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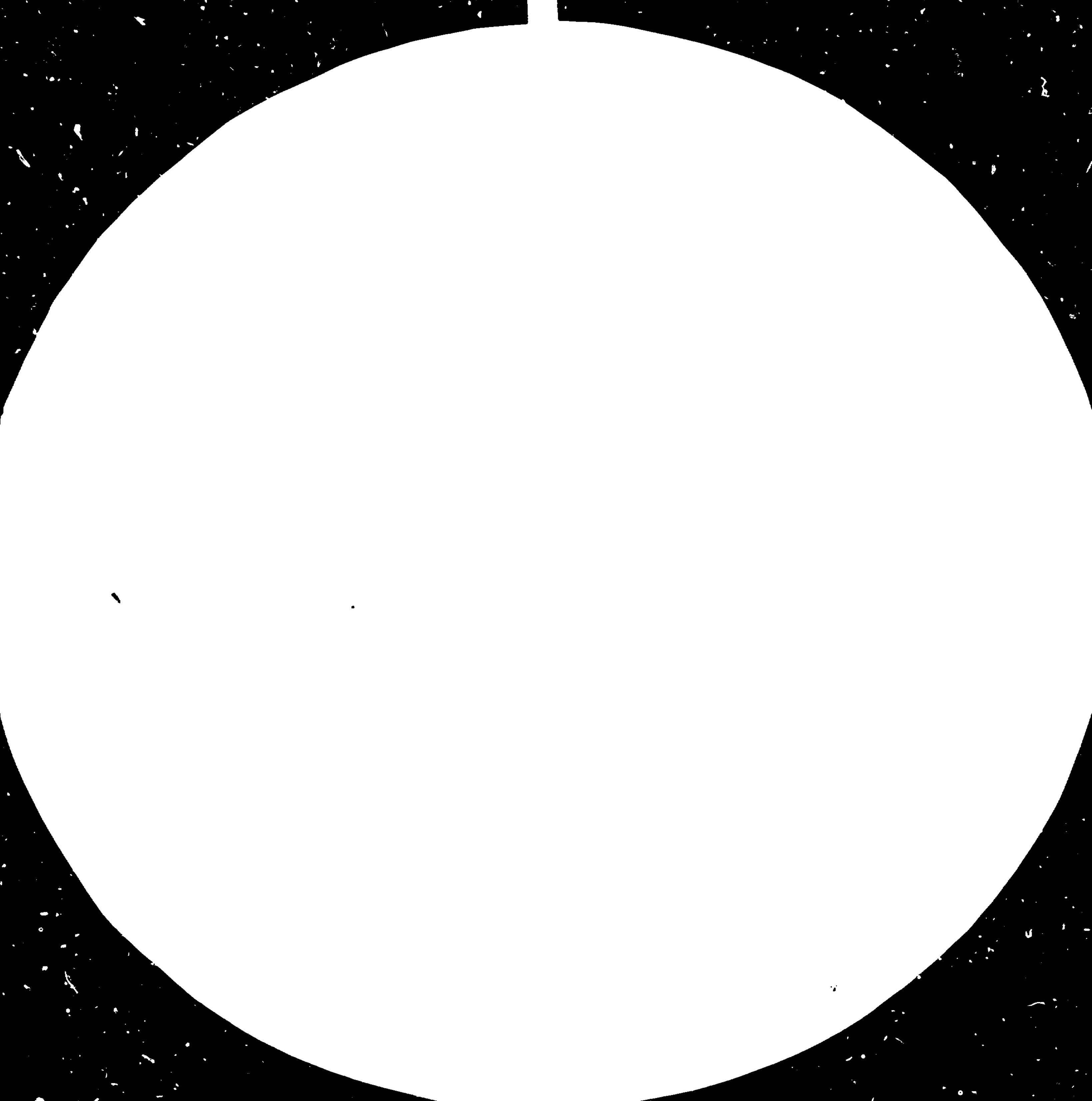

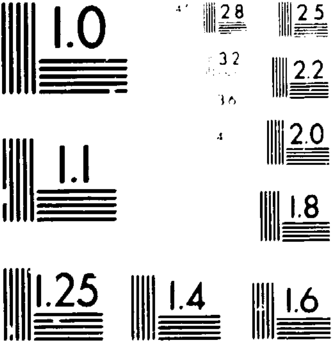

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A REVIEW OF TECHNOLOGY AND TECHNOLOGICAL DEVELOPMENT IN THE WOOD AND WOOD PROCESSING INDUSTRY AND ITS IMPLICATIONS FOR DEVELOPING COUNTRIES

Sectoral Working Paper Series

No. 8

John F. Brotchie

Sectoral Studies Branch
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Preface

This paper has been prepared in connection with the First World-Wide Study of the Wood and Wood Processing Industries. It contains a detailed description of the technical aspects of various production processes and products in the wood and wood processing industries. Particular emphasis is placed on showing how these various technologies relate to conditions in the developing countries.

The information in this report is used extensively in the World-Wide Study, however there are many details included in this original report which it has not been possible to include in the main report. Thus this report is being issued separately in the Sectoral Working Papers Series.

This paper has been prepared by Mr. John F. Brotchie, of the Commonwealth Scientific and Industrial Research Organization, as a UNIDO consultant.

* * *

The following UNIDO documents (including the present paper) have been prepared in the context of the world-wide study.

1. "First world-wide study of wood and wood-processing industries", prepared by the UNIDO Secretariat, (UNIDO/IS.398).

2. "Wood resources and their use as raw material", prepared by the Food and Agriculture Organization of the United Nations, (UNIDO/IS.399).

3. "A review of technology and technological development in the wood and wood-processing industry and its implications for developing countries", prepared by J.F. Brotchie, (UNIDO/IS.).

4. "Environmental aspects of the wood and wood-processing industry", prepared by K.M. Strzepek, (UNIDO/IS.394).

5. "Health and safety problems in wood and wood-processing industries", prepared by the secretariat of the International Labour Organization, (UNIDO/IS.410)

6. "Potentials and requirements of increasing the degree of wood-processing in developing countries of Asia and the Pacific", prepared by H.P. Brion, (UNIDO/IS.395).

7. "Tariff and non-tariff measures in world trade of wood and wood products", prepared by the Secretariat of the Secretariat of the United Nations Conference on Trade and Development, (UNIDO/IS.396).

8. "The USSR forest and woodworking industries", prepared by N.A. Burdin and V.A. Sylantyev, (UNIDO/IS.406).

9. "Wood and wood-processing industry as a consumer and supplier of energy", prepared by Swedforest Consulting AB, (UNIDO IS.-), in preparation.

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EXPLANATORY MATERIAL

Conventions

References to dollars ($) are to United States dollars, unless otherwise stated.

A billion is 1,000 million

A comma (,) is used to distinguish thousands and millions.

A full stop (.) is used to indicate decimals.

A slash between dates (e.g., 1980/81) indicates a crop year, financial year or academic year.

Use of a hyphen between dates (e.g., 1960-1965) indicates the full period involved, including the beginning and end years.

Metric tons have been used throughout.

The following forms have been used in tables:

> Three dots (...) indicate that data is not available or is not separately reported.
>
> A dash (-) indicates that the amount is nil or negligible;
>
> A blank indicates that the item is not applicable or not available.
>
> Totals may not add up precisely because of rounding.

Besides the common abbreviations, symbols and terms and those accepted by the International System of Units (SI), the following abbreviations and contractions have been used in this report:

Economic and technical abbreviations

C	Temperature Celsius
con	Coniferous

GDP	Gross domestic product
GFCF	Gross fixed capital formation
ISIC	International Standard Industrial Classification of all Economic Activities
kg	Kilogram
LDC	Least developed country, per UN General Assembly Resolution 2768 (XXVI)
mc	Moisture content
mm	Millimetre
MPa	Megapascals
m^3(r)	Cubic metres roundwood equivalent
m^3sub	Cubic metre, solid under bark
MVA	Manufacturing value added
$m^3 yr^{-1} ha^{-1}$	Cubic metres per year per hectare
ncon	Non-coniferous
OSB	Oriented strand board
psi	Pounds per square inch
R and D	Research and Development
SITC	Standard International Trade Classification, Rev.1
t/a	Tons per annum
TCDC	Technical co-operation between developing countries
TNC	Transnational corporation

Organizational abbreviations

CSIRO	Commonwealth Scientific and Industrial Research Organization
ECE	Economic Commission for Europe
EIU	Economic Intelligence Units
ETTS	European Timber Trends Study
FAO	Food and Agriculture Organization
GATT	General Agreement on Tariffs and Trade

IIASA	International Institute for Applied Systems Analysis
ILO	International Labour Organization
IUFRO	International Union of Forestry Research Organization
SEALPA	Southeast Asian Lumber and Plywood Association
UN	United Nations
UNIDO	United Nations Industrial Development Organization
UNCTAD	United Nations Conference on Trade and Development
UNEP	United Nations Environmental Programme

Glossary

Forestry terms:

The definitions used in this paper are the same as those used in "The first world-wide study of the wood and wood processing industries" and are generally consistent with those used in the FAO papers "Tropical forest resources", (Forestry paper no. 30, 1983) and "Classification and definitions of forest products", (Forestry paper no. 32, 1983).

Allowable annual cut:	volume that according to management plans can be removed from standing timber without depleting forest capital.
Annual increment:	the volume growth per year of standing timber; sometimes expressed as "gross annual increment" without deducting natural losses, or as "net annual increment", net of natural losses.
Broadleaved:	or non-coniferous refers to trees classified botanically as "angiospermae", also sometimes referred to as "hardwoods".
Closed forest:	forest with closed canopy, in contrast with forest with open canopy which are referred to as "other wooded lands".
Coniferous:	refers to trees classified botanically as "gymnospermae", also sometimes referred to as "softwoods".
Forest:	vegetative association made up by trees.
Forest under management:	forest with classical management plans, or any type of forest where extraction of roundwood is subject to some institutional regulation.

Growing stock:	total volume of standing timber expressed as gross bole volume of trees above 10 cm diameter at breast height.
Operable forest or productive forest:	closed forest which is considered productive; excludes forest which is classified as unproductive by legal restrictions, or because of poor quality. Some countries include economically inaccesible forest as unproductive.

Forest product and wood processing terms:

Fuelwood:	wood in the rough used as a source of energy.
Furniture:	refers to household, office and institutional furniture and built-in cabinets and counters made primarily of wood.
Industrial roundwood:	all wood in the rough not used for fuelwood.
Joinery:	includes doors and doorsets (i.e. with frames), windows and frames, mouldings and trim, stairs, flooring (tongue and groove, parquets, etc.), non-load-bearing wooden partitions and shop fittings.
Other industrial roundwood:	wood in the rough used as poles, piling and posts and other uses in the rough.
Pulpwood:	wood in the rough used as a raw material input in the pulp and paper industries, and in some cases, in fibreboard and particle board.
Roundwood:	all wood in the rough as harvested in the forest.
Sawlogs and veneer logs:	roundwood destined for the veneer, plywood and sawnwood industries.
Trussed rafter:	a roof support, usually triangular in outline and having all timber components of the same thickness (monoline) and joints made from metal connector plates, bolts or nailed plywood.

Country groupings

The grouping of countries used in this paper, if not otherwise indicated, is as given below. This list of countries is not comprehensive; it includes only those countries with a recognized forestry potential.

The developed regions: all developed countries are grouped as follows:

- North America: Canada and the USA
- Europe: excluding the USSR.
- the USSR.
- "other" developed countries: all "other" countries with direct importance for forestry: Japan, Australia, New Zealand, South Africa .

The developing countries are grouped by continents, and in sub-regions as shown below. Sub-regions considered as "temperate" are marked with an asterisk.

Latin America

Central America: Costa Rica, El Salvador, Guatemala, Honduras, Mexico, Nicaragua, Panama

Caribbean and CARICOM: Cuba, Dominican Republic, French Guyana, Haiti, Suriname, Belize, Guyana, Jamaica, Trinidad and Tobago

South America-tropical: Bolivia, Brazil, Colombia, Ecuador, Paraguay, Peru, Venezuela

South America-temperate*: Argentina, Chile, Uruguay

Africa

Mediterranean: Algeria, Egypt, Libya, A.J., Morocco, Tunisia

Northern Savanna: Chad, Mali, Mauritania, Niger, Senegal, Upper Volta

West Africa: Benin, Ghana, Guinea, Guinea Bissau, Ivory Coast, Liberia, Nigeria, Sierra Leone, Togo

Central Africa: Angola, Cameroon, Central African Republic, Congo, Equatorial Guinea, Gabon, Zaire

East Africa: Burundi, Ethiopia, Kenya, Rwanda, Somalia, Sudan, Tanzania, Uganda

Southern Africa: Botswana, Madagascar, Malawi, Mozambique, Namibia Swaziland, Zambia, Zimbabwe

Asia

Asia Near East*: Afghanistan, Iran, Iraq, Jordan, Lebanon, Syria, Turkey

East Asia*: China, Mongolia, Democratic People's Republic of Korea, Republic of Korea

South Asia: Bangladesh, Bhutan, India, Nepal, Pakistan, Sri Lanka

Continental South-East Asia: Burma, Kampuchea, Laos, Thailand, Vietnam

Insular South-East Asia: Brunei, Indonesia, Malaysia, Philippines Fiji, Papua New Guinea, Solomon Islands

Temperate and tropical developing countries have been defined as follows:

Developing temperate: South America-temperate, Asia Near East, East Asia

Developing tropical: all other developing sub-regions not marked with an asterisk

INTRODUCTION

This paper concerns technology and technological development in the timber processing sector with focus on mechanical processing and the implications for developing countries. The study looks at recent developments, present trends, and future opportunities. It recognizes the fact that these cannot be viewed in isolation but must be considered as part of a global system which includes:

- the resources available for processing, their location, quantity, and diverse quality;
- the products made from them, recent product innovations, and potential new composite material made viable by changing factors of production;
- the markets for these products, their locations, demands and trends;
- the transport costs involved, and their rates of change;
- an engineering design approach to new product development and to quality control which is developed herein;
- the technological environment for the industry including knowledge, skills, ancilliary industries and infrastructure;
- an information system which defines the resources available, the markets and transport costs, and allows the best mix of products and markets for the resources available to be determined;
- the suitability of these products and technologies for different developing countries and regions;
- the best development strategies taking these various factors into account.

It also recognizes the diversity of endowments of developing countries and the diversity of their technological and production needs. These may include on the one hand a smaller number of large scale high technology industries utilizing abundant wood resources to process products which are competitive on world markets, and, on the other hand, a large number of small low technology low capital industries in other regions providing goods for local markets. It recognizes also the need to bridge the gap between the two as the information revolution fed by modern communications technology, is increasing the expectations of the communities involved.

SUMMARY

This paper takes a system wide view of technology and technological development in the wood and wood processing industry, and its implications for the developing world.

It shows that whereas existing timber resource stocks and growth rates may be sufficient at a global level to meet projected increases in demand to the end of the century, major changes in the distribution of supply between geographic regions and among timber species would be required.

Some of the additional production must come from the increasing area of fast growing (exotic) hardwood and softwood plantation, much of which is in developing countries. However, the remainder, and major share, must come from existing natural hardwood forests in the developing world. These are of mixed species, diverse quality and accessibility, and subject to various utilization and trade constraints.

The paper also sounds the cautionary note that projected increases in demand for industrial roundwood, of 50 per cent over the next two decades (FAO 1982), are at a somewhat greater rate than the increase, of less than 20 per cent, which occurred over the last decade (FAO 1981).

It describes the rapid changes occurring in new structural board and timber products. In response to the decreasing availability of high quality saw logs in the developed world, to changing factor prices of production, and to new automated technology, a range of new structural board products is being developed. This range includes wafer board, oriented wafer board, oriented strand board (OSB), medium density fibre (MDF) board, layered composites of these, and veneer face board. These developments are being extended into the production of composite lumber, and panels (e.g. OSB Folds).

A key contribution of this paper is the development of theoretically based models for engineering design and analysis of these new products, that will allow their extension and adaption to the needs of the developing world.

The models allow strength and stiffness of the composite board (or lumber) to be predicted, or the product to be designed to meet specified strength and stiffness performance criteria, for various material components.

They conceptually allow the automated (on-line) quality control of these products during processing, and the selection and sorting of varying feedstocks to meet precise performance standards, for a range of different products and end uses. The models will thus facilitate the use of diverse species and timber qualities from tropical hardwood forests in these products, and the optimal design and process control of these products to meet export and domestic demands. The models may be used to develop a range of new engineered products, boards, lumber and building components, utilizing mixed timber species, almost all of the tree, and also agricultural and wood wastes.

The models can be utilized with both high technology and low technology, and strategies involving both of these are discussed for developing countries.

The models complement, and increase the effectivenenss of, new developments in high technology based on micro electronics and information processing, which are causing a revolution in technological hardware development and process control. The essence of this revolution is the separation of information from the movement and processing of materials. This allows the processing of this information with the aid of models, such as those above, driven by operational research, mathematical optimization [illegible] control theory techniques. Automatic scanners can provide informa[illegible] inputs; computer based information systems can retrieve materials [illegible]cies and required product performance criteria and demands; and the models and optimization techniques allow the two to be matched to provide an optimal range of end products for the material inputs.

At the low technology end of the process and product spectrum, the models may be used for the engineering design of mineral bonded boards, Relatively high quality boards may be produced for local markets using low capital technology and local materials and skills. Cement bonded boards suitable for external and internal use, and gypsum boards suitable for internal wall and ceiling linings, may be produced in this way.

A range of new technologies, for sawn wood, processed boards and secondary industry products, their potential for further development, and their application to developing countries, are outlined.

The importance of information systems as part of technological development and effective utilization of resources, is discussed. The types of information systems appropriate to the wood processing industries in developing countries are considered. These include information on the quantity and quality of the diverse species in existing hardwood forests, on the processing technologies including maintenance, diagnosis and repair, on performance characteristics required for various end products, on engineering design models for products as developed in this report, on planning models for optimal location and layout of plants as also outlined herein, on plant management, on forest management, and on supply of, and demand for, forest products at a national and global level.

Finally, the potential markets for existing and new forest products are discussed, along with implications for development strategies for the timber processing industry in the developing world, taking the diversity of national needs and endowments into account.

CONCLUSIONS

The demand for industrial roundwood is expected to increase by 50 per cent or more over the next two decades (although this would represent a rate of increase substantially above that of the 1970's). Much of this increase in demand is expected to occur in the developing world.

Some of this increase will be met by plantation softwoods and hardwoods, much of which are in developing countries. The rest of the increase must be met from existing natural forests, largely hardwood forests in the developing world. It will require the harvesting of diverse, partly unfamiliar species of varying quality and accessibility, and more complete utilization of each tree. The demands for wood fibre, and for processed boards are expected to increase at a greater rate than that for sawn wood in both the developed and developing worlds.

The range of products is also increasing. New structural boards, wafer boards, oriented wafer boards, oriented strand boards (OSB), medium density fibre (MDF) boards, multi-layered composites of these, composite lumber of similar composition, and building components (e.g. OSB Folds) are being developed in an environment of high prices for and short supply of high quality logs.

New design models for the engineering design of these products have been developed herein to fill an information-knowledge gap which may have hampered further development of these products or the transfer of their technology to the developing word. The models may also be incorporated in process control techniques to optimally select from a range of inputs to produce products within given performance limits to meet a range of end use demands. Further models have been developed and are presented for the optimal location, composition and layout of production plants.

Other models are being developed as part of the IIASA Forest Sector Study, to project future supply and demand at a global and national level, and world trade in forest products. These will update and refine the projections considered above.

Provided these projections are correct, new, large-scale facilities for production of sawn timber, plywood and other composite products will be required in the medium and long term. These are expected to be located close to the forest resource, so that much of this production capacity would be located in the developing world. The plants should be integrated facilities, enabling the forest resource to be optimally utilized among a range of end products, to meet export and local demands. These plants should be at the high technology end of the spectrum, utilizing micro electronics for scanning inputs, sorting, and process control to meet performance standards for a range of end products. They could be financed, constructed and operated on a partnership basis with high technology firms or countries, with agreements designed to ensure full technology (and eventual equity) transfer including training in management, maintenance and operation. Such agreements should ensure that the interests of both parties are aligned so that the best technology, most appropriate resources, best plant location, composition and design, and best marketing arrangements are secured. Alternatively, independent expert planners should be consulted and the construction contract should be on a turnkey basis and include spare parts and training. The aim in each case is to enable high volume, high quality, low unit cost, production to meet export demands and provide export earnings, and also meet or stimulate national demands.

The appropriate development strategy will depend on the extent of development of a local, technological and information-knowledge base. The effective utilization of the forest resource will require the development of a comprehensive information system with the following components.

- information on the resource - species, locations, quantities, properties;

- information on the markets - demands for various products;

- information on performance standards for these products;

- information on the technologies involved, their operation, maintenance, and adaption to changing needs.

Further information systems should include:

- the engineering design models relating product composition and properties, developed herein;
- process control systems based on these models and utilizing optimization and optimal control techniques as discussed herein;
- planning models for optimal location, composition and layout of the processing plants, as outlined herein;
- supply-demand projection models such as those being developed at IIASA in the Forest Sector Project.

The plants above would be large in scale but small in number and stretch the small pool of technological and skill resources available in developing countries. More importantly, in many ways, to complement these large-scale export based plants, many smaller scale medium and low technology developments will be required to meet local needs in other regions and other countries where the conditions for large-scale development do not apply. These would include smaller sawmills, simple kilns for drying some of the timber produced, and local manufacture of housing components and furniture from this timber. At an even smaller scale and lower technology level, mineral bonded boards for internal and external linings for housing may be produced using cement or gypsum as a binder and wood fibres, vegetable fibres and/or other wood or agricultural wastes as the reinforcement. Details of this process are discussed. The engineering design models developed for other processed boards are again applicable.

