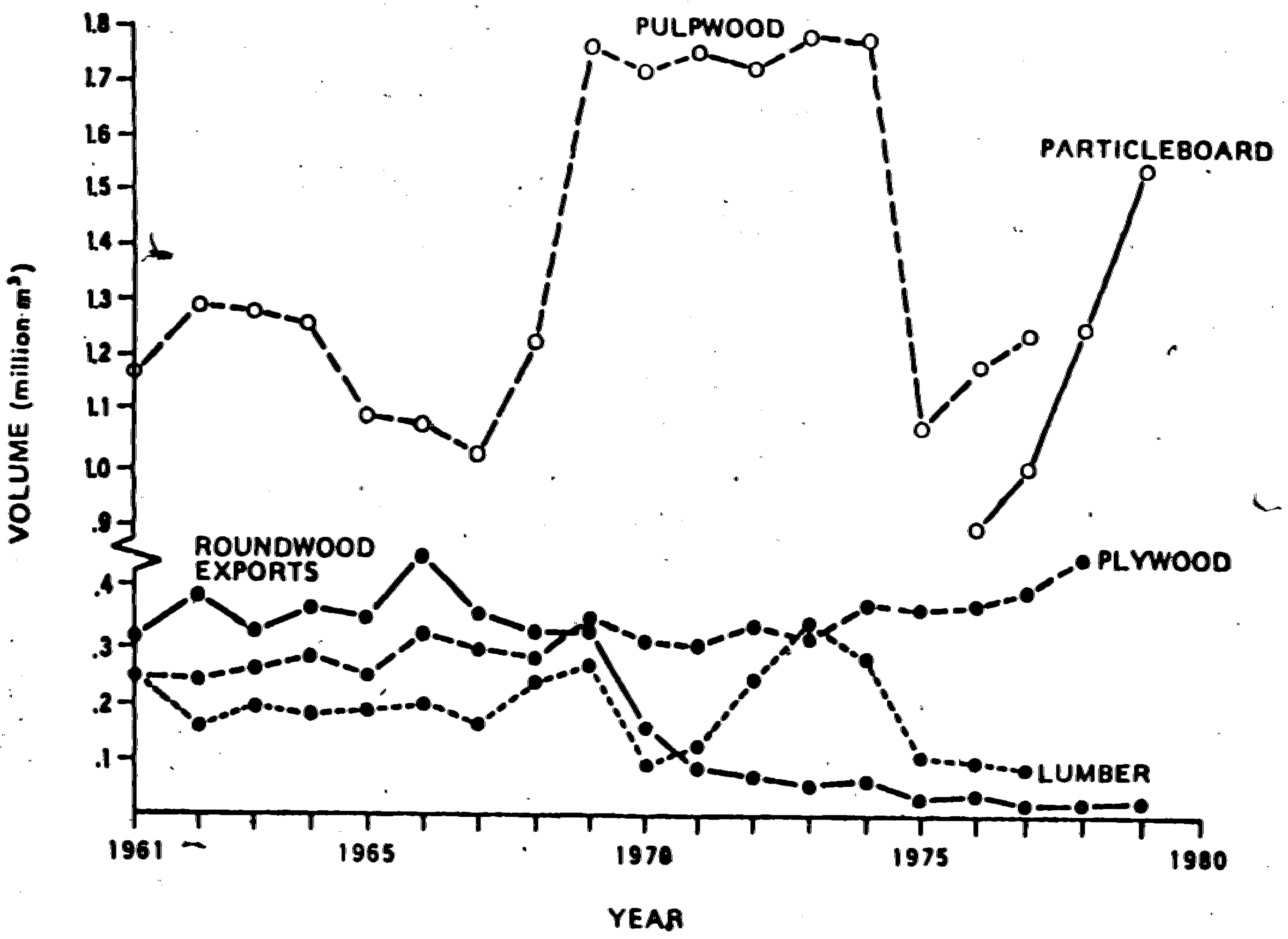
Another reason for increased harvesting costs in aspen involves the hauling of the trees to the mill or concentration yard. On the average, green aspen weighs 805 kg/m³(50.2 lbs/ft³), compared to spruce at 649 kg/m³ (40.5 lbs/ft³)(Dobie and Wright, 1975). The added weight plus a large amount of crook and sweep naturally lead to higher hauling costs. One B.C. firm reported that the volume hauled per load of aspen was 13% less than conifer loads(Neilsen 1975).

2.4 Characteristics of the Products

Aspen can be utilized to produce a wide variety of products. These products can be reviewed under the general categories of solid wood, veneer, composite panel, fibre and minor products.

2.4.1 Solid wood products

Solid wood products made from aspen include construction lumber, factory lumber and other solid wood uses. Nielsen(1980) reported that aspen lumber production has declined steadily from 130,000 m³ in 1973 to 30,000 m³ in 1977(Figure 1). Construction aspen lumber is listed in the "F" species group of Code of Recommended Practices for Engineering Design in Timber(Canadian Standards Association 1972). The "F" group is called the poplar group and includes trembling aspen, largetooth aspen and balsam poplar. The lumber in the poplar group has tension and bending strength equivalent to that of the spruce-pine-fir(SPF) group(Canadian Standards Association 1972). There is disagreement in the literature on whether the stiffness and compression strength of poplar is less than the limits establised for the SPF group. A number of studies report poplar to be weaker in stiffness and compression(Laminated



Source: Nielson, R.W. 1980. Poplar utilization trends and prospects. *In:* Second Annual Meeting of the Poplar Council of Can. Ont. For. Res. Centre, Maple Ridge, Ont. p. 70.

Figure 1. Canadian poplar consumption by end use

Timber Institute of Canada 1972; Kennedy 1974; Canadian Lumber Standard Administration Board 1980). However, Littleford and Roff's(1975) tests showed trembling aspen and balsam poplar to be stiffer than the limits set for the SPF group. Aspen construction lumber is presently being used for pallets, crates, reels and mine timbers(Koepke 1976; Nielsen 1980).

Aspen factory lumber is used in panels, dimension stock, shelving and furniture components(Reeves 1974). The market for these products is excellent(Harris 1968; Hovarter 1978; Dufr[illegible] McLaggan, Dargnault Inc. 1970; Ceasar 1974). The difficulty in utilizing aspen for this market is is the lack of sufficient quantities of high grade lumber. Bailey(1973) concluded that extensive manufacturing of factory lumber is limited due to the generally small diameters of aspen available. Flann(1974) estimates only 10-30% of a given regional aspen volume would be suitable for these types of products. The remaining residue and low grade material must be utilized before factory lumber production can become economically viable(Brese *et.al.* 1977; Leach and Gillies 1972; Flann 1974; Nielson 1980; Bailey 1973).

2.4.2 Veneer products

Consumption of aspen for the making of plywood has shown a moderate but steady increase from 1973 to 1978(Figure 1). Aspen plywood shipments in 1978 totalled

113.3 **Mm**^{3} (128 MMsf,3/8 in basis) utilizing 454 **Mm**^{3} of peeler logs(Nielson 1980). The manufacturing process is essentially the same as for softwood plywood. Higher production costs are incurred because of decay, glue absorption, spin-out and longer drying and press times.

Aspen plywood can be used for painted and unpainted furniture, built in fixtures, wall panelling, furniture backs, sheathing, floor underlay and decking. It has also been approved for core or crossband material with softwood face veneers(Neilson, 1975). A new veneer product called laminated veneer lumber is ~~now~~ being evaluated for its economic feasibility(Hyslop 1980). Laminated veneer lumber~~(LVL)~~ is a series of parallel ply laminations hot-press bonded together to produce a lumber-type product. Aspen LVL is made using 6 mm(1/4 in) veneers. Laminated veneer lumber appears to have excellent marketing potential for furniture parts and construction applications.

The limiting factor on expanding aspen veneer production is the resource itself. Harris(1968) noted that many aspen plywood producers either ceased operations or switched to alternate species due to the inability to secure adequate supplies of peeler bolts. This factor, plus the higher costs of harvesting and production severely limit the potential growth of aspen veneer production.

2.4.3 Composite panel products

Aspen composite panel products include insulation board, hardboard, medium-density fibreboard(MDF), particleboard and flakeboard[3]. Tables 3 and 4 show general information concerning raw materials, density and end use of these products. Medium-density fibreboard, particleboard and flakeboard consumed an estimated 1,007 Mm³ of aspen roundwood in 1977(Nielson 1980). The particleboard line[4] in Figure 1 shows a dramatic increase in aspen consumption for these end products starting in 1976. This trend is expected to continue mainly on the strength of new flakeboard production, particularly waferboard. The expansion of waferboard manufacturing from 1979-1984 given by Gummeson(1979) can be seen in Table 5. While MDF, particleboard and flakeboard consumption is increasing, the demand for insulation board and hardboard remains relatively low. This is basically due to petro-chemical products being substituted for traditional insulation board and hardboard applications.

The limiting factors on expansion of aspen MDF, particleboard and flakeboard are transportation and binder costs. Transportation costs are high for these products because of the heavy weight of the panels and the distance from the mill to large marketing areas. Binder costs will

---

[3] Flakeboard includes both strand or chip board and waferboard.

[4] The particleboard line includes data for MDF, particleboard and flakeboard. Insulation board and hardboard consumption data are included in the pulpwood statistics.

TABLE 3

BASIC PRODUCT-BASIC END USE RELATIONSHIP OF COMPOSITE BOARDS

Basic Product	Binder Type	Density (kg/m^3)	Basic End Use
Insulation board	none	272 - 512	non-structuctral sheathing (exterior-interior) ceiling tiles
Hardboard (S2S S1S).	P. F.	880 - 1120	3 - 6 mm wall paneling
	none	880 - 1120	3 - 6 mm industrial panel
		720 - 880	9 - 11 mm exterior siding
		960 - 1120	3 mm door skins(ext.-int.)
Medium-density fibreboard	U. F.	720 - 960	3 - 6 mm interior wall panel door skins
		640 - 960	9 - 32 mm industrial core board
Particleboard	U. F.	608 - 720	9 - 19 mm construction-grade panel underlayment
Industrial flakeboard	U.F.	400 - 560	28 - 38 mm door core
Structural flakeboard	P. F.	640 - 720	6 - 9 mm all-purpose wall cladding(ext.-int.)
		608 - 720	9 - 19 mm structural sheathing and decking

Source: Vajda, P. 1979. Particleboard and fiberboard processes. *In*: Proc. of Poplar Utilization Symp., ed. R.W. Neilson and C.F. McBride. Environ. Can., West. For. Prod Lab., Inf. Rep. VP-X-127, Vancouver, B.C. p. 220.

Note: P. F.--phenol formaldehyde; U. F.--urea formaldehyde.

TABLE 4

PRODUCT-RAW MATERIAL RELATIONSHIP OF COMPOSITE BOARDS

Product	Particle-fibre Configuration	Raw Material Input Form	Raw Material Supply Form	Species Preference
Insulation board Hardboard Medium-density fibreboard (industrial)	fibre	pulp chips sawdust shavings	roundwood millwaste forestry waste	softwood soft-hardwood almost any species
Particleboard industrial underlayment	particles semi-flakes fines semi-fibre	shavings sawdust plywood trim (chips)	millwaste	softwood (soft-hardwood)
Industrial flakeboard	flakes semi-flakes fines	roundwood plus: chips, shavings	roundwood plus: millwaste	softwood soft-hardwood
Structural flakeboard	flakes ("wafers") ("strands")	roundwood	roundwood	aspen (soft-hardwood, hard-hardwood, softwood)

Source: Vajda, P. 1974. Particleboard and fiberboard processes. *In*: Proc. of Poplar Utilization Symp., ed. R.W. Neilson and C.F. McBride. Environ. Can., West. For. Prod. Lab., Inf. Rep. VP-X-127, Vancouver, B.C. p. 221.

TABLE 5

ESTIMATED WAFERBOARD EXPANSION IN NORTH AMERICA, 1979-1984

Year	Production	
	Mm^3	MMsf, 3/8-inch basis
1979	421.8	715.0
1980	634.2	1075.0
1981	1115.1	1890.0
1982	1613.6	2735.0
1983	1702.1	2885.0
1984	1702.1	2885.0

Source: Gummeson, V. 1979. Composite board challenges. *In:* Utilization of Western Canadian Hardwoods Symp. Proc., ed. J.A. McDonald and M.N. Carroll. Forintek Can. Corp., Spec. Pub. No. SP-2, Vancouver, B.C. p. 7.

continue to escalate with energy prices. However, demand is high and these higher costs have not discouraged investment(Table 5).

2.4.4 Fibre products

Pulp and paper are the major fibre products made from aspen, although hardboard and insulation are also included in the fibre product grouping. Trembling aspen has been used in pulp and paper for many years. The pulp and paper industry has traditionally been the largest user of aspen roundwood until the recent demand in the flakeboard industry. Only a small volume of the aspen in Western Canada is presently being used in pulping(Neilson 1975). Aspen pulp has many desirable papermaking qualities which include excellent sheet formation, softness, bulkiness, high opacity; it is easily bleached and has good printability. The low strength of 100% aspen pulp is due to its short fibres. Therefore aspen pulp usually requires blending with another species to increase paper strength. Major products include newsprint, tissue stock, book stock, magazine stock, and fine writing paper.

2.4.5 Minor products

Small amounts of aspen are used for various other products. Solid wood products include dowels, firewood, mine timbers, snow fencing, novelty items and export logs. Aspen is also utilized to make match splits, excelsior and animal bedding(Koepke 1976). These products are presently using minor quantities of the resource, and with the possible exception of export logs, hold little potential for utilizing significant volumes of aspen.

2.5 Summary

The aspen resource occurs on a wide variety of sites and is extremely variable in phenotypic characteristics. The wood itself is fine-grained, light in colour and generally weak in strength. Harvesting costs for aspen are higher than softwoods due to high incidence of decay, heavy green weight and large amounts of crook and sweep. Aspen has proven suitable for utilization in lumber, veneer, composite panels, fibre products and other minor uses.

3. GENERAL CONCEPTS AND METHODOLOGY

This chapter contains a review of general concepts and methodology in using linear programming models to evaluate the utilization of aspen in Alberta. The discussion will address the benefits and limitations of using a linear programming model and give a general background for the development of the aspen model.

3.1 Benefits and limitations of linear programming

Linear programming analysis is a mathematical method which can allocate scarce resources among competing processes to obtain optimum effectiveness(Sitter 1969). Practically speaking, the method defines a single identifiable objective in the form of a linear equation, and determines the optimal solution of this objective using input restraints and alternate independent activities (Pearse and Sydneysmith 1966). The final solution gives the optimal use and real values of the resources and activities. An added benefit of linear programming analysis is that it provides information on how the optimum solution will change when input data are varied. Because of the interplay of intermediate products and activities in a complex production situation, optimum allocation of resources and critical points of change are very difficult to evaluate without a linear programming model. Thus, linear programming is an excellent tool in management decision-making.

Another benefit of linear programming analysis is the ability to quickly evaluate many types and sizes of systems once the model is constructed. For instance, the allocation of lumber to different types of resaws in a sawmill could be evaluated and optimized. A complex, integrated operation including pulp mills, sawmills and plywood production could also be analyzed. In either case, the linear programming solution would give the optimal utilization of resources and equipment in the system subject to the given constraints.

Although linear programming analysis is a very helpful tool with a wide variety of applications, there are several limitations to the method. The name itself implies an important limitation. Linear programming deals only with linear relationships. Therefore any activities or restraints with quadratic relationships cannot be evaluated unless they are reduced to a linear form. This factor limits the use of the concepts of probability and economies of scale in linear programming studies. The linear relationships also require that unit prices, production technology and unit costs are fixed.

The computer programs used to solve a linear programming model may also be a limitation. If the computer programs do not allow for integer variables(an extension of the linear programming model), precise results may be more difficult to obtain. The difficulty comes when fractional uses of resources or equipment do not represent practical solutions. For instance, purchasing only 26% of a pulp mill is not feasible.

Finally, the effectiveness of linear programming analysis is probably most limited by the completeness and accuracy of the data input. Linear programming models are used to model and evaluate the essence of a system, not necessarily the reality. In so doing, certain areas of the physical system may not be included in the evaluation. Sometimes the areas that are evaluated tend to be ambiguous, making them difficult to define precisely. Because of these problems, linear programming should be considered a tool in the decision making process, and not a means of providing a definitive answer.

3.2 Background on developing the aspen model

The application of linear programming analysis to the aspen utilization problem has both advantages and disadvantages. One advantage is that this technique has the ability to analyze a wide range of resource and production options when determining the combinatons of most profitable operations. The problem with utilizing aspen in Alberta is not in lack of technical knowledge as much as in finding a combination of production options which are economically feasible. Another advantage of using linear programming analysis is the opportunity to determine the critical points of change, either in costs, prices or production, which will cause processes to be viable or unprofitable. Probably the biggest disadvantage to applying linear programming analysis to aspen utilization is the lack of accurate data. The problem of old resource data has already been noted. Conversion data are also poor in certain areas of production(e.g., sawmills) simply because few people are manufacturing aspen products.

The model used in the analysis is constructed from the viewpoint of a large corporation seeking to diversify into potentially lucrative opportunities. Although modern technology in the forest products field will be employed to utilize aspen in the model, experimental or unproven systems will not be evaluated. Areas of production will include harvesting, hauling, lumber, pulp, plywood, particleboard, and waferboard. The model will describe options which have the potential of using relatively large amounts of the aspen resource. Only those products which have been or are presently being marketed will be included in the linear programming model. Re-manufacturing of the primary product, such as a furniture component plant, will not be considered at this time.

4. THE ASPEN MODEL

The previous chapter contains the description of concepts used to evaluate aspen utilization in Alberta. This chapter contains the specifics of the location, the wood resource, the production options and the products in the aspen reference model[5]. The equations used in the reference model assumed that the physical resources of wood, equipment, capital and labour are available for immediate use and that the construction of mills is instantaneous. All cost figures in the reference model are adjusted to 1980 dollars.

4.1 Location

The area chosen for evaluation of aspen utilization is located near Slave Lake, Alberta. The Slave Lake Forest has one of the highest proportions of aspen cover in all of Alberta's forest reserves(Alberta Energy and Natural Resources 1979). This region has traditionally been a centre for aspen utilization in Alberta having, at one time or another, an aspen stud mill, a veneer mill and a waferboard plant. Although the stud mill no longer exists and the veneer plant uses only a small amount of aspen, a newly expanded waferboard plant utilizes 100% aspen for its boards. Many government research projects on aspen

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[5] The model described in Chapters 4 and 5 will be referred to as the reference model. The optimal solution of the reference model will provide benchmark data for further analysis.

utilization have also been conducted in the Slave Lake area. These studies provided a considerable amount of the information utilized in the model.

4.2 Resource

The resource data used in the model are based upon the Alberta Forest Service(1971) publication "Present and Potential Poplar Utilization in the Province of Alberta." The data in this paper are old but they were the best available. The annual allowable cut of aspen on the Slave Lake Forest is 2,268,000 m³. Fire loss deductions and a twenty-five percent deduction for cull are included in the 2,268,000 m³ figure. However, 350,000 m³ of previously committed timber allocations are not removed from this total.

As shown in Table 6, the forest was divided into 5 harvest areas based upon similar stocking characteristics. The sites are assumed to be made up of 80% trembling aspen and 20% balsam poplar, unless otherwise noted. Costs for sawlogs were $0.47/m³, which included $.25/m³ for the wood and $.22/m³ for reforestation(McDonald 1979). Pulpwood costs are a few cents cheaper, but to simplify the model all logs were considered sawlogs. An extra 7% was added to site volumes to account for the full-tree harvesting option(Keays 1971, Bailey 1973). Stumpage is the same with either option.

TABLE 6

DESCRIPTION OF HARVEST AREAS

Harvest Area	Slave Lake Forest Unit	Area Available (ha)	Stocking (m^3/ha)		Stumpage ($/$ha$)
			TL	FT	
1	S15	1910	73.4	78.5	34.50
2	S1,S4	5853	95.0	101.6	44.65
3	S3,S9,S10	4431	130.0	139.1	61.10
4	S5,S8	3876	161.0	172.3	75.67
5	S6,S12	2089	179.0	191.5	84.13

Note: TL—tree length; FT—full tree.

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4.3 Harvesting

In the harvesting portion of the model, clearcutting is assumed using either manual or mechanical felling with wheeled skidding. Productivity and cost figures for these methods are given in Table 7. The model assumes all harvesting will be done by contract. A recent study by Alberta Energy and Natural Resources(1979) provided data the manual felling and road building costs. Feller-buncher costs are 25% higher than manual felling figures(Ryan 1979). The calculations for the data in Table 7 are found in Appendix 1.

4.4 Tree Size

The Alberta Forest Service(1971) divided the available timber volumes into two size classes by diameter at breast height(DBH). They were a 10.2-22.9 cm(4-9 in) class and a 25.4 cm(10 in) and greater class. One must accept two assumptions before these data can be utilized in the model. The first assumption is that only those trees in the 25.4 cm and greater class will be hauled to the mill. This assumption is erroneous, especially considering that the pulp, particleboard and waferboard mills could utilize smaller trees. However, the lack of better information necessitates this limitation. Secondly, an assumption is made that the 25.4 cm and greater volumes include tree sizes down to 22.9 cm(9 in). This assumption was made for the

TABLE 7

HARVESTING PRODUCTIVITY AND COST

Method	Productivity (m^3/hr)	Cost (\$/hr)
TL Manual	5.66	87.22
TL Mechanical	2.80	53.94
FT Manual	8.41	129.60
FT Mechanical	4.36	83.98

Note: TL--tree length; FT--full tree

simplicity of applying the rough diameter distributions obtained by Bailey and Dobie(1977) to the available data. Size class distributions are shown in Appendix 2.

4.5 Hauling

Average hauling distance from the harvest sites to the town of Slave Lake is 145 km(90 mi) return(Alberta Energy and Natural Resources 1979). The common hauling practice in Alberta is either tree-length or full-tree. Tree-length hauling costs totalled \$3.52/m^3. An assumption is made that full-tree hauling would add 10% to the tree-length cost, making the cost for full-tree hauling \$3.87/m^3. Calculations for these costs are found in Appendix 3.

4.6 Processing

All mills are assumed to be located near the town of Slave Lake. Ample industrial property is available in the area for approximately \$4942/ha(\$2000/A)(Holtby 1981). Five different configurations of processing facilities are included in the evaluation. The five were chosen because of their potential to use relatively large quantities of aspen. The facilities included are:

1. four sawmills,
2. a pulp mill,
3. a particleboard mill,
4. a plywood mill, and

5. a waferboard mill.

4.6.1 Sawmills

The model includes the option of a scrag mill or a twin band mill to produce both factory and construction lumber products. Factory lumber is used in items such as furniture and is graded by hardwood lumber standards. Construction lumber, on the other hand, is graded on softwood structural building standards. Table 8 describes the different assumptions of each mill. The scrag sawmill and twin band sawmill were used in the model because pertinent data were available for utilizing aspen in these systems. Studies by Leach and Gillies(1972), Bailey and Dobie(1977), and Boywer(1974) used 2.54 m(100 in) sawlogs to reduce cull but related lumber recovery to tree DBH rather than sawlog size. The sawmills in the model, therefore, produce 2.44 m(8 ft) lumber and base lumber conversion factors on DBH classes. Appendix 4 includes an elaboration on the mills and their products.

4.6.2 Pulp mill

Market pulp production in the model uses the chemi-mechanical process. Production and cost data for the pulp operation were obtained from Woodbridge Reed and Associates(1981). The mill has a capacity of 425 air dry metric ton(admt) per day utilizing a mixture of 50% aspen and 50% spruce. Woodbridge *et.al.*(1981) provided the

TABLE 8

DESCRIPTION OF THE SAWMILLS

Mill Name	Equipment	Products	Average Lumber Recovery (%)	Capacity	
				(m^3)	(MMfbm)
Stud	2-saw scrag, chipping edger	studs, boards	57.0	42250	18.0
Dim.	2-saw scrag, chipping edger	dimension, boards	57.0	42250	18.0
Board	2-saw scrag, chipping edger	factory lumber	47.5	38000	16.
Twin	twin band, 2 vertical resaws	factory lumber	45.8	45312	19

Note: Lumber recovery percentages converted to lumber recovery factors are: 57% = 6.8 fbm/ft^3, 47.5% = 5.7 fbm/ft^3 and 45.8% = 5.5 fbm/ft^3.

production and cost data for the model. Chips are available for pulping from both roundwood and sawmill or plywood residue. The spruce chip component is purchased at $35/bone dry unit(BDU). The pulp yield of aspen is only 31.45% due to the high quality of chips required by the process. Total capital cost of the mill is over $100 million with operating costs of $170.50/admt. A further breakdown of pulping figures is included in Appendix 5.