Thus a range of development strategies from the highest technology to the lowest is proposed for different countries, and different areas in these countries, depending on the resources of timber, technology, skills, knowledge, and information available. However, the high technology, high capital, high volume plants will impose a severe demand on the skills, capital and technological resources of the country and should only be introduced where resources are available and potential export earnings make it viable and desirable. In other cases, lower technology, lower capital, lower skill, production processes should be introduced which are import substituting, utilize local skills and materials, retain income in the region and allow capital accumulation for further industrial development.

RECOMMENDATIONS

The study has highlighted the following development needs. The need for:

(i) better information on the quality and quantity of wood resources available particularly in tropical hardwood forests; for the purposes of strategic planning, management, harvesting and utilization in the wood processing industries;

(ii) development of forest management techniques to ensure maximum sustainable yield subject to conservational, water catchment and other needs;

(iii) recognition and survey of the diverse endowments and needs of each developing country to ensure these are better matched by new industrial developments;

(iv) where material and other necessary resources allow, the development of large scale plants based on large wood resources to meet export demands and provide necessary export income. The quality and scale of production required will necessitate high technology solutions in these cases, and the microprocessor will be a useful tool in these operations. These developments will provide a bridge for transfer of high technology skills from the industrial world.

(v) for the vast majority of situations however, medium and low technology solutions to meet the needs of local and regional markets. These will enable export substitution, utilization of local skills and resources, retention of income in the region, local multiplier effects and accumulation of local capital to allow further stages of development.

(vi) development of a sound information and knowledge basis for these developments for economic and technical analysis and strategic planning including: adaption of the planning models described to the selection, locations, and layout of appropriate large wood processing plants;

(vii) continued support for the supply demand projection models being developed at the global and national level within the IIASA Forest Sector Project as a basis for strategic planning of wood processing in developing countries;

(viii) development of new structural products based on the product design techniques developed herein and appropriate to the needs expressed above;

(ix) further development and calibration of these design techniques to local materials and local technologies, at the high technology end;

(x) adaption of these design techniques, along with optimization techniques and control theory, to on-line quality control of the processing of these new products, utilizing a diverse range of raw material inputs to meet performance standards for a range of end uses, to match given demands;

(xi) further development and use of economic evaluation models to examine, in combination with the models above, the economic viability and cash flow needs of high technology investments in developing countries to meet future global and local demand increases for forest products;

(xii) further study of alternative arrangements for transfer of this high technology in ways which align the objectives of all parties, to ensure the most appropriate technology is transferred, it is transferred in the most effective way, and is utilized to maximum efficiency and effect, with viability under the possible spectrum of future economic and supply/demand conditions;

(xiii) support for the establishment of medium to low technology industries such as sawn timber, small hardboard and small plywood plants to utilize local skills and resources and provide a basis for secondary industries such as furniture, housing construction, frames, components, and utensils.

(xiv) support for the establishment for low technology, low capital industries, such as fibre-cement and fibre-gypsum board plants, as local industries, complementing sawmilling, and providing further import substitution, local employment, with local multiplier effects and no environmental problems. These industries may provide a grass root basis for technological development, even in the least developed regions of the world.

(xv) support for international standards particularly in the construction industry to enable products from developing countries to be designed to meet these and hence have wider markets.

1. THE FOREST RESOURCE

1.1 Existing stocks

Although individual estimates of existing stocks may differ, FAO (1982, 1983) indicates that there are approximately 4100 million hectares (ha) of forests in the world, including 2500 million ha of closed canopy forests with a growing stock of 330 x $10^9 m^3$. These resources are substantial and broadly distributed. Of these, 2000 million ha are classified by FAO (1983) as operable and this excludes presently inaccessible areas such as much of Siberia and other areas inoperable on legal grounds. In operable forest, the USSR has 15.5 per cent of the world's growing stock, North America 14 per cent, Latin America 31 per cent, Asia 16 per cent, Europe 5.5 per cent and Africa 15 per cent (Table 1.1. This and all other tables are found at the end of this paper starting on page 92). About 30 per cent of the total is in conifer (softwood) forests, and the USSR and North America account for 75 per cent of these. The remainder is in broadleafed (hardwood) forests and these are more evenly distributed. However, over half the total operable forest resources are in tropical regions and are largely hardwood forests, characterized by hundreds of species. The apparent potential is far from realized (less than 20 per cent of the world's industrial wood comes from this source (FAO 1978)). Commonly, only the best trees from a few of the species present are utilized. However, there will be a substantial change in the supply of logs and processed woods from tropical countries over the next few years. Exports of logs of some well known species have been stopped and others will follow. Unfamiliar species will be increasingly substituted.

Destruction of forest for agriculture in these regions is also taking its toll (Table 1.2) and will make changes to the land which are irreversable within the period considered here. Population growth rates in these regions are also highest (according to the UN Fund of Population Activites, 80 per cent of total population growth is expected in these tropical regions) increasing needs for agricultural and urban land and demands for wood for building, paper, fuel and other wood products. Some countries are harvesting at a rate close to replacement rate, i.e. at the rate of wood growth of existing forest, e.g. USSR and Sweden (which is actually in excess), and

Canada, will be approaching this point before the end of the century. Long-term effects of harvesting are also not known.

In tundra regions, the ecological balance is fragile and cutting down of forests can greatly increase depth of permafrost (e.g. from 1 m before deforestation to 6 m after, in Fairbanks Alaska (United States, Department of Energy, 1982)), rendering land unsuitable for many other uses including possibly reafforestation.

1.2 Production

World timber production, however, has been increasing steadily, particularly in the developing world (Table 1.3). Total world roundwood production increased from 1670 million m^3 in 1959, to 2560 million m^3 in 1969 and 3020 million m^3 in 1980, and the share of production in the developing world increased from 33 per cent in 1959 to 52 per cent in 1969 to 59 per cent in 1980. Over the period 1969-1980, fuelwood and charcoal production increased from 1330 million m^3 to 1629 million m^3 mainly in developing countries (1141 million m^3 in 1959 to 1471 million m^3 in 1969 to 1471 million m^3 in 1980). World industrial roundwood production increased over the same period from 1232 million m^3 in 1969 to 1393 million m^3 in 1980. This production was mainly in the developed world (1037 million m^3 in 1969 and 1100 million m^3 in 1980). Most of this industrial roundwood production was softwood (71 per cent in 1969, 69 per cent in 1980) but hardwood production was increasing, particularly in the developing world (137 million m^3 in 1969, 199 million m^3 in 1980).

1.3 Demand projections

Over the next twenty years, global demand for wood is expected to increase over 50 per cent, and to double for some wood fibres. By the year 2000, the world is expected to need 2100 million m^3 yr^{-1} of industrial wood and 1800 million m^3 yr^{-1} of fuel wood (FAO 1982) or nearly 4000 million m^3 yr^{-1} total. Various projections for the year 2000 are given in Table 1.4 and vary substantially about this estimate, but present demand for fuelwood (Table 1.3) are already approaching the values projected.

However, production of industrial roundwood over the period 1969-1980 has increased only from 1232 million m^3 yr^{-1} to 1393 million m^3 yr^{-1}, i.e. less than 20 per cent in 12 years or less than 1.5 per cent (compound) per year compared with a projected increase to 2100 million m^3 yr^{-1} or more by the year 2000, i.e. an increase ov over 2 per cent per year. Hence some caution in accepting estimates of future demand may be required, but the question is more one of 'when' than of 'if' this demand will occur.

1.4 Supply projections

The major sources of large sized hardwoods to help meet these needs will be in South East Asia and South America (FAO 1982). The most critical future demand is considered to be for long fibred softwood pulps and the two major regions where these woods are in surplus are North America and the USSR with one half of the world's total softwood inventory being in the latter region.

Growth rates vary markedly, from less than 1 m^3 ha^{-1} yr^{-1} for some natural forests (FAO 1976), including some softwoods in USSR, to a mean of 25 m^3 $ha^{-1}yr^{-1}$ for eucalypt plantations in Brazil (Sedjo 1981). Plantation pines in Brazil also have high growth rates (20 m^3 ha^{-1} yr^{-1}) as do plantation pines and eucalypts in Australia and New Zealand (growth rates for plantation pinus radiata and eucalypts exceed 16 m^3 ha^{-1} yr^{-1} (FAO 1976)), and Southern Africa and parts of Eastern Asia. The largest areas of plantations which could partly fill this gap are in Brazil (eucalypts and pine), Chile, Venezuela, and New Zealand (radiata pine), Fiji Islands (pine), Africa (pines and eucalypts), Korea, Japan, China, Europe, and in the United States (including pines and eucalypts in the Sout East), although the line between plantations and regenerated forests is a fine one except for exotic species. Industrial plantations might be expected to yield in excess of 10 m^3 ha^{-1} yr^{-1} and to cover nearly 80 millions of hectares (Table 1.5) largely in developing countries but also in the developed world (e.g. USA, Europe, Japan, New Zealand, and Australia). Thus plantations trees might provide more than 800 m^3 yr^{-1} representing more than 20 per cent of total projected needs.

Some of the remainder may come from additional plantations created over the next few year and regenerated forests, but most must come from existing natural forests, to the extent they have been conserved. If the net growth rate on these is assumed to be more than 1.5 m^3 ha^{-1} yr^{-1}, and the further loss of forest area is taken as 10 per cent or 300 to 400 million ha, the 2200 to 3700 million ha apparently still available (although not currently operable) would have a potential as a renewable resource of at least 3300-6000 million m^3 yr^{-1} or 80 to 150 per cent of total projected needs in 2000. Other estimates of this potentially sustainable production rate range from 7000 million m^3 yr^{-1} to 19,000 million m^3 yr^{-1}, with a tentative FAO estimate of biological potential of the world's forests of 12,000 million m^3 yr^{-1} (King 1978). Hence the total quantity of wood growth may not be a problem in the remainder of this century, if these quantities are attainable. There are, however, various doubts about the realization of these potentials and the continued quality of wood available (Hillis 1980, Sutton 1981). The fact that 80 per cent of current total supply of wood is coming from virgin forests indicates a lack of real experience of the equilibrium situation and of practical sustainable yields. The fact that few of the many species in tropical hardwood forests have been used commercially also introduces some uncertainty. Furthermore, quality, diversity, access, geographic distribution, policies on conservation and utilization, and restrictions on international trade will be causes of concern, and proper management of this forest resource to ensure and increase the quantity and quality of sustainable yields is a challenge yet to be recognized and accepted.

Thus existing plantations will meet a proportion of expected wood needs to 2000, new plantations planted over the next few years will also contribute, presently utilized species from natural forests will provide a further proportion, but the remainder must come from less accessible, less familiar, diverse species from natural forests, subject to national policies for control and utilization of this multi-purpose resource and to international trade constraints.

1.5 Remarks

If these projected demands are realized, the problems will include:

(1) an information problem - information on the properties, locations, access and harvesting impacts of these species and proper management techniques;

(2) a distribution problem - the imbalances between location of trees, location of processing plants, and locations of markets, and the increasing costs of transportation between these locations, and over international boundaries involving international trade restrictions.

The problems break down further to:

- materials problems - properties of different species in natural forests, and age versus properties of wood in plantations;
- survey problems to provide information on existing stocks;
- information systems problems - storing and retrieving this information;
- forest management problems - in the natural forests to ensure quality and quantity of yield, and its sustainability and associated ecological problems;
- international trade problems;
- access problems and associated transport problems including high transport costs;
- transport planning-logistics operational research problems;
- plant flexibility problems;

- technological problems and technological support and infrastructure problems, particularly in the hardwood tropical forests of the developing world;

- quality control problems;

- plantation location problems;

- problems of multiple uses for forests, and restrictive policies for exploitation and marketing;

- problems of pollution e.g. acid rain and of vulnerability of plantation forests to biological attack.

In addition to plantation logs and natural forest logs, other sources of supply must be considered and utilized.

Nearly all of the wood of the tree may be utilized as wafers, flakes, chips or fibres in processed board and processed structural sections. Many lower quality species might similarly be used. Other wood wastes from mills or further wood processing operations may also be utilized. Supply constraints are reflected in costs, and typical wood costs at the mill for various regions and uses are indicated in Fig. 1.1.

Alternative sources of natural fibre in developing countries, such as rice husks, sisal, bamboo, sugar cane bagasse, lapine, coconut fibre, barley straw, peanut shells, sanseviera, and manila abaca, may similarly be utilized, in flake and fibre boards and similar products.

Cement may be considered as an alternative to resin as a matrix in these products, especially where technological and capital resources are in scarce supply. Gypsum is another possible substitute in internal lining boards.

Thus the challenges to the year 2000 in the wood processing industry lie in improving forest management, and knowledge about this, in the diversity of supply, the mismatch of location of supply, demand and processing, the transport problems involved, the substitution problems resulting, the information base, the technological problems in developing countries of producing processed materials of export grade and the further and much larger problem overall of setting up a vast number of low to medium technology industries to meet rising local aspirations and needs. Information systems to provide data on timber properties and resource quality, quantitative inventories of potential supplies, and models for selection of supplies to meet performance needs and to relate supply, processing and demand locations, have considerable potential value in this area. Other models for projecting supply and demand at the global and national levels are also vital to further investment and planning.

In developing countries, the problems will therefore be:

(i) the effective management of the resource -
  - natural forests
  - plantations forests

  to ensure maximum sustainable yield for the resources available;

(ii) the selection of level of exports of timber, the degree of processing prior to export, and level of technology employed;

(iii) the decisions regarding import substitution and retention of local skills - the extent to which local materials will be promoted on the domestic market.

For import substitution industries, and retention of local skills, development of a technological base from the grass roots level may be an appropriate strategy in many cases. Materials such as wood/cement boards may be produced in this way. Sawn timbers also come into this category. Further processing, e.g. kiln drying, dressing, and plywood manufacture, require increasing levels of technology but may serve local building and furniture making and local and export markets. Other reconstituted boards - hardboard, particle board, flake board, wafer board, oriented wafer boards, strand boards, and medium density fibre boards require further levels of technology and quality control. However, they may provide a useful complementary product in an integrated export oriented plant to enable full utilization of the timber resource.

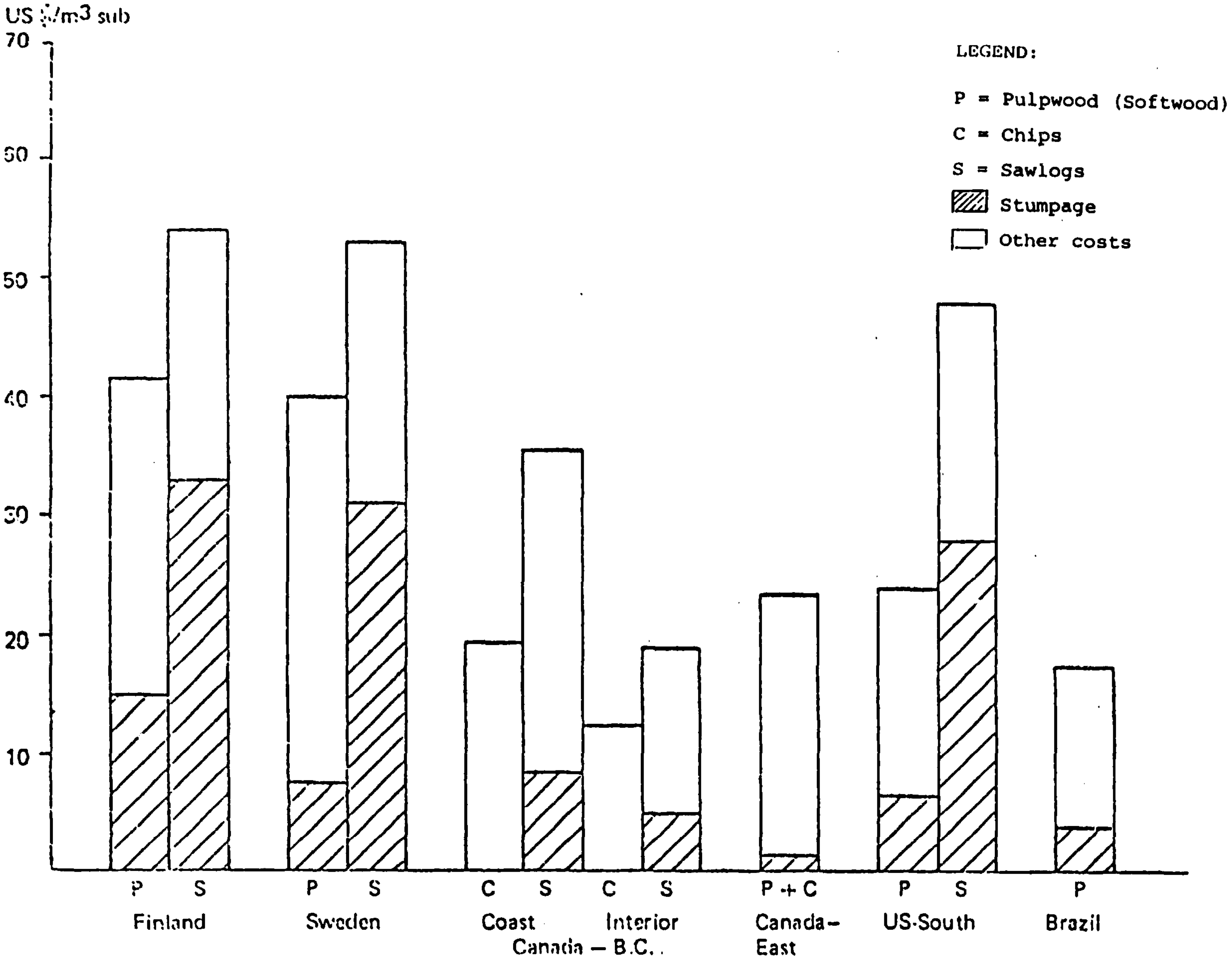


Fig. 1.1. Typical 1979 wood costs at the mill by region. The costs are measured in US dollars per cubic meter solid volume under bark (m^3sub). Stumpage is the commercial value of standing timber; the other costs include harvesting, transportation to the mill, and so on. (Source: Adams et al. 1982)

2. PRODUCTS FROM THIS RESOURCE

The range of products developed from this resource includes fuel wood, paper pulp, and mechanically processed wood. The latter include sawnwood, plywood, wafer boards, flake and particle boards, medium density fibre boards, high density hardboards, strand boards, and combinations of these, and furniture, building components, packaging and other products. The various products and their characteristics are presented in a table at the end of this chapter (see tables 2.1-4).

The primary products may be classified by the quality of resource required, by the level of technology involved in this processing, by the energy and labour inputs required, by the quality and performance of the products, and by their end uses.

2.1 Sawnwood

Sawnwood requires high quality roundwood logs as a raw material, and the supply of these is already constrained in some parts of the world and this scarcity is expected to become more extensive before the end of the century. However, the level of technology involved is within the capacities of developing as well as developed nations and production can be expected to increase proportionally in the developing world. The energy and labour required are not large. The quality of the product can be very high and suitable for framing and finishes in housing and furniture as well as for timber engineering uses. Strength, durability, and other properties vary substantially from species to species and the properties of a range of species from developing countries is given in the extensive reference manual, Keating and Bolza (1982).

2.2 Wood based panels

These are comprised of timber (or other) particles of various size, geometry, and orientation, combined with resin or other binder. They may be considered systematically firstly by particle type and orientation, and secondly by binder type and quantity. 'Particles' may vary from complete sheets of veneer, through relatively large wafers, smaller flakes or other wood particles - shavings, sawdust, etc., strands of fibrous timber material, down to individual wood fibres, as produced for paper pulp (Table 2.1).

Various vegetable fibres and agricultural wastes from the developing world may also be used, e.g., sisal, flax, bamboo, sugar cane bagasse, manila abaca, sansevieria, cereal straws, bark, lapine, water reed, coir, elephant grass, peanut shells and rice husks. Fibre glass, rock fibres, carbon fibres, and synthetic organic fibres may also be incorporated.

These basic elements, particles, and resins may be combined in various ways to produce conventional board products and important new combinations. Some two-element combinations are listed in Table 2.2, and further newer three-element combinations in Table 2.3.

Conventional products include plywood, hardboard, insulation board, block board, and wood wool cement. Later came particle board, wafer board, and more recently medium density fibre board, oriented strand board, and oriented wafer board, and combinations of these - for both boards and also for lumber. The introduction of glass fibre into particle board and particle board lumber further enhances their structural properties. Cement particle boards and cement wood fibre boards are further recent combinations, the latter as a replacement for asbestos-cement.

A better understanding of the structural-mechanical behaviour of these boards allows models to be developed relating the properties of the basic component materials to the properties of the composites allowing the latter to be designed using engineering principles and models as discussed in chapter 4. These same models allow new combinations to be explored and evaluated also - to provide the most suitable and cost effective solutions to different building problems, and to allow new technologies to be exploited and new industries to be developed.

The particles may be distributed randomly in direction and uniformly through the board, or oriented in one (or more) directions, and/or concentrated towards the faces of the board.

The binder may be the natural lignocellulose adhesives in the wood aided by mechanical interlocking of particles, various resins such as phenol formaldehyde (PF), urea formaldehyde, (UF), melamine, isocyanates, tannin extracts or inorganic materials such as cement or gypsum (Table 2.1).

The relative quantities of particles and adhesive may also vary. Wafer boards require only 2-4 per cent by weight of (dry) resin, particle boards 6-12 per cent of resin. In each case, however, the organic resin acts to join particles one to another and produce a continuum in this way. In the case of fibre cement or fibre gypsum boards, however, the fibres constitute only 2-12 per cent of the board by weight and the binder is itself the continuum.

These ratios are also influenced by the costs of materials involved. By weight, resin is normally the most expensive, fibre and particles are less expensive and cement and gypsum are generally less expensive still. There are also upper limits to the amount of fibre which it is feasible to incorporate in the cement or gypsum matrix.

Except in the case of plywood and veneers, the quality of raw material required for panels is less than for sawn wood, and allows raw materials unsuited for sawn timber to be utilized, including lower quality timber species branches, in the case of particle and fibre boards and roots, and sawmill and processing wastes.

The energy required is, of course, higher, for separating the particles, drying them and reconstituting them into a board. The energy level varies, however, with the type of particle, and type and density of board. The level of technology required also varies substantially.

Wafer, flake, particle and strand boards require the highest levels of technology and of energy, plywood requires lower levels of technology and energy, and some cement and gypsum boards can be produced with relatively low levels of technology and energy. Various of the resulting composites are now discussed in further detail.

Plywood

Plywood is perhaps the best established and most conventional of the wood based panel products. It requires only a moderate level of technology, energy, and labour skill and has established world-wide markets as an internal and external sheeting, flooring and formwork.

The external grades are bonded with waterproof resins and are dimensionally stable. The technology is suitable for the developed and developing world and widely established in each.

Material quality particularly in the faces must be high for many puposes, and high quality veneers may be used for furnishing and finishing uses. This panel product is the most suitable for developing countries. However, if more of the tree and species unsuited to veneer production are also to be utilized, other products must also be examined.

Wafer board

Initially developed in 1955, wafer board production has grown dramatically in North America through the last decade, when its lower grade timber quality and low resin needs made it comparatively very cost effective.

Wafers are typically large flakes, e.g. 100 mm x 30 mm x 1 mm or 0.5 mm, may be tapered to reduce voids, and may be cut from lower cost materials such as lower density species, e.g. poplar, aspen, and possibly those parts of the tree having little other use. Plantation softwoods, and hardwoods such as pinus radiata and eucalypts are also suitable (Krilov 1981). Resin contents are also low, e.g. 2-4 per cent by weight. The geometry of the wafers may be varied through the thickness of the board with thinner wafers at the faces to increase the quality of finish. Wafers may also be oriented to enhance the properties of the board for particular uses, such as flooring.

Strength properties are superior to particle board and approach those of plywood. Stability under moisture change is inferior to that of plywood but superior to particle board. However, its markets have expanded enormously and it competes in many of the same markets as plywood on favourable cost terms. The technology required is similar to that of particle board. Production is currently centred in the US and Canada and most new board plants recently completed or planned in North America have been wafer board plants.

Strand board

Strand boards have similar potential applications to wafer boards. The particles are long but in this case narrow and can again be oriented in direction to provide structural properties approaching those of plywood with different orientations in different layers of the board. Oriented strand boards (OSB) are beginning to compete in the same markets as wafer boards, and one recent innovation returns the ends to provide a composite wall panel or roof or floor section for prefabricated or componentized construction.

Particle board

First developed in the 1930's, production of these boards expanded in the 1960's and is now broadly distributed around the industrial, particularly softwood producing, areas of the world. A wide range of particles, chips, flakes, shavings, sawdust and various combinations of these are used. Composition varies through the thickness of the board. Boards are generally for the interior use and have properties inferior to plywood, wafer board, and OSB.

Structural grades using waterproof resins (e.g. PF) have been introduced for flooring and similar uses. Dimensional stability is substantially inferior to natural wood or ply, and strength is also inferior. However, their market and range of (interior) uses is very wide.

Medium density fibreboard (MDF)

Composed of fibres bonded with resin, these boards have relatively high strength and good machining properties which make them particularly suitable to the furnishing industry. Fibres may be oriented (e.g. electrostatically) to enhance their properties for particular uses. They may also be used in the external layers of a composite board. A wide range of fibres may be used including wood fibres and various vegetable fibres and agricultural wastes from the developing world as previously listed.

Technology is again similar to but more sophisticated than that of particle board manufacture but the availability of cheap suitable raw materials may increase their suitability for production in the developing world. The increasing costs of transport would increase the comparative advantages involved in local production and marketing, but decrease their export potential.

Hardboard

Hardboards (developed in 1924) are a long established product. Their density (800 kg/m^3 and above) is higher than that of MDF and, they are bonded by the natural lignin binders and a certain amount of mechanical interlocking of the fibres. The obviation of expensive resins increases their competitive advantage in times of high resin prices. Undoubtedly the recent development of MDF will have some technological flow on into the high density fibreboard area. One potential innovation would be the inclusion of resin in the outer faces to increase flexural strength and water resistance (as an alternative to the tempering process). Hardboard of export quality is already produced in Brazil and sold internationally.

Wood composites

Various composites of the materials above are also being developed. One of these has veneer faces and a particle board core, and has strength properties approaching that of plywood or natural timber. Other composites can consist of differently oriented layers of wafers or strands as previously noted, or different sizes and orientations of particles, to increase the density, strength, and appearance of the board at its external faces. The purpose of variation can also be to reduce moisture penetration or to reduce emissions of gases such as formaldehyde, and can include a variation of resin type and quantity through the thickness of the sheet.

2.3 Mineral bonded boards

Cement boards

Although cement bonded boards such as wood wool have been produced in both developed and developing countries, in some cases since the early part of the century, some recent innovations have been made. Wood cement particle boards are a development from particle board with portland cement replacing the resins normally used. These cement based boards are being produced in substantial quantities in Germany and Japan. They are superior to resin boards in some ways, e.g. virtually incombustible, insect and fungal resistant, dimensionally stable, and moisture resistant; but are inferior in others, e.g. harder to cut, heavy, lower bending strength, lower impact resistance, and higher thermal conductivity. The cost of the board is also higher, and the production process slower. Reaction between the wood and cement must also be suppressed (e.g. with calcium chloride on other additive to the timber prior to contact with the cement).

Wood fibre cement board is also being developed, as a substitute for asbestos cement board. The fibres are separated from natural wood by chemical or mechanical means. They are only 2 to 3 mm in length but with length diameter ratios of 50 to 100 so that provided they can be individually enclosed in the cement matrix to provide adequate bonding, reasonable strength properties for the composite are feasible. The amount of fibre which can be incorporated in this way is presently limited to 2-12 per cent (of the matrix) by weight with flexural strength reaching a maximum in the range 8-10 per cent of fibre by weight.

Further development of the technology including preservation and plasticising additives, may improve the properties to more nearly approach those of asbestos cement. Low technology alternatives are also available. A range of other fibres such as vegetable fibres and agricultural wastes as previously listed may also be incorporated into a cement matrix to make cement-fibre board suitable as a small-scale local industry in all developing countries. Only the minimum of plant and skills, and low cost materials are involved. The product may be made durable and suitable for external use.

It is highly recommended, particularly for less developed regions; and local manufacture minimizes transport costs.

Gypsum boards

Another product in the same low technology category and suitable for internal lining boards is gypsum board or plaster sheet. The industry has been established for many years in Australia and has held a major share of the market for internal wall and ceiling boards. The board is normally of the order of 8 to 10 mm in thickness reinforced with sisal or, more recently, glass fibre. The quantity of fibre is between 3 and 5 per cent by weight. The sheets are cast horizontally and the fibre rolled in prior to setting, or included in mat form for faster turnover in the case of glass fibre.

A range of other fibres including wood fibres and the vegetable fibres and agricultural wastes considered above are also potentially suitable, and cost effective.

Plaster board is a (successfully) competing international product using higher technology and a continuous process to create a gypsum sheet of similar thickness, although generally inferior strength properties as it is reinforced only by a layer of paper bonded to each face.

2.4 Composite lumber

The constrained supply and hence high costs of sawn timber in the U.S.A. and elsewhere have prompted the development of substitutes in the form of composite lumber with properties which may in some ways be superior to those of natural timber.

Laminated lumber (e.g. Press-Lam) is a veneer laminated structural lumber; rotary peeled in thick sheets (e.g. 6-12 mm) and resin bonded.

Particle board-veneer composite (e.g. Comply) is a particle board with veneer faces.

Reinforced particle board lumber (e.g. Pultraform) is an engineered lumber consisting of particle board as a matrix and fibre glass as an additional reinforcement pretensioned in the composite before forming.

Oriented strand lumber is a new innovation from oriented strand board (OSB); The strands may be oriented like the fibres in wood to give enhanced longitudinal properties. Currently used non structurally (mouldings, door joints, etc.), it has potential structural uses also as the process is further developed.

These products generally have the advantage of utilizing lower grade materials to produce a defect-free, dimensionally stable product for building frames or furniture use, at a price (in the US) competitive with that of natural lumber. Some may be moulded to provide a range of engineered structural sections. A basis for their design is presented in chapter 4.

Their markets will no doubt increase with increases in price and scarcity of high grade logs for sawn timber (Youngquist 1981).

Another material still in the development stage is also considered in this category.

Strand, or scrim lumber (e.g. Scrimber), is a reconstituted wood in which the fibrous material is first stranded by rolling, removing knots, etc., in the process, to leave long, continuous fibrous strands which are combined and reformed using a resin binder and moulded into boards or sections of various required forms. The process technology is being developed in Australia (Coleman 1981), and might well have application elsewhere. It might possibly be adapted to utilize vegetable fibres and agricultural wastes in developing countries as well as tree branches, forest thinnings, etc. Glass fibre reinforcement could also be incorporated to increase strength in flexural tension.

2.5 Integrated components

Oriented strand board and oriented strand lumber have, in effect, been combined in the OSB 'folding system' in which the ends of the board are returned to provide a section suitable for walls, floors and certain parts of the roof of buildings. The process has already been used to replace several hundred houses destroyed by the Italian earthquake (in 1980). The process has considerable potential for transferring to the factory and automating a large component of the house construction process - particularly the low cost, large volume sector of the housing market.

2.6 Trends in production

Production, in 1980, the share of total production, and rates of growth in this production, in various regions of the developed and developing market economies of world for different processed wood products discussed herein are shown in Table 2.5. In the developed world, they indicate the influence of constraints of log availability on sawnwood and consequent increases in production of various processed boards. In the developing world, they indicate an increasing rate of production in all products but specially in the newer processed boards resulting at least in part from export constraints on roundwood logs.

Sawnwood

The production of lumber in the developed world (market economies) has remained essentially constant over the period 1969-1980. Over the same period, production in the developing world has increased by over 60 per cent but is still only 20 per cent of that in the developed world. Hence considerable growth potential remains.

Sawn softwood: Production of softwood lumber in the developed world has remained essentially constant over the period 1969-1980, in the range 180-200 million m^3 and represents over 90 per cent of total softwood lumber production. Production in the developing world has increased from 6 per cent to 9 per cent of the total with the major part of this production, and most of the increase, coming from Latin America, particularly Brazil.

Sawn hardwood: Production of sawn hardwood lumber is more evenly distributed between the developed and developing world. Production in the developed world has decreased slightly from 45 to 40 million m^3 over the period 1969-1980. Over the same period, production in the developing world has increased by over 60 per cent from 23 to 36 million m^3. The Far East has been the major producer, increasing from 11 to 17 million m^3 with Latin America increasing from 8 to 12 million m^3 with Brazil again the major producer in this region.

Wood based panels

In wood based panels, the position is similar to that for sawn timber except that growth has occurred in both the developed and developing world as this product continues to be developed and to increase its markets. In the developed world, production increased from 51 to 71 million m^3 over the period 1969-1980.

In the developing world, the proportional increase was more dramatic, from 4 to 11 million m^3 over the same period. The Far East Region with an increase from 2 to 5.3 million m^3 and Latin America with an increase from 1.5 to 4 million m^3 were the major producers in the developing world.

Plywood: Plywood is the longest established of the wood based panels, and one of the simplest of these products to produce. In the developed world, production increased over the period 1969-80 from 25 to 30 million m^3 (or 20 per cent), whereas in the developing world the increase was from 3 to 6 million m^3 (or 100 per cent). The far east was the major producer in the developing world with an increase from 1.7 to 4.1 million m^3. In Latin America, the corresponding figures were 0.7 to 1.5 million m^3.

Particle board: The growth in particle board production has been much more dynamic, and reflects the earlier stage of its development and market penetration curves. In 1969, production in the developed world was 13 million m^3. In 1980, it was 29 million m^3, or more than double. In the developing world, the proportional increase was even greater. In 1969 production was only 0.5 million m^3, whereas by 1980 it had increased to 2.2 million m^3, i.e. by a factor of more than four.

Latin America dominated the developing regions with an increase from 0.34 to 1.4 million m^3. Brazil again has a remarkable growth rate, increasing from 0.1 to 0.55 million m^3 in the period.

Over the next decade, considerable room for expansion in the developing world again exists both from the supply side with softwood plantations developing in a number of countries as indicated in chapter 1, and from the demand side due to increasing domestic demands and export opportunities as discussed in Section 6.

Furthermore, new composites such as wafer board, oriented wafer board and oriented strand board, promise to open up new markets in both the developed and developing world and substantial growth potential exists for these new products.

Fibreboard: High density fibreboards and low density insulation boards are both mature products in the developed world and no growth in production has occurred over the period 1969-80. Production is stable at 11 million m^3. In the developing world, production has increased from 0.5 to 1.3 million m^3, and no doubt further substantial growth potential exists. Latin America is again the dominant producer among the developing regions with an increase in production from 0.34 to 1.0 million m^3, most of which occurred in Brazil. Medium density fibreboard may add to this potential if the high capital costs of plants and high resin and energy costs in production can be met.

Fibreboards and wafer boards are each of special interest in that they can utilize hardwoods as well as softwoods, therby increasing their potential range of supply in the developing regions of the world. The methodology for increasing the strength properties of these composites and hence their range of potential uses and demands is discussed in chapter 4.

2.7 Secondary products

Products of secondary processing of wood include building material and components, furniture, tools, and utensils, The lack of standarization of housing dimensions and components makes large scale export based production difficult and most products are designed to meet local needs. Exceptions are items such as panelled exterior doors, flush panel interior doors, and louvred doors and shutters where a range of sizes suitable for use in housing and joinery are produced (e.g. in East Asia) for export and local consumption, and furniture including knock-down items, and kitchen utensils.

Products for the housing market can also include standard windows, stairs, mouldings, wood frame partitions, cupboards and door jambs.

Timbers must be kiln dried, and in some cases preservation treatment is also required for external use, although many timber species have natural resistance to biological degradation and attack (Keating and Bolza 1982).

The furniture market offers considerable scope for export industries. The availablity of a wide range of excellent furniture timber species in many developing countries, along with lower wage levels, provides competitive advantage. Good design and a knowledge of the export markets and trends are essential however.

3. PROCESS TECHNOLOGY AND TECHNOLOGICAL DEVELOPMENT

3.1 Recent technological developments

The last two decades have seen substantial and accelerating change in the wood processing industry, in products and associated technology tempered partly by the increasing costs of this technology which (recently) have not been accompanied by increases in market prices and in demand.

The computer and micro-processor are also beginning to have substantial impacts on production technology, both at the level of process control of individual machines and operational control of the plant as a whole. New tools such as integrated multi-band saws and chippers, new cutting knives for chipping, sensors to aid in sorting, location and optimal positioning of feed stock, programmable controllers and micro-computers are increasing processing efficiency and yield from raw materials.

New materials and materials combinations are increasing the quality and range of uses of processed boards, as outlined in the previous section. Composite lumber is another product innovation as previously noted.

New methods of breaking down wood into strands, scrim, or wafers have been developed to facilitate these new products.

Electrostatic and mechanical techniques have been developed to orient particles or fibres in these composites, further enhancing the properties involved.

New adhesives are being introduced such as melamines, isocyanates and tannin extracts to reduce costs, diminish formaldehyde emissions or increase dimensional stability of the board. Further mechanization and automation have been introduced into the secondary processing of timber (and composites) for building components, furniture and other uses.

The rapidity of the changes involved is a consequence of a number of interacting factors. The constrained supply in some regions of high quality logs as outlined in chapter 1, and the consequent price increases, have increased the comparative advantages of reconstituted or composite board products which utilize lower grade and consequently cheaper raw materials. The health hazards associated with asbestos have led to its partial replacement as a fibre in cement fibre boards, and wood particles and wood and vegetable fibres are beginning to fill this need. Formaldehyde has been identified as a potential health hazard if present in sufficient quantities and this has led to the search for alternative resins for particle boards.

Transport costs have also increased dramatically as a consequence of the energy crisis and are a substantial part of total product costs. In addition, labour costs have risen quickly over the last decade.

Technology change which merely increases output is difficult to justify in periods of low demand. However, increasing product quality, e.g. by plant conversion from particle board to medium density fibre (MDF) board, to oriented strand board or to wafer board can be justified, because it increases the range of uses or markets in which the product competes, e.g. for structural use. Thus demand for MDF board in the USA increased during the economic downturn of the mid 1970's while that for particle board decreased (Chryst and Rudman 1979). Similarly, technology change which reduces cost, such as conversion from plywood to veneer faced particle board, can also be viable under conditions of reduced demand.

Periods of downturn in the economic cycle have been shown to coincide with periods of innovation in the past. Thus the microprocessor has been introduced into a range of production units and processes in the present recession and has increased labour productivity and cut labour costs.

Micro-processor technology has proved extremely pervasive and adaptable to the processing both of materials and of the information associated with these materials thereby potentially reducing the costs of processing and increasing the yields and output qualities involved.

These conditions have combined to produce major technological changes in the wood processing industry. Even the developed world, however, is still at an early stage of this process of change and much research and development remains to be done to derive full advantage from this new technology. This change will see the processing of lumber products closer to their raw material resources and their potential markets, and the utilization of a diverse and partly inferior range of raw material feedstocks to produce a wide range of high performance, quality controlled, composite products to meet a similarly wide range of needs and demands.

The micro-computer and automation also offer the potential capacity to custom produce processed products for housing or furnishings to meet individual needs.

An essential feature of this new technology is the separation of information from the materials being processed and the use of this information to increase the efficiency and productivity of that process, and to provide information for marketing and management. This information may be obtained directly from scanners of the feedstock, from previous resource data, from sensors reporting on the equipment itself, and from knowledge stored in the system about the materials, processes and end products.

The 'engine' which will drive these information systems towards maximizing efficiency and productivity in processing systems as a whole, is an operational research or mathematical optimization technique, such as linear programming, an assignment model, or non linear technique, which is extremely efficient in itself as well as producing maximum efficiency in the system as a whole. These mathematical systems techniques are extremely powerful and are further considered in a later section under information systems. They can be applied not only to the instant on-line dynamic decisions of process control, but also to the longer term decisions of marketing management and planning including decisions on investments in new plants and new technologies.

The full potential of this acquired information has not yet been fully exploited and will be the source of rapid technological advance in the timber processing industry.

The recent advances in micro biology and its associated technologies also offers considerable potential applications in timber processing. It offers micro biological methods for processing timber and agricultural wastes to produce both the fibres and the resins required for processed boards, as well as foodstuffs, such as glucose, and chemicals or liquid fuels such as ethanol and methanol.

These technological developments are now considered in more detail.

Sawmiiling

In the last decade, the sawmill industry experienced a tremendous development in log breakdown technology. The most important innovations were the taking over of process control by computers, the development of thin kerf sawing techniques, including (multiple) band saws and circular saws, and the employment of chipping machines in both primary and secondary log breakdown processes. The benefits of this new sawmill technology are substantial and include higher productivity and/or higher efficiency and lumber yield and, in turn, maintained or improved profitability.

In Europe, the major equipment suppliers have developed comprehensive, sophisticated computer based systems for harvesting, sorting and sawing with particular application to small logs. These equipment manufacturers offer a broad product line including in some cases complete systems for harvesting and processing from the forest through to the finished lumber product, and for delivery anywhere in the world. There are advantages in purchase of the complete package in that performance specifications can be written into the contract and responsibilities fixed. Adequate spare parts and other back-ups can also be incorporated.

Relatively new technologies such as electronic scanning of feedstocks, and use of this information in computer controlled processing of these feedstocks, have been developed and are being introduced. Ball screw carriages, digital networks, high strain, accurate band mills and side dogging overhead carriages, automatic tensioning of saw blades, new round saw technology, tooth hardening and tooth tip techniques, are among recent innovations. Mechanization and automation are becoming increasingly sophisticated.

The inclusion of sensing devices, micro-processors, and automated log handling potentially allows optimal assignment of logs to various processes and optimal selection of cutting patterns to maximize quality and quantity of yield and match market demands to log supply.

This technology change is expected to continue and accelerate also because of the environment of increasing log and labour costs and decreasing availablity of large, high quality logs.

In developing countries, the high technology end of the range, including chippers on the head rig, would only be suited to a large, integrated installation based on a suitable resource where the chips could be utilized in wood based panel products or where a market for them exists, and economies of scale and export markets warranted this investment.

Lower technology, labour intensive facilities would be desirable for smaller local markets.

Kiln drying

The aims of this process are to improve wood quality and stability at minimal added cost. Kiln drying utilizes air circulation, heat, and humidity control. It can be used for both hardwoods and softwoods. Use of liquid fossil fuel for heating is becoming prohibitive in cost. Alternatives include electricity, which is also becoming prohibitive, natural gas, wood waste, and solar energy. Two different solutions are the use of solar energy kilns, and the use of high temperature drying using as an energy source wood wastes, high pressure steam, hot oil, direct natural gas, or whatever fuel is available. Both technologies have particular application for developing countries, and simple, practical prototype kilns have been developed in Australia.

Developed by CSIRO, Australia, the high temperature kiln is a continuous feed kiln capable of drying up to 21 m^3 of softwood lumber per 24 hr/day. It has two versions for (i) vertical, and (ii) horizontal lumber flows. The advantage of the former is the increasing restraint applied to the lumber from the stock above, as the drying process continues.