4.6.3 Particleboard mill

Particleboard production in the model is based upon the mill described by Bowyer(1974). The operation has an annual capacity of 100,359 m^3(56.7 MMsf, 3/8-inch basis). The mill converts 78.9% of the raw material input into a three-layer board with a density of 640 kg/m^3(40 lbs/ft^3). Chips are again available from roundwood and mill residue. Four board thicknesses from 9 mm(3/8 in) to 19 mm(3/4 in) were arbitrarily chosen for production sizes. A product mix was not specified, thus allowing the model to choose the most profitable thickness. The particleboard cost data are outlined in Appendix 8.

4.6.4 Waferboard mill

Waferboard production and cost information was obtained from Columbia Engineering International Ltd.(1981). The mill has an annual capacity of 141,600 m^3(160 MMsf,3/8-inch basis) using a 2.44 m(8 ft) by 4.88 m(16 ft) twelve opening press. The assumption was made that wafers are generated only from roundwood. Five different thicknesses of waferboard were arbitrarily chosen to describe options for production. The capital cost of the operation exceeds \$37.5 million, with operating costs of \$76.55/m^3. Appendix 6 shows the details of the waferboard costs and conversion factors.

4.6.5 Plywood mill

The equations to describe the production of aspen plywood were not as straightforward as those for the other mills. Conversion data for specific log sizes were available in Boywer(1974) but resource information refers to only tree sizes by DBH class. Using data from Leach and Gillies(1972), Bailey(1973) and Bailey and Dobie(1977), a log mix was derived for the various tree class sizes(see Appendix 7). A summary of this mix is found in Table 9. Cull material is chipped for pulp or particleboard production at a cost of \$7.94/m^3(see Appendix 5). Bowyer's(1974) technique was then utilized to determine the volume of dry veneer, core, drying loss and rounding and trimming for the different log classes shown in Table 10 and developed in Appendix 7. Capital and manufacturing costs of the 27,450 m^3/yr plywood operation were also obtained from Bowyer(1974).

TABLE 9

SUMMARY OF PLYWOOD LOG MIX

Tree Size Class (cm)	Percent Of Log Sizes				
	20 cm	28 cm	36 cm	43 cm	Cull
23	25.00	. . .	. . .	. . .	. . .
30	37.50	18.75	. . .	. . .	43.75
38	44.40	33.30	16.60	. . .	5.70
46	10.00	40.00	35.00	15.00	0.00

TABLE 10

BREAKDOWN OF PLYWOOD LOGS

Log Size (cm)	Dry Veneer ($)	Core ($)	Rounding and Trim ($)	Drying ($)
20	43	27	19	11
28	49	15	25	11
36	53	9	27	11
43	55	6	28	11

4.7 Chips and residue

The chip and residue component of production is handled in a number of different ways. Chips are generated from lumber production, plywood production or from roundwood. The chips produced at the sawmills and plywood facility can be utilized for pulp and particleboard at zero cost. An assumption was made that other chip markets are not presently available. Except for the waferboard operation, the mills in the model do not generate any of their own energy requirements from hogfuel, plywood trim or rounding material[6]. All mills, however, were assumed to utilize only barked wood. Market prices were obtained for hogfuel and plywood residue in order to quantify the amount of this material in the optimal solution. The hogfuel price is \$6.11/m³ and the plywood trim and rounding material price is \$8.14/m³(Columbia Engineering International Ltd. 1981).

4.8 Products and prices

Some of the products which can be manufactured in the model have already been listed in the individual mill discussions. A complete list of potential products and their prices is found in Table 11. The stud and dimension prices shown were obtained by subtracting \$10.00/Mfbm from the **Madison's Canadian Lumber Reporter**(Friesen 1981) for

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[6] Although plywood trim and rounding residue can be used in particleboard furnish, this material is not made available for that use in order to simplify the model.

TABLE 11

PRODUCT OPTIONS AND PRICES USED IN REFERENCE MODEL

Mill	Product Grade or Thickness	Price
stud	studs	$149.00/Mfbm
	econ. stud	85.00
stud and dimension	select board	$305.00/Mfbm
	const. board	200.00
	std. board	195.00
	util. board	120.00
	econ. board	85.00
dimension	construction	$152.00/Mfbm
	standard	152.00
	utility	103.00
	economy	85.00
twin and board	#1&BTR board	$425.00/Mfbm
	#2A board	200.00
	#2B board	200.00
	#3 board	150.00
pulp	pulp	$510.00/admt
particleboard	9 mm	\$229.32/m^3
	13 mm	211.86
	16 mm	211.86
	19 mm	203.04
waferboard	6 mm	\$317.80/m^3
	8 mm	296.61
	9 mm	264.83
	11 mm	248.18
	16 mm T&G	296.02
plywood	6 mm	\$557.94/m^3
	13 mm	337.46
	19 mm	284.04

spruce-pine-fir. The $10.00 discount is a measure of market reluctance to use aspen lumber when compared to alternatives(Karim 1981). Prices on factory lumber were obtained from Nielson(1979). The pulp price came from Woodbridge *et.al.* (1981). MacMillian Bloedel Building Materials Ltd.(1981) supplied the waferboard and particleboard prices, and plywood prices were obtained through reducing retail prices(University of Alberta 1981) by 12%.

4.9 Capital and operating costs

In order to analyze the optimum combination of activities for harvesting, milling and marketing aspen, financial requirements were not limited. All operating costs are deducted from the profit as they occur; however, 24% interest is charged for the use of the money. Likewise, depreciation is deducted when mills are utilized, and 12% interest is charged on capital purchases.

5. THE LINEAR PROGRAMMING MATRIX

The content of this chapter outlines the arrangement of the information discussed in Chapter 4 into a linear programming matrix format. The matrix will be referred to as the reference matrix. The optimal solution of the matrix will yield baseline data for sensitivity analysis of the model. The reference matrix consists of the linear objective function plus a set of constraining equations. The constraining equations define the limits and inter-relationships of the variables in the objective function. The matrix can be separated into the general sections of harvesting, milling, marketing and resource limits, as illustrated in Figure 2. The complete matrix is found in Appendix 9.

5.1 The objective function

The objective function in the aspen reference matrix calculates net profit. The function evaluates 127 variables and their associated coefficients. Variables indicate the level of use of a paticular activity. The associated coefficients take into account costs in the harvesting and milling sections and the returns on various products in the marketing section.

$$Z_{max} = Hw + My + Sx$$

subject to:

$$\begin{array}{lllll} Aw & & & = & R_1 \\ Bw & Cy & & = & R_2 \\ & Dy & Ex & = & 0 \end{array}$$

where:

Z_{max} = the objective function to be maximized.

H = row vector of coefficients associated with the cost of harvesting(1 X 56).

M = row vector of coefficients associated with the cost of milling(1 X 31).

S = row vector of coefficients associated with the returns of marketing(1 X 39).

w = column vector of harvesting variables(38 X 1).

y = column vector of milling variables(68 X 1).

x = column vector of marketing variables(29 X 1).

A = matrix of harvesting coefficients(24 X 30).

B = matrix of production coefficients(14 X 26).

C = matrix of wood requirement coefficients for mills(39 X 31).

D = matrix of coefficients for product output(29 X 8).

E = matrix of coefficients to market products(29 X 39).

R_1 = column vector of resource limitations on harvesting(24 X 1).

R_2 = column vector of resource limitations on milling(39 X 1).

Figure 2. General equations of model matrix

5.2 Harvesting section

The harvesting section of the reference matrix contains resource limitations, available felling options and hauling variables.

5.2.1 Resource limitations

Ten variables in the matrix deal with the aspen resource in the Slave Lake Forest. Although only five potential harvest areas are available in the model, ten variables are necessary to define stand volumes using tree-length or full-tree harvesting methods. The units of the resource variables are hectares. Stand volumes on each area are shown in Table 6.

The resource variables are limited in two ways. The first limits the number of hectares that can be harvested in each area. The second limits the volume removed from the whole forest by the annual allowable cut. The allowable cut from the individual harvest areas is determined using tree-length volumes. The extra volume associated with full-tree harvesting is included when volumes are transferred to the felling options.

5.2.2 Felling options

The volume of trees from the harvest areas is transferred to the felling variables through transfer equations. Four felling variables are needed for each harvest area. Two of the variables represent tree-length felling. The other two represent full-tree felling. Felling productivity coefficients(Table 7) convert tree volumes into the felling variable units(hours). Felling costs are deducted from the objective function as a specific variable is utilized.

The equations used to transfer quantities out of the felling variables perform two functions. The first function uses conversion figures to calculate tree volumes(m^3). Secondly, tree size classes are delinated by utilizing an equation for each size class. An explanation of the method used to determine these transfer coefficients is found in Appendix 2.

5.2.3 Hauling

Tree volumes are transferred from the felling variables into hauling variables utilizing eight equations. These equations account for four tree size classes and keep tree-length and full-tree volumes distinct. There are a total of twenty-six hauling variables. The function of these variables is to calculate tree volumes that could be utilized at the different mills. A small percentage of the tree volume transferred into all hauling variables is subsequently transferred to a variable which accounts for tree bark. The full-tree volumes also have a branch and top percentage removed. The remaining percentage of tree volume is transferred to the milling section.

In the sawmill and plywood hauling variables, the integrity of tree sizes was maintained to account for recovery differences with respect to size class. Usable tree volumes in the chip hauling variables were transferred to the pulp and particleboard mills. The volumes of wood transferred to the waferboard mill were converted directly into waferboard by the hauling variable coefficients. The treatment of tree volumes in the hauling variables are calculated for sawmills, chips, waferboard and plywood in Appendicies 4, 5, 6 and 7, respectively.

5.3 Milling section

The variables in the milling section of the reference matrix represent the various processing facilities available to the hypothetical firm. The milling variables take into account conversion factors, operating costs, capital costs and depreciation.

5.3.1 Lumber, pulp, particleboard and waferboard production

The arrangement of the variables representing the sawmills, pulp mill, particleboard mill and waferboard mill is similar. Two variables are used for each mill. The stud sawmill variables will illustrate the function of the two variables. Tree volumes separated by size class are transferred into the first stud mill variable from the hauling variables. The coefficients of these transfer equations in the stud mill column are lumber recovery figures. Operating costs are deducted from the objective function as the first stud mill variable is utilized.

The volume of lumber manufactured is then transferred to the second stud mill variable. This variable represents the fixed cost portion of the sawmill. Deductions for depreciation are taken from the objective function and capital to build the mill is transferred from the stud capital-lending variable. The volume of lumber according to grade(see Appendix 4) is subsequently transferred to the marketing section.

5.3.2 Plywood production

The modelling of the plywood mill required five variables. Veneer recovery varies with log size. Because the hauled material is designated by DBH class, additional transfer equations were necessary to represent the separation of tree volumes into log size classes, as seen in Appendix 7. The volume of logs in each class is subsequently transferred into four variables which account for plywood production. Operating costs are deducted by these variables. The plywood manufactured is then transferred to a single variable which is used to calculate the depreciation, the amount of capital required to buy the mill and the volume of plywood available to the marketing section.

5.3.3 Other activities

The milling section of the matrix also includes variables representing the volume of chips, the quantity of money borrowed and tax and advertising costs. The chip variables represent the volume of chips resulting from the chipping of log-ends in plywood log production. The chips can be utilized for pulp and particleboard production or they can be sold on the open market. The money variables deduct interest charges from the objective function for both operating and capital costs. The tax and advertising variables are used to deduct 2.75% of the value of gross sales from the revenue to pay property taxes and advertising costs.

5.4 Marketing section

The marketing section of the matrix calculates the revenue in the model. The variables in this section represent eleven grades of construction lumber, four grades of factory lumber, market pulp, four thicknesses of particleboard, five thicknesses of waferboard, three thicknesses of plywood, chips, hogfuel and plywood trimming and rounding residue. Sawmill variables transfer a prescribed grade mix into the lumber marketing variables utilizing a number of transfer equations. The volume of particleboard produced is transferred by one equation. This volume can be utilized by any of the four particleboard thickness variables which results in the most profitable product mix. The transfer of waferboard and plywood production to the marketing section is modelled in the same manner. The hogfuel and trimming and rounding variables were included for reference purposes only.

5.5 Resource limitations

The resource limitations section defines the variable limits in the reference matrix. Most coefficients in this section are zero because many equations are transfer equations. A balance equation is used to transfer values from one variable to another. For instance, the transfer equation from the variable representing particleboard production(PARTMIL) to the variable representing capacity of the particleboard mill(PARTCAP) is:

$$-0.789 \times PARTMIL + 1.0 \times PARTCAP \leq 0$$

For this equation to be true, the activity level of the PARTMIL variable(i.e. m^3 of production) must be matched with the activity level of the PARTCAP variable(i.e. m^3 of plant capacity).

The equations that have non-zero coefficients represent physical resource limits. The equations limit annual allowable cut, land area available for harvest and production facility capacities. These resource limits are shown in Table 12.

TABLE 12

UPPER LIMITS ON ACTIVITIES IN THE MATRIX

Activity	Limit
annual allowable cut	2,268,000 m^3
harvest area 1	1,910 ha
harvest area 2	5,853 ha
harvest area 3	4,431 ha
harvest area 4	3,876 ha
harvest area 5	2,089 ha
stud and dimension sawmill	42,250 m^3
twin sawmill	45,312 m^3
board sawmill	38,000 m^3
pulp mill	157,500 admt
particleboard mill	100,539 m^3
waferboard mill	141,600 m^3
plywood mill	27,450 m^3

6. RESULTS OF THE ANALYSIS

The optimal solution of the aspen reference model was found using the linear programming package[7] on the Amdal 470 v/8 computer at the University of Alberta. Various techniques of sensitivity analysis were subsequently utilized on the reference matrix to demonstrate the effect of model variation.

6.1 The optimal solution of the reference matrix

The optimal solution using the coefficients in the reference matrix shows that a net profit of nearly $25.0 million would be realized. Operating expenses would total $49.2 million and capital costs would be $55.6 million. The profit was derived from selling lumber, particleboard, waferboard and plywood. Table 13 gives the summary of major solution variables. The complete solution is found in Appendix 10.

6.1.1 Harvesting results

A total of 937,062 m^3 of aspen would be harvested annually using activities in the optimal solution. This amounts to 41% of the deciduous allowable cut on the Slave Lake Forest. The model utilized all the land available in harvest area 5 and ninety percent of the land in harvest

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[7] The Mathmatical Programming System/360(360A-CO-14X) Linear and Separable Programming package supplied by International Business Machines Corporation was used to solve the matrix.

TABLE 13

OPTIMUM SOLUTION OF REFERENCE MODEL

Model Variable		Limit of Utilization	Activity Level
Z_{max}($)		...	24,952,490
operating cost($)		...	48,360,606
capital cost($)		...	55,585,223
harvesting	**area 1**(*ha*)	1,910	...
	area 2(*ha*)	5,853	...
	area 3(*ha*)	4,431	...
	area 4(*ha*)	3,876	3,496
	area 5(*ha*)	2,089	2,089
hauling	**sawlogs**(m^3)	...	218,067
	chips(m^3)	...	...
	waferboard(m^3)	...	342,615
	plywood(m^3)	...	64,880
mills	**stud**(m^3)	42,250	42,250
	dimension(m^3)	42,250	...
	twin(m^3)	45,312	...
	board(m^3)	38,000	38,000
	pulp(*admt*)	157,500	...
	particleboard(m^3)	100,359	100,359
	waferboard(m^3)	141,600	141,600
	plywood(m^3)	27,450	27,450

area 4. Tree-length and full-tree harvesting methods are employed using manual labour for felling. The sawmill and plywood mill receive both tree-length and full-tree material. The waferboard mill uses only the full-tree component. Roundwood is not chipped. Eighty-seven percent of the wood directed to the plywood mill is in the 46 cm DBH size class.

6.1.2 Mill utilization and products

The optimal solution includes variables representing two sawmills, the particleboard mill, the waferboard mill and the plywood mill. All mills operate at 100% capacity. The chips required for particleboard production come from the sawmills and plywood mill. The products sold by the mills include construction and factory lumber, 9 mm(3/8 in) sheets of particleboard and 6 mm(1/4 in) thicknesses of waferboard and plywood. Table 14 shows the quantity of products which were manufactured. The volume of residue generated by the model totalled 6,146 m³ of hogfuel and 13,833 m³ of plywood trim and rounding.

6.2 Variations in harvesting

Sensitivity analysis in the harvesting section of the model concentrated on the variables associated with the wood resource and harvesting methods. The effects of stand variation on the optimal solution were analyzed and the

TABLE 14

PRODUCTS IN OPTIMAL SOLUTION OF REFERENCE MODEL

Product	Grade or Thickness	Production
construction lumber (boards)	select	901 Mfbm
	construction	382
	standard	546
	utility	355
	economy	27
construction lumber (studs)	stud	21,767 Mfbm
	economy stud	3,359
factory lumber	#1&BTR	3,270 Mfbm
	#2A	4,088
	#2B	4,088
	#3	4,905
particleboard	9 mm	100,359 m^3
waferboard	6 mm	141,600 m^3
plywood	6 mm	27,450 m^3

critical costs of harvesting methods on area 5 were identified.

6.2.1 The resource

The aspen stand data used in the reference model are evauated in this section. The cost of aspen stumpage accounts for less than 1% of the total operating cost of the optimal solution. Variation of these costs in the model would provide little relevant information on aspen utilization. The assumption that all stands contain the same mix of tree sizes effectively eliminates the significance of varying volume statistics on the harvest areas. Increasing or decreasing the volume stand statistics areas will cause the model to choose the areas with the highest stand volumes. However, the effect of tree size on the optimal solution can be evaluated by changing the DBH size distributions.

The tree size distributions in the reference model were varied in two ways. The DBH size mix of the reference model has almost one-half of the volume of the stands in trees 38 cm and greater. Only 14.9% of the volume is assumed to be in the 23 cm DBH class. The first variation of the model changed the mix on area 5 to forty percent of the volume in the 23 cm class, thirty-five percent in the 30 cm class, fifteen percent in the 38 cm and ten percent in the 46 cm class. The tree size mix was not altered on any of the other harvest areas. The second variation changed the DBH classes in areas 4 and 5 to the 40/35/15/10 mix.

The effects of the mix variations on the optimal solution of the reference matrix are tabulated in Table 15. In variation 1, the mix changes did not effect the optimal mill production of the reference model. The new size class mix on area 5 caused the harvesting of six more hectares of area 4 and some distribution changes of tree sizes and volumes delivered to the mills. The optimal solution of the reference matrix was further altered in variation 2 where tree sizes on areas 4 and 5 were adjusted. Mill production included all the mills of the reference solution, but the stud mill ran at 92% of capacity instead of the 100% capacity utilized in the optimal solution. The number of hectares harvested on area 4 was reduced and 1098 hectares of area 2 was cut. The hauling statistics indicate that the tree volumes used by the different mills changed as tree size mix changed.

The conclusion from evaluating size class variation is that size class distribution has little effect on production. The reason for this lies in the integrated system of mills. Various tree sizes can be brought into the facility and distributed in an optimal fashion to the mills. Therefore, sufficient volumes of trees are more critical to aspen utilization than tree size.

TABLE 15

VARYING TREE SIZE DISTRIBUTION IN THE REFERENCE MODEL

	Model Variable	Reference Matrix	Variation 1	Variation 2
Z_{max} ($)		24,952,490	24,917,680	24,714,596
harvesting	area 2(*ha*)	...	...	1,098
	area 4(*ha*)	3,496	3,502	2,851
	area 5(*ha*)	2,089	2,089	2,089
hauling	sawlogs(m^3)	218,067	217,382	208,131
	waferboard(m^3)	342,615	344,306	345,928
	plywood(m^3)	64,880	64,676	69,561
mills	stud(m^3)	42,250	42,250	38,771
	board(m^3)	38,000	38,000	38,000
	particleboard(m^3)	100,359	100,359	100,359
	waferboard(m^3)	141,600	141,600	141,600
	plywood(m^3)	27,450	27,450	27,450

6.2.2 Harvesting methods

Harvesting methods can be evaluated in the model using the range report. The optimal solution of the reference matrix utilizes the full-tree, manual felling option for harvesting area 5. Tree-length harvesting would be employed on this area if full-tree harvesting costs would increase by $0.50/hr. A lowering of the cost of tree-length, manual harvesting from $87.22/hr to $86.71/hr would produce the same change. Switching from manual to mechanical methods of harvesting would require full-tree, mechanical harvesting costs to drop from $83.98/hr to $63.13/hr. Changing to strictly tree-length harvesting would not add significantly to the cost of harvesting aspen, but a switch to mechanical felling would have a significant cost impact.

6.3 Variation of the mills

The sensitivity of the reference model to changes in mill cost is examined in this section.

6.3.1 Mill operating costs

The effect of increased operating costs for a mill in the reference model can be evaluated using the range report. The report shows the highest operating cost a mill can have before the variables in the optimal solution will change. Table 16 records the critical upper costs for the mills. An operating cost increase of $\$5.00/\text{m}^3$ produced at the stud

TABLE 16

UPPER LIMIT OF MILL OPERATING COSTS BEFORE SOLUTION CHANGE

Mill	Operating Cost($/m^3)	
	reference model	upper limit
stud	15.33	20.23
board	17.06	52.13
particleboard	52.33	105.89
waferboard	76.55	135.62
plywood 1	49.08	64.31
plywood 2	55.92	118.15
plywood 3	60.49	69.01
plywood 4	62.77	69.94

sawmill will cause the dimension sawmill to enter the solution. The board mill ceases production when costs escalate to \$52.13/m^3 and the particleboard operation is profitable up to an operating cost of \$105.89. The operating cost of the waferboard mill can increase over \$59.00/m^3 produced before waferboard will no longer be manufactured in the reference model. Production of waferboard will decrease at a rate of 788 m^3 per dollar as this cost increases. The cost figures for the plywood mills give an indication of relative sensitivity of the model to bolt size. Trees will be hauled for chips when the cost of veneer production from 28 cm bolts increases to \$64.31/m^3. The type and size of trees delivered to plywood mills 2,3 and 4 are changed when the upper cost limits are attained in these operations. With the exception of the stud sawmill and plywood mills 3 and 4, the operating costs of mills in the optimal solution could increase \$15.00/unit and not effect the mill combination in the optimal solution.

6.3.2 Realignment of mill operating and capital costs

The selection process of mill variables in the optimal solution of the reference matrix first chooses the mill operating cost variable. The capital cost variable enters the solution immediately after the operating cost variable. Under this system, the model calculates capital costs for only the mill capacity needed to support production levels(i.e. the model assumes linear relations between mill cost and capacity). This was not a problem in the optimal solution of the reference model because all mills operated at full capacity. The analysis of this section utilized separable programming to alter the pulp and particleboard mills. These changes described the situation where a mill of specified capacity must be built before production would begin.

Four evaluations of the altered matrix were conducted. The first run allowed the model to find the optimal solution utilizing any combination of mills. The second evaluation forced the model to include the pulp mill, but did not require the production of pulp. Similarly, the particleboard mill was forced into the solution in the third run. The fourth evaluation forced the model to include both the pulp mill and the particleboard mill in the solution. The results of the evaluation are shown in Table 17.

The results of the first evaluation showed that neither the pulp mill nor the particleboard mill entered the solution. These results contradict the optimal solution of the reference matrix where the particleboard mill operates at full capacity. The reason for this problem orginates in the mathematical procedures utilized to solve linear programming. These procedures can generate erroneous data because a local optimum. The results of the first analysis are due to a local optimum.

The second and third analyses show profitable operations when either the pulp mill or the particleboard

TABLE 17

SEPERABLE PROGRAMMING OF PULP AND PARTICLEBOARD PRODUCTION IN MODEL

	Model Variable	Mill forced into Solution			
		none	pulp	particlebd	both
Z_{max}($)		16,109,106	6,674,818	27,212,617	-4,209,273
harvesting	area 2(*ha*)	...	5,853	...	...
	area 3(*ha*)	...	1,355	...	...
	area 4(*ha*)	1,308	3,876	3,498	3,502
	area 5(*ha*)	2,089	2,089	2,089	2,089
hauling	sawlogs(m^3)	...	215,376	218,025	217,970
	chips(m^3)	...	470,215	...	...
	waferboard(m^3)	342,813	338,245	342,608	342,599
	plywood(m^3)	60,761	91,383	65,150	65,483
mills	stud(m^3)	...	42,250	42,250	42,250
	board(m^3)	...	38,000	38,000	38,000
	pulp(*admt*)	...	157,500	...	100
	particleboard(m^3)	...	...	100,359	100,359
	waferboard(m^3)	141,600	141,600	141,600	141,600
	plywood(m^3)	27,450	27,450	27,450	27,450

mill is forced into the solution. In both cases, the optimal solution builds the mill and operates it at full capacity. The $20.0 million difference in profit between runs two and three clearly shows the advantage of operating an aspen particleboard mill rather than a pulp mill. A loss of $5.3 million occurs when both mills are forced to be built. The loss is incurred because a large capital investment for the pulp mill must be made even though it is not profitable.