Temperature is 200°C, humidity 60 per cent and air velocity 12 m/s, the process can be controlled by micro-processor or programmable controller. The kiln can be transportable and low in cost and is suitable for use in all developing countries (Christensen and Northway 1978, 1979, 1981). Because of its high temperature and continuous feeding it is also suited to a higher technology, higher volume, higher capital cost, automated processing operation. However, further development of this high technology solution is required.

A prototype solar kiln has been developed by the Queensland Department of Forestry for hardwood timbers. The kiln operates at a temperature of 18°C to 24°C above ambient. The operation is most effective if air drying to 20-25 per cent mc is used as an initial stage. Capacity is 15 m^3 and is designed to suit the needs of small sawmillers. The system uses passive solar energy (the glass house principle). Drying from 25 per cent to 1.2 per cent mc can take from 20-50 days for 25 mm timber depending on thickness and timber species (Gough and Hiley 1981).

In a developing country the kiln serves two purposes - utilizing mill and other wood wastes as an energy source, and providing kiln dried timbers to support a local wood working industry, e.g. for housing materials and components, and for furniture and other utensils.

Platten dryer for veneer

At the higher end of the technology spectrum, platten driers for veneer produce a more uniform, quality controlled drying process with less energy; and only half the drying time. Hot plates instead of hot air allow a more uniform, more controlled, faster and more efficient drying process with less process damage to the veneer. This also provides a uniform moisture content for better bonding. The sheet is smoother, flatter and simpler to handle and requires less pressure and less glue to bond. This is a high technology, high capital solution, but with substantial dollar and energy saving and fast payback period (Lambert, 1980).

Stress grading

Stress grading of timber is demanded for structural applications, and the need for increased efficiency in this process has resulted in machine stress grading. Various models of machines have been developed from research carried out at CSIRO in Melbourne, Australia, in the USA, and more recently in Finland, UK, and South Africa. The basis in each case is non-destructive testing using the relationship between modulus of elasticity and strength, to relate machine measured flexural stiffness to predicted ultimate strength. The process is simplest, of course, with single species, and it is utilized extensively for grading of plantation grown, kiln dried pines.

The advantages of machine grading (Lambert 1980) are:

(1) elimination of guesswork of visual grading;

(2) detects hidden flaws;

(3) does not alter end use potential;

(4) improves marketability, design information, reliability and value added.

For smaller mills, and developing countries, an alternative, proof testing process has been developed at CSIRO, Melbourne. The process proof tests a percentage of the sawn timber, by proof loading. This process does result in a small percentage of breakages, but the remainder is both graded and its mean strength increased in the process. Details are available in Leicester (1982) and from the Division of Building Research, CSIRO, Australia.

Automated log centreing for improved veneer recovery

An example of the use of on-line information acquisition, processing, and use for control, in the wood processing operation is in the automated centreing of logs for production of veneer. Scanners provide the information on shape of the log. Mathematical models provide the information on recovery rates for logs of different shapes and different centreing locations. The matching of these data allow the optimal location to be determined and yield to be predicted. Scanning of actual output allows predicted and actual yields to be compared. From this comparison an improved centreing model can be obtained.

Optimal centreing can substantially increase yields. Accurate scanning and modelling allow a number of parameters to be taken into account in the centreing process - many more than could be considered manually.

Yield increases of the order of 10% can be obtained from logs using the automated process (Hunter, 1980).

Wood based panels

Performance standards for wood-based structural board products

In the USA, a recent move was made towards performance standards for structural wood-based panels. This is timely in view of (i) the recent rapid increase in the range of potentially suitable board products, (ii) the ability to design the composition of these panels to meet performance standards, (iii) the flexibility within this design process to vary composition to meet this standard at minimal cost or material usage, (iv) the mathematical models for product design later derived and developed in this report as an aid to products design and to on-line variation of this design to suit variations in feedstock or variations of end use.

Thus the way will be cleared for product innovations, for automated quality control of these innovations - and for new processing plants based on these concepts. Thus an environment is created which facilitates the derivation of full benefits from the product, process, and design innovations outlined herein, utilizing high technology. These innovations will best be suited to new processing plants and will facilitate the utilization of a diverse range of wood inputs. Hence they are well suited to new processing plants in hardwood and softwood forests, and many of the most suitable potential locations for these are in developing countries.

The need for international performance standards should therefore be stressed as a means of establishing world-wide markets for these products and facilitates the participaction of products from developing countries in these markets.

New technology is easier to introduce in new plants where layout and space requirements are more easily met. This holds even when the new technology is merely an addition to existing equipment. The location of the plant can also provide competitive advantage due to proximity to new raw materials sources, markets, or cheaper labour, energy, or transport facilities.

Increases in efficiency can also be expected as reductions of labour, material and energy costs are given a high priority in plant design. (Examples of reduced energy use with new vintage wood processing plants are given later in Table 3.10. They show an almost doubling of productivity of sawn timber plants with respect to energy inputs.)

A comprehensive study across an industrial sector, including data on productivity vs plant vintage, is reported from Sweden (Johansson and Strömquist 1982), where information systems have been developed to process and present the results as a reducing profile of productivity vs cumulative proportion of the sector as later discussed. From this profile, the impacts of changes in factor costs may be readily determined and the portion of the sector vulnerable to technological change is indicated.

Panel types

Plywood is the conventional structural panel product and has the major share of the market. Composite panels consisting of veneer faces and a structural core also share in this market.

Other non-veneered structural panels such as wafer board and its variants, and the recently developed oriented strand board will also be included.

The performance requirement would be expected to specifiy stiffness and strength and the testing of these. A requirement in each case is stability and strength under wetting and drying conditions, and hence the use of water resistant resins and suitable timber species would be implied.

Wood based panel board plants

Technological developments in this area include moves towards the use of computers to scan and sort the inputs and control the process in order to optimize the output of the plants. Various degrees of automation for monitoring and process control have already been introduced including micro-processor based systems, and much more will follow.

The range of new products such as veneer faced particle boards, wafer boards, oriented wafer boards, oriented strand boards, medium density fibre boards, and multi layered combinations of these, and composite lumber products outlined in the previous section, allow high quality boards to be produced from lower quality, cheaper wood resources. New knife systems for production of better quality flakes and wafers are being evolved. Alternative means of breaking down round wood into strands or fibre bundles as in oriented strand board production and scrim board development have been introduced. Mechanized and electrostatic means for orientation of particles and fibres to increase board strength have been developed.

New adhesives such as isocyanates, emulsified isocyanates and tannin extracts have been introduced as lower cost alternatives for phenol formaldehyde and to overcome the problems of formaldehyde emission which can occur mainly with urea formaldehyde resins.

Considerable product development and technological development has gone into the composition of boards, including dimensioning of particles, e.g. strands, wafers, flakes, etc., and variation of this composition over the thickness of the board. The relationship of these properties to performance of the board has also received substantial empirical study in this development and is facilitating an engineering design approach to further product development. A theoretical underpinning and extension of that development is derived and presented in chapter 4. The purpose of this section on further development is twofold: (i) to provide a comprehensive, rational, technical basis or model for board design for structural use, and to facilitate the use of this model in on-line sorting of inputs and control of processing to produce an engineered product with given performance attributes to meet a given range of structural board demands. Thus chapter 4 fills a gap in the theory of board strength analysis and will be important in the engineering development of new structural board products and their design to meet various structural performance criteria. It will also facilitate on-line quality control to match these performance standards with the properties of the board products produced.

Wafer board

In North America, wafer board is the dominant member of the structural composition board class. 60 per cent of wafer board produced is used in the market as a structural substitute for plywood. Despite rapid growth in production capacity, the wafer board manufacturing processes and products have remained basically unchanged since the first plant was completed in 1961.

Process innovations introduced over the years include flaking of 1400 mm bolts on a cylinder type wafer cutter, drying at low temperature ($175^{\circ}C$) with an indirect thermo oil heated dryer of the rotary bundle type, a 2500 mm wide forming/pressing line utilizing a single caul plate with caul frames. Product innovations include a distinct three-layer structural panel with surface layer stock of 0.5 mm thick x 72 mm long dried to 6 to 8 per cent mc to press the face layers to a higher density than the core. Core layers thicker and shorter, 0.7 mm thick x 36 mm long dried to 2 per cent give greater density variation. A more recent innovation at the product development level, is the orientation of wafers in the faces of the sheet (wafer board plus) or throughout (oriented wafer board) to increase structural strength and stiffness. Wafer board plus uses long oriented wafers in the faces of the sheet and a conventional core. Oriented wafer board uses long wafers throughout, oriented in different directions in faces and core. Plant design considerations to facilitate this product are flexibility to produce wafer board, wafer board plus, and oriented wafer board (Moeltner, 1980). The oriented products are suited to single layer flooring applications and a broader share of the structural plywood market.

Mineral-wood board production

Medium-high technology

(i) Wood wool:

Wood wool is manufactured in automated plants by a simple process. Pine logs are shredded, then mixed in a hopper with cement water slurry. This drops onto a conveyor belt into moulds of a specified length. The moulds are surcharged with the mixture and then stacked under compression to give the required density. The stack remains under compression for 24 hours. The slabs are then demoulded, trimmed and stacked to cure. The process is also suited to lower technology operations.

(ii) Wood cement particle board:

Softwood logs are flaked, passed through a hammer mill, separated into surface and core material, and mixed with cement, water and chemical additives. The mix is spread on continuous conveyor presses under automatic control. The board is initially cured in an autoclave under heat and pressure and then stacked to continue curing. The need for pressure during curing means the process is not well suited to low technology - but the time required for curing does not suit well to high technology, large scale production either, although this is the present mode.

(iii) Wood fibre cement:

In this process the wood is reduced to fibre chemically or mechanically, and mixed with cement and water or cement-silica water slurry, and dewatered in a pressure mould. Again, the process is not suited to low technology but can provide a medium-high technology alternative to asbestos cement sheet.

The essential fastures in each case above are mechanical or chemical production of particles or fibre, mixing with cement or mortar slurry and additives, pressing, forming, dewatering, and (autoclave) curing.

Low technology

(i) Fibre cement board:

A range of fibres might be considered as reinforcement in fibre cement boards. The cement silica water may be mixed and spread on casting tables or slabs. A variety of fibrous materials may be incorporated in the mixer by rolling in after casting as the cement is setting. Fibres can include wood fibres if available, a variety of vegetable fibres, agricultural wastes, or wood processing wastes, as discussed in chapter 2.

(ii) Fibre gypsum board:

The gypsum is mixed with water and cast on steel tables or concrete slabs as above. The fibre if loose is rolled in as the plaster is setting or fibre mats may be placed initially and the gypsum poured over them. Again a wide range of fibres may be utilized. Rolling in of the fibre allows long fibres such as sisal, flax, or coir, to be incorporated. Longer fibres give additional strength as shown in chapter 4. Fibre mats, e.g. fibre glass, allow faster turnaround.

Both processes above require only low technology, e.g. mixing of the mortar or plaster, casting, and rolling in of the fibre or placing of mats can all be manual processes. Preparation of the fibre can also be a low technology manual process. Demoulding and stacking for drying is also manual.

On the other hand, the quality of the finish of the sheets can be quite high - if the casting table is of high quality finish and all voids are removed in casting and rolling. The strength is adequate as a lining board and durability is high. Cement sheets may be suitable for exterior use, and gypsum sheets are for internal use only.

The process is well suited to small scale local production - and may be initiated with a minimum of capital. The weight of the board makes it less suited to transportation over long distances.

Secondary processing

The further processing of lumber into housing components such as window frames, door jambs, doors, panels, etc., or into furniture and other wood products also lends itself to both high and low technology processes. Standardization and systematic processing in each case lead to substantial economies of scale. (These standards are a most important part of the information system required for effective development of both primary and secondary wood processing industries).

At the high technology end, the micro-processor facilitates its own economies by allowing rapid throughput of materials, and fast changes in tool settings, thereby increasing the productivity of each machine and reducing the number of machines required. For example, on large machines the changeover period required between machining of one section and another can take seconds or minutes where previously it took hours.

The micro-processor facilitates flexibility of output to the extent that individual orders might be processed, reducing delivery times and inventories. Custom building of housing components and furniture is also feasible within limits using this process because of the flexibility which can be incorporated. A further complementary feature is the number of different operations that can be performed with a single, multi-tool unit.

Hence high technology micro-processor based units can produce high volume throughputs and also a range of outputs so that scale economies and flexibility are now combined.

At the low technology end, tools are simple and can be manual or mechanical. Skill provides the flexibility and productivity in this case. Scale of operation can be medium or small and capital requirements can vary similarly. Quality of output can also vary from medium or low to extremely high depending on the levels of skill, time, and markets involved.

3.2 The present technology gap

Although half of the existing timber resources are in developing countries as indicated in chapter 1, only 21 per cent of industrial roundwood in 1980 was produced in the developing world. The proportion produced in the developing world of total sawn wood was only 18 per cent, wood based panels 13 per cent, plywood 19 per cent, particle board 6 per cent, fibre board 10 per cent, and wood pulp 7 per cent. These figures indicate a substantial gap in processing technology resources and a larger gap for products for which a higher level of processing technology is required. To partly offset this, the higher quality of logs available in many developing countries allows the economic production of solid wood boards and plywoods requiring simpler technologies, whereas particle and fibre boards are more appropriate in the resource scarce developed world in which high quality logs are at a premium.

In contrast, the proportions of total exports in 1980 (FAO 1981) from the developing world were:

for industrial roundwood	41%
sawnwood	14%
wood based panels	31%
plywood	51%
particle board	1%
fibreboard	10%
wood pulp	10%

These figures indicate firstly the proportionally high levels of export of products requiring a minimum of processing technology, e.g. industrial roundwood, or simple processing technology such as plywood. For the products requiring higher levels of technology, e.g. particle board, the corresponding exports are minimal. Secondly, the high proportion of total product being exported indicates the lack of development of local markets.

The problems underlying these figures and highlighted by them are common to many developing countries, but in different degrees. They include:

- lack of development of domestic and regional markets;
- need to add value to raw materials before exporting in order to increase foreign currency earnings;
- lack of capital for high technology processing plants;
- lack of information on appropriate plants for particular resources, their planning, design, location, and integration, leading to purchase of inappropriate, obsolete and poorly located and unintegrated plants;
- lack of management and maintenance skills, made worse by urban drift in the case of remote locations;
- lack of foreign exchange for spare parts;
- lack of infrastructure;
- lack of standardization of product requirements, including secondary processing requriements for housing;
- lack of training and knowlege of design and construction of housing using timber products;
- lack of information and techniques on preservation and protection of timber for these uses.

The spectrum of conditions in developing countries varies enormously, so that the problems are present to vastly different degrees among these countries. Singapore, at one end of the spectrum, is developing as a leader in high technology in its region. Papua-New Guinea is at the other end of this development sprectrum. The South American countries of Brazil and Chile have rapidly developing wood processing technologies increasing local markets.

3.3 Investment strategies for developing countries

Two strategies at extreme ends of the technology spectrum are proposed initially for the timber processing industry. The first extreme strategy proposed is that of high technology for large scale production to meet both export and domestic demands in areas where the various resources required for this - the raw material, access, transport, skills, knowledge, and infrastructure - are available or can be easily provided.

The other extreme proposed is low technology and small scale production for import substitution to meet local needs in regions where these large scale resources, etc., are not available.

These proposals are made with the expectation that intermediate solutions will also be appropriate in various cases and to varying degrees. The range of products, processes and technological factor requirements of each is summarized in Table 3.1.

High technology

On the data presented in chapter 1, the high technology solutions will be required to meet projected world demands for timber products, utilizing the natural closed canopy hardwood forests of the developing world, and the hardwood and softwood plantation forests in some of these countries. The scale of production, the rapidly decreasing price of the micro-processor, and the increasing ability to build into it the skills and knowledge required to effectively and efficiently operate these large plants, makes this a feasible and viable future solution. Even programmes for fault diagnosis and repair recommendations can be incorporated into the system, and with micro-processor prices as low as they are and continuing to decrease, system reliability can be readily increased by inclusion of one or more backup units in the system.

The high technology option would require collaboration with governments, firms, or other organizations in the developed, or more advanced developing, countries. There would have to be procedures for acquiring the necessary capital, technology, training, plant and equipment, and supplies.

For some management and technical positions the scarcity of experienced nationals would result in expatriates filling these positions. The extent to which such a high technology firm would be linked to the local economy in terms of purchasing supplies and selling its product would depend on the circumstances and policies prevailing in each situation.

Micro-computers could conceptually be programmed to take the diverse species and log qualities feeding into the plant, scan their physical properties, help identify and associate species properties, appropriately sort prior to further processing and allocate inputs to different end uses in such a way that quality control and performance characteristics of a diverse range of output products are precisely met; and a range of high quality products matching market demands is produced. This processing is within the capacity of present technology with human operator input for species identification. The long term need for these new plants, located in hardwood resource areas and plantation areas in the developing (and developed) world is identified from FAO data on resources and expected future demands outlined in chapter 1.

A number of factors must be taken into account in investment decisions of this type. One is the unstable or fluctuating nature of demand, particularly for the construction industry. The construction industry is supported by investment, not consumption, and approximately 60 per cent of investment finds its way into the construction industry. However, investment itself depends on increments of consumption beyond the capacity of present plants. Hence its demands are based on upswings in consumption and are consequently more volatile than consumption itself, and much of the demand for forest products is from this construction sector and subject, therefore, to these same fluctuations. Hence plants can be under utilized during economic downturns and the cyclic nature of this demand must be taken into account in investment and financing decisions. The need to secure marketing arrangements to ensure that as much as possible of the plant capacity is used during these downturns in order to maintain cash flows is also vital.

Another factor is the increasing levels of substitution occurring with resource constraints and technological change. The increasing range of services offered by telecommunications will interact with demands for published material, substituting for some of these demands, and stimulating others, but the net effect on demand for paper is by no means clear at this stage. Similarly, plastic packaging will also impact on demand for wood based packaging materials. At the same time, the introduction of polymers into paper products will dramatically improve their characteristics in a number of areas, possibly increasing range of applications and demands.

Thus the increasing rates of technological change and substitutions make demand predictions ever more difficult. Investment strategies which take these factors into account are therefore required, with flexibility of timing to match fluctuations in demand and with flexibility of end product mix through use of the micro-processor and selection of suitable plant to meet short term variations and longer term changes in the spectrum of demands.

These can include sawn lumber and various processed boards, and chips or wafers for pulp making, thereby effectively utilizing the diverse range of species, parts of the tree, and quality of wood available as inputs to the process.

In the interests of the developing country, the agreements for establishment of these high technology plants should allow for training in operation and management, increasing participation in this operation and management, and increasing equity of the developing nation in this development.

The plant should be integrated - producing a spectrum of products that utilizes all of the wood of the tree and meeting a range of export demands. It should be planned, designed and located by the best, most experienced, independent expertise available and constructed as a turnkey operation so that responsibilities can be fixed and erformance specifications enforced. Adequate parts, maintenance and management training should be included in the technology transfer agreement. A partnership arrangement with a producer from a high technology nation could be effective for technology transfer. A profit sharing arrangement would align the objectives of both partners to ensure that development is viewed as a benefit to both partners and that no conflicts of interest arise which could result in an inferior performance or product.

A partnership development with a high technology nation or firm in which benefits were appropriately shared may thus help to ensure that the best and most appropriate technology was obtained and effectively utilized, and eventually transferred.

The concept of alignment of objectives is an important one and can be extended to other parties involved, e.g. management, labour, suppliers and marketers, to ensure maximum productivity and minimum conflict at all stages of development and operation. It cannot be too highly stressed.

Low technology

At the other end of the scale in size of plant and level of technology, is the production of sawn lumber and processed boards for local use in areas unsuited to these larger plants. Small saw mills or use of small round timbers may be appropriate in some of these regions. Processed boards can have a mineral binder of cement, cement silicia, or gypsum. Reinforcement in the sheet can be wood or vegetable fibres or agricultural wastes. The properties and compositions of these boards, including the range of possible fibres and their properties, are given in chapters 2 and 4. The process can be suited to small scale production, hand mixing of matrix, casting on flat (e.g. concrete) tables, and rolling in of fibre during setting. Cement based sheets are suitable for external and internal linings of buildings. Gypsum sheets are suitable as internal lining boards only.

The weight of the sheet makes it less suitable for transport but quite suitable for local use. The inert matrix means that it is fireproof and not subject to biological attack. The quality of finish can be very high. The strength is less than for resin bonded sheets but quite adequate for wall and ceiling sheets. Cement based sheets can have external and further internal applications also, including flooring, if suitable sheet dimensions and material quantities are selected.

The advantage of these low technology, import substitution solutions is that local skills are retained or reinforced, the income earned remains in the region, and has multiplier effects in the region, minimum damage occurs to the environment, and opportunities for employment, retention and development of local skills, and local capital generation are provided, and a base is formed for further technological development from the grass roots level.

3.4 Costs of plant, production and transport

The costs of the various factors of production and distribution obviously differ from region to region as do the constraints on availability of the resources involved. Unit costs of timber at the mill are given in Fig. 1.1 (in US$/m^3 gross in 1979) for sawlogs, chips and pulpwood for several developed and developing regons. Plant costs (1981, 1975) for various wood based panel types and plants sizes are given in Tables 3.3 to 3.9. Production costs are also given in these tables. Some sea transport costs (from developing countries in SE Asia to the developed world) are also noted.

Changes in cost with scale of technology and with type of technology are also indicated in Tables 3.3 to 3.9. Changes in energy use with new (Scandinavian) technology in wood processing plants vs energy requirements from previous (existing) technology are indicated in Table 3.10. Note that the energy savings are almost 50 per cent in the case of sawn timber plants. (However, the index of plant costs rose faster than the consumer price index over the last decade (Fig. 3.1) so that some tradeoff between efficiency and capital cost may have occurred.)

Scale economies:

There are essentially no scale economies with quantity of labour involved in a process, and little or no returns to scale for quantity of materials used. Scale economies relate basically to the technology and plant size involved. For low technology, low capital cost processes, small scale operations suffice. In the case of low technology mineral bonded boards, higher transport costs due to high densities are an offsetting factor to scale economies, and small regional or local plants may be expected to be more economical overall. Thus the plants are import substituting, not export oriented (Fig. 3.2).

With higher technologies and plant costs, scale economies become more important as indicated in Tables 3.3 and 3.6 and production costs decrease substantially with scale of plant. Thus marginal costs of production with increase in capacity are small and as the densities are also less than with mineral bonded boards, unit transport costs are less and it is feasible to seek export markets or expand domestic markets to absorb the increased output with increased scale. As shipping costs vary little with distance carried, large export markets are potentially available for these products provided no trade barriers exist.

Hence there are advantages in small scale, low technology production for import substitution - with scale governed by relatively large, local transport costs. There are also advantages in large scale, high technology plants making lower density, high strength, more robust, and hence more transportable products, using micro electronics for quality control, and utilizing relatively low international shipping costs to increase market size and hence reduce unit costs.

Advantages of the low technology solution are low capital costs, low skill requirements, labour intensive operations and local retention of income with local multiplier effects on all income generated.

Advantages of the high technology solution are greater total income, greater value added to exported products, greater export earnings, acquisition of skills and technology, and necessary infrastructure, but greater leakage of these earnings outside the region and the nation, and greater capital, technological knowledge and skill requirements.

The costs of plant automation are of the order of $500,000. The additional cost per unit of production and potential savings in material and labour costs are indicated in Table 3.7. Higher and lower costs of automation are also shown. Substantial savings are indicated and these would still exist at a diminished level for unit costs in developing countries.

The plaster-fibre board industry is a relatively low technology industry and requires relatively low capital input, e.g. US$200,000 or less per plant if mechanized, and even lower capital costs if a more labour intensive process is used. A plant (in Australia) producing 10 m^3 per day requires a production staff of 7 including cutters and loaders. (The plant manufacturer is Donald, New Zealand. The casting table size is 6.8^m x 2.7^m. This and two smaller plants are compared in Table 3.8).

The production process is a partially mechanized batch process with capacity of 5 castings/hr (i.e. 5 table uses) made feasible by the short setting time of gypsum. Plaster is stored in bulk in a hopper, and is mechanically mixed. Glass reinforcement is in preformed mats. Cast boards are cut by manually operated power saws, hand loaded into driers and dried in a kiln by hot, fan forced air. Australian costs (1983) are given in Table 3.8. Less mechanization and greater labour intensity are economically feasible in a developing country - with concrete slabs replacing the metal table, hand mixing of gypsum and water, and hand spreading of vegetable fibre, e.g. sisal, hand stacking, and air drying of sheets.

In Australia, glass fibre in mat form has already replaced loose vegetable (sisal) fibre. Higher technology is already replacing the plaster-fibre board itself with paper faced plaster boards produced in a continuous process. This latter product now has over 95 per cent of the plaster lining board market and is a higher capital, higher volume, less labour intensive process. However, the plaster board reinforced with vegetable fibres, e.g. sisal, or agricultural wastes, e.g. straw, still appears most appropriate for those developing countries requiring low capital, low technology, low skill, labour intensive industries.

The largest, most economic plants of each type above are compared in Table 3.9. Plant types are plywood, composite ply, OSB, hardboard and fibrous plaster board. Technologies range from high to low. Percentage distribution of costs between fibre or particles, binder, labour and overheads are given.

Cost breakdowns between materials, labour and overheads do not differ greatly between products. Material costs are highest for plywood because wood quality required is high. Labour costs are highest for plaster board because it is a relatively low capital, labour intensive process. Labour costs are lowest for OSB where the level of technology is highest. For a developing country, reduced labour costs therefore favour plaster board. Substitution of sisal or agricultural wastes for glass fibre will further favour plaster board through maaterial cost savings (Table 3.9).

Thus in a developing country, the production costs of plaster board in Table 3.9 will reduce by the largest factor due to lower labour and vegetable fibre costs. The cost of plywood will reduce by the next largest factor because wood (veneer log) costs will reduce (Fig. 1.1) significantly, and labour costs will also reduce. The other composites will be less affected. Thus the most appropriate product for a particular developing country will depend on local material and labour costs, and may be determined by substitution of the relevant costs in the tables above. A mathematical formulation of optimal factor ratios is given in the Appendix.

Appropriate products for a range of material, labour and capital costs are also indicated in Fig. 3.11.

Viewing Table 3.9, a feature is the similarity of the cost breakdowns for the various products (and processes). This is not too surprising in one way in that each represents a practical optimum ratio of factors involved in a system where substitutions between factors are assumed to be feasible.

Such an optimum may be obtained theoretically by considering the production problem as that of seeking optimal quantities x_i of each factor of production i with unit costs c_i to minimize total cost $C = \sum c_i x_i$ subject to a performance constraint $P = P_o$ in which P is given by a production function $P = b \prod x_i^{a_i}$. Where the a_i's are constants.

As is shown in chapter 8.5, the optimal expenditure on factor j is $c_j x_j = a_j P_o$. Thus as the price of factor j falls, the quantity x_j increases, and hence the total cost share of that factor is less sensitive to cost changes than the cost coefficients c_j themselves would indicate. Similarly if there are large scale economies, a_j is large and hence the total share of factor j is large and where there are little or no scale economies a_j is less and the factor share is less.

Note that although the unit cost coefficients c_j vary between countries, the quantities $c_j x_j$ are less variable and hence unit costs are also less variable, i.e. the quantities of each factor will vary as substitutions between factors occur but unit costs will be less variable. Even so the variations which do occur tend to favour plywood and mineral bound fibreboard production in the developing countries because of lower labour and material costs.

3.5 Overview of technological conditions in the sector

The sector utilizes a wide range of levels of technology from sophisticated, highly automated, composite panel plants to manual production of sawn timber, cement-fibre boards, house framing and components and hand crafted furniture. The matrix of timber products and technological levels of processing is indicated in Table 3.12. A prime purpose of increasing the level of technology is to reduce the unit costs (and increase quality of outpout) and this generally requires also an increase in scale. Ranges of plant size appropriate to various levels of technology are indicated in Table 3.2. The distribution of production costs is shown in Table 3.9.

In the composite - veneer (Comply) and OSB plants, capital - labour and capital - material ratios are higher than for plywood and gypsum board plants. The Comply and OSB plants offer the advantage of utilizing more of the tree and thus providing more product and more value per unit of forest resource. They are particularly suited therefore to large forest resources where quality is variable or where there is a scarcity of high quality timber suited to veneer or sawn timber production.

On the other hand, sawn timber, plywood, mineral bonded boards, housing, construction and furniture production offer a wider range of scales and levels of mechanization to suit the range of conditions in developing countries. Each may be produced in highly mechanized plants with various levels of automation or in smaller semi-mechanized or largely manual plants - depending on scale, end use, skills and resources available.

Thus there is a substantial range of substitution possible between capital and labour, and also between capital and material quality and cost in the case of the composite plants. There is also room for substitution between materials and labour: In the case of gypsum board, fibre glass in mat form has been substituted for loose vegetable fibre (e.g. sisal), in order to substantially increase labour productivity at the expense of material costs (e.g. fibre glass $1600/t, loose sisal $500/t).

Traditionally, the level of technology in wood construction has been low; although off the construction site, higher technologies are appropriate: Pressure treatment for preservation is a prerequisite for many species to be exposed to weather or ground contact. Kiln drying is often used for joinery and structural materials and stress grading is used to establish strength properties. Timber connectors such as gang nails have facilitated a small industry in prefabricated roof trusses.

Further mechanization is feasible in the off-site manufacture of building components, e.g. windows, doors, roof trusses, cupboards, benches, fabricated beams, and of course wood based panels as already discussed. Similar mechanization occurs in the manufacture of furniture and utensils for the house.

On the construction site, the use of powered hand tools (saws, drills, planes, etc.) is increasing and building hardware is being designed to suit this change.

3.6 Potential for technology transfer and the development of new technology

Each of the processes and products above has direct relevance to developing countries. As shown previously, demands for timber products in the developing world are expected to grow substantially over the next two decades. Opportunities for export of processed timber are also expected to increase as national policy constraints on log exports continue to take effect.

The demands, therefore, will be for large volume export quality production and large and smaller volume production to meet domestic needs. Thus a range of technologies is expected to be appropriate from large scale, highly mechanized and even automated plants needed to meet export and large urban market demands, to small scale regional production to satisfy local markets, less accessible to products from the larger plants.

Various modes of transfer of these technologies must also be considered from partnership arrangements with larger firms in the developed world and agreements on a government to government basis, to purely local enterprises financed from development funds. Further technological developments must also be taken into account.

The cost of the micro processor is continuing to fall and its capabilities continue to develop, so that a greater degree of automation and process control can be expected. Furthermore, each of the production processes considered above is effectively a batch process. Hence there is scope in many cases for development of new continuous process technologies, providing further potential economies of production.

Hence there is scope not only for continued improvement and automation of present primary processes but also for change to new processes with the promise of further potential economies of production. The scope for technological development at the secondary level is less because of the greater diversity of processes and products involved, but continued mechanization can be expected.

Standardization and modular co-ordination are useful concepts here and facilitate scale economies. Prefabrication of housing has less advantages and only a small market share.

To develop these industries, information on properties of a wide range of tropical timber species is required. Information on sizes, strengths and durabilities etc. is also necessary for acceptance by various groups, e.g. architects, engineers, and regulatory authorities.

In fact, a substantial investment in information on timber construction is warranted to ensure its acceptance by the building industry and its clients. This is particularly important as timber construction creates the major potential demand for the products of primary timber processing.

Other potential areas for further development include:

(i) integrated composite panels
(ii) moulded composite beams for longer spans, and
(iii) durable external sheeting material.

Plant cost index and consumer price index in Sweden

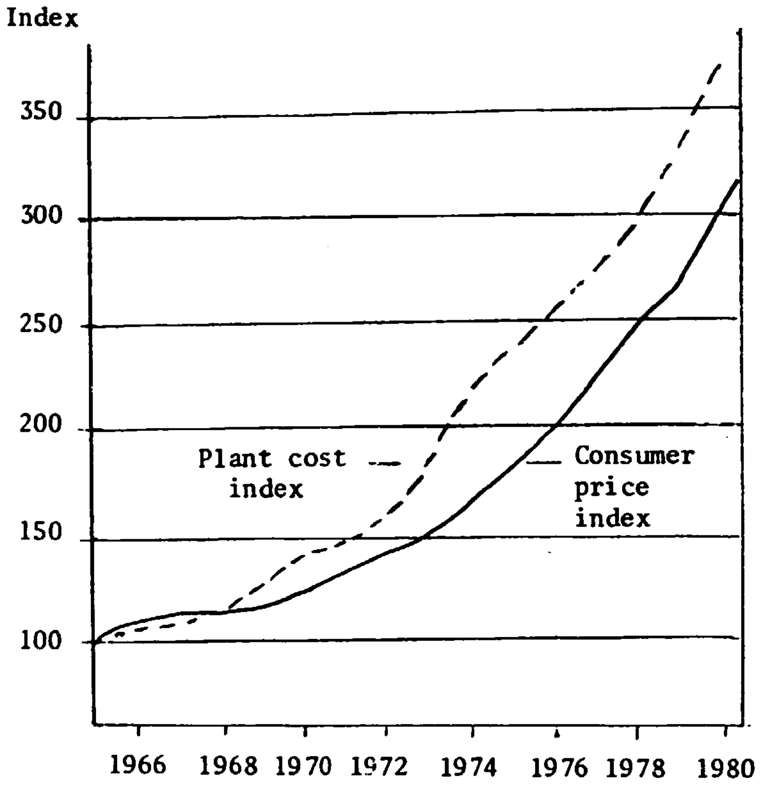


Fig. 3.1 Plant cost index and consumer price index in Sweden.
Source: IIASA Forest Sector Project - unpublished.

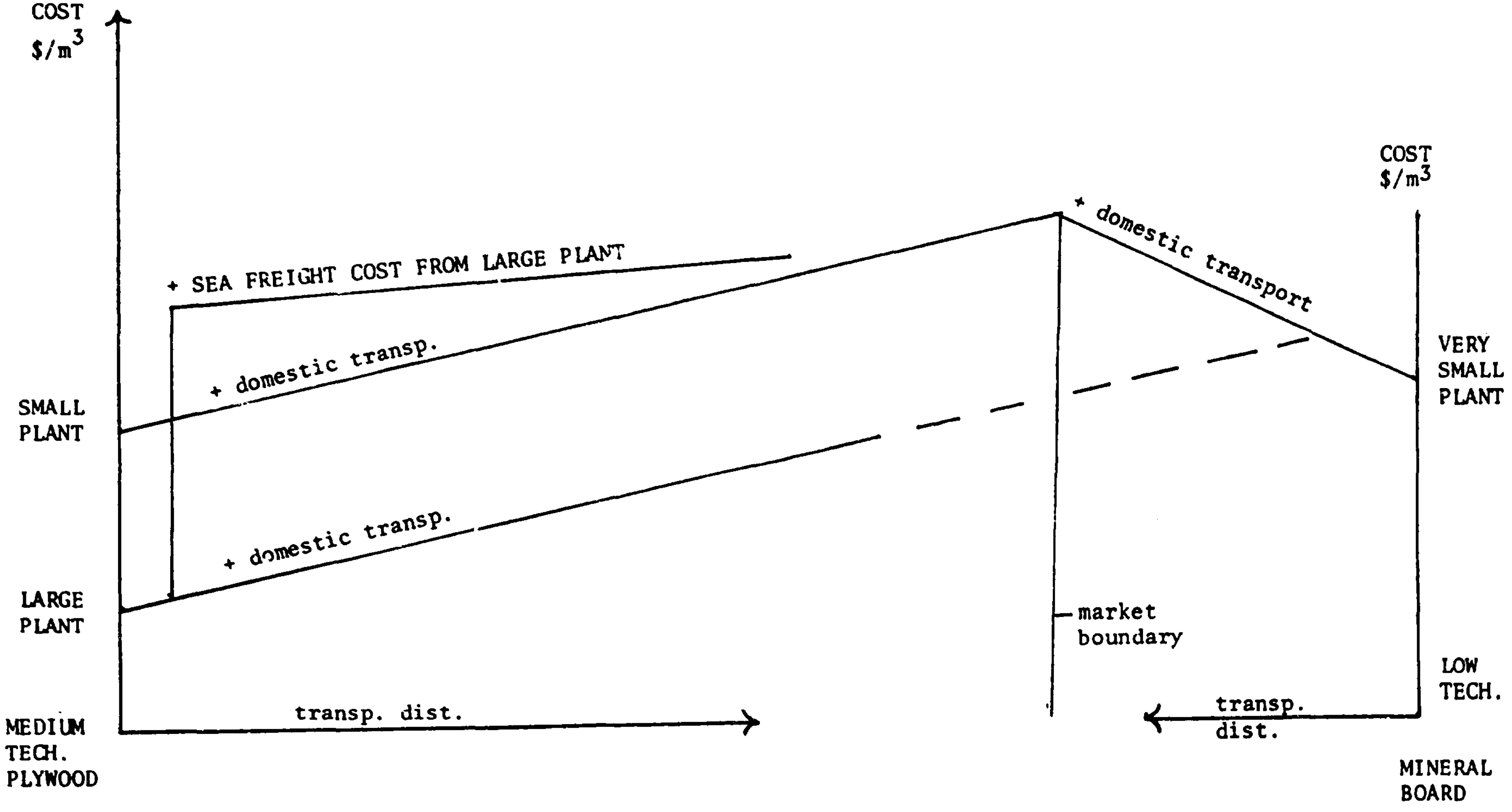


Fig. 3. 2 Costs of production for small and large scale plywood plants and very small mineral board plants + transport costs with distance, indicating market size for each.

4. WOOD QUALITY MODEL

In order to study the potential for product improvements or for new products in the area of reconstituted boards and structural sections, an understanding in depth of the structural mechanics of timber and timber composites is required.

Natural timber board consists of wood fibres and the organic structures and lignin materials which bond the fibres together. The strength of the natural timber in tension or in flexure depends on the strength of the fibres, on the number, distribution and orientation of fibres, on the strength of the bond between them and on the length and width of the fibre which determines the surface area over which that bond can develop.

In a reconstituted board product, particles which may be flakes, wafers, chips, or bunches of fibres, act as large fibres; and a binder material such as a resin or cement, provides the bond between them. A general model for flexural and tensile strength of composite materials is derived to cover each of these cases. Thus the strength of this composite board again depends on the strength of the particles (flakes, wafers, chips, or bunches of fibres) the number, distribution and orientation of these particles, the dimensions - length, width, and thickness of the particles, and the bond between them. The integrity of these particles, i.e. the extent to which they are undamaged or unflawed, is also a factor in board strength, as is the alignment of wood fibres within the particle.

Just as the binder may consist of non-organic materials such as cement, so the particles can consist of other organic and inorganic materials, plant fibres, including agricultural wastes, and inorganic materials such as glass fibre.

Strength theories for both natural wood and reconstituted materials are now considered.

4.1 Formulation - natural timber

The fibres in natural timber are assumed initially to be straight and aligned in the direction of tension or flexure, to be of one length L, and to be randomly distributed along the timber. The number of fibres is assumed to be sufficient that this randomness constitutes uniformity of distribution throughout the board. (Many timbers of course will violate these assumptions, particularly at defects such as knots.)

Consider a particular critical section of the timber at which a crack in the matrix may occur as shown in Fig. 4.1. It is assumed that at the ultimate strength of the fibre matrix composite, full bond stresses can develop uniformly along the fibre from the end to the critical section where the crack occurs.

When the end of the fibre coincides with the crack, the fibre is held on one side of the crack only, and no stress in the fibre can be developed across the crack. Where the critical section coincides with the mid point of the fibre, both ends of the fibre are equally well held by the matrix on each side of the crack, and maximum stress can be developed across the crack. With a uniform (random) distribution of fibre there will be a linear distribution of shorter end lengths between the two extremes above, i.e. between 0 and L/2 with mean L/4 (Fig. 4.2). Now there will be a critical length of fibre L' at which if the crack occurs at the mid point of the fibre, the ultimate strength p of the fibre in tension will just equal the force required to pull (the ends of length L'/2 of) the fibre out of the matrix, i.e. to break the bond between fibre and matrix (consisting of binder and other fibres).

If the length of fibre L is less than (or equal to) L' then all of the fibres will fail in bond, i.e. by pulling out of the matrix, and the average strength developed is (1/2)L/L'.p (Fig. 4.1). If the length of fibre is just equal to the critical length L' then the average strength developed is 1/2 p. If the length of fibre L is greater than L' some of the fibres (a proportion (L-L')/L will fail by rupture, at force p and the remaining proportion (L'/L) will fail by pulling out at strength (1/2) p and hence the mean strength is

$$p(L-L')/L + 0.5pL'/L = p(L-0.5L')/L$$
$$= p(1-0.5L'/L)$$

If p is defined as the strength of the fibre per unit of linear density, i.e. the tenacity of the fibre (Brotchie and Urbach 1963) and q is defined as the weight of fibre per unit area of the timber board then the tensile strength T of the board after a tensile crack in the matrix has occured (assuming no tensile strength in the matrix) is

$$T = a\ k\ p\ q \qquad (1)$$

in which $a = 0.5L/L'$ for $L \leq L'$

and $a = 1 - 0.5L'/L$ for $L \geq L'$

and k is a factor close to unity which allows for variability of the fibre strength and length. For elastic fibres of one length, but variable strength, k is found (Brotchie and Urbach 1963) to be given by $k = 1 - c_v$ in which c_v is the statistical coefficient of variation of fibre strength.

For fibres of varying length of mean L, no reduction would appear to be required where the range of fibre lengths is between 0 and L', and for fibres in the range L' to ∞, a small reduction only is involved, which may be ignored for purposes of design so that a constant length equal to the mean L may be assumed.

Note that k can also allow for variations in fibre distribution along the board and can include the ratio minimum number of fibres over average number as a factor allowing for variations, including knots, along the section.

Similarly, for failure of the board in flexure due to rupture or pullout of the fibres, the ultimate moment M is given for elastic fibre behaviour (Brotchie and Urbach 1963) over the part of the section in tension as

$$M = (1/3)\ a\ k\ (1-c)\ p\ q\ t \qquad (2)$$

in which t is the thickness of the board and c is the proportion of this thickness on the compressive side of the neutral axis and varies between 0.2 and 0.5 depending on the relative stiffness of fibres in tension and the composite in compression.

The critical pullout length L' may be expressed in terms of the fibre and matrix properties by equating pullout and tensile strengths, e.g.

$$0.5L'k\pi\ d\ b = p'd^2\pi/4$$

where d is fibre diameter, b is average bond strength per unit area, and p' is ultimate tensile stress, or rupture force per unit area of fibre, which may be related to the previous measure p of tensile strenth by $p'vt = p\ q$ in which v is the volume fraction of fibre and is assumed here to be 1. giving

$$L' = 0.5\ pqd/tb$$

$$\text{or } L'/d = 0.5\ pq/tb = 0.5\ p'/b \qquad (3)$$

Hence Eqns. 1, 2 and 3 describe the tensile and flexural strength of natural timber in terms of the properties of the fibres and matrix of which it is composed. Reconstituted boards may be considered similarly.