The conclusion to the realignments analysis indicates that either a pulp or particleboard mill could operate profitably in an integrated aspen facility. The facility with a particleboard mill is considerably more profitable than one with a pulp mill. An aspen utilization facility could not operate with both a pulp and particleboard mill.

6.4 Variation of product prices

The effect of product price change on the optimal solution of the aspen model is evaluated in this section.

6.4.1 Particleboard, waferboard and plywood variation

Particleboard prices, waferboard prices and plywood prices were varied using parametric programming techniques. The price of particleboard was lowered to $\$129.32/m^3$. Waferboard and plywood prices were reduced to $\$217.80/m^3$ and $\$235.94/m^3$, respectively. Optimal solutions were calculated as product prices were incremented by $25.00 and other model coefficients remained constant. This was done in order to determine when production of the product became profitable. Another analysis evaluated the interaction between the three products by incrementing their prices simultaneously.

The first evaluation analyzed particleboard prices, as summarized in Table 18. The particleboard mill cannot operate at a profit when the product price is \$129.32/m³. When the price of particleboard is incremented to \$154.32/m³, the particleboard mill and stud mill enter the solution and operate at full capacity. Table 19 records the critical prices for waferboard production. The mill operates at 26% of its capacity when the selling price of waferboard is \$242.80/m³. The waferboard mill runs at full capacity when the waferboard price is \$292.80/m³. Similarly, the plywood mill enters the optimal solution at \$260.94/m³, but does not reach full mill capacity until the price is \$285.94/m³, as seen in Table 20.

The final price evaluation using parametic procedures simultaneously incremented the particleboard, waferboard and plywood prices. Particleboard prices started at \$104.32/m³, waferboard prices at \$192.80/m³ and plywood prices at \$235.94/m³. The results of the analysis show that aspen utilization is not profitable at the starting prices(Table 21). The first increment of \$25.00/m³ caused the board sawmill, the pulp mill and the plywood mill to enter the solution. The chips produced from the manufacturing of lumber and plywood are sufficient for the pulp mill to

TABLE 18

EFFECT OF PARTICLEBOARD PRICE VARIATION ON THE OPTIMAL SOLUTION

Model Variable		Particleboard Price($/m^3$)	
		129.32	154.32
Z_{max} ($)		18,786,774	20,543,997
harvesting	area 4 (*ha*)	2,226	3,496
	area 5 (*ha*)	2,089	2,089
hauling	sawlogs (m^3)	93,849	218,067
	waferboard (m^3)	342,717	342,615
	plywood (m^3)	60,761	64,880
mills	stud (m^3)	...	42,250
	board (m^3)	38,000	38,000
	pulp (*admt*)	19,499	...
	particleboard (m^3)	...	100,359
	waferboar[illegible]^3)	141,600	141,600
	plywood ([illegible])	27,450	27,450

TABLE 19

EFFECT OF WAFERBOARD PRICE VARIATION ON THE OPTIMAL SOLUTION

	Model Variable	Waferboard Price($/$m^3$)		
		217.80	242.80	292.80
Z_{max} ($)		17,809,461	17,944,621	24,530,922
harvesting	area 4(*ha*)	32	1,119	3,496
	area 5(*ha*)	2,089	2,089	2,089
hauling	sawlogs(m^3)	150,514	218,996	218,067
	chips(m^3)	15,200	...	...
	waferboard(m^3)	...	90,034	342,615
	plywood(m^3)	85,863	64,650	64,880
mills	stud(m^3)	20,013	41,789	42,250
	board(m^3)	38,000	38,000	38,000
	particleboard(m^3)	100,359	100,359	100,359
	waferboard(m^3)	...	37,084	141,600
	plywood(m^3)	27,450	27,450	27,450

TABLE 20

EFFECT OF PLYWOOD PRICE VARIATION ON THE OPTIMAL SOLUTION

Model	Variable	Plywood Price($/$m^3$)		
		235.94	260.94	285.94
Z_{max} ($)		19,951,651	20,033,620	20,604,522
harvesting	area 4(*ha*)	3,007	3,085	3,496
	area 5(*ha*)	2,089	2,089	2,089
hauling	sawlogs(m^3)	218,722	217,111	218,067
	chips(m^3)	14,802	...	...
	waferboard(m^3)	341,483	341,630	342,615
	plywood(m^3)	...	20,793	64,880
mills	stud(m^3)	42,250	42,250	42,250
	board(m^3)	38,000	38,000	38,000
	particleboard(m^3)	100,359	100,359	100,359
	waferboard(m^3)	141,600	141,600	141,600
	plywood(m^3)	...	4,847	27,450

TABLE 21

PARTICLEBOARD, WAFERBOARD AND PLYWOOD PRICE VARIATION IN THE REFERENCE MODEL

	Model Variable	Initial Price	Increment 1	Increment 2
Z_{max} (\$)		...	206,976	2,951,297
harvesting	area 4 (*ha*)	...	...	1,119
	area 5 (*ha*)	...	1,373	2,089
hauling	sawlogs (m^3)	...	92,141	218,996
	waferboard (m^3)	...	...	90,034
	plywood (m^3)	...	70,081	64,650
mills	stud (m^3)	...	...	41,789
	board (m^3)	...	38,000	38,000
	pulp (*admt*)	...	25,394	...
	particleboard (m^3)	...	...	100,359
	waferboard (m^3)	...	...	37,084
	plywood (m^3)	...	22,652	27,450

Note: Initial price was particleboard = \$104.32/m^3, waferboard = \$192.80/m^3 and plywood = \$235.94/m^3. Prices were incremented in \$25.00 units.

operate at 16% of capacity. The next price increment brings the stud mill, the particleboard mill and the waferboard mill into the solution. The pulp mill is no longer profitable at this increment. Further increments of prices do not alter the solution.

Analysis of price variation revealed additional information on aspen utilization besides critical production price data. The final analysis illustrates that aspen utilization can only be profitable with an integrated system of mills. The minimum number of mills appears to be three, as shown in Table 21, when the plywood, pulp and board mills are in the solution. Another interesting point is that plywood production becomes profitable at a lower price in the final analysis than when prices are individually incremented. This is due to the lack of competition for tree volumes in the final analysis. The profitable operation of the stud mill is directly linked to the utilization of stud chips in the particleboard mill. This is illustrated in Tables 18 and 21 by the stud mill entering the solution when the particleboard operation became profitable. Likewise, in Table 20, chips from the manufacture of plywood replace the chips produced from roundwood when plywood production is profitable.

6.4.2 Chip, pulp and stud prices

The effects of changes in the price of chips, pulp and studs were evaluated using a range report. Chips in the reference model have the option of being utilized in the pulp mill and the particleboard mill or being sold on the open market. The optimal solution showed that all chips would be used in particleboard production. The market price for chips needs to be at a minimum of $114.00/BDU before chips could be sold at a profit. The high price of market chips indicates the value of these chips within the model. The price for pulp must increase from $510.00/admt to $564.43/admt before pulp production becomes profitable. Stud prices can drop only $9.52/Mfbm to $139.48/Mfbm before dimension lumber becomes more profitable to produce. This shows that an aspen sawmill producing studs should have the flexibility to move into the dimension lumber market.

7. SUMMARY AND RECOMMENDATION

The forest resource in Alberta contains 680 MMm³ of deciduous, merchantable timber. Although the net annual allowable cut for this timber is 11.7 MMm³, only 1% of this amount is utilized every year. This study showed that the utilization of Alberta's untapped deciduous resource is both possible and profitable.

7.1 Summary

The aspen utilization model developed in this analysis showed that an integrated system of mills is necessary to use aspen. The optimal system includes sawmill, particleboard, waferboard and plywood facilities. The model showed tree-length harvesting of aspen does not have a significant cost difference from the full-tree method. However, a switch from manual felling to mechanical methods would greatly affect harvesting cost. The volume of aspen in a stand was determined to be more critical to utilization than the tree size distribution. This is due to the ability of the integrated system to optimally direct incoming tree volumes to the different mills. Maximum profit is attained in the model when chip residue can be utilized. Either a particleboard mill or pulp mill can be used in this regard, but the particleboard mill is more profitable. The analysis also showed that sawmills must be versatile in their ability to meet market demands.

7.2 Recommendation for validation

The conclusions derived from this analysis are based upon the assumptions and the data used in the model. The results could vary significantly when either the assumptions or the data are altered. The sensitivity analysis performed in the study illustrated the procedure that would be used to validate other groups of coefficients in the model.

This analysis identified three areas of evaluation which need further study. The first area deals with the aspen resource data. Accurate information needs to be obtained on stand volumes, tree sizes and decay percentages. The analysis showed that total harvest area volume was more important than tree size. However, both volume and tree size information is critical to utilization. The amount of decay will also have an effect on product conversion factors, particularly plywood. The second area of evaluation is that of mill data. Current mill costs and utilization techniques need to be applied to the aspen utilization problem. Other types of processing mills should also be introduced. Finally, cost and productivity data for harvesting and hauling of aspen need to be evaluated and validated.

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APPENDIX 1. HARVESTING APPENDIX

The harvesting appendix is divided into two sections which include felling and skidding productivity and harvesting costs.

A. Felling and skidding productivity

The harvesting options in the model include the methods of tree-length or full-tree harvesting. The trees were all skidded by wheeled skidder. Productivity data for tree-length harvesting using a three-man crew were taken from Leech and Gillies(1972). The productivity of full-tree harvesting with a three-man crew was derived by increasing the tree-length productivity figure by 67%. This increase was based on the differences between tree-length and full-tree productivity in the Hinton, Alberta area(Ryan 1979). Productivity data for mechanical felling were obtained from the Canadian Pulp and Paper Association(1979, 1980). Tree-length figures are taken from the 1980 publication, whereas full-tree data was calculated by averaging the data from both years. The average was used because data varied so widely between publications. Table 22 outlines harvesting productivity.

B. Harvesting costs

As calculated in Table 23, manual harvesting costs totalled $15.41/m³. Mechanical harvesting costs are 25%

TABLE 22

PRODUCTIVITY OF HARVESTING METHODS

Method	Productivity	
	cunits/hr	m^3/hr
TL manual	2.00*	5.66
FT manual	2.97*	8.41
TL mechanical	0.99	2.80
FT mechanical	1.54	4.36

Note: TL--tree length;FT--full tree

*Assumed 3-man crew

TABLE 23

TREE LENGTH HARVESTING COSTS

Cost Centre	Costs ($\$/m^3$)	
	1977*	1980**
felling, limbing, skidding	4.81	7.21
skidroads, landings	0.37	0.54
loading	0.37	0.54
camp costs	0.67	0.97
overhead	2.14	3.21
road costs	2.03	2.94
TOTAL	10.39	15.41

*Source: Alberta Energy and Natural Resources. 1979. Energy and chemicals from wood. Energy and Natural Res. Rep. No. 90, Edmonton, Alta. p. 13.

**Source for price indexes: Statistics Canada. 1981. Construction price statistics. Min. of Supply and Services Can., Cat. 62-007, Vol. 8, No. 3, Ottawa, Ont. p. 43.; Statistics Canada, 1981. Estimates of labour income. Min. of Supply and Services Can., Cat. 72-005, Vol. 35, No. 1, Ottawa, Ont. p. 34.

higher or $\$19.26/\text{m}^3$. The units of the harvesting variables in the matrix are in hours, therefore these costs must be expressed in $\$/\text{hr}$ to satisfy equation units. The productivity figures used for the conversion are:

tree-length manual: $\$15.41/\text{m}^3 \times 5.66\ \text{m}^3/\text{hr} = \$87.22/\text{hr}$,
tree-length mechanical: $\$19.26/\text{m}^3 \times 2.80\ \text{m}^3/\text{hr} = \$53.94/\text{hr}$,
full-tree manual: $\$15.41/\text{m}^3 \times 8.41\ \text{m}^3/\text{hr} = \$129.60/\text{hr}$,
full-tree mechanical: $\$19.26/\text{m}^3 \times 4.36\ \text{m}^3/\text{hr} = \$83.98/\text{hr}$.

APPENDIX 2. TREE SIZE CALCULATIONS

The content of this appendix discribes the development of aspen size classes, the distribution of size classes on the harvest areas and the calculations describing the harvesting of individual size classes.

A. Aspen size classes

Bailey and Dobie(1977) recorded the size class distribution of an aspen stand in the Slave Lake region. The stand contained 72% trembling aspen and 28% balsam poplar. The weighted tree size distribution in Table 24 was developed from this information.

B. Distribution of size classes

Alberta Forest Service(1971) information provides stand volume data for trees smaller than 25.4 cm DBH and trees larger than 25.4 cm DBH. As was noted in Chapter 4, an assumption is made that only the 25.4 cm and greater portion will be delivered to the mills. This portion of the volume is assumed to include tree sizes down to 23 cm DBH. Multiplying the weighted averages from Table 24 by the percentage volumes of 25.4 cm and greater trees on each area gives the percentage of tree sizes available from the harvest areas as seen in Table 25.

C. Harvesting individual size classes

TABLE 24

WEIGHTED AVERAGES OF TREE SIZE CLASSES

DBH Class (cm)	Trembling Aspen (%)	Balsam Poplar (%)	Weighted Average (%)
23	16.0	12.0	14.9
30	41.0	29.0	37.6
38	24.0	30.0	25.7
46	19.0	29.0	21.8

TABLE 25

PERCENT DISTRIBUTION OF TREE SIZE CLASSES ON THE HARVEST AREAS

Harvest Area	Volume of trees 23+ cm (%)	DBH Class (cm)			
		23	30	38	46
1	53	7.9	19.9	13.6	11.6
2	59	8.8	22.2	15.2	12.9
3	57	8.5	21.2	14.6	12.4
4	62	9.2	23.3	15.9	13.5
5	66	9.8	24.8	17.0	14.4

Figure 3 illustrates the flow of the tree volumes through the felling portion of the matrix. The letters A and B are coefficients in the felling column and indicate the productivity(m³/hr) for the different felling methods. The model assumes clearcutting on all areas but only a percentage of the volume felled will be hauled to the mills. These portions by size class are found in Table 25. The B coefficient is found by multiplying the A productivity coefficient by the portion assigned for an individual size class. For example, the productivity of tree length manual felling is 5.66 m³/hr. On harvest area 1, 7.9% of the harvested trees will be of the 23 cm class. The B coefficent entered into the matrix for tree-length, manual felling on area 1 would be,

$$5.66 \text{ m}^3/\text{hr} \times 7.9\% = 0.448 \text{ m}^3/\text{hr}.$$

The other B coefficients were calculated in a similar manner.

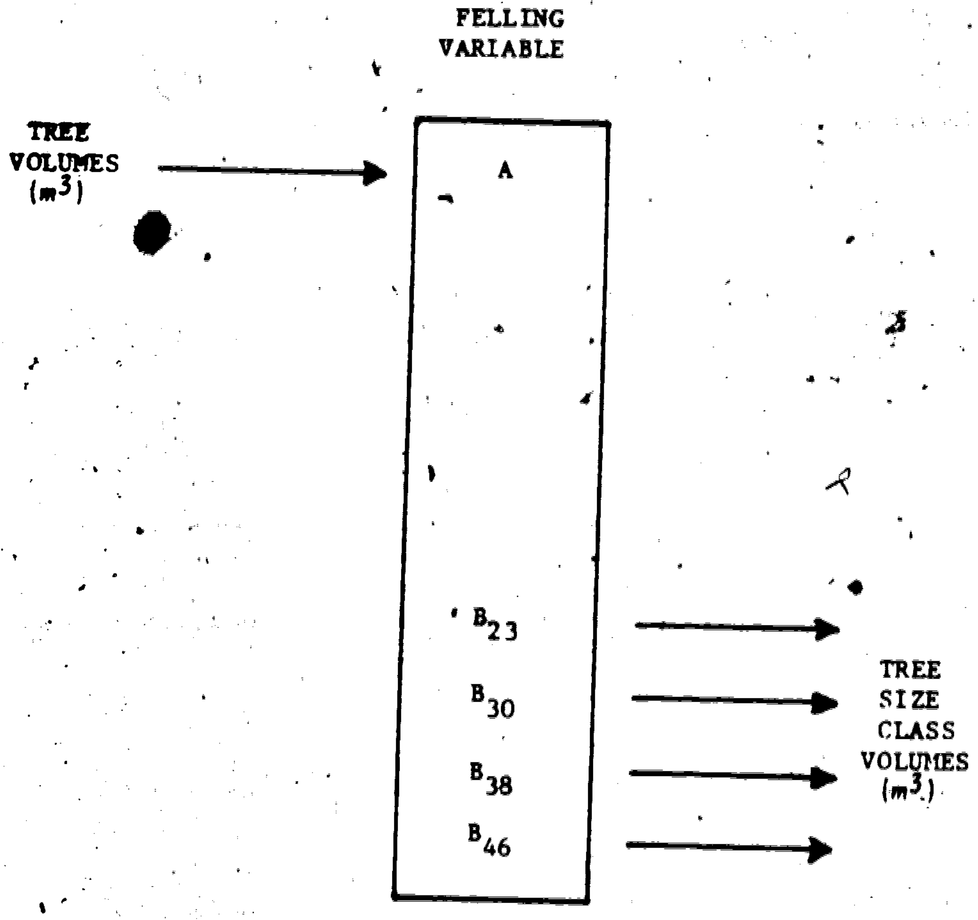

Figure 3. Flow of tree volumes through felling variables

APPENDIX 3. HAULING COST CALCULATIONS

McDougall(1978) reported a 1977 hauling cost in the Slave Lake area of \$0.07 per cord(cd) per running mile. By utilizing an average of both diesel fuel and wages and salaries price indexes[8], this figure was increased 66% to \$0.12/cd per running mile. The haul to Slave Lake is an average 145 km(90 mi) return. Hauling cost is:

$$\$0.12/cd/mi \times 90\ mi \times 0.2759\ cd/m^3 = \$2.98/m^3.$$

Unloading costs are assumed to be the same as loading costs(see Table 23) which amounts to \$0.54/m³. Therefore, the total cost for tree-length hauling and unloading comes to \$3.52/m³. Full-tree hauling costs are assumed to be 10% higher, thus totalling \$3.87/m³.

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[8] Statistics Canada. 1981. Industry price indexes. Minister of Supply and Services Canada, Cat. 62-011, Vol. 7, No.5, Ottawa, Ont. p. 57. and, Statistics Canada. 1981. Estimates of labour income. Minister of Supply and Services Canada, Cat. 72-005, Vol. 35, No. 1, Ottawa, Ont. p. 34.

APPENDIX 4. SAWMILL CONVERSION CALCULATIONS

This appendix includes a discussion of trees to sawlogs and sawmill conversion.

A. Conversion of trees to sawlogs

The amount of tree volume arriving at the sawmills must be adjusted to account for bark, branches and top and bucking to proper lengths. Keays(1971) determined the percentage of bark and branches and tops for different size classes of trembling aspen(Table 26). Tree-length volumes removed only the bark component, while percentages for bark, branches and tops were removed from full-tree volumes.

Log volumes as a percentage of tree volume for trembling aspen and balsam poplar in Alberta were documented by Bailey and Dobie(1977). These percentages were weighted according to the 80/20 assumed mix of trembling aspen to balsam poplar, then applied to the volume of the boles calculated in Table 26. Table 27 shows these calculations.

B. Stud and dimension sawmills conversion factors

Because the stud and dimension sawmills are essentially the same mill, lumber recovery is assumed to be the same for each. Lumber recovery factors(LRF) for both trembling aspen and balsam poplar were taken from the Bailey and Dobie(1977). The conversion of these factors into a percentage of lumber recovered and weighting to account for

TABLE 26

PERCENT VOLUME OF TREES FOR SAWLOGS

	Size Class (cm)			
	23	30	38	46
Bark	0.08	0.08	0.08	0.08
Branches and Top	0.06	0.05	0.04	0.03
Tree Length Bole	0.92	0.92	0.92	0.92
Full Tree Bole	0.86	0.87	0.88	0.89

TABLE 27

WEIGHTED SAWLOG VOLUMES AS PERCENT OF TREE VOLUMES

Size Class	Log Volumes TA (%)	Log Volumes BP (%)	Weighted Average (%)	Sawlog Volume, Tree Length (%)	Sawlog Volume, Full Tree (%)
23	81.0	81.0	81.4	0.749	0.700
30	87.0	83.0	86.5	0.796	0.752
38	86.0	81.0	85.0	0.782	0.748
46	89.0	84.5	88.1	0.810	0.784

Note: TA--trembling aspen; BP--balsam poplar.

stand mix is shown in Table 28.

The scrag-chipping edger mill system produces 100 tons of dry chips per day(Boywer 1974). This figure is converted to the proper units for matrix equations as follows:

100 tons/day X 909.1 kg/ton X 2.7 m^3 SWE /1000 kg
= 245 m^3 chips/day.

Then,

245 m^3 chips/day X 0.00592 days/m^3 lumber
= 1.45 m^3 chips/m^3 lumber.

SWE is the solid wood equivalent of 1000 kg of trembling aspen wood(Dobie and Wright 1979).

The grades of lumber produced from aspen were evaluated by Bailey and Dobie(1977). These data were used to develop a weighted product mix of boards, studs and dimension lumber. The study showed that 8% of the lumber sawn became one-inch boards, with the remainder ending up as two-inch stock. Tables 29, 30 and 31 show the product calculations for boards, studs and dimension lumber respectively.

C. Twin and board sawmills conversion factors

The twin band system described by Leech and Gillies(1972) and the scrag mill used by Boywer(1974) manufactured factory lumber in the model. The twin system had a lumber recovery of 45.8% or a LRF of 5.5. Bailey(1973) found that straight aspen logs could achieve a LRF of 6.7 for one-inch factory lumber. This high LRF was attained because the study used large, straight logs. Bailey and

TABLE 28

LUMBER RECOVERY FOR STUD AND DIMENSION SAWMILLS

Size Class	LRF TA	Lumber Recovered TA (%)	LRF BP	Lumber Recovered BP (%)	Weighted Lumber Recovery (%)
23	5.90	49.0	5.80	48.0	48.8
30	7.00	58.0	6.30	52.0	56.8
38	7.30	61.0	6.70	56.0	60.0
46	7.60	63.0	7.40	61.0	62.6

Note: TA--trembling aspen; BP--balsam poplar.

TABLE 29

PRODUCT MIX FOR BOARDS

Grade	Volume of TA (fbm)	Percent of TA Total	Volume of BP (fbm)	Percent of BP Total	Weighted Average ($)	Percent of Total Production
select	1,273	42.0	836	40.0	41.6	0.033
construction	458	15.0	523	25.0	17.0	0.014
standard	742	25.0	474	23.0	24.6	0.020
utility	510	17.0	244	12.0	16.0	0.013
economy	32	1.0	8	...	0.8	0.001
TOTAL	3,016	100.0	2,084	100.0	100.0	...

Note: TA—trembling aspen; BP—balsam poplar.

TABLE 30

PRODUCT MIX FOR STUDS

Grade	Volume of TA (fbm)	Percent of TA Total	Volume of BP (fbm)	Percent of BP Total	Weighted Average (%)	Percent of Total Production
stud	29,787	87.0	22,550	85.0	86.6	0.797
economy stud	4,364	13.0	3,975	15.0	13.4	0.123
TOTAL	34,151	100.0	26,525	100.0	100.0	...

TABLE 31

PRODUCT MIX FOR DIMENSION LUMBER

Grade	Volume of TA (fbm)	Percent of TA Total	Volume of BP (fbm)	Percent of BP Total	Weighted Average ($)	Percent of Total Production
construction	17,351	50.0	11,216	42.0	41.6	0.445
standard	4,736	14.0	6,031	23.0	15.8	0.145
utility	8,001	23.0	5,302	20.0	22.4	0.206
economy	4,364	13.0	3,975	15.0	13.4	0.123
TOTAL	34,151	100.0	26,525	100.0	100.0	...

Note: TA--trembling aspen; BP--balsam poplar.

Dobie(1977) showed that smaller trees have a significantly lower LRF. Both Boywer (1974) and Bailey(1973) showed recovery for factory lumber to be lower than that of construction lumber. A LRF of 5.7(47.5%) is employed for the scrag mill to account for crooked, sweepy and smaller logs. Data could not be found on lumber recovery of factory lumber for different tree sizes. Therefore all size classes used the same average recovery.