4.2 Models for reconstituted boards and composites

Equations 1 to 3 have been developed for natural wood fibres in natural wood matrix. However, they may be readily extended to cater for reconstituted boards. Using lower case letters for natural wood fibre and matrix properties and for board constants, as before, and upper case letters for reconstituted wood component properties, i.e. particle and matrix properties, the following equations are obtained:

Tensile strength T of the board is given by treating the particles as large 'fibres', and substituting the properties of these macro fibres in Eqn. 1 to give the modified formula for tensile strength of

$$T = f\ a\ k\ P\ Q \qquad (4)$$

in which $a = 0.5\ L/L'$ for $L \leq L'$

and $a = 1 - 0.5\ L'/L$ for $L \geq L'$

in which L is the length and L' the critical length of the particle, P is the tensile strength of the particle per unit linear density and Q is the weight of particles per unit area of board, f is the orientation factor for the particle = 1 for particles aligned in the direction of tensile strength, and 1/2 for random ones.

Similarly the ultimate moment M per unit width of the board due to rupture or pullout of the particles, is given by

$$M = f\ g\ a\ k\ (1-c)\ P\ Q\ t \qquad (5)$$

in which t is the thickness of the board as before, and g depends on particle or fibre density variation over the thickness of the sheet. For uniform distribution of particles over the depth of board, g = 1/3 whereas for concentration of fibres or particles at the surface of the board $g = 1/2$; c is the proportion of total depth in compression.

The critical particle length L' is similarly given by

$$L'/D = h\ PQ/tB = h\ P'/B \qquad (6)$$

in which $h = 1/2$ for round or square cross section particles, and $h = 1$ for wide, flat particles of thickness D, B is the bond strength of the matrix to the particle, and P' is the tensile strength of the particle per unit of cross sectional area.

The bond strength B will depend on the quantity of resin used where this is insufficient to provide a continuous matrix, and with very low resin quantities this can be expected to be the case.

From Eqns. 5 and 6, modulus of rupture (MOR) is given by

$$MOR = 3\ f\ g\ k\ (1-c)\ \frac{B}{h}\frac{L}{D} \qquad \text{for } L \leqq L' \qquad (7)$$

$$= 6\ f\ g\ k\ (1-c)\ P'\ (1 - \frac{h}{2}\frac{P'}{B}\frac{D}{L}) \qquad \text{for } L \geqq L' \qquad (8)$$

For random particles $f = 1/2$, for uniform density $g = 1/3$ and for uniform particle strength $k = 1$, for flat particles $h = 1$. Thus for $c = 0.3$, Eqn. 7 reduces approximately to

$$MOR = \frac{0.35\ BL}{D} \qquad (L \leqq L')$$

and Eqn. 8 to

$$MOR = 0.7\ P'\ (1 - \frac{P'}{2B}\frac{D}{L}) \qquad (L \geqq L')$$

Assuming that stress in the particle is reduced near the ends as calculated above, the modulus of elasticity (MOE) of the composite will be similarly reduced giving

$$MOE = f\ a\ E \qquad (9)$$

in which E is the modulus of elasticity parallel to the grain of the parent wood from which the particle is cut, and f and a are as defined for Eqns. 4, 5 and 6. (See Appendix 1, for alternative derivation).

Substituting from Eqn. 6 for a then gives the design equation

$$\text{MOE} = f\,E\,\left(\frac{B}{2hP'}\,\frac{L}{D}\right) \qquad (L \leq L') \qquad (10)$$

or

$$\text{MOE} = f\,E\,\left(1 - \frac{h}{2}\,\frac{P'}{B}\,\frac{D}{L}\right) \qquad (L \geq L') \qquad (11)$$

where L' is defined by Eqn. 6.

Note the importance of bond for smaller values of $\frac{L}{D}$ $(L \leq L')$ and its decreasing importance as $\frac{L}{D}$ increases $(L \gg L')$. Of particular importance, however, is the ratio $\frac{L}{D}$ or more comprehensively the ratio $\frac{B}{P'}\,\frac{L}{D}$.

Thus high strength and high stiffness result from long, thin wafers or fibres, and high bond strengths. These strengths and stiffnesses can be predicted from the Eqns. 4-11, which may be applied to the engineering design of boards and other structural sections, to meet an identified (Youngquist 1981) technological need.

Various types of resin and various materials other than resin such as cement or gypsum may be used for bonding. In hardboard, the natural lignin materials in the wood and mechanical or hydrogen bonding are utilized. Cement provides a useful matrix for external panels, particularly in areas subject to biological degradation. For interior use, gypsum may be substituted for cement. The gypsum may be from natural deposits or chemical gypsum which is a waste product of the chemical industry.

Where the fibres in the particle are aligned along the length of the particle, so that they are neither cut nor damaged by the cutting process, the tensile strength P of a particle is equal to the tensile strength T, of clear timber from Eqn. 1, obtained using the properties of the fibre and matrix of which it is composed) per unit weight of timber board. Thus the strength of the timber board is based on the strength of the fibre reduced by factors allowing for fibre length and variability and internal bond strength.

The strength of the composite board is this timber strength (reduced already from fibre strength) and further reduced by factors allowing for particle dimensions and matrix strength. The particles may be wafers, flakes, shavings, chips, fibre bundles and separated fibres produced in various chemical and mechanical ways.

The formulae indicate the potential strengths of various material composites and allow optimal dimensions and quantities of the components to be determined. Information on particle costs, matrix costs and processing costs may be added to allow the cost effectiveness of each material combination to be evaluated. These equations and data provide a basis for selection of stronger and more cost effective composites. They also indicate the benefits to be gained by changes to a particular composite.

For example, aligned wafers or particles give twice the strength of randomly oriented ones - in the direction of alignment from Eqns. 4 and 5. Concentration of wafers or particles at the faces of the sheet produces a further 50 per cent increase in flexural strength (Eqn. 5 - for the values of f and g assumed).

Potential strength also increases (Eqns. 4-8) with increases in particle length, and length thickness ratio. A possibly limiting criterion here is that surface area increases as thickness decreases, increasing the area on which resin is required, but reducing the bond strength required and hence the amount of resin per unit of surface required to develop bond. However, internal bond will then also reduce - so that a trade-off is required.

Smaller particles require more resin and will generally give less strength. Medium density fibre board also has high resin requirements but greater fibre length thickness ratio. Optimal design criteria are discussed in the Appendix.

Fibre and flake boards have an advantage, however, in that a wider range of fibre materials may be used including various agricultural wastes and wood wastes which are widely available in developing countries, e.g. bark, sugar cane bagasse, coconut fibre, lupine, cereal crop straws, bamboo, peanut shells, rice husks, sisal, manila abaca, sanseviera, sawdust, wood shavings, sawmill wastes, and so on.

Typical values of strength for some of these and other fibres are given in Table 4.1, and tenacity and stiffness in Table 4.2 (from Brotchie and Urbach 1963).

These fibres may be combined with various binders, adhesives from wood (e.g. tannins) or from petrochemicals, portland cement, or cast gypsum.

Costs versus strengths of various fibres are given in Table 4.3. Local prices should be substituted for the typical values given when estimating cost effectiveness for a particular fibre in a particular country (see also Fig. 1.1) Availability is another factor to consider and will vary from country to country and region to region.

The models above (Eqns. 4-8) are compared with test results in Figs. 4.3 and 4.4. Agreement is relatively close.

4.3 Mineral bonded boards

For a fibre in a mineral matrix, only a limited quantity of fibre, generally between 2 and 12 per cent of fibre by weigth of the matrix is required. Eqns. 4-6 again apply. The upper limit of fibre is generally determined from the fact that fibre does not significantly increase the bending compressive strength, and if more than a certain quantity of fibre is added, the bending tensile strength exceeds the bending compressive strength and failure occurs at the compressive face. The quantity of fibre at which tensile and compressive flexural strengths are just equal, is given by equating ultimate flexural compressive force in the matrix and ultimate flexural tensile force in the fibre to give (Brotchie and Urbach 1963)

$$Q = \frac{2}{3}\,\frac{S}{fgk}\,\frac{c}{(1-c)}\,\frac{t}{a}\,\frac{R}{P}$$

$$\approx 1.5\ \frac{tR}{aP} \qquad (12)$$

if fibre is uniformly distributed and

$$Q = \frac{tR}{aP}$$

if fibre is concentrated at the faces of the board; in which $S = 0.8$ is a factor allowing for non-linearity of stress in the matrix, R is the ultimate flexural compressive stress in the matrix, and other parameters were previously defined. Eqn. 12 provides an upper bound to useful fibre quantity in a mineral bonded board.

Gypsum-fibre boards have been very widely used in Australia for a number of years as a standard internal lining board. Their manufacture constitutes a relatively low technology industry suited to developing countries. Fibres used have included sisal, coconut fibre, and, more recently, fibreglass - on availability and cost effectiveness grounds. Modulus of rupture strengths of the order of 7 to 14 MPa (1000 to 2000 psi) were obtained in tests. Critical fibre length, L', is 50 to 75 mm (2-3 ins) for sisal-gypsum and 40 to 60 mm (1.5 to 2.5 ins) for coconut-gypsum. Fibre lengths L used for sisal are typically 500-1000 mm (18 ins - 36 ins). Coconut fibres are shorter, e.g. 200 mm (7-8 ins). Fibre quantities are typically 3-5 per cent by weight for 9 mm (3/8 in) thickness boards, and the fibre is rolled in as the gypsum is setting. Casting is done on flat tables.

Fibre cement boards allow higher strengths and are suitable for external use, e.g. external sheeting for houses, fences, etc., internal linings in wet areas of the house and as flooring, floor overlays, or flooring underlays, provided the fibre is not subject to degradation under this use, as later discussed.

Portland cement and cement mortar (cement and sand) as a matrix has a potentially higher strength than cast gypsum, e.g. cement mortars can range in compressive strength from 18 up to even 70 MPa (1500 to 10,000 psi) or more compared to 10 to 20 MPa (1500 to 2000 psi) for cast gypsum. And it is suitable for external use. The higher matrix strengths generally give higher bond strengths and hence allow shorter fibres.

Health aspects have caused a search for a replacement for asbestos as a reinforcement in cement sheets. Wood and plant fibres provide a practical alternative. New chemical additives (e.g. super-plasticizers) may provide a means of incorporating this fibre at lower energy costs and higher cement matrix strength and this is a potentially profitable area for research and development. A potentially suitable fibre and cement combination may be determined from the models and data presented here, and could be developed by laboratory experiments and pilot testing. Some practical combinations are already being marketed as a substitute for asbestos cement sheet (Coutts 1981).

Combinations more appropriate to developing countries may be selected using the tables of cost effectiveness presented - but inserting local prices for those given and assuming the material properties are transferable. Short fibres are more readily incorporated in the matrix. This requires a small diameter fibre in order to achieve a high ratio of length to diameter and a low value of critical fibre length. Wood fibres produced for paper making or for hard board are short but extremely fine and, with a length to width ratio of 50 to 100, are suitable if they can be bonded and if the technology for fibre production is available. Weight of wood fibre incorporated varies from 2 to 12 per cent by weight with 8 to 10 per cent appearing to be an optimum (Coutts 1981). Surface area of fibre then also increases, but high wetting agents such as super-plasticizers could potentially facilitate this and allow additional fibre without reducing matrix strength and bond. Investigation of this cement-fibre-additive combination is highly recommended.

The discussion above concerns the strength of the fibre and the board in which it is incorporated. In the case of wood and vegetable fibres, durability of the fibre should be considered for external applications or for internal wet areas. While the inert, inorganic matrix will protect the fibre from some biological attacks, it may not protect it from decay, and there is some evidence of this occuring. This is another important area for future research and development.

In the same way, glass fibres in cement matrix would be subject to alkali attack unless suitable, alkali resistant glass is used. Some such combinations are in commercial use. Research and development may be required on this aspect also, to extend this application to developing countries.

Fig. 4.1 Fibre board or particle board in flexure. Crack is assumed to occur in matrix on tensile side of neutral axis

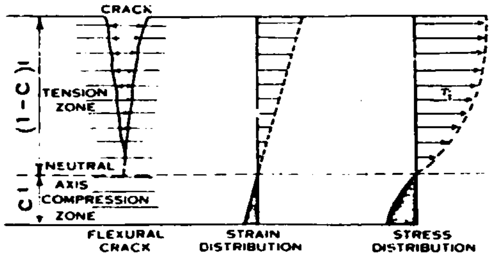


Fig. 4.2 Diagram showing positions of fibres with respect to crack. Fibre ends failing by pulling out rather than by rupture are shown in heavier lines

(a) L = L'; (b) L L'; (c) L L'.

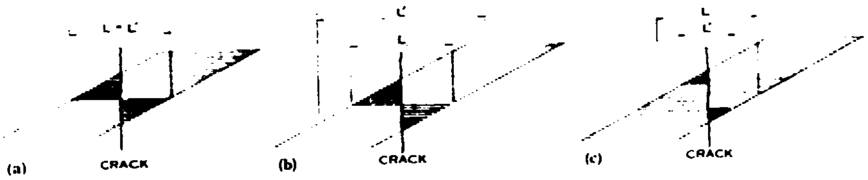


Fig. 4.3 Modulus of rupture (MOR) vs particle length/thickness ratio (L/D). Comparison of test results and theory - oak wood particles - flakes - wafers

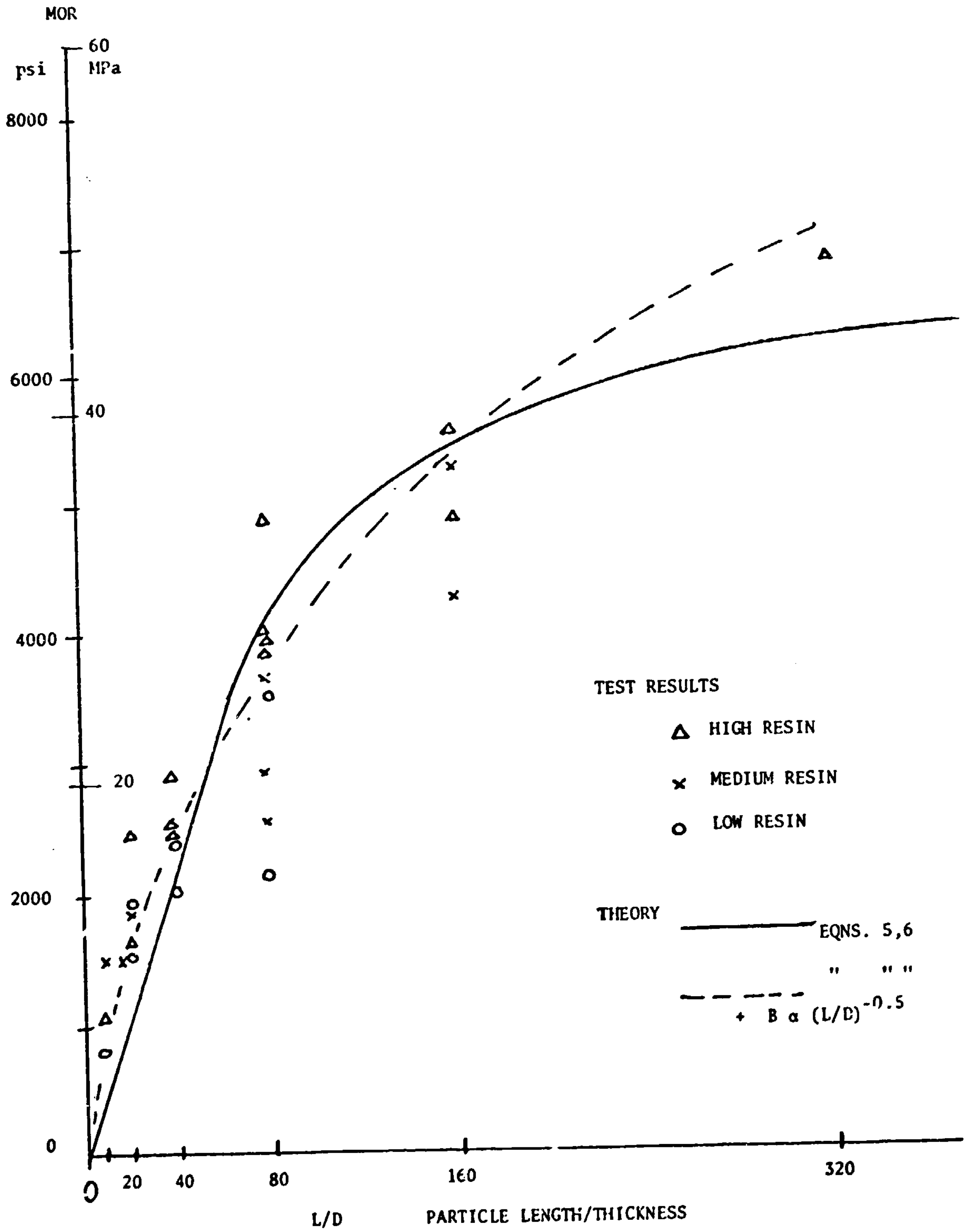
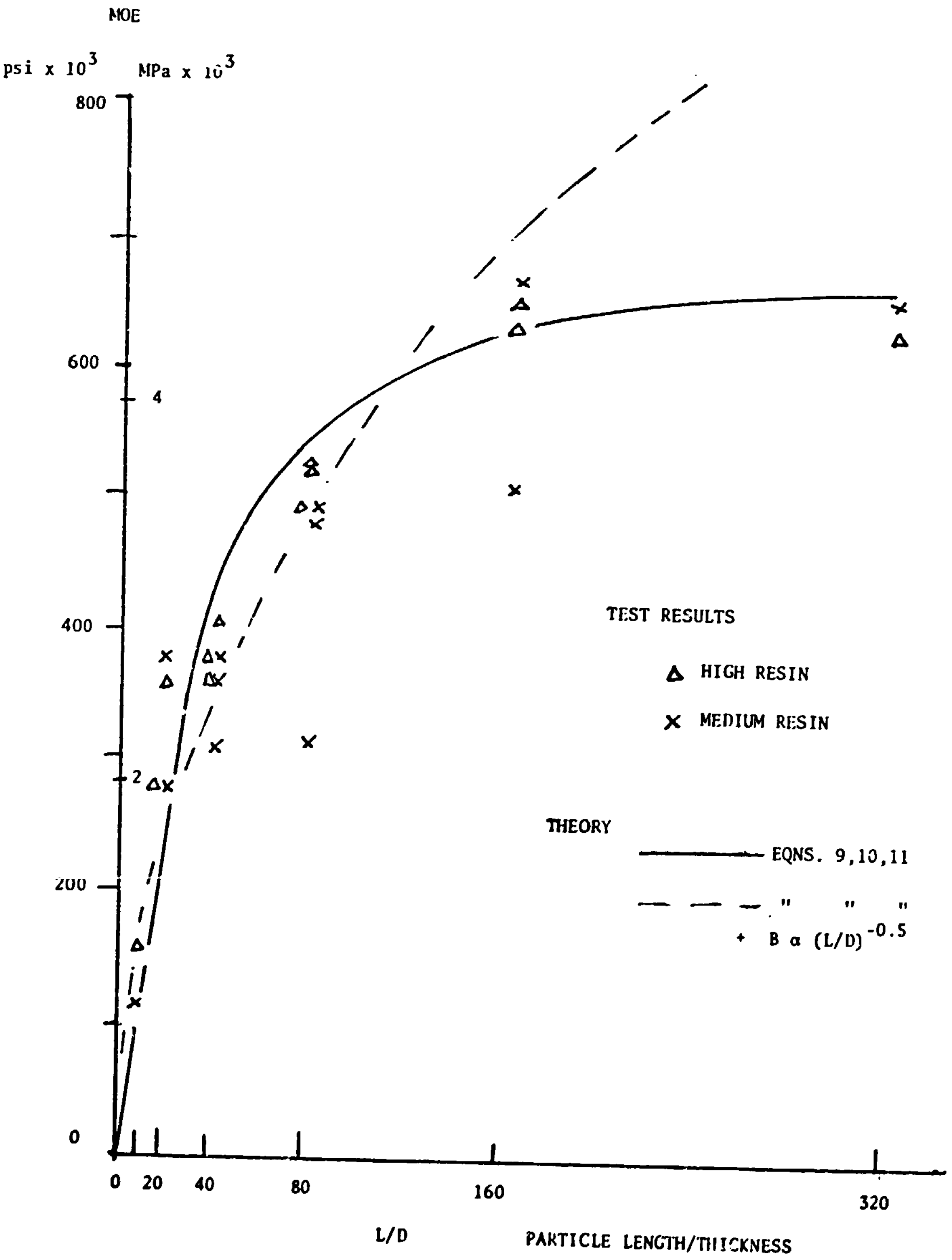


Fig. 4.4 Modulus of elasticity (MOE) vs particle length thickness ratio (L/D). Comparison of test results and theory - oak wood particles - flakes - wafers



5. KNOWLEDGE-INFORMATION SYSTEMS

5.1 Information technology

The major technological achievement of the second half of this century has been the development of information technology. It has been said "take care of the information and the materials take care of themselves". The process of separating information from the movement and processing of materials began with penny postage or even before. However, real advances only became possible with further developments in micro electronics - firstly telecommunications or electronic transmission of information, and secondly computers and micro-processors for the processing of this information. Scanners or sensors for direct input of information, magnetic devices for storage of information and display devices have also contributed.

5.2 Systems techniques

These developments have allowed the separation of information from existing resources, their movement and processing. They have also allowed the development of data banks for storage of this and other relevant information, and are allowing the coding of further information and knowledge and skills concerning these processes. They are further allowing the operation on this knowledge, etc., with techniques of a different kind. These are not the skills or knowledge of wood technology but the ancillary skills of operations research and mathematical modelling which allow the many variables in the process to be related and to be manipulated systematically until an optimal overall result is obtained.

These systems techniques have a wide range of application in the timber processing industry and form the basis of much of the present and future technological change in the industry.

5.3 Information systems

Firstly, information systems, including data banks, will be required to identify the diverse timber resources available for future wood processing, particularly the diverse hardwood resources of the developing world.