Chip production from the twin band mill equalled 0.70 odt/Mfbm. This figure converts to 0.728 m^3 chips/m^3 of lumber produced using the technique outlined in stud and dimension chip conversion. Likewise the scrag mill produces 92 odt/day or 1.45 m^3 chips/m^3 of lumber. The chipping edger in the scrag system significantly increases the amount of chips produced by a mill.

Leech and Gillies(1972) study provided product mix data for both mills. The mixes are seen in Table 32.

TABLE 32

PRODUCT MIX OF FACTORY LUMBER

Grade	Twin Mill (%)	Board Mill (%)
#1&BTR	17	20
#2A	24	25
#2B	25	25
#3	34	30

APPENDIX 5. PULP CONVERSION CALCULATIONS

This appendix gives a detailed explaination of the conversion of roundwood to chips and the conversion of chips to pulp. The amount of chips available from roundwood is first considered. Woodbridge, *et.al.*(1981) noted that 85% of the usable bole of an aspen tree can be made into chips. This figure applied to the bole data shown in Table 26 gives the amount of chips available for pulp or particleboard from roundwood.

The second area of consideration is the conversion of chips to pulp. Pulp yield from aspen is calculated as follows: the pulp mill has a yearly solid wood requirement of 425,000 m^3, only half of which is aspen(i.e. 212,500 m^3). Eighty-five percent of the aspen wood brought to the mill is usable. The amount of aspen roundwood needed is:

$$212{,}500\ m^3/0.85 = 250{,}000\ m^3.$$

The mill's yearly production is 157,500 admt. The amount of aspen/admt is:

$$250{,}000\ m^3/157{,}500\ \text{admt} = 1.59\ m^3/\text{admt}.$$

Only 50% of aspen chips are usable in chemi-mechanical pulp, so

$$1.59\ m^3/0.50 = 3.18\ m^3/\text{admt or } 0.1345\ \text{admt}/m^3$$

Spruce chips are also needed in the pulping process. The amount of spruce necessary for a single air-dry metric ton is 0.468 BDU.

Woodbridge, *et.al.*(1981) listed the operating cost of one air-dry metric ton of pulp as $215.00. This figure includes $44.50/ admt for harvesting. Because the model takes harvesting costs into account, the operating cost of the pulp mill was reduced to $170.50/admt.

APPENDIX 6. WAFERBOARD CONVERSION AND COSTS

Conversion and cost figures for waferboard production were obtained from Columbia Engineering International Ltd. (1981). Waferboard requires 0.763 odt of wood/Mcf, 3/8-inch basis. The metric conversion of this figure is 2.116 m³ of wood input per cubic metre of waferboard, or 0.473 m³ produced/m³ input. The 0.473 m³/m³ can be used to convert the percentage of bole available into waferboard (Table 33).

The capital cost of the waferboard mill used in the model is $37,546,665. The information available did not differentiate depreciable items, but used 10 year, straight-line depreciation in the analysis. Manufacturing costs are shown in Table 34.

TABLE 33

ROUNDWOOD TO WAFERBOARD CONVERSION

Tree Type	Size Class (cm)	Percent Bole	Waferboard Conversion (m^3/m^3)
tree length	all	92	0.435
full tree	23	86	0.407
full tree	30	87	0.412
full tree	38	88	0.416
full tree	46	89	0.421

TABLE 34

MANUFACTURING COSTS OF WAFERBOARD

Item	Cost ($/Msf, 3/8-inch basis)
resins and wax	24.28
power	8.00
fuel	3.00
labour	14.70
supplies	8.75
administration	5.50
insurance and local taxes	3.25
TOTAL	67.75
TOTAL($/$m^3$)	76.55

APPENDIX 7. PLYWOOD PRODUCTION CALCULATIONS

This appendix is composed of two parts. The first describes the method of deriving log sizes from tree size data. The second part uses Boywer's(1974) method of determining veneer production from different log sizes.

A. Log sizes

Roundwood to plywood conversion factors can be calculated using data from the literature(Boywer 1974). These factors are based upon the top diameter of 2.54 m(100 in) logs. The tree volumes used in the model must be converted into log volumes to utilize the conversion factors. Please refer to Table 35 as the logic of the calculations to determine log sizes is explained.[9]

The first step in calculating the logs in a tree is to determine tree height. Tree heights to merchantable tops were determined by utilizing rough height information from Bailey(1973). Next, the number of logs in a tree of a given diameter was evaluated. Both Bailey(1973) and Bailey and Dobie (1977) gave some data on the number of 8.33 ft logs that could be expected in a given sized trees. The usable and cull portions of the tree length was then calculated. The length of usable tree-length was determined by multiplying the number of logs in the tree by 8.33 ft. Cull lengths were found by subtracting the usable portion of the

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[9] All calculations in this section were done in English units because the literature used these units.

TABLE 35

CALCULATING THE DIAMETER OF PLYWOOD LOGS

Tree Size Class (cm)	DBH (in)	Height (ft)	Logs per Tree	Usable Log Length (ft)	Cull Length (ft)	Butt Dia. (in)	First Log Bottom Dia. (in)
23	9	38	3.50	29.2	8.8	9.5	8.8
	10	41	4.00	33.3	7.7	10.5	9.9
	11	41	4.50	37.5	3.5	11.5	11.2
30	12	50	4.50	37.5	12.5	12.5	11.6
	13	53	5.00	41.6	11.4	13.5	12.6
	14	56	5.50	45.8	10.2	14.5	13.7
38	15	58	5.50	45.8	12.2	15.5	14.6
	16	58	6.00	50.0	8.0	16.5	15.9
	17	58	6.25	52.0	6.0	17.5	17.0
46	18	62	6.25	52.0	10.0	18.5	17.8
	19	62	6.50	54.2	7.8	19.5	18.9
	20	62	6.75	56.2	5.8	20.5	20.1

tree from the total tree length.

Diameters along the length of the tree could be calculated using Leech and Gillies(1972) reported aspen taper of 0.15 in/ft. Butt diameter was calculated by multiplying the taper by 3.5 ft and subtracting the result from the DBH. The calculations to derive the diameters of the logs rely on the assumption that the cull portions of the tree-length are evenly divided between top and bottom. In other words, crook, sweep and rot were assumed to be either at the top or bottom of the tree. The length of cull in the butt portion of the tree is one-half the total cull length. The butt-cull length multiplied by the taper gives the amount of diameter taper over the butt-cull length. This figure was then subtracted from the butt diameter to give the bottom diameter of the first log. The top diameter of the first usable log was determined by subtracting 1.25 in(8.33 ft X 0.15 in/ft) from the bottom diameter. Similarly, log top diameters were calculated by 8.33 ft increments until the diameter was 8 in or smaller.

Two factors limit the utilization of every possible log in the tree. The first is that logs with a top diameter of 8 in or less cannot be processed by the mill at a profit. The other limitation is the number of logs that are possible in a tree. A tree could have nine logs of 8 in and greater top diameter but have only 7 possible logs in the tree. In the smaller DBH size classes, the opposite is true. There are three logs possible per tree but only one of them has a top diameter of 8 in or greater. The figures in Table 36 were tablulated using these limitation factors. The percentage of logs in the tree size classes was calculated by dividing the total number of logs in a particular top diameter class by the total number of logs possible in the tree size class.

An example of one tree may be helpful. A tree of 11 in DBH was assumed to have a merchantable length of 41 ft and contain 4.5 logs. The total length of usable logs is:

$$8.33 \text{ ft/log} \times 4.5 \text{ logs} = 37.5 \text{ ft.}$$

This leaves 3.5 ft of unusable material. The butt diameter is:

$$11 \text{ in} = (3.5 \text{ ft} \times 0.15 \text{ in}) = 11.5 \text{ in.}$$

The bottom diameter of the first usable log is:

$$11.5 \text{ in} - (3.5 \text{ ft}/2 \times 0.15 \text{ in/ft}) = 11.24 \text{ in.}$$

The top diameter of the first log is:

$$11.24 \text{ in} - 1.25 \text{ in} = 9.99 \text{ in.}$$

Likewise, the second log's top diameter is 8.74 in and the third's 7.5 in. Even though this DBH size can have 4.5 logs, only 2 can meet the top diameter limitation of 8 in. In the whole 9 in(23 cm) DBH size class, only 25% of all logs possible can be used in the plywood mill.

Cull material can be chipped and utilized for pulp or particleboard. Alberta Energy and Natural Resources(1979) gave a 1977 chipping price of $13/odt. The 1980 price is

TABLE 36

CONVERSION OF TREE VOLUMES TO PLYWOOD LOG VOLUMES

Tree Size Class (cm)	Logs in Trees	Log Size Classes (%) 20 cm	28 cm	36 cm	43 cm	cull
23	12	0.250	...	...	...	0.750
30	16	0.375	0.188	...	...	0.438
38	18	0.444	0.333	0.667	...	0.057
46	20	0.100	0.400	0.350	0.150	...

inflated to \$19.50/odt[10] or 7.94 m^3. A conversion factor of 2.945 m^3/BDU was used in the matrix to adjust chip production to proper units (Dobie and Wright 1979).

B. Veneer production

Boywer's(1974) explanation of veneer production is used in Table 37. Log volumes for various top diameter classes are calculated and a percentage of this volume is removed to account for the five-inch core. The amount of 1/8-inch veneer is calculated, then reduced by 39.59% to account for drying and cull. Finally, the cubic feet of veneer is determined and the percentage of veneer to total log volume is calculated.

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[10] Source: Statistics Canada. 1981. Estimates of labour income. Minister of Supply and Services Can., Cat. 62-011, Ottawa, Ont. p. 34.

TABLE 37

VENEER PRODUCTION FROM PLYWOOD BOLTS

Log Top Dia. (in)	Log Vol. (ft^3)	Core Vol. (ft^3)	Core to Log Vol. ($)	Core Av. Vol. ($)	1/8-in Veneer (lineal ft)	1/8-in Veneer (bf)	Drying and Cull Ded.	Oven Dry Veneer (ft^3)	Veneer to Log Vol. (ft^3)	Veneer Av. Vol. ($)
8	3.30	1.09	33	...	25.7	206	125	1.3	39	...
9	4.14	1.09	26	27	35.5	284	172	1.8	43	43
10	5.27	1.09	21	...	48.6	389	235	2.4	46	...
11	6.26	1.09	17	...	60.1	481	291	3.0	48	...
12	7.37	1.09	15	15	73.0	584	353	3.6	40	49
13	8.72	1.09	13	...	83.5	688	416	4.2	49	...
14	10.12	1.09	11	...	105.0	840	508	5.2	52	...
15	11.62	1.09	9	9	122.4	879	592	6.1	53	53
16	13.22	1.09	8	...	141.0	1128	683	7.0	53	...
17	14.92	1.09	7	...	160.8	1280	775	8.0	54	...
18	16.72	1.09	6	6	181.9	1456	881	9.1	55	55
19	18.62	1.09	6	...	203.8	1630	986	10.3	55	...

Note: The drying and cull deduction is 39.5% of possible veneer.

APPENDIX 8. COSTS FOR LUMBER, PARTICLEBOARD AND PLYWOOD PRODUCTION

The capital and manufacturing costs for the sawmills, the particleboard mill and the plywood mill are described in this appendix. Boywer(1977) supplied the cost data for all mills with the exception of the twin band sawmill. The costs for the twin came from Leech and Gillies(1972). The data given in these publications were adjusted to 1980 prices using Statistics Canada price index information. Buildings and equipment are depreciated over 8 years using the straight-line method. The sawmill sites require 23 hectares of land and the sites for the particleboard mill and plywood mill each need 16 hectares. Land is available for $4942/ha (Holtby 1981). An advertising and property tax cost is included for every mill in the model. This cost is based upon the amount of goods sold, and is deducted from the profit at that time. Table 38 outlines sawmill costs and Table 39 shows particleboard and plywood costs.

TABLE 38

COST OF LUMBER PRODUCTION

Item	Index	Scrag System ($ X 1000)		Twin System ($ X 1000)	
		1974	1980	1972	1980
Capital Costs					
building and engineering	1	167	304	360	833
equipment	2	865	1508	790	1751
land	...	36	100	...	100
TOTAL	...	1068	1912	1150	2684
Depreciation/year	...	...	226	...	323
Manufacturing Costs					
telephone	3	6	8	...	...
general supplies	4	20	38	...	...
supplies and fuel	5	...	...	106	395
heat	6	1	3	...	...
electricity	7	25	55	...	...
office supplies	8	3	5	...	...
insurance	9	13	25	...	202
fuel for trans.	10	2	6	...	...
wages and salaries	11	207	509	303	1066
TOTAL	...	277	649	409	1663

Note: Index gives the reference number at end of appendix.

TABLE 39

COST OF PARTICLEBOARD AND PLYWOOD PRODUCTION

Item	Index	Particleboard Mill ($ X 1000)		Plywood Mill ($ X 1000)	
		1974	19[illegible]	1974	1980
Capital Costs					
building and engineering	1	1077	1959	1149	2090
equipment	2	3528	6149	2019	3520
land	...	72	80	72	80
TOTAL	...	4677	8188	3240	5690
Depreciation/year	...	...	1014	...	701
Manufacturing Costs					
adhesives	12	1219	2036	234	391
packaging	13	57	96	23	39
telephone	3	12	15	12	15
general supplies	4	8	15	6	12
repair and mant.	14	130	153	60	106
heat and power	15	218	508	86	200
insurance	9	57	97	41	67
fuel for trans.	10	8	22	6	17
wages and salaries	11	939	2310	928	2286
TOTAL	...	2648	5252	1396	3133

Note: Index gives the reference number at end of appendix.

INDEX REFERENCE

Many indicies were used from Statistics Canada to update mill costs to a 1980 basis. For ease of reference, the index entries will refer to the following publications by source letter.

SOURCE

A Statistics Canada. 1978. Fixed capital flows and stocks, 1926-1978. Minister of Supply and Services Can., Cat. 13-568, Ottawa, Ont.

B Statistics Canada. 1981. Construction price statistics. Minister of Supply and Services Can., Cat. 62-007, Vol. 8, No. 3, Ottawa, Ont.

C Statistics Canada. 1981. Consumer price indexes. Minister of Supply and Services Can., Cat. 62-010, Vol. 7, No. 3, Ottawa, Ont.

D Statistics Canada. 1981. Estimates of labour income. Minister of Supply and Services Can., Cat. 72-005, Vol. 35, No. 1, Ottawa, Ont.

E Statistics Canada. 1981. Industry price indexes. Minister of Supply and Services Can., Cat. 62-011, Vol. 7, No. 5, Ottawa, Ont.

INDEX NO.	DESCRIPTION
1	An average of source A(wood, p. 248) and source B (industrial buildings, p. 28).
2	Sawmill and plywood equipment came from source E (sawmill machinery, p. 48). Particleboard equipment used source E(pulp and paper machinery and parts, p. 48).
3	Telephone cost index came from source C(telephone, p. 29).
4	All general supplies indices came from source E and averaged: bolts and nuts and headed or threaded

rods with or without nuts, p.45; carpenter mechanic hand tools, p. 45; lighting fixtures, p.51; electrical industrial equipment, p. 51; misc. electrical products, p. 52; indicating, recording and controlling instruments and accessories, p. 62.

5 The supplies and fuel index averaged all the items listed in index 4 plus the diesel fuel index(p. 57) of source E.

6 Heat was assumed to utilize natural gas which is indexed in source C, p. 29.

7 The cost of electricity was indexed in source E (Alberta-over 5000 Kw, p. 67).

8 Office supplies were indexed using an average in source E of typewriter supplies(p. 63), pen and pencils manufactured(p. 63), pads and tablets(p. 40) and envelopes manufactured(p. 41).

9 Insurance was determined by calculating 1% of the sum of capital expenditures and estimated working capital.

10 Fuel was indexed using source E, diesel fuel(p. 57).

11 Wages and salaries utilized source C, labour income of Alberta manufacturing industries(p. 34).

12 Adhesives were indexed using source E, glues-all types(p. 62).

13 Packaging used source E, paperboard, container grades, liners, Kraft paper board(p. 38).

14 Repair and maintenance was calculated by taking 1% of the building and equipment cost and multiplying this figure by the number of shifts per day.

15 The heat and power index was calculated by averaging natural gas indexes(source C, p. 29) and electricity indexes(source E, p. 67).

APPENDIX 9. REFERENCE MATRIX

This appendix contains [illegible]sting of the reference matrix variables, a picture of the reference matrix and the reference matrix itself.

A. Listing of the matrix variables

1. ROWS

ZMAX --objective function($)
OPCAP --operating capital($)
ALLOWCUT--total annual allowable cut(m³)
LIMHAR1 --limit of harvest area 1(ha)
LIMHAR2 --limit of harvest area 2(ha)
LIMHAR3 --limit of harvest area 3(ha)
LIMHAR4 --limit of harvest area 4(ha)
LIMHAR5 --limit of harvest area 5(ha)
TLAMT1 --tree length volume from harvest area 1(m³)
TLAMT2 --tree length volume from harvest area 2(m³)
TLAMT3 --tree length volume from harvest area 3(m³)
TLAMT4 --tree length volume from harvest area 4(m³)
TLAMT5 --tree length volume from harvest area 5(m³)
FTAMT1 --full tree volume from harvest area 1(m³)
FTAMT2 --full tree volume from harvest area 2(m³)
FTAMT3 --full tree volume from harvest area 3(m³)
FTAMT4 --full tree volume from harvest area 4(m³)
FTAMT5 --full tree volume from harvest area 5(m³)
TLSIZ9 --tree length 23 cm trees(m³)
TLSIZ12 --tree length 30 cm trees(m³)
TLSIZ15 --tree length 38 cm trees(m³)
TLSIZ18 --tree length 46 cm trees(m³)
FTSIZ9 --full tree 23 cm trees(m³)
FTSIZ12 --full tree 30 cm trees(m³)
FTSIZ15 --full tree 38 cm trees(m³)
FTSIZ18 --full tree 46 cm trees(m³)
BARK --bark component of trees(m³)
BRAN-TOP--branch and top component of full trees(m³)
CHIPS --chips(m³)
LOGS9 --volume OF 23 cm boles(m³)
LOGS12 --volume OF 30 cm boles(m³)
LOGS15 --volume OF 38 cm boles(m³)
LOGS18 --volume OF 46 cm boles(m³)
LOG8 --volume OF 20 cm plywood bolts(m³)
LOG11 --volume OF 28 cm plywood bolts(m³)
LOG14 --volume OF 36 cm plywood bolts(m³)

LOG17 --volume OF 43 cm plywood bolts(m^3)
STUDTRAN--stud transfer(m^3)
CAPSTUD --capital transfer for stud mill($)
LIMS&D --limit on stud and dimension sawmills(m^3)
DIMTRAN --dimension lumber transfer(m^3)
CAPDIM --capital transfer for dimension mill($)
TWINMILL--twin mill's production transfer(m^3)
CAPTWIN --capital transfer for twin mill($)
LIMTWIN --limit on twin mill production(m^3)
BOARDTRN--board mill's production transfer(m^3)
CAPBOARD--capital transfer for board mill($)
LIMBOARD--limit on board mill production(m^3)
PULPTRAN--pulp transfer(admt)
CAPPULP --capital transfer for pulp mill($)
LIMPULP --limit on pulp production(admt)
SPNEED --spruce transfer(m^3)
PBTRAN --particleboard transfer(m^3)
CAPPART --capital transfer for particleboard mill($)
LIMPB --limit on particleboard production(m^3)
WAFERCON--waferboard conversion(m^3)
WAFTRAN --waferboard transfer(m^3)
CAPWAFER--capital transfer for waferboard mill($)
LIMWAFER--limit on waferboard production(m^3)
PLYCON --plywood conversion(m^3)
CAPPLY --capital transfer for plywood mill($)
LIMPLY --limit on plywood production(m^3)
PLYTRIM --plywood trim produced(m^3)
LOGCHIP --plywood bolt trim volume(m^3)
AD&TAX --advertising and property tax transfer($)
PULPPROD--pulp production(admt)
PBPROD --particleboard production(m^3)
WAFERPRO--waferboard production(m^3)
PLYPROD --plywood production(m^3)
STSLETBD--select boards from stud mill(m^3)
STCONBD --construction boards from stud mill(m^3)
STSTDBD --standard boards from stud mill(m^3)
STUTILBD--utility boards from stud mill(m^3)
STECONBD--economy boards from stud mill(m^3)
DMSLETBD--select boards from dimension mill(m^3)
DMCONBD --construction boards from dimension mill(m^3)
DMSTDBD --standard boards from dimension mill(m^3)
DMUTILBD--utility boards from dimension mill(m^3)
DMECONBD--economy boards from dimension mill(m^3)
DMCONST --construction lumber from dimension mill(m^3)
DMSTAND --standard lumber from dimension mill(m^3)
DMUTIL --utility lumber from dimension mill(m^3)
DMECON --economy lumber from dimension mill(m^3)
TWINBD1 --#1 and better boards from twin mill(m^3)
TWINBD2A--#2A boards from twin mill(m^3)
TWINBD2B--#2B boards from twin mill(m^3)
TWINBD3 --#3 boards from twin mill(m^3)
BOARD1 --#1 and better boards from board mill(m^3)
BOARD2A --#2A boards from board mill(m^3)
BOARD2B --#2B boards from board mill(m^3)

BOARD3 --#3 boards from board mill(m³)

2. COLUMNS

HARVEST1--tree length portion of harvest area 1(ha)
HARVEST2--tree length portion of harvest area 2(ha)
HARVEST3--tree length portion of harvest area 3(ha)
HARVEST4--tree length portion of harvest area 4(ha)
HARVEST5--tree length portion of harvest area 5(ha)
HARVES1A--full tree portion of harvest area 1(ha)
HARVES2A--full tree portion of harvest area 2(ha)
HARVES3A--full tree portion of harvest area 3(ha)
HARVES4A--full tree portion of harvest area 4(ha)
HARVES5A--full tree portion of harvest area 5(ha)
TL1AR1--tree length, manual harvesting of area 1(hr)
TL2AR1--tree length, mechanical harvesting of area 1(hr)
FT1AR1--full tree, manual harvesting of area 1(hr)
FT2AR1--full tree, mechanical harvesting of area 1(hr)
TL1AR2--tree length, manual harvesting of area 2(hr)
TL2AR2--tree length, mechanical harvesting of area 2(hr)
FT1AR2--full tree, manual harvesting of area 2(hr)
FT2AR2--full tree, mechanical harvesting of area 2(hr)
TL1AR3--tree length, manual harvesting of area 3(hr)
TL2AR3--tree length, mechanical harvesting of area 3(hr)
FT1AR3--full tree, manual harvesting of area 3(hr)
FT2AR3--full tree, mechanical harvesting of area 3(hr)
TL1AR4--tree length, manual harvesting of area 4(hr)
TL2AR4--tree length, mechanical harvesting of area 4(hr)
FT1AR4--full tree, manual harvesting of area 4(hr)
FT2AR4--full tree, mechanical harvesting of area 4(hr)
TL1AR5--tree length, manual harvesting of area 5(hr)
TL2AR5--tree length, mechanical harvesting of area 5(hr)
FT1AR5--full tree, manual harvesting of area 5(hr)
FT2AR5--full tree, mechanical harvesting of area 5(hr)
HAULSAW1--hauling 23 cm tree length sawlogs(m³)
HAULSAW2--hauling 30 cm tree length sawlogs(m³)
HAULSAW3--hauling 38 cm tree length sawlogs(m³)
HAULSAW4--hauling 46 cm tree length sawlogs(m³)
HAULSAW5--hauling 23 cm full tree sawlogs(m³)
HAULSAW6--hauling 30 cm full tree sawlogs(m³)
HAULSAW7--hauling 38 cm full tree sawlogs(m³)
HAULSAW8--hauling 46 cm full tree sawlogs(m³)
HAULCHP1--hauling all tree lengths for chips(m³)
HAULCHP2--hauling 23 cm full trees for chips(m³)
HAULCHP3--hauling 30 cm full trees for chips(m³)
HAULCHP4--hauling 38 cm full trees for chips(m³)
HAULCHP5--hauling 46 cm full trees for chips(m³)
HAULWAF1--hauling all tree lengths for wafers(m³)
HAULWAF2--hauling 23 cm full trees for wafers(m³)
HAULWAF3--hauling 30 cm full trees for wafers(m³)
HAULWAF4--hauling 38 cm full trees for wafers(m³)
HAULWAF5--hauling 46 cm full trees for wafers(m³)
HAULPLY1--hauling 23 cm tree lengths for plywood bolts(m³)
HAULPLY2--hauling 30 cm tree lengths for plywood bolts(m³)