This information must include the identification of existing stocks by species, physical characteristics, e.g. quantity and quality, and accessibility, and the knowledge of sustainable yields discussed in chapter 1. Further information concerning the timber products outlined in chapter 2 is also required. This knowledge includes performance characteristics and material composition or composition ranges for various end uses. International standardization of these performance characteristics by end use is an initial step, and is vital to the development of wide export markets for the processed products of developing countries.

5.4 Models for product design and quality control

A knowledge of the relationships between these compositions, component materials properties, and composite performance characteristics discussed in chapter 4 is also required. The knowledge should be in the form of mathematical models (e.g. Eqns. 4-12) which may be manipulated using operational research techniques, to select the combination of materials to produce the required performance at minimal cost. These models may be used for engineering design of the product. They may be further utilized in process control. Knowledge of the technological process and its control mechanisms must also be encoded, to enable this process to be controlled to produce the required end products and their specified performance characteristics outlined above. This process control system will also require information concerning the raw material (e.g. log) inputs. Some of this will be obtained directly from scanners in the log handling and sorting process. Supplementary information must come from the inventory of resources, and a data bank of recorded characteristics of each species. The micro-processor, mathematical models and operational research techniques may then be combined to optimize the processed material outputs to meet end use requirements for these particular inputs. However, species identification must be a manual process at the present stage of development.

5.5 Monitoring systems

Other information systems are more introspective. They concern the automation of the wood processing plant itself for the purposes of

(i) modification to meet changing inputs, end uses and further product or technology development, (ii) facilitating maintenance of the technology, (iii) self diagnosis of internal faults and provision of information on their correction, (iv) covering these faults by selection of alternative parallel paths, i.e. bringing into line backup micro-processing process-control equipment.

5.6 Market supply/demand projection

Further models may be developed to quantitatively identify the end products required. This requires the modelling of market demands as well as potential product supplies. In the case of export products, both supply and demand at an international level, and information on factor costs including transport costs, is required. The International Institute of Applied Systems Analysis (IIASA), with the help of a number of national research groups, is presently constructing a model of this kind. At the international level, it models supply and demand in each country or region, and world trade flows to match or partially match the imbalances involved, subject to the various constraints applicable to these flows. At the national level, it is modelling national supplies and demands - and the imbalances resulting from these. Regional supplies, demands and imbalances may be similarly modelled. These models provide the information on national supply and demand needed for the international trade flow model. These models may be used for investment planning decisions on establishment of new plantations or new processing plants. They may also be used for forest management planning on where and when to thin or to harvest and to what end uses should this harvest be directed. They are scheduled for completion in 1985.

5.7 Planning models

A further information system may be based on planning models for location, composition, and/or layout of the processing plants. Such a model is TOPAZ (Technique for optimal placement of activities in zones (Brotchie et al. 1980)). TOPAZ models a set of activities and the interactions between them and with fixed sources and sinks. It allocates the activities, e.g. plants, to potential sites on the basis of minimizing the sum of establishment, operating and interaction costs, or maximizing the income less costs incurred. The same technique may be applied at the level of an individual plant on the basis of minimizing overall costs of establishing and operating the plant, including flows of materials to the plant, within the plant between processing units, and to final destinations. Costs of paid labour movements within the plant and to other locations may also be included. Alternatively, total value of production less costs incurred may be maximized. The model utilizes operational research - mathematical programming techniques to optimize the decisions made. This optimal planning process allows the income less costs or the productivity of the plant to be maximized, increasing its viability and reducing its (unit) production costs. These techniques are operational and have been widely applied to location and layout problems (Brotchie *et al.* 1982).

5.8 Technology transfer

The transfer of this technology from the developed to the developing countries will play an important role in stimulating productivity growth in this sector as in the rest of the manufacturing sector. This is true of microprocessor controlled production processes and also for the accounting and other managerial and planning tasks that can be done much better and cheaper with the use of a micro computer. While the development and implementation of the microprocessor controlled production line is a capital intensive high technology activity, it does not follow that the operational aspects of its use are likewise capital intensive nor that the skills necessary to operate them are necessarily more demanding than for traditional processes.

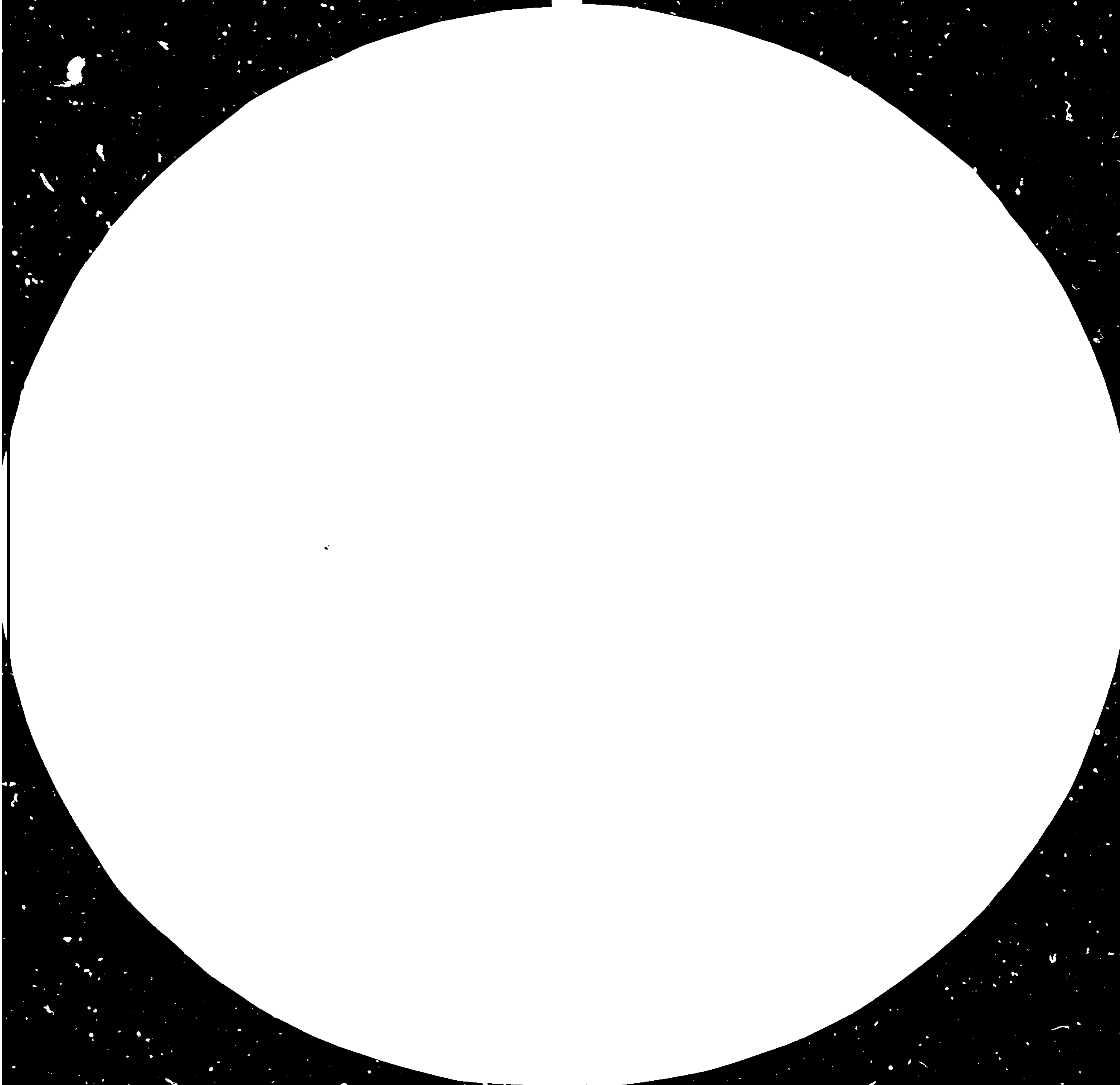
Actually the use of microprocessors in controlling certain types of production processes and the use of micro computers to increase the effectiveness of various planning and accounting aspects of firm management, in some respect simplifies technology transfer from the developed to the developing countries. This is because some production and management tasks which in the traditional system required great skill can be simplified by the use of these devices. None-the-less, a plant intending to implement this technology and anything other than a very limited basis will have to have a group of competent technicians within easy access of the plant to service the electronics and software involved. At least in the long run this means that it will be necessary to increase the size and sophistication of this service sector, not just for the wood and wood-processing industries, but because of the role which this technology will play throughout all sectors of the economy.

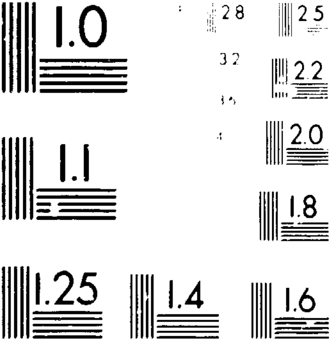
In implementing these new technological developments there is a danger on the one hand of not taking advantage of crucial cost reducing and quality enhancing technological innovations and on the other of developing too great a reliance on non-local resources to install and service the equipment. At one extreme would be a situation where the main local input is the forest and a limited amount of unskilled local labour, with most of the supplies, equipment and even skilled labour and management coming from outside. This sort of facility may contribute capital to be used in developing other industries, but without being integrated with the local economy it will not contribute significantly in any other way to overall economic development.

The advanced technology discussed here is very much consistent with a gradual approach. It is possible to have labour-intensive production methods integrated with the use of two or three small (inter-changeable) micro computers for doing inventory, payroll, billing, and other accounting and perhaps planning jobs. It is also possible to use this sort of technology in upgrading existing machines (low-cost automation), or to introduce one or two machines using sophisticated micro electronics while leaving the remainder of the machinery as is.

5.9 Remarks

The information systems above are components of high technology development in the timber industry: The application of this high technology to forest resources in developing countries will enhance development and increase export earnings in the countries concerned, and finance the management of the forest resources in these countries as renewable resources. Some of these systems are also useful for development planning, product design and resource management with lower technology solutions.





MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS

STANDARD REFERENCE MATERIAL 1010a

(ANSI and ISO TEST CHART No. 2)

Two further types of information system should also be mentioned: One is an economic analysis model which analyses investment and operating expenditures and income flows, to make an economic evaluation of the project (Linzey et al. 1973). The other is a national industry-productivity model as currently being developed in Sweden (Johansson and Strömquist 1982) to examine the spectrum of productivites of firms (e.g. plants) across the industry at a national level - and hence the vulnerability or robustness of these firms under changes in factor prices, as earlier noted.

Large scale enterprises have generally been at the forefront of technological change, but not always. When welding was introduced into the steel industry, the inertia of investments in rivetting equipment prevented many of the largest firms from switching. Smaller firms took up the new, low cost technology first.

The micro electronic revolution has some of these features also. Micro computers are within the price range of nearly all firms, and new, small, dynamic, innovative firms are capable of adapting most readily to this new technology, and to utilizing it with maximum effect. Operations research software can be used by such firms to determine optimal sawing patterns, inputs to composite products, and to design optimal product mixes for given inputs and market prices. It can also be used to study the viability of new plant investments as noted above. Some of this software already exists, and could be specialized, and the remainder developed by applied systems research groups.

The world trade model being developed at IIASA in the Forest Sector Project as discusses above, requires a larger computer facility; however, the results could be disseminated through national industry associations, or government forestry departments.

6. MARKETS - PRESENT AND FUTURE

The market supply demand models being developed in the IIASA Forest Sector Project will provide information on present and future supply and demand at the global and national levels. These global and national models will throw further light on future world trade in forest products. These models are still in an early stage of development but might be expected to be available in the next few years. Some obvious trends are discussed in the following.

Internal markets for housing materials, furniture, paper, etc., in developing countries including the Middle East may also be expected to increase as economic expansion in these areas continues. Among the demands for housing materials will be demands for internal and external sheeting materials including wood based panels. The new structural boards, composites, reconstituted lumber, and integrated panels, will continue to expand into existing markets and to create new ones.

Substantial growth in sawnwood and faster growth in various forms of reconstituted timber may be expected in the decades ahead, and much of the increased production capacity in each of these areas will be in the developing world. Much of the increased markets for these products will also be in the developing world - except for the new structural composites which will also expand their markets in the developed world (FAO 1982).

Current trends in production, consumption and world trade are indicated in Tables 6.1 through 6.5.

They show North America (softwoods) and the developing nations of the Far East (Indonesia and Malaysia - hardwoods) as the current major exporting regions for industrial roundwood and Europe and the developed Far East (Japan) as the major importers of both hardwoods and softwoods.

They also imply that increased production in the future might come from new and maturing hardwood and softwood plantations in the developing and developed world, from presently unused species and unused parts of the tree in currently producing natural forests, particularly in the tropics, and possibly from much less accessible virgin hardwood and softwood forests. The regions where these potential increases are expected are primarily Latin America (particularly Brazil), North America, the Far East, Africa and U.S.S.R. (particularly if transport access to the Siberian softwood forests is increased) with minor increases also from Europe, Oceania and other developed regions (FAO 1982).

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8. Appendix

8.1 Stiffness and strength of composites

In previous studies (Brotchie 1969) it was shown that stiffness and strength of a linear elastic structural system are simultaneously maximized for a given material volume, if potential energy of the system is maximized for a given (virtual) displacement of the system under loads. Potential energy and internal strain energy were shown to be an absolute maximum when the optimality criterion of uniform, maximum strain (increment) throughout the system is satisfied for a given (virtual) displacement under loads.

A simple explanation is as follows: Internal strain energy is equal to work done by the loads (i.e. the product of load and its displacement), and if internal strain energy is maximized for a given displacement then the loads themselves must be maximized also. The ratio of load to displacement is then also maximized and hence stiffness is also maximized. As a corollary, displacements and hence strain energy are minimized for a given magnitude of load, and hence since strain is uniform, maximum (and mean) strain is minimized for this given loading. Hence the margin below ultimate strain is a maximum and strength is also a maximum for the given material volume.

In the case of a particle and matrix system in flexure, strain (increment) is uniform, and a maximum, if

(i) particles are aligned (oriented) into the direction of bending;

(ii) particles are concentrated at the faces of the board or the extreme faces of the beam;

(iii) particles are distributed along the board or beam in proportion to bending moment at each section;

(iv) particles carry full stress and strain throughout their length.

Condition (iii) would be suited only to some special uses for a board but would be more practical in the case of a beam.

8.2 Effect of particle length and bond

Condition (iv) requires either infinite bond strength so that full stress is transferred at the end of the particle, or particles are infinitely long or the full length of the board so that there are no intermediate ends.

For shorter (finite) particle length L and for finite bond stress B giving finite critical length L', the stress and strain in the particles reduces towards the ends and the total strain energy and potential energy, and hence stiffness, are consequently reduced.

The potential energy (increment) under a given (virtual) displacement is

$$PE = \int_{0}^{V} esdV \qquad (A1)$$

in which V is the volume of material (e.g. particles), s is the stress in the material, and e is the (virtual) strain (increment) under the given (virtual) displacement. Stress s in the particle is assumed to increase linearly from the end to the point L'/2 (or L/2 whichever is smaller). The proportional reduction in total stress volume in the system due to this end effect is

$$a' = \frac{1}{2}\frac{L}{L'}r \qquad (\text{for } L \leq L')$$

or

$$a' = 1 - \frac{1}{2}\frac{L'}{L}r \qquad (\text{for } L \geq L') \qquad (A2)$$

where r is the ratio of load applied to the ultimate load capacity of the system. If (virtual) strain e is assumed initially to be constant over the particle to provide an upper bound to total strain energy, integration of Eqn. A1 results in Eqn. A2 as a lower bound to the reduction coefficient a^{o}, for total strain energy, due to finite particle length. The upper bound is obtained by assuming the virtual strain   is proportionate to stress s in the particle, i.e. it also reduces (with stress) due to the end effect; and integrating Equation (A1) for strain energy over the total particle length (and total volume V) gives the proportional reduction

$$a'' = \frac{1}{3}\frac{L}{L'}r \qquad (\text{for } L \leq L') \qquad \text{(A3)}$$

or

$$a'' = 1 - \frac{1}{3}\frac{L'}{L} r \qquad (\text{for } L \geq L')$$

Stiffness and modulus of elasticity (MOE) are proportional to the total strain energy (increment) for a given (virtual) displacement and their proportional reduction, a^o, due to finite particle length also lies between the two bounds above.

Strain in the particle will vary with stress but total strain energy reduction will be less than the upper bound assumed because the shear strain energy in the matrix has been neglected. Under uniform strain this shear strain is zero. Relaxing the assumption of uniform strain reduces total strain energy but not to the extent assumed in Eqn. A3. Hence the actual reduction coefficient for MOE lies between Eqns. A2 and A3. These equations indicate the variation in MOE with increasing load through the resulting variation in r. If r is chosen close to but less than 1, its value may be set so that the actual reduction coefficient for MOE is given for practical purposes by the design equation

$$a^o = \frac{1}{2}\frac{L}{L'}r \qquad (\text{for } L \leq L') \qquad \text{(A4)}$$

or

$$a^o = 1 - \frac{1}{2}\frac{L'}{L}r \qquad (\text{for } L \geq L')$$

The bending strength, or ultimate moment M, at a critical section for bending is given by integration over the depth t of the section

$$M = \int_o^t sydy \qquad \text{(A5)}$$

and assuming uniform distribution of particles as in Fig. 4.2, the reduction here due to finite particle length L is again given by Eqn. A4. Hence the one coefficient $a = a^o$ may be used when designing for stiffness MOE and strength MOR.

Thus the conditions (i) to (iv) above give the optimal design under a given loading condition. Equations A4-A11 presented herein give the reduction in this optimum due to finite particle or fibre length, random orientation, and uniform distribution of particles over the depth of the board and over its length.

8.3 Reductions in strength from the ideal optimum

It is of interest to consider practical values of the reductions involved. Consider the case of one-way bending of the board under a concentrated line load at the centre: Optimality conditions (i) to (iv) require:

(i) oriented particles - in the direction of span;

(ii) particles concentrated at the faces;

(iii) particles increasing linearly in density or quantity across the span from 0 at the ends to a maximum at the centre (under the load, i.e. proportional to bending moment in the board);

(iv) infinite bond strength or very long particles (the latter is inconsistent with (iii)).

This would give the idealized absolute maximum strength for a given volume or mass of particles. Nominating this absolute maximum strength as 100 per cent, the reductions which occur in practice from this may be examined, e.g.

(a) distributing particles uniformly along the board instead of according to (iii) gives a reduction in strength of 50 per cent;

(b) orienting particles randomly instead of aligning them in the direction of bending (condition (i)), results in a further reduction of 50 per cent to a net strength of 25 per cent;

(c) distributing particles uniformly over the depth of the board instead of concentrating them at the faces (condition (ii) which is an almost feasible idealization for some composites) results in a further reduction of 33 per cent to 16.7 per cent net.

Further reduction comes from finite bond strength and finite particle length (a departure from condition (iv)). For $L = L'$, e.g. $L/D = 60$ for the oak particles of Fig. 4.3, the reduction is a further 50 per cent to 8.3 per cent net. For particle boards, the particles may be shorter than this and hence an even greater reduction occurs. For wafer boards with L/D in the 100 to 200 range, the reduction is less. Thus the current standard, uniform, random board products have strengths of only 5 to 15 per cent of their absolute maximum potentials. The oriented, layered, or variable density boards, however, increase this proportion (of potential maximum strength) to nearly 40 per cent.

For special purpose boards - and for beams - higher proportions of the absolute maximum potential strength may be achieved.

8.4 Efficiency versus robustness

Thus these departures from the optimum conditions (i) to (iv) above substantially decrease the efficiency of the board under the given design loading condition. However, they generally tend to increase its robustness or capacity to handle random variations from this design loading condition.

A mathematical relationship between structural efficiency and robustness was developed recently (Brotchie 1981) and may be expressed in the form

$$U = W + X/V \qquad \text{(A6)}$$

in which U is the total effectiveness of the design W is its efficiency under design load, and X is entropy, a measure of uncertainty of loading and resistance expressed as the log of the number of ways the load and resistance elements (e.g. particles) can be combined for a given design distribution (of these particles) and V is a weighting factor on this uncertainty. X and V have utility interpretations also. In fact, Eqn. A6 relates two basic approaches to design and these will each be considered briefly:

Utility approach

The first is the utility approach in which the utility or effectiveness of particles under a random variation from the design loading is also assumed to vary randomly. The effectiveness under the design loading is taken as constant.

Consider two or more design options j representing alternative distributions of particles. The effectiveness B_j of these particles under the design loading is assumed to be a constant B_j. However, the effectiveness B_j of individual particles under the random loading is assumed to vary randomly and is $B_j = \bar{B}_j + b_j$ where b_j is the random component. If b_j is normally distributed with mean 0 and standard deviation d, the cumulative normal distribution may be closely approximated by the logistic distribution

$$y_j = 1/(\exp (V_j b_j + 1) \qquad \text{(A7)}$$

in which $V_j = 1.7/d_j = V$, assuming the same variation in each option at this stage. Thus 1/V is a measure of diversity of effectiveness of utility B_j.

If the two or more design options j are complementary in that they cater best for different parts of the random loading distribution, effectiveness is maximized by assigning different parts of this expected distribution to the different design options j such that total load is catered for and all resistance elements with effectiveness above a certain threshold B_o are included.

This total effectiveness is given by integration of each effectiveness distribution B_j above this threshold B_o, to give (for $y_j = x_j$ at $B_j = B_o$)

$$U = \sum_j \int_0^{x_j} B_j \, dyN_j = \sum_j \int_0^{x_j} b_j dyN_j + \sum \bar{B}_j \, x_j \, N_j$$

$$= \sum_j \frac{1}{v} \left(x_j \log x_j - (1-x_j) \log (1-x_j)) + \bar{B}_j \; x_j\right) N_j \qquad \text{(A8)}$$

in which N_j is the number of particles in option j required to carry the design loads and x_j is the proportion of these particles selected in the design.