HAULPLY3--hauling 38 cm tree lengths for plywood bolts(m³)
HAULPLY4--hauling 46 cm tree lengths for plywood bolts(m³)
HAULPLY5--hauling 23 cm full trees for plywood bolts(m³)
HAULPLY6--hauling 30 cm full trees for plywood bolts(m³)
HAULPLY7--hauling 38 cm full trees for plywood bolts(m³)
HAULPLY8--hauling 46 cm full trees for plywood bolts(m³)
STUDMILL--stud sawmill production(m³)
STUDCAP --stud sawmill depreciation and purchase(m³)
DIMMILL --dimension sawmill production(m³)
DIMCAP --dimension sawmill depreciation and purchase(m³)
TWINMILL--twin sawmill production(m³)
TWINCAP --twin sawmill depreciation and purchase(m³)
BOARDMIL--board sawmill production(m³)
BOARDCAP--board sawmill depreciation and purchase(m³)
PULPMILL--pulp mill production(admt)
PULPCAP --pulp mill depreciation and purchase(admt)
SPRUCE --spurce needed for pulp(BDU)
PARTMILL--particleboard mill production(m³)
PARTCAP --particleboard mill depreciation and purchase(m³)
WAFERMIL--waferboard mill production(m³)
WAFERCAP--waferboard mill depreciation and purchase(m³)
PLYMILL1--20 cm plywood mill production(m³)
PLYMILL2--28 cm plywood mill production(m³)
PLYMILL3--36 cm plywood mill production(m³)
PLYMILL4--43 cm plywood mill production(m³)
PLYCAP --plywood mill depreciaton and purchase(m³)
CHIPLOG --plywood tree residue that is chipped(m³)
TAX&AD --property tax and advertising cost deduction(m³)
AVALCHIP--selling chips(m³)
SLECTBD --select boards from stud mill(Mfbm)
CONSTBD --construction boards from stud mill(Mfbm)
STANDBD --standard boards from stud mill(Mfbm)
UTILBD --utility boards from stud mill(Mfbm)
ECONOBD --economy boards from stud mill(Mfbm)
SLECTBDD--select boards from dimension mill(Mfbm)
CONSTBDD--construction boards from dimension mill(Mfbm)
STANDBDD--standard boards from dimension mill(Mfbm)
UTILBDD --utility boards from dimension mill(Mfbm)
ECONOBDD--economy boards from dimension mill(Mfbm)
CONSTDIM--construction lumber from dimension mill(Mfbm)
STANDDIM--standard lumber from dimension mill(Mfbm)
UTILDIM --utility lumber from dimension mill(Mfbm)
ECONODIM--economy lumber from dimension mill(Mfbm)
STUD --studs from stud mill(Mfbm)
ECONOSTD--economy studs from stud mill(Mfbm)
BD#1BTR --#1 and better boards from board sawmill(Mfbm)
BD#2A --#2A boards from board sawmill(Mfbm)
BD#2B --#2B boards from board sawmill(Mfbm)
BD#3 --#3 boards from board sawmill(Mfbm)
BD#1BTRT--#1 and better boards from twin sawmill(Mfbm)
BD#2AT --#2A boards from twin sawmill(Mfbm)
BD#2BT --#2B boards from twin sawmill(Mfbm)
BD#3T --#3 boards from twin sawmill(Mfbm)
PULP --pulp(admt)

PB3/4 --19 mm sheets of particleboard(m^3)
PB5/8 --16 mm sheets of particleboard(m^3)
PB1/2 --13 mm sheets of particleboard(m^3)
PB3/8 --9 mm sheets of particleboard(m^3)
WAF1/4 --6 mm sheets of waferboard(m^3)
WAF5/16 --8 mm sheets of waferboard(m^3)
WAF3/8 --9 mm sheets of waferboard(m^3)
WAF7/16 --11 mm sheets of waferboard(m^3)
WAF5/8TG--16 mm sheets of waferboard(m^3)
PLY1/4 --6 mm sheets of plywood(m^3)
PLY1/2 --13 mm sheets of plywood(m^3)
PLY3/4 --19 mm sheets of plywood(m^3)
TRIMROND--plywood trim and rounding residue(m^3)
HOGFUEL --hogfuel(m^3)
MONEYSTD--capital cost of stud sawmill($)
MONEYDIM--capital cost of dimension sawmill($)
MONEYTWN--capital cost of twin sawmill($)
MONEYBOR--capital cost of board sawmill($)
MONEYPLP--capital cost of pulp mill($)
MONEYPRT--capital cost of particlebard mill($)
MONEYWAF--capital cost of waferboard mill($)
MONEYPLY--capital cost of particleboard mill($)
OPERAT$$--operating costs($)

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                         PICTURE OF MATRIX

              H H H H H H H H H H                                         H H H H H H H H H H H H H H H H H H H H H H H H H
              A A A A A A A A A A                                         A A A A A A A A A A A A A A A A A A A A A A A A A
              R R R R R R R R R R T T F F T T F F T T F F T T F F T T F F U U U U U U U U U U U U U U U U U U U U U U U U U
              V V V V V V V V V V L L T T L L T T L L T T L L T T L L T T L L L L L L L L L L L L L L L L L L L L L L L L L
              E E E E E E E E E E 1 2 1 2 1 2 1 2 1 2 1 2 1 2 1 2 1 2 1 2 S S S S S S S S C C C C C W W W W W P P P P P P P
              S S S S S S S S S S A A A A A A A A A A A A A A A A A A A A A A A A A A A A H H H H H A A A A A L L L L L L L
              T T T T T 1 2 3 4 5 R R R R R R R R R R R R R R R R R R R R W W W W W W W W P P P P P P P P P P V V V V V V V
              1 2 3 4 5 A A A A A 1 1 1 1 2 2 2 2 3 3 3 3 4 4 4 4 5 5 5 5 1 2 3 4 5 6 7 8 1 2 3 4 5 1 2 3 4 5 1 2 3 4 5 6 7

ZMAX      N  -B-B-B-B-B-B-B-B-B-B-B-B-C-B-B-B-C-B-B-B-C-B-B-B-C-B-B-B-C-B-A-A-A-A-A-A-A-A-A-A-A-A-A-A-A-A-A-A-A-A-A-A-A-A-A
SPCAP     L   B B B B B B B B B B B B C B B B C B B B C B B B C B B B C B A A A A A A A A A A A A A A A A A A A A A A A A A
ALLOWCUT  L   B B C C C B B C C C
LIMHAR1   L   1         1
LIMHAR2   L     1         1
LIMHAR3   L       1         1
LIMHAR4   L         1         1
LIMHAR5   L           1         1
TLANT1    L  -B                   A A
TLANT2    L    -B                         A A
TLANT3    L      -C                               A A
TLANT4    L        -C                                     A A
TLANT5    L          -C                                           A A
FTANT1    L            -B             A A
FTANT2    L              -B                   A A
FTANT3    L                -C                         A A
FTANT4    L                  -C                               A A
FTANT5    L                    -C                                     A A
TLSIZ8    L                      -T-T    -T-T    -T-T    -T-T    -T-T     1               1         1         1
TLSIZ12   L                      -A-T    -A-T    -A-T    -A-T    -A-T       1             1         1           1
TLSIZ15   L                      -T-T    -T-T    -T-T    -T-T    -T-T         1           1         1             1
TLSIZ18   L                      -T-T    -T-T    -T-T    -T-T    -T-T           1         1         1               1
FTSIZ8    L                          -T-T    -T-T    -T-T    -T-T    -T-T         1         1         1               1
FTSIZ12   L                          -A-T    -A-T    -A-T    -A-A    -A-A           1         1         1               1
FTSIZ15   L                          -A-T    -A-T    -A-T    -A-T    -A-T             1         1         1               1
FTSIZ18   L                          -T-T    -A-T    -A-T    -A-T    -A-T               1         1         1
BARK      L                                                              -U-U-U-U-U-U-U-U-U-U-U-U-U          -U-U-U-U-U-U-U
BRAN-TOP  L                                                                      -U-U-U-U  -U-U-U-U                  -U-U-U
CHIPS     L                                                                              -T-T-T-T-T
LOGS8     L                                                              -T      -T
LOGS12    L                                                                -T      -T
LOGS15    L                                                                  -T      -T
LOGS18    L                                                                    -T      -T
LOG8      L                                                                                                  -T-T-T-U-T-T-T
LOG11     L                                                                                                    -T-T-T  -T-T
LOG14     L                                                                                                      -T-T    -T
LOG17     L                                                                                                        -T
STUDTRAN  L
CAPSTUD   L
LIMSAD    L
DIMTRAN   L
CAPDIM    L
TWINTRAN  L
CAPTWIN   L
LIMTWIN   L
BOARDTRN  L
CAPBOARD  L
LIMBOARD  L
PULPTRAN  L
CAPPULP   L
LIMPULP   L
SPWEED    L
PBTRAN    L
CAPPART   L
LIMPB     L
WAFERCON  L
WAFTRAN   L                                                                                        -T-T-T-T-T
CAPWAFER  L
LIMWAFER  L
PLYCON    L
CAPPLY    L
LIMPLY    L
PLYTRIM   L
LOGCHIP   L
ADBTAX    L                                                                                                  -T-T-U  -T-T-U
PULPPROD  L
PBPROD    L
WAFERPRO  L
PLYPROD   L
STSLETBD  L
STCONBD   L
STSTDBD   L
STUTILBD  L
STECONBD  L
STSTUD    L
STECON    L
DMSLETBD  L
DMCONBD   L
DMSTDBD   L
DMUTILBD  L
DMECONBD  L
DMCONST   L
DMSTAND   L
DMUTIL    L
DMECON    L
TWINBD1   L
TWINBD2A  L
TWINBD2B  L
TWINBD3   L
BOARD1    L
BOARD2A   L
BOARD2B   L
BOARD3    L
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             N S       T   B B P     P   W W P P P P       A           S C S   E C     E   E         B
             A T S D   W T O O U P   A P A A L L L L   C   V S C S   E L O T U C O S U C   C O       B                   W
             U U T I D I W A A L U S R A F F Y Y Y Y P H T A L B Z U C E N A T O N T T O   O D       F B B             W A
             L O U M I N I R R P L P T R E E M M M M L I A L E R A T O C B N I N S A I N   U F U B   I B B B   F F F F A F
             P M D M M M N D D M P R M T R R I I I I Y P X C C S B I N T T D L B T N L D S O I B B B B F F B F B B B B F B
             L I C I C I C M C I C U I C M C L L L L C L A H T T B L D B B B B B D D D B T S B F F B T 2 2 F U 3 5 1 3 1 /
             Y L A L A L A I A L A C L A I A L L L L A O A I B B B B B D B B D D I I I I U T T 2 3 F B A B 3 L / / / / / 1
             B L P L P L P L P L P E L P L P 1 2 3 4 P E D P D D D D D D D D D M M M M M D D B A B 3 T T T T F 4 8 2 8 4 6

ZMAX      N -A-B-A-B-A-B-A-B-A-B-B-B-B-B-B-B-B-B-B-B-B-A-U X C C C C B C C C C B C C C B C B C C C C C C C C C C C C C C C
OPCAP     L  A B A B A B A B A B B B B B B B B B B B B A U
ALLOWCUT  L
LIMHAR1   L
LIMHAR2   L
LIMHAR3   L
LIMHAR4   L
LIMHAR5   L
TLAMT1    L
TLAMT2    L
TLAMT3    L
TLAMT4    L
TLAMT5    L
FTAMT1    L
FTAMT2    L
FTAMT3    L
FTAMT4    L
FTAMT5    L
TLSIZ9    L
TLSIZ12   L
TLSIZ15   L
TLSIZ18   L
FTSIZ9    L
FTSIZ12   L
FTSIZ15   L
FTSIZ18   L  1
BARK      L -U
BRAN-TOP  L -U
CHIPS     L   -A  -A  -T  -A   1    -1      -T-T-B-B  -1   A                                                             1
LOGS9     L    T   T   T   T
LOGS12    L    T   T   T   T
LOGS15    L    T   T   T   T
LOGS18    L    T   T   T   T
LOG8      L -U                               1
LOG11     L -T                                 1
LOG14     L -T                                   1
LOG17     L -T                                     1
STUDTRAN  L   -1 1
CAPSTUD   L      B
LIMSTD    L      1   1
DIMTRAN   L       -1 1
CAPDIM    L          B
TWINTRAN  L           -1 1
CAPTWIN   L              B
LIMTWIN   L              1
BOARDTRN  L               -1 1
CAPBOARD  L                  B
LIMBOARD  L                  1
PULPTRAN  L                   -T 1
CAPPULP   L                      C
LIMPULP   L                      1
SPHERD    L                      T-A
PBTRAN    L                           -T 1
CAPPART   L                              B
LIMPB     L                              1
WAFERCON  L        A                     1
WAFTRAN   L                             -1 1
CAPWAFER  L                                C
LIMWAFER  L                                1
PLYCON    L                                 -T-T-T-T 1
CAPPLY    L                                          C
LIMPLY    L                                          1
PLYTRIM   L                                 -T-T-T-T
LOGCHIP   L                                            1
ADDTAX    L                                             -1   C C C C B C C C C B C C C B C B C C C C C C C [illegible] C C C C
PULPPROD  L                     -1
PBPROD    L                           -1                                                                       1 1 1 1
WAFERPRO  L                               -1                                                                           1 1
PLYPROD   L                                         -1
STSLETBD  L   -U                                             A
STCONBD   L   -U                                               A
STSTDBD   L   -U                                                 A
STUTILBD  L   -U                                                   A
STECONBD  L   -V                                                     A
STSTUD    L   -T                                                                         A
STECON    L   -T                                                                           A
DMSLETBD  L       -U                                                   A
DMCONBD   L       -U                                                     A
DMSTDBD   L       -U                                                       A
DMUTILBD  L       -U                                                         A
DMECONBD  L       -V                                                           A
DMCONST   L       -T                                                             A
DMSTAND   L       -T                                                               A
DMUTIL    L       -T                                                                 A
DMECON    L       -T                                                                   A
TWINBD1   L           -T                                                                             A
TWINBD2A  L           -T                                                                               A
TWINBD2B  L           -T                                                                                 A
TWINBD3   L           -T                                                                                   A
BOARD1    L               -T                                                                 A
BOARD2A   L               -T                                                                   A
BOARD2B   L               -T                                                                     A
BOARD3    L               -T                                                                       A
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                        W           T     M  M  M  M  M  M  M  M  O
                     W  A           R  H  O  O  O  O  O  O  O  O  P
                  W  A  F  P  P  P  I  O  N  N  N  N  N  N  N  N  E
                  A  F  S  L  L  L  M  G  E  E  E  E  E  E  E  E  R
                  F  T  /  Y  Y  Y  B  F  Y  Y  Y  Y  Y  Y  Y  Y  A  R
                  3  /  5  1  1  3  O  U  S  D  T  B  P  P  W  P  T  H
                  /  1  T  /  /  /  S  E  T  I  W  B  L  R  A  L  E  S
                  8  6  6  4  2  4  D  L  D  M  N  R  P  T  F  Y  S  1

ZMAX       N      C  C  C  C  C  C  A  A -T -T -T -T -T -T -T -T -T
OPCAP      L                                                     -1
ALLOWCUT   L                                                         6
LIMHAR1    L                                                         D
LIMHAR2    L                                                         D
LIMHAR3    L                                                         D
LIMHAR4    L                                                         D
LIMHAR5    L                                                         D
TLAMT1     L
TLAMT2     L
TLAMT3     L
TLAMT4     L
TLAMT5     L
FTAMT1     L
FTAMT2     L
FTAMT3     L
FTAMT4     L
FTAMT5     L
TLSIZ8     L
TLSIZ12    L
TLSIZ15    L
TLSIZ18    L
FTSIZ8     L
FTSIZ12    L
FTSIZ15    L
FTSIZ18    L
BARK       L                           1
BRAN-TOP   L                           1
CHIPS      L
LOGS8      L
LOGS12     L
LOGS15     L
LOGS18     L
LOG8       L
LOG11      L
LOG14      L
LOG17      L
STUDTRAN   L
CAPSTUD    L                             -1
LIMSUD     L                                                         8
DIMTRAN    L
CAPDIM     L                                -1
TWINTRAN   L
CAPTWIN    L                                   -1
LIMTWIN    L                                                         8
BOARDTRN   L
CAPBOARD   L                                      -1
LIMBOARD   L                                                         8
PULPTRAN   L
CAPPULP    L                                         -1
LIMPULP    L                                                         P
SPWOOD     L
PBTRAN     L
CAPPART    L                                            -1
LIMPB      L                                                         P
WAFERCON   L
WAFTRAN    L
CAPWAFER   L                                               -1
LIMWAFER   L                                                         P
PLYCON     L
CAPPLY     L                                                  -1
LIMPLY     L                                                         8
PLYTRIM    L                        1
LOGCHIP    L
ADDTAX     L      C  C  C  C  C  C
PULPPROD   L
PBPROD     L
WAFERPRO   L      1  1  1
PLYPROD    L               1  1  1
STSLETOD   L
STCONOD    L
STSTOOD    L
STUTILOD   L
STSECOND   L
STSTUD     L
STECON     L
DMSLETOD   L
DMCONOD    L
DMSTOOD    L
DMUTILOD   L
DMSECOND   L
DMCONST    L
DMSTAND    L
DMUTIL     L
DMECON     L
TWINSS1    L
TWINSS2A   L
TWINSS2B   L
TWINSS3    L
BOARD1     L
BOARD2A    L
BOARD2B    L
BOARD3     L
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                    SUMMARY OF MATRIX
SYMBOL                   RANGE                         COUNT (INCL RHS)
  Z                 LESS THAN              .000001
  Y              .000001  THRU             .000009
  X              .000010                   .000099         1
  W              .000100                   .000999
  V              .001000                   .009999         2
  U              .010000                   .099999        49
  T              .100000                   .999999       151
  1             1.000000                  1.000000       107
  A             1.000001                 10.000000       134
  B            10.000001                100.000000       102
  C           100.000001              1,000.000000        92
  D         1,000.000001             10,000.000000         6
  E        10,000.000001            100,000.000000         4
  F       100,000.000001          1,000,000.000000         3
  G              GREATER THAN     1,000,000.000000         1
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          REFERENCE MATRIX
           HARVEST1      HARVEST2      HARVEST3      HARVEST4      HARVEST5      HARVES1A      HARVES2A      HARVES3A        1    1

ZMAX       34.50000-     44.85000-     61.10000-     75.67000-     84.13000-     34.50000-     44.85000-     61.10000-     ZMAX
OPCAP      34.50000      44.85000      61.10000      75.67000      84.13000      34.50000      44.85000      61.10000      OPCAP
ALLOWCUT   73.40000      85.00000     130.00000     161.10000     170.00000      73.40000      85.00000     130.00000      ALLOWCUT
LIMHAR1     1.00000                                                               1.00000                                   LIMHAR1
LIMHAR2                   1.00000                                                               1.00000                     LIMHAR2
LIMHAR3                                 1.00000                                                               1.00000       LIMHAR3
LIMHAR4                                               1.00000                                                               LIMHAR4
LIMHAR5                                                             1.00000                                                 LIMHAR5
TLAMT1     73.40000-                                                                                                        TLAMT1
TLAMT2                   85.00000-                                                                                          TLAMT2
TLAMT3                                130.00000-                                                                            TLAMT3
TLAMT4                                              161.10000-                                                              TLAMT4
TLAMT5                                                            170.00000-                                                TLAMT5
FTAMT1                                                                           76.50000-                                  FTAMT1
FTAMT2                                                                                        101.60000-                    FTAMT2
FTAMT3                                                                                                      139.10000-      FTAMT3


           HARVES4A      HARVES5A      TL1AR1        TL2AR1        FT1AR1        FT2AR1        TL1AR2        TL2AR2          2    1

ZMAX       75.67000-     84.13000-     87.22000-     53.84000-    120.80000-     83.88000-     87.22000-     53.84000-     ZMAX
OPCAP      75.67000      84.13000      87.22000      53.84000     120.80000      83.88000      87.22000      53.84000      OPCAP
ALLOWCUT  161.10000     170.00000                                                                                           ALLOWCUT
LIMHAR4     1.00000                                                                                                         LIMHAR4
LIMHAR5                   1.00000                                                                                           LIMHAR5
TLAMT1                                  5.66000       2.60000                                                               TLAMT1
TLAMT2                                                                                          5.66000       2.60000       TLAMT2
FTAMT1                                                              6.41000       4.35000                                   FTAMT1
FTAMT4    172.30000-                                                                                                        FTAMT4
FTAMT5                  181.60000-                                                                                          FTAMT5
TLSI20                                   .48800-       .22100-                                   .49600-       .24000-      TLSI20
TLSI212                                 1.10000-       .55700-                                  1.20000-       .62300-      TLSI212
TLSI216                                  .77000-       .30100-                                   .88000-       .42000-      TLSI216
TLSI218                                  .65700-       .32500-                                   .73000-       .36100-      TLSI218
FTSI20                                                               .66400-       .34400-                                  FTSI20
FTSI212                                                             1.57400-       .66800-                                  FTSI212
FTSI216                                                             1.14600-       .59300-                                  FTSI216
FTSI218                                                              .97600-       .50600-                                  FTSI218


           FT1AR2        FT2AR2        TL1AR3        TL2AR3        FT1AR3        FT2AR3        TL1AR4        TL2AR4          3    1

ZMAX      120.80000-     83.88000-     87.22000-     53.84000-    120.80000-     83.88000-     87.22000-     53.84000-     ZMAX
OPCAP     120.80000      83.88000      87.22000      53.84000     120.80000      83.88000      87.22000      53.84000      OPCAP
TLAMT3                                  5.66000       2.60000                                                               TLAMT3
TLAMT4                                                                                          5.66000       2.60000       TLAMT4
FTAMT2      6.41000       4.35000                                                                                           FTAMT2
FTAMT3                                                              6.41000       4.35000                                   FTAMT3
TLSI20                                   .48100-       .23000-                                   .52100-       .25600-      TLSI20
TLSI212                                 1.21100-       .55900-                                  1.31000-       .65200-      TLSI212
TLSI216                                  .82300-       .40900-                                   .90000-       .44600-      TLSI216
TLSI218                                  .70300-       .34700-                                   .76400-       .37600-      TLSI218
FTSI20       .74000-       .34400-                                   .71600-       .37100-                                  FTSI20
FTSI212     1.56700-       .66600-                                  1.60000-       .63300-                                  FTSI212
FTSI216     1.27600-       .65300-                                  1.22600-       .62000-                                  FTSI216
FTSI218     1.06500-       .56200-                                  1.04300-       .56100-                                  FTSI218
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            FT1AR4      FT2AR4      TL1AR5      TL2AR5      FT1AR5      FT2AR5      HAULSAW1    HAULSAW2      4 . 1

ZMAX        120.00000-  63.88000-   67.22000-   53.84000-   120.00000-  63.88000-   3.52000-    3.52000-    ZMAX
OPCAP       120.00000   63.88000    67.22000    53.84000    120.00000   63.88000    3.52000     3.52000     OPCAP
TLAMT5                              5.66000     2.60000                                                     TLAMT5
FTAMT4      6.41000     4.30000                                                                             FTAMT4
FTAMT5                                                      6.41000     4.36000                             FTAMT5
TLSIZ8                              .55500-     .27400-                             1.00000                 TLSIZ8
TLSIZ12                             1.40400-    .89400-                                         1.00000     TLSIZ12
TLSIZ16                             .90200-     .47500-                                                     TLSIZ16
TLSIZ18                             .61500-     .40200-                                                     TLSIZ18
FTSIZ8      .77400-     .40100-                             .83400-     .42700-                             FTSIZ8
FTSIZ12     1.80000-    1.01800-                            2.00000-    1.08100-                            FTSIZ12
FTSIZ16     1.33700-    .80300-                             1.43000-    .74100-                             FTSIZ16
FTSIZ18     1.13500-    .58000-                             1.21100-    .53800-                             FTSIZ18
BARK                                                                                .08000-     .09000-     BARK
LOGS8                                                                               .74000-                 LOGS8
LOGS12                                                                                          .75000-     LOGS12


            HAULSAW3    HAULSAW4    HAULSAW5    HAULSAW6    HAULSAW7    HAULSAW8    HAULCHP1    HAULCHP2      5 . 1

ZMAX        3.52000-    3.52000-    3.67000-    3.67000-    3.67000-    3.67000-    3.52000-    3.67000-    ZMAX
OPCAP       3.52000     3.52000     3.67000     3.67000     3.67000     3.67000     3.52000     3.67000     OPCAP
TLSIZ8                                                                              1.00000                 TLSIZ8
TLSIZ12                                                                             1.00000                 TLSIZ12
TLSIZ16     1.00000                                                                 1.00000                 TLSIZ16
TLSIZ18                 1.00000                                                     1.00000                 TLSIZ18
FTSIZ8                              1.00000                                                     1.00000     FTSIZ8
FTSIZ12                                         1.00000                                                     FTSIZ12
FTSIZ16                                                     1.00000                                         FTSIZ16
FTSIZ18                                                                 1.00000                             FTSIZ18
BARK        .08000-     .08000-     .08000-     .08000-     .06000-     .05000-     .08000-     .08000-     BARK
BRAN-TOP                            .01000-     .05000-     .04000-     .03000-                 .01000-     BRAN-TOP
CHIPS                                                                               .73200-     .73200-     CHIPS
LOGS8                               .70000-                                                                 LOGS8
LOGS12                                          .75200-                                                     LOGS12
LOGS16      .76200-                                         .74000-                                         LOGS16
LOGS18                  .81000-                                         .78400-                             LOGS18


            HAULCHP3    HAULCHP4    HAULCHP5    HAULWAF1    HAULWAF2    HAULWAF3    HAULWAF4    HAULWAF5      6   1

ZMAX        3.67000-    3.67000-    3.67000-    3.52000-    3.67000-    3.67000-    3.67000-    3.67000-    ZMAX
OPCAP       3.67000     3.67000     3.67000     3.52000     3.67000     3.67000     3.67000     3.67000     OPCAP
TLSIZ8                                          1.00000                                                     TLSIZ8
TLSIZ12                                         1.00000                                                     TLSIZ12
TLSIZ16                                         1.00000                                                     TLSIZ16
TLSIZ18                                         1.00000                                                     TLSIZ18
FTSIZ8                                                      1.00000                                         FTSIZ8
FTSIZ12     1.00000                                                     1.00000                             FTSIZ12
FTSIZ16                 1.00000                                                     1.00000                 FTSIZ16
FTSIZ18                             1.00000                                                     1.00000     FTSIZ18
BARK        .08000-     .08000-     .08000-                                                                 BARK
BRAN-TOP    .05000-     .04000-     .03000-                                                                 BRAN-TOP
CHIPS       .74000-     .74000-     .75500-                                                                 CHIPS
WAFERCON                                        .43500-     .40700-     .41200-     .41800-     .42100-     WAFERCON
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	HAULPLY1	HAULPLY2	HAULPLY3	HAULPLY4	HAULPLY5	HAULPLY6	HAULPLY7	HAULPLY8	7 . . . 1
ZMAX	3.52000-	3.52000-	3.52000-	3.52000-	3.67000-	3.67000-	3.67000-	3.67000-	ZMAX
OPCAP	3.52000	3.52000	3.52000	3.52000	3.67000	3.67000	3.67000	3.67000	OPCAP
TLSIZ8	1.00000								TLSIZ8
TLSIZ12		1.00000							TLSIZ12
TLSIZ15			1.00000						TLSIZ15
TLSIZ18				1.00000					TLSIZ18
PTSIZ8					1.00000				PTSIZ8
PTSIZ12						1.00000			PTSIZ12
PTSIZ15							1.00000		PTSIZ15
PTSIZ18								1.00000	PTSIZ18
BARK	.08000-	.08000-	.08000-	.08000-	.08000-	.08000-	.08000-	.08000-	BARK
BRAN-TOP					.06000-	.05000-	.04000-	.03000-	BRAN-TOP
LOGS	.33000-	.34500-	.40800-	.09200-	.21500-	.32600-	.38100-	.08900-	LOGS
LOGS11		.17300-	.30700-	.36800-		.18300-	.25300-	.35500-	LOGS11
LOGS14			.15300-	.32200-			.14700-	.31200-	LOGS14
LOGS17				.13800-				.13400-	LOGS17
LOGCHIP	.59000-	.40200-	.05200-		.64500-	.36100-	.05000-		LOGCHIP

	STUDMILL	STUDCAP	DIMMILL	DIMCAP	TWINMILL	TWINCAP	BOARDMIL	BOARDCAP	8 . . . 1
ZMAX	15.33000-	5.34000-	15.33000-	5.34000-	35.70000-	7.13000-	17.06000-	5.85000-	ZMAX
OPCAP	15.33000	5.34000	15.33000	5.34000	35.70000	7.13000	17.06000	5.85000	OPCAP
CHIPS	1.45000-		1.45000-		.72000-		1.45000-		CHIPS
LOGS8	.44500		.44500		.46500		.47500		LOGS8
LOGS12	.55500		.55500		.46500		.47500		LOGS12
LOGS15	.60000		.60000		.46500		.47500		LOGS15
LOGS18	.62500		.62500		.46500		.47500		LOGS18
STUDTRAN	1.00000-	1.00000							STUDTRAN
CAPSTUD		45.20000							CAPSTUD
LIMSAD		1.00000		1.00000					LIMSAD
DIMTRAN			1.00000-	1.00000					DIMTRAN
CAPDIM				45.20000					CAPDIM
TWINTRAN					1.00000-	1.00000			TWINTRAN
CAPTWIN						55.23000			CAPTWIN
LIMTWIN						1.00000			LIMTWIN
BOARDTRN							1.00000-	1.00000	BOARDTRN
CAPBOARD								55.23000	CAPBOARD
LIMBOARD								1.00000	LIMBOARD
STSLETBD		.03300-							STSLETBD
STCONBD		.01400-							STCONBD
STSTDBD		.02000-							STSTDBD
STUTILBD		.01300-							STUTILBD
STECONBD		.00100-							STECONBD
STSTUD		.78700-							STSTUD
STECON		.12300-							STECON
DMSLETBD				.03300-					DMSLETBD
DMCONBD				.01400-					DMCONBD
DMSTDBD				.02000-					DMSTDBD
DMUTILBD				.01300-					DMUTILBD
DMECONBD				.00100-					DMECONBD
DMCONST				.44500-					DMCONST
DMSTAND				.76800-					DMSTAND
DMUTIL				.20000-					DMUTIL
DMECON				.12300-					DMECON
TWINBD1						.17000-			TWINBD1
TWINBD2A						.24000-			TWINBD2A
TWINBD2B						.25000-			TWINBD2B
TWINBD3						.34000-			TWINBD3
BOARD1								.20000-	BOARD1
BOARD2A								.25000-	BOARD2A
BOARD2B								.25000-	BOARD2B
BOARD3								.30000-	BOARD3

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             PULPMILL      PULPCAP       SPRUCE        PARTMILL      PARTCAP       WAFERMIL      WAFERCAP      PLYMILL1        9      1

ZMAX         53.52000-     55.40000-     35.00000-     52.33000-     10.10000-     75.55000-     25.55000-     48.05000-
OPCAP        53.52000      55.40000      35.00000      52.33000      10.10000      75.55000      25.55000      48.05000     ZMAX
CHIPS         1.00000                                   1.00000                                                  .27000-    OPCAP
LOGS                                                                                                            1.00000     CHIPS
PULPTRAN       .31450-      1.00000                                                                                         LOGS
CAPPULP                   744.13000                                                                                         PULPTRAN
LIMPULP                     1.00000                                                                                         CAPPULP
SPREED                      1.00000      3.13700-                                                                           LIMPULP
PBTRAN                                                   .75000-      1.00000                                               SPREED
CAPPART                                                              81.55000                                               PBTRAN
LIMPB                                                                 1.00000                                               CAPPART
WAFERCON                                                                            1.00000                                 LIMPB
WAFTRAN                                                                             1.00000-      1.00000                   WAFERCON
CAPWAFER                                                                                        305.18000                   WAFTRAN
LIMWAFER                                                                                          1.00000                   CAPWAFER
PLYCON                                                                                                         .43000-      LIMWAFER
PLYTRIM                                                                                                        .19000-      PLYCON
PULPPROD                    1.00000-                                                                                        PLYTRIM
PBPROD                                                               1.00000-                                               PULPPROD
WAFERPRO                                                                                          1.00000-                  PBPROD
                                                                                                                            WAFERPRO


             PLYMILL2      PLYMILL3      PLYMILL4      PLYCAP        CHIPLOG       TAXSAD        AVALCHIP      SLECTBD        10      1

ZMAX         55.92000-     60.45000-     62.77000-     25.54000-      7.84000-       .02750-       .00010      305.00000
OPCAP        55.92000      60.45000      62.77000      25.54000       7.84000        .02750                                 ZMAX
CHIPS          .15000-       .05000-       .05000-                    1.00000-                    3.84500                   OPCAP
LOG11         1.00000                                                                                                       CHIPS
LOG14                       1.00000                                                                                         LOG11
LOG17                                     1.00000                                                                           LOG14
PLYCON         .48000-       .53000-       .55000-      1.00000                                                             LOG17
CAPPLY                                                207.25000                                                             PLYCON
LIMPLY                                                  1.00000                                                             CAPPLY
PLYTRIM        .25000-       .27000-       .24000-                                                                          LIMPLY
LOGCHIP                                                               1.00000                                               PLYTRIM
ADSTAX                                                                              1.00000-                    305.00000   LOGCHIP
PLYPROD                                                 1.00000-                                                            ADSTAX
STSLETBD                                                                                                                    PLYPROD
                                                                                                                  1.84700   STSLETBD


             CONSTBD       STANDBD       UTILBD        ECONBD        SLECTBDD      CONSTBDD      STANDBDD      UTILBDD        11      1

ZMAX        200.00000     195.00000     120.00000      85.00000     305.00000     200.00000     195.00000     120.00000
ADSTAX      200.00000     195.00000     120.00000      85.00000     305.00000     200.00000     195.00000     120.00000     ZMAX
STCONBD       1.84700                                                                                                       ADSTAX
STSTDBD                     1.84700                                                                                         STCONBD
STUTILBD                                  1.84700                                                                           STSTDBD
STECONBD                                                1.84700                                                             STUTILBD
DMSLETBD                                                              1.84700                                               STECONBD
DMCONBD                                                                             1.84700                                 DMSLETBD
DMSTDBD                                                                                           1.84700                   DMCONBD
DMUTILBD                                                                                                        1.84700     DMSTDBD
                                                                                                                            DMUTILBD
```

```
             ECONSUBD     CONSTDIM     STANDIM      UTILDIM      ECONODIM     STUD         ECONOSTD     BD#1STR       12     1

ZMAX         85.00000     152.00000    152.00000    103.00000    85.00000     149.00000    85.00000     425.00000     ZMAX
ADSTAX       85.00000     152.00000    152.00000    102.00000    85.00000     149.00000    85.00000     425.00000     ADSTAX
STSTUD                                                                        1.54700                                 STSTUD
STECON                                                                                     1.54700                    STECON
DMECONSD      1.54700                                                                                                 DMECONSD
DMCONST                    1.54700                                                                                    DMCONST
DMSTAND                                 1.54700                                                                       DMSTAND
DMUTIL                                               1.54700                                                          DMUTIL
DMECON                                                            1.54700                                             DMECON
BOARD1                                                                                                  2.32400       BOARD1


             BD#2A        BD#2B        BD#3         BD#1STRT     BD#2AT       BD#2BT       BD#3T        PULP          12     1

ZMAX         280.00000    200.00000    150.00000    425.00000    280.00000    200.00000    150.00000    510.00000     ZMAX
ADSTAX       280.00000    200.00000    150.00000    425.00000    280.00000    200.00000    150.00000    510.00000     ADSTAX
PULPPROD                                                                                                  1.00000     PULPPROD
TWINBD1                                              2.32400                                                          TWINBD1
TWINBD2A                                                          2.32400                                             TWINBD2A
TWINBD2B                                                                       2.32400                                TWINBD2B
TWINBD3                                                                                     2.32400                   TWINBD3
BOARD2A       2.32400                                                                                                 BOARD2A
BOARD2B                    2.32400                                                                                    BOARD2B
BOARD3                                  2.32400                                                                       BOARD3


             PB3/4        PB5/8        PB1/2        PB3/8        WAF1/4       WAF5/16      WAF3/8       WAF7/16       14     1

ZMAX         203.04000    211.88000    211.88000    228.32000    317.80000    298.81000    264.83000    248.18000     ZMAX
ADSTAX       203.04000    211.88000    211.88000    228.32000    317.80000    298.81000    264.83000    248.18000     ADSTAX
PBPROD         1.00000      1.00000      1.00000      1.00000                                                         PBPROD
WAFERPRO                                                            1.00000      1.00000      1.00000      1.00000    WAFERPRO
```

```
              WAFS/STS      PLY1/4       PLY1/2       PLY3/4      TRIMBOND     HOGFUEL      MONEYSTD     MONEYDIM      15      1

ZMAX         266.02000    557.94000    327.48000    284.04000     6.14000      5.11000       .12000-      .12000-    ZMAX
BARK                                                                           1.00000                                BARK
BRAN-TOP                                                                       1.00000                                BRAN-TOP
CAPSTUD                                                                                     1.00000-                  CAPSTUD
CAPDIM                                                                                                   1.00000-    CAPDIM
PLYTRIM                                                                1.00000                                        PLYTRIM
ABSTAX       266.02000    557.94000    327.48000    284.04000                                                         ABSTAX
WAFERPRD       1.00000                                                                                                WAFERPRD
PLYPROD                     1.00000      1.00000      1.00000                                                         PLYPROD


              MONEYTWN     MONEYBRD     MONEYPLP     MONEYPRT     MONEYWAF     MONEYPLY     OPERATSS      RHS1         15      1

ZMAX           .12000-      .12000-      .12000-      .12000-      .12000-      .12000-      .24000-                  ZMAX
OPCAP                                                                                       1.00000-                  OPCAP
ALLOWCUT                                                                                                 2254000.0    ALLOWCUT
LIMHAR1                                                                                                  1910.0000    LIMHAR1
LIMHAR2                                                                                                  5853.0000    LIMHAR2
LIMHAR3                                                                                                  4431.0000    LIMHAR3
LIMHAR4                                                                                                  3670.0000    LIMHAR4
LIMHAR5                                                                                                  2050.0000    LIMHAR5
LIMSAD                                                                                                   42250.000    LIMSAD
CAPTWIN       1.00000-                                                                                                CAPTWIN
LIMTWIN                                                                                                  46312.000    LIMTWIN
CAPBOARD                   1.00000-                                                                                   CAPBOARD
LIMBOARD                                                                                                 36000.000    LIMBOARD
CAPPULP                                 1.00000-                                                                      CAPPULP
LIMPULP                                                                                                  157500.00    LIMPULP
CAPPART                                              1.00000-                                                         CAPPART
LI[illegible]                                                                                                         LIMPRT
CA[illegible]R                                                    1.00000-                                            CAPWAFER
LIMWA[illegible]R                                                                                        141000.00    LIMWAFER
CAPPLY                                                                          1.00000-                              CAPPLY
LIMPLY                                                                                                   27460.000    LIMPLY
```

APPENDIX 10. COMPUTER PRINTOUT OF OPTIMAL SOLUTION

```
REFERENCE MATRIX SOLUTION

SOLUTION    (OPTIMAL)

TIME =    0.03 MINS  ITERATION NUMBER =    101

  NAME            ACTIVITY           DEFINED AS

FUNCTIONAL     24082400.0000        ZMAX
RESTRAINTS                          RHS1
```

```
SECTION 1 - ROWS

NUMBER     ROW       AT       ACTIVITY      SLACK ACTIVITY   LOWER LIMIT     UPPER LIMIT    DUAL ACTIVITY

    1   ZMAX        BS  24053400.8500   24053400.8500-           NONE            NONE         1.00000
    2   DPCAP       UL                                            NONE                          .24000-
    3   ALLOWCUT    BS    937062.11737   1330937.88263            NONE    2268000.00000
    4   LIMHAR1     BS                      1010.00000            NONE       1010.00000
    5   LIMHAR2     BS                      5853.00000            NONE       5853.00000
    6   LIMHAR3     BS                      4431.00000            NONE       4431.00000
    7   LIMHAR4     BS      3495.53766       380.46234            NONE       3876.00000
    8   LIMHAR5     UL      2060.00000                            NONE       2060.00000     240.44053-
    9   TLAMT1      BS                                            NONE
   10   TLAMT2      BS                                            NONE
   11   TLAMT3      BS                                            NONE
   12   TLAMT4      UL                                            NONE                          .64244-
   13   TLAMT5      UL                                            NONE                         1.07632-
   14   FTAMT1      BS                                            NONE
   15   FTAMT2      BS                                            NONE
   16   FTAMT3      BS                                            NONE
   17   FTAMT4      UL                                            NONE                          .54450-
   18   FTAMT5      UL                                            NONE                         1.84732-
   19   TLSIZ8      UL                                            NONE                        33.66476-
   20   TLSIZ12     UL                                            NONE                        30.07000-
   21   TLSIZ15     UL                                            NONE                        33.76026-
   22   TLSIZ18     UL                                            NONE                        33.82103-
   23   FTSIZ8      UL                                            NONE                        31.10044-
   24   FTSIZ12     UL                                            NONE                        31.85007-
   25   FTSIZ15     UL                                            NONE                        31.90240-
   26   FTSIZ18     UL                                            NONE                        32.34461-
   27   BARK        BS     10013.24046-     10013.24046            NONE
   28   BRAN-TOP    UL                                            NONE                         6.11000-
   29   CHIPS       UL                                            NONE                        36.70000
   30   LOGS8       UL                                            NONE                        50.77377-
   31   LOGS12      UL                                            NONE                        41.35650
   32   LOGS15      UL                                            NONE                        46.74040
   33   LOGS18      UL                                            NONE                        47.14300-
   34   LOG8        UL                                            NONE                        41.22300-
   35   LOG11       UL                                            NONE                        41.18513-
   36   LOG14       UL                                            NONE                        41.70676-
   37   LOG17       UL                                            NONE                        41.90178-
   38   STUDTRAN    UL                                            NONE                        55.92035-
   39   CAPSTUD     UL                                            NONE                          .12000-
   40   LIMSAD      UL     42250.00000                            NONE      42250.00000      10.10026-
   41   DIMTRAN     UL                                            NONE                        55.02193-
   42   CAPDIM      UL                                            NONE                          .12000-
   43   TWINTRAN    UL                                            NONE                        63.56604-
   44   CAPTWIN     UL                                            NONE                          .12000-
   45   LIMTWIN     BS                     46312.00000            NONE      46312.00000
   46   BOARDTRN    UL                                            NONE                        54.35120-
   47   CAPBOARD    UL                                            NONE                          .12000-
   48   LIMBOARD    UL     36000.00000                            NONE      36000.00000      35.00701-
   49   PULPTRAN    UL                                            NONE                       200.00740-
   50   CAPPULP     UL                                            NONE                          .12000-
   51   LIMPULP     BS                    167500.00000 .          NONE     167500.00000
   52   SPHEED      BS                                            NONE
   53   PBTRAN      UL                                            NONE                       131.20040-
   54   CAPPART     UL                                            NONE                          .12000-
   55   LIMPB       UL    100250.00000                            NONE     100250.00000      67.60002-
   56   WAFERCON    UL                                            NONE                        66.22063-
   57   WAFTRAN     UL                                            NONE                       163.14063-
   58   CAPWAFER    UL                                            NONE                          .12000-
   59   LIMWAFER    UL    141600.00000                            NONE     141600.00000      60.07319-
   60   PLYCON      UL                                            NONE                       200.50003-
   61   CAPPLY      UL                                            NONE                          .12000-
   62   LIMPLY      UL     37450.00000                            NONE      37450.00000     272.67102-
   63   PLYTRIM     UL                                            NONE                         6.14000-
   64   LOGCHIP     UL                                            NONE                        26.00046-
   65   ADSTAX      UL                                            NONE                          .03010-
   66   PULPPROD    UL                                            NONE                       402.50000-
   67   PBPROD      UL                                            NONE                       221.50010-
   68   WAFERPRO    UL                                            NONE                       306.56302-
   69   PLYPROD     UL                                            NONE                       536.91425-
   70   STSLETOD    UL                                            NONE                       100.43277-
   71   STCONSD     UL                                            NONE                       124.87305-
   72   STSTOOD     UL                                            NONE                       121.75210-
   73   STUTILOD    UL                                            NONE                        74.82437-
   74   STECONOD    UL                                            NONE                        53.07143-
   75   STSTUD      UL                                            NONE                        53.03100-
   76   STECON      UL                                            NONE                        53.07143-
   77   DMSLETOD    UL                                            NONE                       100.43277-
   78   DMCONSD     UL                                            NONE                       124.87305-
   79   DMSTOOD     UL                                            NONE                       121.75210-
   80   DMUTILOD    UL                                            NONE                        74.82437-
   81   DMECONOD    UL                                            NONE                        53.07143-
   82   DMCONST     UL                                            NONE                        54.50420-
   83   DMSTAND     UL                                            NONE                        54.50420-
   84   DMUTIL      UL                                            NONE                        54.31006-
   85   DMECON      UL                                            NONE                        53.07143-
   86   TWINOD1     UL                                            NONE                       176.53834-
   87   TWINOD2A    UL                                            NONE                       116.37240-
   88   TWINOD2B    UL                                            NONE                        53.12302-
   89   TWINOD3     UL                                            NONE                        52.34204-
   90   BOARD1      UL                                            NONE                       176.53834-
   91   BOARD2A     UL                                            NONE                       116.37240-
   92   BOARD2B     UL                                            NONE                        53.12302-
   93   BOARD3      UL                                            NONE                        52.34204-
```

```
SECTION 2 - COLUMNS

NUMBER   .COLUMN.   AT     ...ACTIVITY...   ..INPUT COST..   ..LOWER LIMIT.   ..UPPER LIMIT.   .REDUCED COST.

    94   HARVEST1   LL                         34.50000-                          NONE           42.70000-
    95   HARVEST2   LL                         44.05000-                          NONE           55.30000-
    96   HARVEST3   LL                         61.10000-                          NONE           70.70400-
    97   HARVEST4   BS       1832.71810        75.87000-                          NONE
    98   HARVEST5   BS                         84.13000-                          NONE
    99   HARVES1A   LL                         34.50000-                          NONE           42.70000-
   100   HARVES2A   LL                         44.05000-                          NONE           55.30000-
   101   HARVES3A   LL                         61.10000-                          NONE           70.70400-
   102   HARVES4A   BS       1881.83291        75.87000-                          NONE
   103   HARVES5A   BS       2000.00000        84.13000-                          NONE
   104   TL1AR1     LL                         87.22000-                          NONE           11.27020-
   105   TL2AR1     LL                         53.94000-                          NONE           10.87058-
   106   FT1AR1     LL                        120.80000-                          NONE           10.10570-
   107   FT2AR1     LL                         83.98000-                          NONE           30.70253-
   108   TL1AR2     LL                         87.22000-                          NONE            1.77808-
   109   TL2AR2     LL                         53.94000-                          NONE           14.24100-
   110   FT1AR2     LL                        120.80000-                          NONE            2.81180-
   111   FT2AR2     LL                         83.98000-                          NONE           22.31085-
   112   TL1AR3     LL                         87.22000-                          NONE            5.73003-
   113   TL2AR3     LL                         53.94000-                          NONE           16.21480-
   114   FT1AR3     LL                        120.80000-                          NONE            8.75883-
   115   FT2AR3     LL                         83.98000-                          NONE           28.30767-
   116   TL1AR4     BS      46000.20000        87.22000-                          NONE
   117   TL2AR4     LL                         53.94000-                          NONE           13.30427-
   118   FT1AR4     BS      38144.11038       120.80000-                          NONE
   119   FT2AR4     LL                         83.98000-                          NONE           20.81021-
   120   TL1AR5     LL                         87.22000-                          NONE             .40810-
   121   TL2AR5     LL                         53.94000-                          NONE           13.88841-
   122   FT1AR5     BS      47687.88810       120.80000-                          NONE
   123   FT2AR5     LL                         83.98000-                          NONE           20.84073-
   124   HAULSAW1   BS      24228.63000         3.52000-                          NONE
   125   HAULSAW2   BS      52824.13000         3.52000-                          NONE
   126   HAULSAW3   BS      41880.24027         3.52000-                          NONE
   127   HAULSAW4   BS      35528.20308         3.52000-                          NONE
   128   HAULSAW5   BS      20317.40818         3.87000-                          NONE
   129   HAULSAW6   LL                          3.87000-                          NONE            4.02118-
   130   HAULSAW7   BS      14280.80048         3.87000-                          NONE
   131   HAULSAW8   BS      20083.82103         3.87000-                          NONE
   132   HAULCHP1   LL                          3.52000-                          NONE          103.81158-
   133   HAULCHP2   LL                          3.87000-                          NONE            7.20878-
   134   HAULCHP3   LL                          3.87000-                          NONE            7.40137-
   135   HAULCHP4   LL                          3.87000-                          NONE            7.80873-
   136   HAULCHP5   LL                          3.87000-                          NONE            7.88032-
   137   HAULWAF1   LL                          3.52000-                          NONE           88.80118-
   138   HAULWAF2   BS      38401.75871         3.87000-                          NONE
   139   HAULWAF3   BS     173088.47787         3.87000-                          NONE
   140   HAULWAF4   BS     104781.48237         3.87000-                          NONE
   141   HAULWAF5   BS      24474.18300         3.87000-                          NONE
   142   HAULPLY1   LL                          3.52000-                          NONE            8.83482-
   143   HAULPLY2   BS       8600.73183         3.52000-                          NONE
   144   HAULPLY3   LL                          3.52000-                          NONE             .73801-
   145   HAULPLY4   LL                          3.52000-                          NONE             .02313-
   146   HAULPLY5   LL                          3.87000-                          NONE            8.00307-
   147   HAULPLY6   LL                          3.87000-                          NONE            4.94103-
   148   HAULPLY7   LL                          3.87000-                          NONE             .70700-
   149   HAULPLY8   BS      88388.88043         3.87000-                          NONE
   150   STUDMILL   BS      42280.00000        15.33000-                          NONE
   151   STUDCAP    BS      42280.00000         5.34000-                          NONE
   152   DIMMILL    LL                         15.33000-                          NONE            4.80442-
   153   DIMCAP     BS                          5.34000-                          NONE
   154   TWINMILL   LL                         36.70000-                          NONE           15.40710-
   155   TWINCAP    BS                          7.13000-                          NONE
   156   BOARDMIL   BS      38000.00000        17.00000-                          NONE
   157   BOARDCAP   BS      38000.00000         5.85000-                          NONE
   158   PULPMILL   LL                         53.52000-                          NONE           17.11083-
   159   PULPCAP    BS                         88.40000-                          NONE
   160   SPRUCE     LL                         35.00000-                          NONE           43.40000-
   161   PARTMILL   BS     127107.71883        52.33000-                          NONE
   162   PARTCAP    BS     100388.00000        10.10000-                          NONE
   163   WAFERMIL   BS     141800.00000        76.55000-                          NONE
   164   WAFERCAP   BS     141800.00000        28.55000-                          NONE
   165   PLYMILL1   BS       7082.77488        49.08000-                          NONE
   166   PLYMILL2   BS      21838.88380        55.52000-                          NONE
   167   PLYMILL3   BS      17887.38814        60.49000-                          NONE
   168   PLYMILL4   BS       7883.88118        63.77000-                          NONE
   169   PLYCAP     BS      27480.00000        25.54000-                          NONE
   170   CHIPLOG    BS       3820.81307         7.84000-                          NONE
   171   TAXBAS     BS   81449022.0033           .02750-                          NONE
   172   AVALCHIP   LL                           .00010                           NONE          113.88030-
   173   ELECTSD    BS        801.28080       305.00000                           NONE
   174   CONSTSD    BS        382.38284       200.00000                           NONE
   175   STANDSD    BS        848.21848       195.00000                           NONE
   176   UTILSD     BS        355.04302       120.00000                           NONE
   177   ECONOSD    BS         27.31082        85.00000                           NONE
   178   ELECTSDD   BS                        305.00000                           NONE
   179   CONSTSDD   BS                        200.00000                           NONE
   180   STANDSDD   BS                        195.00000                           NONE
   181   UTILSDD    BS                        120.00000                           NONE
   182   ECONOSDD   BS                         85.00000                           NONE
   183   CONSTDIM   BS                        152.00000                           NONE
   184   STANDDIM   BS                        152.00000                           NONE
   185   UTILDIM    BS                        103.00000                           NONE
   186   ECONODIM   BS                         85.00000                           NONE
   187   STUD       BS      21788.80872       145.00000                           NONE
   188   ECONOSTD   BS       2307.24370        85.00000                           NONE
   189   SD#1STR    BS       3270.22378       425.00000                           NONE
   190   SD#2A      BS       4087.77000       280.00000                           NONE
   191   SD#2B      BS       4087.77000       200.00000                           NONE
   192   SD#3       BS       4805.33863       150.00000                           NONE
   193   SD#1STRT   BS                        425.00000                           NONE
```

```
NUMBER   COLUMN     AT      ACTIVITY          INPUT COST      LOWER LIMIT     UPPER LIMIT    REDUCED COST

  194   SDF2AT      BS                         200 00000                          NONE
  195   SDF2ST      BS                         200 00000                          NONE
  196   SDF3T       BS                         150 00000                          NONE
  197   PULP        BS                         510 00000                          NONE
  198   PB3/4       LL                         203 04000                          NONE          25 30365-
  199   PB5/8       LL                         211 80000                          NONE          18 86461-
  200   PB1/2       LL                         211 80000                          NONE          18 86461-
  201   PB3/8       BS      100350 00000       220 32000                          NONE
  202   WAF1/4      BS      141800 00000       317 80000                          NONE
  203   WAF5/16     LL                         298 61000                          NONE          20 [illegible]742-
  204   WAF3/8      LL                         264 63000                          NONE          51 1[illegible]72-
  205   WAF7/16     LL                         248 18000                          NONE          57 24[illegible]-
  206   WAF5/8TE    LL                         286 02000                          NONE          30 69630-
  207   PLY1/4      BS       27480 00000       557 84000                          NONE
  208   PLY1/2      LL                         337 46000                          NONE         212 00103-
  209   PLY3/4      LL                         384 04000                          NONE         284 86001-
  210   TRIMWOOD    BS       13759 58488         8 14000                          NONE
  211   HOGFUEL     BS        4022 51707         8 11000                          NONE
  212   MONEYSTD    BS     1000700 00000           12000-                         NONE
  213   MONEYDIM    BS                               12000-                         NONE
  214   MONEYTWN    BS                               12000-                         NONE
  215   MONEYSDR    BS     2250740 00000           12000-                         NONE
  216   MONEYPLP    BS                               12000-                         NONE
  217   MONEYPBT    BS     6186200 60988           12000-                         NONE
  218   MONEYWAF    BS    37540558.8885           12000-                         NONE
  219   MONEYPLY    BS     5080836.[illegible]           12000-                         NONE
  220   OPERATBS    BS    48300000 1442           24000-                         NONE
```

APPENDIX 11. RANGE REPORT OF OPTIMAL SOLUTION

REFERENCE MATRIX RANGE REPORT

SECTION 1 - ROWS AT LIMIT LEVEL

NUMBER	ROW	AT	ACTIVITY	SLACK ACTIVITY	LOWER LIMIT UPPER LIMIT	LOWER ACTIVITY UPPER ACTIVITY	UNIT COST UNIT COST	UPPER COST LOWER COST	LIMITING PROCESS	AT AT
2	OPCAP	UL			NONE	INFINITY- 46360552.0000	24000- 24000		NONE OPERATES	 LL
8	LIMHAR8	UL	2050.00000		NONE 2050.00000	1767.95313 3000.07026	240.44052- 240.44052		LIMHAR4 FTIAR4	UL LL
12	TLAMT4	UL			NONE	61202.48313- 263101.50000	.58244- .58244		LIMHAR4 HARVEST4	UL LL
13	TLAMT5	UL			NONE	57405.51326-	1.87632- 1.87632		LIMHAR4 HARVEST5	UL LL
17	FTAMT4	UL			NONE	65553.62500- 320702.00000	.54458- .54458		LIMHAR4 HARVES4A	UL LL
18	FTAMT5	UL			NONE	61478.57422- 300850.37500	1.84732- 1.84732		LIMHAR4 FTIAR4	UL LL
19	TLSI29	UL			NONE	24328.63672- 27300.52734	33.66476- 33.66476		HAULSAW1 HAULSAW5	LL LL
20	TLSI212	UL			NONE	20002.60156- 61333.64375	26.57688- 26.57688		HAULSAW7 HAULSAW1	LL LL
21	TLSI215	UL			NONE	36651.35937- 13648.47656	33.75024- 33.75024		LIMHAR4 HAULSAW7	UL LL
22	TLSI218	UL			NONE	30431.26516- 19410.21484	33.82101- 33.82101		HAULWAF5 HAULSAW5	LL LL
23	FTSI29	UL			NONE	41301.70000- 110258.18750	31.10844- 31.10844		LIMHAR4 HAULWAF5	UL LL
24	FTSI212	UL			NONE	40000.55469- 112858.56250	31.55057- 31.55057		LIMHAR4 HAULWAF5	UL LL
25	FTSI215	UL			NONE	40405.24219- 111784.31250	31.90347- 31.90347		LIMHAR4 HAULWAF5	UL LL
26	FTSI218	UL			NONE	31440.46826- 105302.50000	32.34450- 32.34450		HAULWAF5 FTIAR4	LL LL
28	BRAN-TOP	UL			NONE	4622.51562- 10012.24000	6.11000- 6.11000		HOGFUEL BARK	LL UL
29	CHIPS	UL			NONE	8281.33203- 3035.80016	36.70007- 36.70007		HAULSAW7 CHIPLOG	LL LL
30	LOGS9	UL			NONE	35611.25381- 20622.24000	50.77376- 50.77376		LIMHAR4 HAULSAW5	UL LL
31	LOGS12	UL			NONE	15022.07031- 42047.50000	41.36658- 41.36658		HAULSAW7 HAULSAW2	LL LL
32	LOGS15	UL			NONE	30225.30326- 10075.10037	48.74046- 48.74046		LIMHAR4 HAULSAW7	UL LL
33	LOGS18	UL			NONE	24648.33044- 15722.27344	47.14209- 47.14209		HAULWAF5 HAULSAW5	LL LL
34	LOG8	UL			NONE	8611.10707- 24306.43564	41.22306- 41.22306		PLYMILL1 CHIPLOG	LL LL
35	LOG11	UL			NONE	30270.57031- 53447.52344	41.15812- 41.15812		HAULWAF5 PLYMILL4	LL LL
36	LOG14	UL			NONE	35185.23626- 46183.75391	41.70675- 41.70675		HAULWAF5 PLYMILL4	LL LL
37	LOG17	UL			NONE	8153.57656- 43204.30453	41.80176- 41.80176		PLYMILL4 PLYMILL3	LL LL
38	STUDTRAN	UL			NONE	2714.34463- 5840.50625	65.02635- 65.02635		HAULPLY2 HAULSAW7	LL LL
39	CAPSTUD	UL			NONE	INFINITY- 1000000.00000	12000- 12000		NONE MONEYSTD	 LL
40	LIMB40	UL	42250.00000		NONE 42250.00000	30500.60375 44054.34563	10.18526- 10.18526		HAULSAW7 HAULPLY2	LL LL
41	SIMTRAN	UL			NONE	 5840.50625	65.02153- 65.02153		MONEYSIM HAULSAW7	LL LL
42	CAPSIM	UL			NONE	INFINITY-	12000- 12000		NONE MONEYSIM	 LL
43	TWINTRAN	UL			NONE	 45312.00000	63.56602- 63.56602		MONEYTWN LIMTWIN	LL UL
44	CAPTWIN	UL			NONE	INFINITY-	12000- 12000		NONE MONEYTWN	 LL
46	BOARDTRN	UL			NONE	2714.34463- 5834.10635	64.35136- 64.35136		HAULPLY2 HAULSAW7	LL LL
47	CAPBOARD	UL			NONE	INFINITY- 2250730.00000	12000- 12000		NONE MONEYBRD	 LL

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NUMBER      ROW      AT      ACTIVITY      SLACK ACTIVITY     LOWER LIMIT     LOWER ACTIVITY      UNIT COST        UPPER COST      LIMITING    AT
                                                              .UPPER LIMIT    UPPER ACTIVITY      UNIT COST        LOWER COST      PROCESS     AT

    48   LIMBOARD   UL    38000.00000                                NONE     32105.50003         35.00780-                        HAULSAWT    LL
                                                              38000.00000     40714.34003         35.00780                         HAULPLY2    LL

    49   PULPTRAN   UL                                               NONE                        280.08737-                        MONEYPLP    LL
                                                                                                 280.08737                         SPEEDD      UL

    50   CAPPULP    UL                                               NONE        INFINITY-           12000-                           NONE
                                                                                                     12000                         MONEYPLP    LL

    53   PBTRAN     UL                                               NONE      7390.30078-       131.20048-                        HAULSAWT    LL
                                                                               3105.30058        131.20048                         HAULPLY2    LL

    54   CAPPART    UL                                               NONE        INFINITY-           12000-                           NONE
                                                                            8188290.00000            12000                         MONEYPBT    LL

    55   LIMPB      UL   100258.00000                                NONE     87253.84041         87.88581-                        HAULPLY2    LL
                                                             100258.00000    107858.30078         87.88581                         HAULSAWT    LL

    56   WAFERCON   UL                                               NONE     18800.83813-        88.32003-                        LIMBOARA    UL
                                                                              40803.38128         88.32003                         HAULWAFS    LL

    57   WAFTRAN    UL                                               NONE     18800.83813-       183.14803-                        LIMBOARA    UL
                                                                              40803.38128        183.14803                         HAULWAFS    LL

    58   CAPWAFER   UL                                               NONE        INFINITY-           12000-                           NONE
                                                                           37848840.0000             12000                         MONEYWAF    LL

    59   LIMWAFER   UL   141800.00000                                NONE     88007.71878         88.07318-                        HAULWAFS    LL
                                                             141800.00000    188408.83813         88.07318                         LIMBOARA    UL

    60   PLYCON     UL                                               NONE     11878.18828-       208.80003-                        HAULWAFS    LL
                                                                              22803.73047        208.80003                         PLYMILL4    LL

    61   CAPPLY     UL                                               NONE        INFINITY-           12000-                           NONE
                                                                            8888838.00000            12000                         MONEYPLY    LL

    62   LIMPLY     UL    27480.00000                                NONE      4847.28853        272.87088-                        PLYMILL4    LL
                                                              27480.00000     30328.18828        272.87088                         HAULWAFS    LL

    63   PLYTRIM    UL                                               NONE     13788.88303-         8.14000-                        TRIMBOND    LL
                                                                                 INFINITY          8.14000                            NONE

    64   LOGCHIP    UL                                               NONE      8281.33303-        28.88047-                        HAULSAWT    LL
                                                                               3038.80888         28.88047                         HAULPLY2    LL

    65   ADSTAX     UL                                               NONE        INFINITY-            03410-                          NONE
                                                                           91448818.0000              03410                        TAXBAD      LL

    66   PULPPROD   UL                                               NONE                        402.80880-                        PULP        LL
                                                                                 INFINITY        402.80880                            NONE

    67   PBPROD     UL                                               NONE    100258.03750-       221.80018-                        PB3/4       LL
                                                                                 INFINITY        221.80018                            NONE

    68   WAFERPRD   UL                                               NONE    141800.03750-       308.88280-                        WAF1/4      LL
                                                                                 INFINITY        308.88280                            NONE

    69   PLYPROD    UL                                               NONE     27480.00000-       838.81400-                        PLY1/4      LL
                                                                                 INFINITY        838.81400                            NONE

    70   STSLETBD   UL                                               NONE      1384.24070-       100.43277-                        ELECTBD     LL
                                                                                 INFINITY        100.43277                            NONE

    71   STCONBD    UL                                               NONE       881.80081-       124.87388-                        CONSTBD     LL
                                                                                 INFINITY        124.87388                            NONE

    72   STSTDBD    UL                                               NONE       844.80081-       121.78200-                        STANDBD     LL
                                                                                 INFINITY        121.78200                            NONE

    73   STUTILBD   UL                                               NONE       840.24070-        74.82438-                        UTILBD      LL
                                                                                 INFINITY         74.82438                            NONE

    74   STECONBD   UL                                               NONE        42.24087-        83.07143-                        ECONBD      LL
                                                                                 INFINITY         83.07143                            NONE

    75   STSTUD     UL                                               NONE     33072.24000-        83.03100-                        STUD        LL
                                                                                 INFINITY         83.03100                            NONE

    76   STECON     UL                                               NONE      8108.74000-        83.07143-                        ECONOSTD    LL
                                                                                 INFINITY         83.07143                            NONE

    77   DMELETBD   UL                                               NONE                        100.43277-                        ELECTBDD    LL
                                                                                 INFINITY        100.43277                            NONE

    78   DMCONBD    UL                                               NONE                        124.87388-                        CONSTBDD    LL
                                                                                 INFINITY        124.87388                            NONE

    79   DMSTDBD    UL                                               NONE                        121.78200-                        STANDBDD    LL
                                                                                 INFINITY        121.78200                            NONE

    80   DMUTILBD   UL                                               NONE                         74.82438-                        UTILBDD     LL
                                                                                 INFINITY         74.82438                            NONE

    81   DMECONBD   UL                                               NONE                         83.07143-                        ECONBDDD    LL
                                                                                 INFINITY         83.07143                            NONE

    82   DMCONST    UL                                               NONE                         84.80418-                        CONSTDIM    LL
                                                                                 INFINITY         84.80418                            NONE

    83   DMSTAND    UL                                               NONE                         84.80418-                        STANDIM     LL
                                                                                 INFINITY         84.80418                            NONE
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NUMBER    ROW      AT    ACTIVITY    SLACK ACTIVITY   LOWER LIMIT   LOWER ACTIVITY    UNIT COST     UPPER COST   LIMITING   AT
                                                      UPPER LIMIT   UPPER ACTIVITY    UNIT COST     LOWER COST   PROCESS    AT

    84    DHUTIL   UL                                        NONE                      84.31007-                 UTILBIN    LL
                                                                          INFINITY     84.31007                      NONE

    85    DHECON   UL                                        NONE                      53.07143-                 ECONODIN   LL
                                                                          INFINITY     53.07143                      NONE

    86    TWINDD1  UL                                        NONE                     176.83834-                 DD#1STRT   LL
                                                                          INFINITY    176.83834                      NONE

    87    TWINDD2A UL                                        NONE                     116.37340-                 DD#2AT     LL
                                                                          INFINITY    116.37340                      NONE

    88    TWINDD2B UL                                        NONE                      83.12302-                 DD#2BT     LL
                                                                          INFINITY     83.12302                      NONE

    89    TWINDD3  UL                                        NONE                      62.34204-                 DD#3T      LL
                                                                          INFINITY     62.34204                      NONE

    90    BOARD1   UL                                        NONE     7500.00000-     176.83834-                 BD#1STR    LL
                                                                          INFINITY    176.83834                      NONE

    91    BOARD2A  UL                                        NONE     9400.00000-     116.37340-                 BD#2A      LL
                                                                          INFINITY    116.37340                      NONE

    92    BOARD2B  UL                                        NONE     8000.00000-      83.12302-                 BD#2B      LL
                                                                          INFINITY     83.12302                      NONE

    93    BOARD3   UL                                        NONE    11300.00420-      62.34204-                 BD#3       LL
                                                                          INFINITY     62.34204                      NONE
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SECTION 2 - COLUMNS AT LIMIT LEVEL

NUMBER   COLUMN    AT      ACTIVITY          INPUT COST     LOWER LIMIT   LOWER ACTIVITY     UNIT COST      UPPER COST     LIMITING   AT
                                                            UPPER LIMIT   UPPER ACTIVITY     UNIT COST.     LOWER COST     PROCESS    AT

    94   HARVEST1  LL                         34.50000-                                    42.75000      INFINITY-     TLAMT1     UL
                                                                  NONE     1910.00000      42.75000-      8.25000      LIMHAR1    UL

    95   HARVEST2  LL                         44.64000-                                    55.35000      INFINITY-     TLAMT2     UL
                                                                  NONE     5853.00000      55.35000-     10.71000      LIMHAR2    UL

    96   HARVEST3  LL                         61.08900-                                    75.75300      INFINITY-     TLAMT3     UL
                                                                  NONE     4431.00000      75.75300-     14.66400      LIMHAR3    UL

    99   HARVES1A  LL                         34.50000-                                    42.75000      INFINITY-     FTAMT1     UL
                                                                  NONE     1910.00000      42.75000-      8.25000      LIMHAR1    UL

   100   HARVES2A  LL                         44.64000-                                    55.35000      INFINITY-     FTAMT2     UL
                                                                  NONE     5853.00000      55.35000-     10.71000      LIMHAR2    UL

   101   HARVES3A  LL                         61.08900-                                    75.75300      INFINITY-     FTAMT3     UL
                                                                  NONE     4431.00000      75.75300-     14.66400      LIMHAR3    UL

   104   TL1AR1    LL                         87.21000-                 12472.85186-       11.27920      INFINITY-     LIMHAR4    UL
                                                                  NONE                     11.27920-     75.93080-     TLAMT1     UL

   105   TL2AR1    LL                         53.83000-                 25570.73828-       19.57880      INFINITY-     LIMHAR4    UL
                                                                  NONE                     19.57880-     34.25343-     TLAMT1     UL

   106   FT1AR1    LL                        120.59000-                  9102.45313-       10.16570      INFINITY-     LIMHAR4    UL
                                                                  NONE                     10.16570-    110.43422-     FTAMT1     UL

   107   FT2AR1    LL                         83.98000-                 17558.02570-       30.76251      INFINITY-     LIMHAR4    UL
                                                                  NONE                     30.76251-     53.21749-     FTAMT1     UL

   108   TL1AR2    LL                         87.21000-                 11347.83672-        1.77808      INFINITY-     LIMHAR4    UL
                                                                  NONE                      1.77808-     85.44190-     TLAMT2     UL

   109   TL2AR2    LL                         53.83000-                 22926.15234-       14.34058      INFINITY-     LIMHAR4    UL
                                                                  NONE                     14.34058-     39.68000-     TLAMT2     UL

   110   FT1AR2    LL                        120.59000-                  6184.79688-        2.91156      INFINITY-     LIMHAR4    UL
                                                                  NONE                      2.91156-    126.66643-     FTAMT2     UL

   111   FT2AR2    LL                         83.98000-                 19745.70312-       22.31654      INFINITY-     LIMHAR4    UL
                                                                  NONE                     22.31654-     61.66146-     FTAMT2     UL

   112   TL1AR3    LL                         87.21000-                 11764.34375-        5.73063      INFINITY-     LIMHAR4    UL
                                                                  NONE                      5.73063-     81.48908-     TLAMT3     UL

   113   TL2AR3    LL                         53.83000-                 23620.20618-       16.21487      INFINITY-     LIMHAR4    UL
                                                                  NONE                     16.21487-     37.72611-     TLAMT3     UL

   114   FT1AR3    LL                        120.59000-                  6478.80719-        6.75983      INFINITY-     LIMHAR4    UL
                                                                  NONE                      6.75983-    120.84316-     FTAMT3     UL

   115   FT2AR3    LL                         83.98000-                 16356.20853-       25.35766      INFINITY-     LIMHAR4    UL
                                                                  NONE                     25.35766-     58.61214-     FTAMT3     UL

   117   TL2AR4    LL                         53.83000-               4677167.00000-       13.39427      INFINITY-     OPERATOR   LL
                                                                  NONE       94070.31250   13.39427-     40.54573-     TL1AR4     LL

   119   FT2AR4    LL                         83.98000-               2880374.00000-       20.81920      INFINITY-     OPERATOR   LL
                                                                  NONE       73674.31250   20.81920-     63.16080-     FT1AR4     LL

   120   TL1AR5    LL                         87.21000-                                      .40810      INFINITY-     HARVEST5   LL
                                                                  NONE     42088.07813       .40810-     86.72180-     HARVEST4   LL

   121   TL2AR5    LL                         53.83000-                                    13.88841      INFINITY-     HARVEST5   LL
                                                                  NONE     88377.25000     13.88841-     40.27358-     HARVEST4   LL

   123   FT2AR5    LL                         83.98000-               2870572.00000-       20.44573      INFINITY-     OPERATOR   LL
                                                                  NONE       91753.08250   20.44573-     63.13327-     FT1AR5     LL

   129   HAULSAW5  LL                          3.87000-                 21172.88484-        4.92116      INFINITY-     HAULSAW7   LL
                                                                  NONE       55914.88672    4.92116-      1.05116      HAULSAW2   LL

   132   HAULCHP1  LL                          3.82000-                  9276.16797-      103.91186      INFINITY-     HAULSAW7   LL
                                                                  NONE        5032.50500  103.91186-    100.39156      HAULPLY2   LL

   133   HAULCHP2  LL                          3.87000-                 12636.43359-        7.20670      INFINITY-     HAULSAW7   LL
                                                                  NONE        5376.76125    7.20670-      3.33670      HAULPLY2   LL

   134   HAULCHP3  LL                          3.87000-                 12501.80078-        7.40137      INFINITY-     HAULSAW7   LL
                                                                  NONE        5316.66625    7.40137-      3.53137      HAULPLY2   LL

   135   HAULCHP4  LL                          3.87000-                 12288.00375-        7.50673      INFINITY-     HAULSAW7   LL
                                                                  NONE        5281.75863    7.50673-      3.63673      HAULPLY2   LL

   136   HAULCHP5  LL                          3.87000-                 12237.21094-        7.89831      INFINITY-     HAULSAW7   LL
                                                                  NONE        5206.06084    7.89831-      3.02831      HAULPLY2   LL

   137   HAULWAF1  LL                          3.52000-                 43905.01562-       55.90115      INFINITY-     HAULSAW7   LL
                                                                  NONE       12672.16234   55.90115-     52.38115      LIMHAR4    UL

   142   HAULPLY1  LL                          3.52000-                 12721.12100-        8.63452      INFINITY-     HAULSAW7   LL
                                                                  NONE        9411.08004    8.63452-      5.11452      HAULPLY2   LL

   144   HAULPLY3  LL                          3.52000-                 11587.74000-         .73601      INFINITY-     HAULSAW7   LL
                                                                  NONE       32038.14844     .73601-      2.78199-     HAULPLY2   LL

   145   HAULPLY4  LL                          3.60000-                 19498.60750-         .92313      INFINITY-     HAULSAW8   LL
                                                                  NONE       35523.41016     .92313-      3.46687-     HAULSAW4   LL
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NUMBER   COLUMN    AT     ACTIVITY        INPUT COST     LOWER LIMIT   LOWER ACTIVITY     UNIT COST      UPPER COST    LIMITING   AT
                                                         UPPER LIMIT   UPPER ACTIVITY     UNIT COST      LOWER COST    PROCESS    AT

   146   HAULPLY5  LL                       3.87000-                   13606.54062-        6.06367       INFINITY-    HAULSAW7   LL
                                                               NONE     6760.63606         6.06367-       4.10367     HAULPLY2   LL

   147   HAULPLY6  LL                       3.87000-                   21113.07656-        4.00103       INFINITY-    HAULSAW7   LL
                                                               NONE     6662.54207         4.00103-       1.03103     HAULPLY2   LL

   148   HAULPLY7  LL                       3.87000-                   33137.06250-         .70700       INFINITY-    PLYMILL1   LL
                                                               NONE    34276.87656          .70700-       3.16300-    HAULPLY2   LL

   152   DIMMILL   LL                      10.33000-                                       4.90442       INFINITY-    MONEYDIM   LL
                                                               NONE    42249.07656         4.90442-      10.42658-    MONEYSTD   LL

   154   TWINMILL  LL                      36.70000-                                      10.46709       INFINITY-    MONEYTWN   LL
                                                               NONE     6406.32422        10.46709-      17.23201-    HAULPLY2   LL

   156   PULPMILL  LL                      53.62000-                                      17.11082       INFINITY-    MONEYPLP   LL
                                                               NONE                       17.11082-      36.60317-    SPREED     UL

   160   SPRUCE    LL                      35.00000-                                      43.30000       INFINITY-    SPREED     UL
                                                               NONE        INFINITY       43.30000-       8.30000         NONE

   172   AVALCHIP  LL                        .00010                     1336.43652-      113.06620       INFINITY-    HAULPLY2   LL
                                                               NONE     3141.30003       113.06620-     113.06630     HAULSAW7   LL

   196   PB3/4     LL                     203.03000                        INFINITY-      25.38385       INFINITY-        NONE
                                                               NONE   100356.03750        25.38385-     228.42384     PB3/8      LL

   198   PB5/8     LL                     211.65000                        INFINITY-      16.66461       INFINITY-        NONE
                                                               NONE   100356.03750        16.66461-     228.72458     PB3/8      LL

   200   PB1/2     LL                     211.65000                        INFINITY-      16.66461       INFINITY-        NONE
                                                               NONE   100356.03750        16.66461-     228.72458     PB3/8      LL

   203   WAF5/16   LL                     296.60000                        INFINITY-      20.46741       INFINITY-        NONE
                                                               NONE   141598.03750        20.46741-     317.07727     WAF1/4     LL

   204   WAF3/8    LL                     264.63063                        INFINITY-      51.18371       INFINITY-        NONE
                                                               NONE   141598.03750        51.18371-     315.98356     WAF1/4     LL

   205   WAF7/16   LL                     248.17000                        INFINITY-      67.24606       INFINITY-        NONE
                                                               NONE   141598.03750        67.24606-     315.42596     WAF1/4     LL

   206   WAF5/8TG  LL                     286.01076                        INFINITY-      30.60620       INFINITY-        NONE
                                                               NONE   141598.03750        30.60620-     316.71606     WAF1/4     LL

   208   PLY1/2    LL                     337.48008                        INFINITY-     212.96162       INFINITY-        NONE
                                                               NONE    27449.06600       212.96162-     550.42158     PLY1/4     LL

   209   PLY3/4    LL                     264.03079                        INFINITY-     264.56661       INFINITY-        NONE
                                                               NONE    27449.06600       264.56661-     548.59961     PLY1/4     LL
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SECTION 3 - ROWS AT INTERMEDIATE LEVEL

NUMBER    ROW      AT     ACTIVITY      SLACK ACTIVITY    LOWER LIMIT     LOWER ACTIVITY     UNIT COST     UPPER COST    LIMITING   AT
                                                          .UPPER LIMIT    UPPER ACTIVITY     UNIT COST     LOWER COST    PROCESS.   AT

    3   ALLOWCUT   BS   937163.00000    1330837.00000            NONE    937163.00000          .32019-                  TL1AR2     LL
                                                        2268000.00000    998355.44531          .58244-                  FTAMT4     UL

    4   LIMHAR1    BS                      1810.00000            NONE                        INFINITY-                      NONE
                                                           1810.00000     18132.08025        42.78000-                  HARVEST1   LL

    5   LIMHAR2    BS                      5853.00000            NONE                        INFINITY-                      NONE
                                                           5853.00000     14009.45938        55.38800-                  HARVEST2   LL

    6   LIMHAR3    BS                      4431.00000            NONE                        INFINITY-                      NONE
                                                           4431.00000     10237.87656        76.76300-                  HARVEST3   LL

    7   LIMHAR4    BS     3495.53784        380.46216            NONE      3495.53784        53.03304-                  TL1AR2     LL
                                                           3876.00000     11757.09253        93.63080-                  TLAMT4     UL

    9   TLAMT1     BS                                            NONE    140183.93750-         .58283-                  HARVEST1   LL
                                                                         307766.56750         1.09281-                  TL1AR1     LL

   10   TLAMT2     BS                                            NONE    558025.00000-         .58280-                  HARVEST2   LL
                                                                         278393.93750          .31416-                  TL1AR2     LL

   11   TLAMT3     BS                                            NONE    578030.00000-         .58260-                  HARVEST3   LL
                                                                         288583.50000         1.01253-                  TL1AR3     LL

   14   FTAMT1     BS                                            NONE    148835.00000-         .54497-                  HARVES1A   LL
                                                                         374611.56250         2.27882-                  FT1AR1     LL

   15   FTAMT2     BS                                            NONE    594884.68750-         .54494-                  HARVES2A   LL
                                                                         336022.43750          .34520-                  FT1AR2     LL

   16   FTAMT3     BS                                            NONE    916352.00000-         .54487-                  HARVES3A   LL
                                                                         348947.87500         1.04124-                  FT1AR3     LL

   27   BARK       BS  -10013.20000-      10013.20000            NONE     22636.76172-        6.11000-                  BRAN-TOP   UL
                                                                          16868.28876-       21.50446-                  HAULPLY3   LL

   45   LIMTWIN    BS                     48312.00000            NONE                        63.98892-                  TWINTRAN   UL
                                                          48312.00000      8406.32422        18.48700-                  TWINMILL   LL

   51   LIMPULP    BS                    157800.00000            NONE                       280.08737-                  PULPTRAN   UL
                                                         157800.00000                        64.42881-                  PULPMILL   LL

   52   SPNEED     BS                                            NONE       INFINITY-        20.30884-                  SPRUCE     LL
                                                                           2008.84348        64.42881-                  PULPMILL   LL
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SECTION 4 - COLUMNS AT INTERMEDIATE LEVEL

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NUMBER  COLUMN    AT     ACTIVITY      INPUT COST    LOWER LIMIT  LOWER ACTIVITY   UNIT COST     UPPER COST    LIMITING  AT
                                                     UPPER LIMIT  UPPER ACTIVITY   UNIT COST     LOWER COST    PROCESS   AT

    97  HARVEST4  BS     1822.71508     75.57000-                                   13.32142-     88.89142-  TLIAR5    LL
                                                          NONE       2014.17700     92.83080-     17.26080   TLAMT4    UL

    98  HARVEST5  BS                    84.12000-                                   INFINITY-     INFINITY-      NONE
                                                          NONE       1381.32000     15.75643-     68.36357-  TLIAR5    LL

   102  HARVES4A  BS     1861.62251     75.57000-                    1861.62251     62.46204-    138.03204-  FTIAR2    LL
                                                          NONE       3488.17508     13.31632-     62.25368-  TLIAR5    LL

   103  HARVES5A  BS     2068.08876     84.12000-                     707.87285     15.75643-     99.87643-  TLIAR5    LL
                                                          NONE       2068.08876     INFINITY-     INFINITY       NONE

   116  TLIAR4    BS    48500.28563     87.21000-                                     .48803-     87.69803-  TLIAR5    LL
                                                          NONE      60856.27734      6.05389-     81.15611-  LIMSAD    UL

   118  FTIAR4    BS    38144.11328    120.59000-                   38144.11328      3.04070-    122.64070-  FTIAR2    LL
                                                          NONE      71627.04141       .64097-    126.05002-  TLIAR5    LL

   122  FTIAR5    BS    47567.68706    120.59000-                   10114.07612       .60102-    130.20101-  TLIAR5    LL
                                                          NONE      47567.68706     INFINITY-     INFINITY       NONE

   124  HAULSAW1  BS    24225.63672      3.52000-                   16453.36710      3.32637-      6.84637-  HAULPLY1  LL
                                                          NONE      29022.11710     10.66005-      7.14005   LIMSAD    UL

   125  HAULSAW2  BS    52624.11710      3.52000-                    8609.72086-     5.20012-      8.72012-  HAULSAW5  LL
                                                          NONE      72626.70703     33.04370-     29.52370   LOGS12    UL

   126  HAULSAW3  BS    41860.23626      3.52000-                    3205.62500       .62712-      4.14712-  HAULPLY3  LL
                                                          NONE      61170.64463      6.17088-      2.65088   LIMSAD    UL

   127  HAULSAW4  BS    35626.20313      3.52000-                   18076.73628-      .02313-      3.54313-  HAULPLY4  LL
                                                          NONE      43436.10831      7.26848-      3.74848   LIMSAD    UL

   128  HAULSAW5  BS    29317.49800      3.87000-                   18611.61250      5.92003-      9.79003-  LIMSAD    UL
                                                          NONE      30704.60063      4.97782-      1.10782   HAULPLY1  LL

   130  HAULSAW7  BS    14268.86326      3.87000-                    6300.60155-     4.03088-      7.90088-  LIMSAD    UL
                                                          NONE      54670.03806       .59986-      3.27014-  HAULPLY3  LL

   131  HAULSAW8  BS    20053.02187      3.87000-                    7378.46313      4.53052-      8.40052-  LIMSAD    UL
                                                          NONE      56764.27344       .02239-      3.84761-  HAULPLY4  LL

   136  HAULWAF2  BS    39401.75000      3.87000-                   34074.46312      7.28121-     11.15121-  HAULCHP2  LL
                                                          NONE      42264.72314     20.08855-     16.21855   LIMSAD    UL

   138  HAULWAF3  BS   173088.43750      3.87000-                  166860.64453      3.31030-      7.18030-  LIMSAD    UL
                                                          NONE     182892.06804      2.72192-      1.14808-  HAULPLY3  LL

   140  HAULWAF4  BS   104781.43750      3.87000-                   70422.70868       .70880-      4.57880-  HAULPLY3  LL
                                                          NONE     107200.26302     23.48721-     19.61721   LIMSAD    UL

   141  HAULWAF5  BS    24474.14844      3.87000-                   15136.70703      4.28311-      8.15311-  HAULCHP5  LL
                                                          NONE      46768.67080       .85849-      3.01151-  HAULPLY3  LL

   143  HAULPLY2  BS     8500.73047      3.52000-                    6543.54297-     2.84777-      6.36777-  HAULPLY7  LL
                                                          NONE      36184.66047      3.25230-       .26770-  LIMSAD    UL

   148  HAULPLY8  BS    56368.85838      3.87000-                   10685.42187       .02241-      3.89241-  HAULPLY4  LL
                                                          NONE      60781.00000      8.82887-      4.95887   HAULCHP2  LL

   150  STUDMILL  BS    42240.99600     15.33000-                                    4.90442-     20.23442-  DIMMILL   LL
                                                          NONE      42240.99600     95.02193-     79.69193   DIMTRAN   UL

   151  STUDCAP   BS    42240.99600      5.34000-                                    4.90442-     10.24442-  DIMMILL   LL
                                                          NONE      42240.99600     95.02193-     89.68193   DIMTRAN   UL

   153  DIMCAP    BS                     5.34000-                                   95.02193-     70.36193-  DIMTRAN   UL
                                                          NONE      42240.97266      4.90442-       .43558-  DIMMILL   LL

   155  TWINCAP   BS                     7.13000-                                   83.98802-     91.11802-  TWINTRAN  UL
                                                          NONE       8408.33031     19.46700-     12.33700   TWINMILL  LL

   156  BOARDMIL  BS    37999.99606     17.06000-                   32155.69063     35.06780-     52.12780-  LIMBOARD  UL
                                                          NONE      40714.34446     54.28136-     37.22136   BOARDTRN  UL

   157  BOARDCAP  BS    37999.99606      5.95000-                   32155.69063     35.06780-     41.01780-  LIMBOARD  UL
                                                          NONE      37999.99606     INFINITY-     INFINITY       NONE

   159  PULPCAP   BS                    99.39000-                                  280.06737-    379.45737-  PULPTRAN  UL
                                                          NONE                      54.42561-     44.96439-  PULPMILL  LL

   161  PARTMILL  BS   127187.68750     52.32000-                  123251.60403     53.86200-    106.18200-  LIMPB     UL
                                                          NONE     136449.01172    103.90621-     51.58621   PBTRAN    UL

   162  PARTCAP   BS   100356.03750     10.10000-                   97253.58716     67.88801-     77.98801-  LIMPB     UL
                                                          NONE     100356.03750     INFINITY-     INFINITY       NONE

   163  WAFERMIL  BS   141599.93750     76.54000-                   85097.86016     59.07316-    135.61316-  LIMWAFER  UL
                                                          NONE     158400.76172    183.14802-    106.60802   WAFTRAN   UL

   164  WAFERCAP  BS   141599.93750     26.54000-                   85097.86016     59.07316-     85.61316-  LIMWAFER  UL
                                                          NONE     141599.93750     INFINITY-     INFINITY       NONE

   165  PLYMILL1  BS     7882.77344     49.07000-                    6407.72656     15.22063-     64.29063-  HAULCHP2  LL
                                                          NONE      10203.03516      2.03746-     47.03254-  HAULPLY3  LL

   166  PLYMILL2  BS    21839.85156     55.92000-                   21150.44946-    62.23322-    118.15322-  HAULPLY7  LL
                                                          NONE      21856.92663     52.41632-      3.50368-  HAULPLY4  LL
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NUMBER  COLUMN     AT    ACTIVITY          INPUT COST     LOWER LIMIT  LOWER ACTIVITY    UNIT COST        UPPER COST      LIMITING   AT
                                                          UPPER LIMIT  UPPER ACTIVITY    UNIT COST        LOWER COST      PROCESS    AT

  167   PLYMILL3   BS      17587 38453     80 48889-                   14742 84280        8 81021-        80 00820-       HAULPLY3   LL
                                                          NONE         18857 43140       28 28126-        32 18872-       HAULCHP2   LL

  168   PLYMILL4   BS       7883 88850     82 78889-                    4173 82898        7 17081-        88 84000-       HAULPLY3   LL
                                                          NONE          8141 87168       85 87219-         3 10220        HAULCHP2   LL

  169   PLYCAP     BS      27449 99809     25 53889-                    4847 28883      272 87088-       298 41084-       LIMPLY     UL
                                                          NONE         27449 99800       INFINITY-        INFINITY             NONE

  170   CHIPLOG    BS       3420 81187      7 84000-                                     11 33034-        19 27034-       HAULCHP2   LL
                                                          NONE         10830 18140        8 00030-           15030        LIMSAD     UL

  171   TAXSAD     BS   81448818 0000          02780-                80011348 8780          10685-           13435-       LIMSAD     UL
                                                          NONE            INFINITY          03410-           00080        ABSTAX     UL

  173   SLECTBD    BS        901 28080    305 00000                                     229 81348-        75 08888        DIMMILL    LL
                                                          NONE           901 28080     3048 14817-      3383 14817        DIMTRAN    UL

  174   CONSTBD    BS        382 38278    200 00000                   488888 84722-     193 17089-         8 82001        STCONBD    UL
                                                          NONE           382 38278     7184 82188-      7384 82188        DIMTRAN    UL

  175   STANDBD    BS        848 21828    195 00000                   488428 08424-     188 38049-         8 84081        STSTDBD    UL
                                                          NONE           948 21828     8029 44821-      5224 44821        DIMTRAN    UL

  176   UTILBD     BS        385 04198    120 00000                   781724 38881-     115 90788-         4 09201        STUTILBD   UL
                                                          NONE           385 04198     7727 80838-      7887 80838        DIMTRAN    UL

  177   ECONBBD    BS         27 31081     85 00000                  1078848 88800-      82 10180-         2 88880        STECONBD   UL
                                                          NONE            27 31081   100888 87800-    100873 87800        DIMTRAN    UL

  178   SLECTBDD   BS                     305 00000                   299834 78000-     384 88937-        10 40083        DMSLETBD   UL
                                                          NONE           901 28977      229 81348-       834 81349        DIMMILL    LL

  179   CONSTBDD   BS                     200 00000                   457248 00000-     193 17089-         8 82001        DMCONBD    UL
                                                          NONE           382 38284      841 93872-       741 93872        DIMMILL    LL

  180   STANDBDD   BS                     195 00000                   888872 31280-     188 38049-         8 84081        DMSTDBD    UL
                                                          NONE           848 21802      379 38718-       874 38718        DIMMILL    LL

  181   UTILBDD    BS                     120 00000                   782079 43780-     115 90789-         4 08201        DMUTILBD   UL
                                                          NONE           385 04178      583 82822-       703 82822        DIMMILL    LL

  182   ECONBBDD   BS                      85 00000                  1078877 00000-      82 10180-         2 88880        DMECONBD   UL
                                                          NONE            27 31000     7887 14083-      7872 14083        DIMMILL    LL

  183   CONSTDIM   BS                     152 00000                   801842 12800-     148 81879-         8 18321        DMCONST    UL
                                                          NONE         12183 38188       17 04878-       169 04878        DIMMILL    LL

  184   STANDIM    BS                     152 00000                   801842 12800-     148 81879-         8 18321        DMSTAND    UL
                                                          NONE          3000 08184       82 32812-       204 32812        DIMMILL    LL

  185   UTILDIM    BS                     103 00000                   887889 82800-      99 48789-         3 81231        DMUTIL     UL
                                                          NONE          5028 04888       38 83080-       138 83080        DIMMILL    LL

  186   ECONODIM   BS                      85 00000                  1078877 00000-      82 10180-         2 88880        DMECON     UL
                                                          NONE          3380 24148       81 88408-       148 88408        DIMMILL    LL

  187   STUD       BS      21788 80489    148 00000                                       8 81883-       138 48037        DIMMILL    LL
                                                          NONE         21788 80489      428 20044-       278 20044        DIMTRAN    UL

  188   ECONOSTD   BS       3389 24388     85 00000                                      81 88408-        23 31882        DIMMILL    LL
                                                          NONE          3380 24388      817 78814-       802 78814        DIMTRAN    UL

  189   BD#1STR    BS       3270 22383    425 00000                     2788 14817      407 48801-        17 81098        LIMBOARD   UL
                                                          NONE          3270 22383       INFINITY-        INFINITY             NONE

  190   BD#2A      BS       4087 77984    280 00000                   322817 00788-     270 48180-         9 84810        BOARD2A    UL
                                                          NONE          4087 77984       INFINITY-        INFINITY             NONE

  191   BD#2B      BS       4087 77984    200 00000                   483180 87040-     193 17089-         8 82001        BOARD2B    UL
                                                          NONE          4087 77984       INFINITY-        INFINITY             NONE

  192   BD#3       BS       4808 33203    150 00000                   804788 48047-     144 88801-         5 11489        BOARD3     UL
                                                          NONE          4808 33203       INFINITY-        INFINITY             NONE

  193   BD#1STRT   BS                     425 00000                   218178 80000-     410 80732-        14 48288        TWINBD1    UL
                                                          NONE           388 47118      288 12848-       881 12848        TWINMILL   LL

  194   BD#2AT     BS                     280 00000                   320808 88780-     270 48180-         9 84810        TWINBD2A   UL
                                                          NONE           888 31201      188 80838-       488 80838        TWINMILL   LL

  195   BD#2BT     BS                     200 00000                   457247 78000-     193 17089-         8 82001        TWINBD2B   UL
                                                          NONE           881 87488      180 88813-       380 88813        TWINMILL   LL

  196   BD#3T      BS                     150 00000                   808883 81280-     144 88801-         5 11489        TWINBD3    UL
                                                          NONE           700 84238      133 08328-       283 08328        TWINMILL   LL

  197   PULP       BS                     510 00000                                     280 08737-       228 84283        PULPTRAN   UL
                                                          NONE                           84 42881-       884 42881        PULPMILL   LL

  201   PB3/8      BS     100388 83780    228 31889                  8137304 08280-      18 88481-       212 48838        PB3/8      LL
                                                          NONE        100388 83780       INFINITY-        INFINITY             NONE

  202   WAF1/4     BS     141800 83780    317 79880                  4178088 08280-      20 48741-       207 33240        WAF8/18    LL
                                                          NONE        141800 83780       INFINITY-        INFINITY             NONE

  207   PLY1/4     BS      27449 99809    887 93884                   387328 00281-     212 88182-       344 87832        PLY1/2     LL
                                                          NONE         27440 00000       INFINITY-        INFINITY             NONE

  210   TRIMBOND   BS      13788 88203      8 14000                        INFINITY-        8 14000-                        PLYTRIM    UL
                                                          NONE         19801 82800      411 88038-       419 88037        PLYCON     UL
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NUMBER   COLUMN     AT    ACTIVITY         INPUT COST   LOWER LIMIT   LOWER ACTIVITY    UNIT COST     UPPER COST   LIMITING   AT
                                                        UPPER LIMIT   UPPER ACTIVITY    UNIT COST     LOWER COST   PROCESS    AT

  211   HOGFUEL     BS       4622.51662      6 11000                       INFINITY-      6 11000-                 DRAG-TOP   UL
                                                           NONE         6450 50220     16 73667-      26 44666     HAULPLY3   LL

  212   HONEYSTD    BS   1908688 00000        12000-                                      10850-        .22850-    DIMMILL    LL
                                                           NONE          INFINITY         12000-                   CAPSTUD    UL

  213   HONEYDIM    BS                        12000-                                    1 43484-       1 55484-    DIMTRAN    UL
                                                           NONE     1908688 00000         10850-         01150-    DIMMILL    LL

  214   HONEYTWN    BS                        12000-                                    1 41788-       1 53788-    TWINTRAN   UL
                                                           NONE          INFINITY         12000-                   CAPTWIN    UL

  215   HONEYBDR    BS   2250739 00000        12000-                1005184 75000         59206-         71206-    LIMBOARD   UL
                                                           NONE          INFINITY         12000-                   CAPBOARD   UL

  216   HONEYPLP    BS                        12000-                                      37830-         49830-    PULPTRAN   UL
                                                           NONE                          .07314-         04686-    PULPMILL   LL

  217   HONEYPRT    BS   6168290 00000        12000-                7034024 00000         83204-         95204-    LIMPS      UL
                                                           NONE          INFINITY         12000-                   CAPPART    UL

  218   HONEYWAF    BS   27648840 0000        12000-                25215100 0000         22278-         34278-    LIMWAFER   UL
                                                           NONE          INFINITY         12000-                   CAPWAFER   UL

  219   HONEYPLY    BS   5669625 00000        12000-                1004742 00000       1 31644-       1 43644-    LIMPLY     UL
                                                           NONE          INFINITY         12000-                   CAPPLY     UL

  220   OPERATSS    BS   46350692 0000        24000-                47987881 3125         06422-         30422-    LIMSAD     UL
                                                           NONE     46350692 0000         14329-         09671-    PULPMILL   LL
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