Uncertainty approach

In the uncertainty approach, the utility of each design option is taken to be $\bar{B}_j$ under the uncertain loading, but variations in the utility of particles within each option are not considered. The particles, however, are considered to be distinguishable. (Load elements may be considered to be distinguishable if they are variable in the utility approach.)

Hence if M is the number of load elements, the number of possible combinations of distinguishable load elements and particles is given by

$$n = \frac{M! \;\; N_j!}{(N_j - n_j)! \;\;\; n_j!}$$

in which n_j is the number of particles selected in option j and N_j is the number required to carry all of the design load. Uncertainy X is then obtained (Brotchie 1981) by substituting $x_j = n_j/N_j$, and using Stirling's approximation,

$$X = \log n = \sum_j (x_j \log x_j - (1 - x_j) \log (1 - x_j)) \, N_j \qquad \text{(A9)}$$

The least biased or most likely distribution of particles to carry the uncertain loading distribution is then obtained by maximizing entropy X subject to a given level of (base) utility

$$W = \sum \bar{B}_j n_j = \sum \bar{B}_j x_j N_j \qquad (A10)$$

This optimization problem may be solved by a Lagrangian technique, giving Eqn. A7 as before (for $V_j = V$). Furthermore, Eqns. A8, A9 and A10 yield Eqn. A7.

Unified theory

Thus maximizing total utility U subject to a given diversity 1/V also maximizes entropy X subject to a given level of base utility W. Thus the term X/V has two interpretations. From the utility approach, it is the total surplus utility or effectiveness realized above the basis $\bar{B}_j$ for the particles selected, i.e. $(B_j - \bar{B}_j)$ over all particles selected in the design.

From the entropy approach, X is the total uncertainty or flexibility of assignments of loads to particles, and B is a weighting on this uncertainty. Thus X/B is the premium value derived from this flexibility to handle uncertain load distributions, and is a measure of robustness of the design.

A negative measure of effectiveness of particles is the strain energy induced in them by the design loads. A positive measure would be the strains or strain energy induced by a given (virtual) displacement under loads.

Thus for the optimal particle distribution, j, satisfying conditions ((i) to (iv)) under given design loading

$$B_j = \bar{B}_j = \text{constant} > \bar{B}_k \text{ all } k \neq j \qquad (A11)$$

i.e. alternative distribution options, k, would have lower base utilities, $\bar{B}_k$. Hence if the loading is certain, only the optimum distribution j need be selected.

Under random variations from this loading, however, B_j will vary randomly also and selecting some particles from distribution j and some from complementary distribution k will provide a greater expected utility U or a greater expectation of matching uncertain loads and resistance elements to provide a suitably large robustness premium X/V and total utility U.

Thus for a known distribution of load, conditions (i) to (iv) may be satisfied to give the most efficient distribution of particles for design. More generally, however, a more robust design is required to provide greater effectivness over a range of possible loading conditions.

Oriented (aligned) and random distributions of particles may be considered in this light. Robustness is thus a measure of (lack of) sensitivity of the design to changes in the load parameters. The most efficient design with all particles placed according to conditions (i) to (iv) is sensitive to changes in the assumed load distribution.

Oriented wafer or strand boards will have some of this sensitivity in that they are suited to bending in the direction of orientation only and vulnerable in the other direction, but are not sensitive to bending moment distributions in this direction as their particles are uniformly distributed along the span. Randomly oriented wafer or strand boards are more robust. Hence in general both will be required, with the oriented boards meeting special purposes such as floors or roofs spanning in one direction only.

Where the load elements do not vary, but only particles vary, the term X/V in Eqn. 6 merely represents the premium obtained by preselection of the best particles (over the performance obtained by random selection).

These problems of design can now be considered rationally and optimally using the theory, equations, optimality conditions, and robustness and effectivness measures presented herein. The optimal design to suit a given loading spectrum may be directly and optimally determined from these equations.

Thus, where the variation in effectiveness 1/V is small, the most efficient distribution of particles (satisfying conditions (i) to (iv)) is appropriate. Where the variation 1/V is larger, oriented distributions satisfying conditions (i) and (ii) are appropriate, and where larger still, random distributions satisfying condition (ii) only are required.

The theory presented in chapter 4 and this Appendix represents a fundamental contribution to design theory and method for the design of particle and fibre composites. It fills a gap, identified by Youngquist (1981) and Maloney (1981) which would have hampered the full technological development and structural application of these materials.

Further development and application of this theory is strongly recommended to meet current and future design and online quality control needs. Further study of material properties for the various species of the hardwood forests yet to be effectively utilized is also required to complement these design techniques and enable them to be applied more widely.

The concepts of efficiency and robustness have wider application and might be related to investment policies in wood processing technology. Further research on this topic is also strongly recommended.

8.5 Optimal ratios of cost factors

Viewing Table 3.9, a feature is the similarity of the cost breakdown for the various products (and processes). This is not too surprising in one way, in that each represents a practical optimum ratio of factors involved in a system where substitutions between factors are assumed to be feasible.

Such an optimum may be sought theoretically by considering the production problem as that of seeking optimal quantities x_i of each factor of production i with unit costs c_i to minimize total cost $C = \sum c_i x_i$ subject to a performance constraint $P = P_o$ in which P is given by a performance model of the type previously developed or a production function such as $P = b\prod x_i^{a_i}$. In the latter case, a solution may be obtained analytically by forming a Lagrangian

$$L = \sum c_i x_i - V(b\prod x_i^{a_i} - P_o)$$

which gives the optimality conditions

$$\partial L/\partial x_j = 0 = c_j - a_j V b \prod x_i^{a_i}/x_j = c_j - a_j VP/x_j$$

$$\text{and } \partial L/\partial V = 0$$

or $P_o = b\prod x_i^{a_i}$, and substituting between these gives

$$c_j x_j = a_j VP_o = \text{constant.}$$

Thus the optimal expenditure on factor j is $c_j x_j = a_j V P_o$ where a_j is a factor relating to the productivity of the j^{th} input. Thus if the unit cost of factor j, c_j, falls, the quantity x_j increases, and hence the total cost share of factor j is less sensitive to cost changes than the cost coefficient c_j itself would indicate.

Table 1.1 World forest resources by region

(Operable forest)

Regions	Area in million of hectares	Volume (1,000 million m^3)			Total volume as a percentage of world
		Total	CON	NC	
1. Developed:					
North America	366	36.4	26.6	9.8	14.1
Europe	131	14.1	8.4	5.7	5.5
U.S.S.R.	389	40.0	33.2	6.8	15.5
Other	55	5.5	3.9	1.6	2.1
Total developed	940	95.9	72.1	23.9	37.2
2. Developing:					
Temperate developing	149	12.7	6.6	6.1	4.9
Tropical developing	885	148.9	2.1	147.0	57.8
Latin America	531	79.8	1.2	78.6	31.0
Africa	162	38.8	0.7	38.1	15.1
Asia	341	41.7	7.2	34.5	16.2
Total developing	1,034	161.6	7.9	151.2	62.8
3. World	1,974	257.5	80.8	176.7	100.0

Sources: FAO 1982 and 1983.

Note on abreviations: CON, coniferous; NC, non-coniferous.

Table 1.2 Annual deforestation in tropical forest: 1980

(in millions of hectares)

Region	Operable forest	In all closed forest	In all tree formations
Tropical America	3.15	4.35	5.60
Tropical Africa	1.25	1.35	3.70
Tropical Asia	1.70	1.80	2.00
Total	6.10	7.45	11.30

Source: FAO 1982.

Table 1.3 World production

(in thousands of cubic meters)

		1969	1980
Roundwood	World	2,561,393	3,020,306
	Developed	1,226,257	1,253,391
	Developing	1,335,126	1,769,915
Coniferous	World	1,064,170	1,181,766
	Developed	899,862	938,083
	Developing	164,308	233,674
Non-coniferous	World	1,423,885	1,750,919
	Developed	325,895	311,783
	Developing	1,097,990	1,439,137
Fuelwood and charcoal	World	1,329,639	1,626,835
	Developed	188,338	150,810
	Developing	1,141,301	1,476,025
Industrial roundwood	World	1,231,754	1,393,471
	Developed	1,037,929	1,099,581
	Developing	193,825	287,790
Coniferous	World	879,775	967,252
	Developed	823,375	872,043
	Developing	56,400	95,209
Non-coniferous	World	351,979	426,219
	Developed	214,554	227,538
	Developing	137,425	198,681
Sawnwood, coniferous	World	310,759	322,445
	Developed	290,351	291,240
	Developing	20,408	31,235
Sawnwood, non-coniferous	World	93,327	102,804
	Developed	64,470	58,322
	Developing	23,857	44,482
Wood based panels	World	65,576	101,974
	Developed	60,314	88,595
	Developing	5,262	13,379

Table 1.3 (Continued)

		1969	1980
Veneer sheets	World	2,948	4,856
	Developed	2,381	3,277
	Developing	567	1,619
Plywood	World	30,949	40,275
	Developed	27,554	32,554
	Developing	3,395	7,721
Particle board	World	17,343	40,330
	Developed	16,732	38,033
	Developing	611	2,297
Fibreboard	World	14,336	16,514
	Developed	13,647	14,771
	Developing	689	1.743
Wood pulp	World	98,286	126,755
	Developed	95,154	117,761
	Developing	3,132	8,995

Source: FAO 1981.

Table 1.4 Year 2000 projections world wood demand

Authority (date of forecast)		Projected demand (million m^3/year)		
		Fuelwood	Industrial	Total
Madas (1974)		1,000-1,200	3,170-3,770	4,170-4,970
King (1978)		-	-	5,220-6,410
FAO (1979)		1,280	2,085	3,365
EIU (1981)		1,900	2,800	4,700
FAO (1982)		1,820	2,085	3,905
IIASA (1982)	Low		2,000	
	Medium		2,200	
	High		2,500	
Actual 1980 values for comparison		1,630	1,390	3,020

Sources: Sutton 1981, Adams, Kallio and Seppälä 1982 and FAO 1982.

Table 1.5 Estimated areas of plantation forests in 1980

Region	Millions of hectares
Asia - Far East Region	55
South Asia	2.3
Continental S.E. Asia	.4
Insular S.F. Asia	.9
East Asia	11.6
Oceania developing	.9
Oceania developed	1.3
Centrally planned	39
North America	10
Europe	8
Latin America	5
Tropical	4.3
Africa	2
Tropical	1.8
Total	80

Sources: FAO 1976, Sedjo 1981, FAO 1982.

Note: The figures above are based on various partial surveys only and may be incomplete. Industrial and non-industrial plantation forests are included in these figures.

Table 2.1 Components

Particles	Binders
Plys - veneers	Resins - Phenol formaldehyde (PF)
Wafers, e.g. 100 x 36 x 1 mm 100 x 36 x 0.5 mm	Urea formaldehyde (UF)
Strands	Melamine formaldehyde
Flakes, chips, shavings	Tannin extracts
Wood wool	Isocyanates
Fibres - wood	Minerals -
Fibres - vegetable	Cement
Fibres - glass, rock, plastic	Gypsum

Table 2.2 Composites

Combinations*	Board Product
Veneer, resin	Plywood
Wafers, resin	Wafer board
Strands, resin	Strand board
Scrim, resin	Scrim board
Flake, chips, shavings, resin	Particle board
Fibres, resin	Medium density fibre board - (high density) hardboard (low density) insulation board
Wood wool, cement	Wood wool cement board
Wood flakes, cement	Wood cement particle board
Wood fibres, cement	Wood cement fibre board
Vegetable fibres, cement	" " "
Glass fibres, cement	Cement " "
Wood fibres, gypsum	Fibrous plaster board
Vegetable fibres, gypsum	" "
Glass fibres, gypsum	Plaster glass board.

* Particles may be randomly distributed, oriented in direction, and may vary in density and composition over thickness of board.

Table 2.3 Further Combinations

Combinations	Products
Veneer, flake, resin	Veneer face, particle board core
	"Plystran" - board
	"Comply" - lumber
Fibre, veneer, resin	Veneer core, MD fibre board faces
Strand, strand, resin	Strandboard board
	Oriented strand board
Wafer, wafer, resin	Oriented wafer board
Ply, Ply, resin	"Press-Lam" lumber
Ply, board, resin	"Laminboard" - board
	Block board - board
Fibre, flake, resin	MD fibre board face, particle board core
Flake, fibreglass, resin	Reinforced particle board
	"Pultraform"
	Reinforced particle board lumber.

Face materials may also include metals, plastic sheet, resin impregnated paper.

Core materials may also include plastic foams and other cellular (e.g. honeycomb) materials.

Table 2.4 Board products and potential board products

Board	Particle	Particle Dimension (typical) (mm)	Orientation	Layering or variation over thickness	Resin*	Strength (potential)	Use (potential)
Plywood	Veneer sheet		Oriented	Several	PF, UF	High	Ext., int. structural
Wafer board	Wafer	100 x 30 x 1 x 0.5	Random	Variation	PF	Med.-high	Ext., int. structural
			Oriented	Several	PF	high	Ext., int. structural
Strand boards	Strands	100 x 2 x 1	Random	Variation	PF	Med.-high	Ext., int. structural
			Oriented	Several	PF	High	Ext., int. structural
MDF board	Wood fibres	3 x 0.03	Random	Variation	PF,UF	Med.-high	Ext.*, int.
	Wood fibres		Oriented	Variation several	PF,UF	High	Ext.*, int.
	Veg. fibres Agric. wastes	50 x 0.5	Random	Variation	PF,UF	Med.-high	Ext.*, int.
			Oriented	Variation several	PF,UF	High	Ext.*, int.
Particle board	Flakes, Chips, Shavings	50 x 25 x .3	Random	Variation	UF	Medium	Int.
					PF	Medium	Int. struct.
Hardboard	Fibres	3 x 0.03	Random		-	Medium	Ext., int.
				Variation	PF	High	Ext., int. structural
Veneer particle composite	Veneer face & particle core		Oriented	Several	PF	High	Ext., int. structural
Cement-wood	Flakes		Random	Variation	Cement	Medium	Ext., int.
	Wood Fibres	3 x .03	Random	Variation	Cement	Medium-low	Ext., int.
	Veg. fibres	100 x .5	Random	Variation	Cement	Medium-low	Ext., int.
			Oriented	Variation	Cement	Medium	Ext., int.
Gypsum-wood	Vegetable fibres	>200 x .5	Random	Variation	Gypsum	Medium-low	Int.
			Oriented	Variation	Gypsum	Medium-low	Int.

* Isocyanate and melamine resins may be substituted for PF (phenol formaldehyde) or UF (urea formaldehyde) resins. PF, isocyanate, cement, are suitable for external and internal use, UF, gypsum are suited only to internal use. Cellulose based fibres used externally may require treatment for durability.

Table 2.5 Production of sawnwood and processed boards - developed and developing countries by region[a]

		1969	1980
Sawnwood (C)	Developed market economies	177.275	188,564
	N. America	95,252	98,800
	W. Europe	46,085	54,679
	Oceania	2,462	2,982
	Other developed	33,476	32,103
	Developing market economies	11,027	17,189
	Africa	344	493
	Latin America	6,994	11,096
	Near East	2,164	2,968
	Other developing	41	39
Sawnwood (NC)	Developed market economies	44,642	40,005
	N. America	21,376	18,458
	W Europe	11,533	12,996
	Oceania	2,510	1,986
	Other developed	9,243	6,555
	Developing market economies	22,661	36,086
	Africa	2,540	5,486
	Latin America	8,010	12,584
	Near East	610	1,126
	Far East	11,363	16,666
	Other developing	137	225
Wood based panels	Developed market economies	51.159	71.354
	N. America	26,529	32,548
	W. Europe	16,548	26,972
	Oceania	686	1,160
	Other developed	7,395	10.675
	Developing market economies	4,392	11,291
	Africa	466	883
	Latin America	1,467	4,194
	Near East	306	832
	Far East	2,134	5,348
	Other developing	19	34

Table 2.5 (Continued)

		1969	1980
Plywood	Developed Mmarket economies	24,857	29,650
	N. America	15,639	18,338
	W. Europe	3,064	2,699
	Oceania	119	129
	Other developed	6,035	8,484
	Developing market economies	2,729	6,136
	Africa	229	413
	Latin America	657	1,497
	Near East	91	109
	Far East	1,735	4,100
	Other developed	16	17
Particle board	Developed market economies	13,371	29,342
	N. America	3,415	7,367
	W. Europe	9,307	20,023
	Oceania	275	743
	Other developed	375	1,209
	Developing market economies	583	2,253
	Africa	40	140
	Latin America	346	1,407
	Near East	143	606
	Far East	54	100
Fibreboard	Developed market economies	11,391	10,038
	N. America	7,289	6,343
	W. Eurpe	3,107	2,800
	Oceania	249	246
	Other developed	745	649
	Developing market economies	513	1,283
	Africa		12
	Latin America	342	1,022
	Near East	66	92
	Far East	105	156

Source: FAO 1981.

Note: C, coniferous; NC, non-coniferous.

a/ Market economies only.

Table 3.1 Board products - technological levels and factor requirements of each

Aspect	Sawn lumber	Resin Bonded						Mineral Bonded			
								Wood-cement			Wood Gypsum fibres
		Plywood	Fibre board, Hard board	MDF	Particle board	Wafer board	Strand board	Particles	W. fibres	Veg. fibres	
RAW MATERIAL Form	Logs	Logs	Logs, offcuts, chips	Logs offcuts, chips	Same	Logs offcuts chips	Logs offcuts	Logs offcuts	Logs offcuts	Veg. fibre, agricultural	Wood, wafer, veg. fibres, agric. wastes
RANGE OF SPECIES	Most	Most	Limited density range	More limited	All	Many	Most	Most	Most	Many	Many
BINDERS	None	PF, UF, 4%-8%	Wet proc. = 0 Dry proc. = 3% PF	UF 9% MF	UF 8-10% MF	PF 3%	PF 6%+	Cement	Cement silica	Cement silica	Gypsum
COST Wood	Very high	Very high	Low	Low	Low	Low	Low	Low	Low	Low	Low
Transport	High	High	Low	Low	Low	1000	Low	Low	Low	Low	Low
Binder *	None	High	High	High	High	Medium High*	Medium-high *	Low	Low	Low	Low
TECHNOLOGY	Simple	Simple	Simple to advanced	Advanced	Medium	Medium-advanced	Medium-advanced	Simple-medium	Simple-medium	Simple	Simple
MAINT. SUPPORT	Simple	Simple	Inter-advanced	Advanced	Medium	Medium-advanced	Medium-advanced	Simple-medium	Simple-medium	Simple	Simple
INDUSTRIAL INFRASTRUCTURE	Simple	Simple	Medium	Medium	Medium	Medium	Medium	Simple-medium	Simple-medium	None	None
OPERATION	Intermittant OK	Intermittant OK	Continuous	Continuous	Int-Cont.	Int-Cont.	Int-Cont.	Int.	Int.	Int.	Int.
SCALE REQUIRED	Medium	Large	Large	Large	Large	Large	Large	Medium-small	Medium-small	Small	Small
ENERGY	Low	Med	High	High	Medium	Medium	Medium	Medium-low	Medium-low	Low	Low
MANPOWER	Local skilled un-skilled	Local skilled un-skilled	Imported local skilled unskilled	Imported skilled unskilled	Imported local skilled un-skilled	Imported local skilled unskilled	Imported local skilled un-skilled	Imported local skilled unskilled	Local skilled unskilled	Local skilled unskilled	Local skilled unskilled
CAPITAL	Low	Med	Medium	High	High	High	High	Medium-low	Medium-low	Very low	Very low

* PF - Phenol formaldehyde, more expensive than UF (Urea formaldehyde). Both these products are more expensive in developing countries.

Table 3.2 Technological considerations for developing countries

Aspect	Sawn wood Sawmill	Plywood	Fibre board hardboard	Medium density fibre board	Particle board	Wafer board	Strand board	Cement particle board	Cement fibre board	Gypsum fibre board	Kiln dryer for sec processing
Wood raw material yield (%)	40-50%	30-50%	85%	90%	90%	85%	85%	90%	90%	90%	-
Suitability for developing countries	Simple	Simple	Wet batch. Simple Wet cont. Inter dry-advanced	Advanced	Suitable most devel. countries	Suitable most devel. countries	Advanced	Suitable most	Simple all	Simple all	Yes
Maintainability of plant	Simple	Simple	Medium-sophisticated	Sophisticated	Medium	Medium	Sophisticated	Medium	Very simple	Very simple	Simple
Industrial infrastructure required	Simple	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Very simple	Very simple	Simple
Operation of process	One shift possible	One shift possible	Continuous except batch	Cont.	Cont.	Cont.	Cont.	Cont.	One shift simple	One shift simple	One shift or cont.
Min. econom. capacity	Varies	m^3/day	m^3/day	m^3/day	m^3/day	m^3/day	High	m^3/day	Low	Low	m^3/day 5-10 or less
Local market		20	15-20	75-100	30-40	30-40		20-30			
export		120	70	200	200	200		50			
Energy	Low	Medium	High	Higher	Medium	Medium	Medium	Medium	V. low	V. low	High
Fuel (heating)	None	Medium	High	High	Medium	Medium	Medium	Medium	-	-	
Water	-	small	Wet high Dry small	Small	Small	Small	Small	Medium	Low	Low	-
Ecological considerations	Small	Medium problem	Wet serious dry medium	Medium	Medium	Medium	Medium	Low	Nil	Nil	Small

Table 3.3 Comparison of three wood based panel plants - plywood, composite ply and OSB - 1981 prices - location: Southern USA

	Plywood		Comply	OSB	
	Small[a]	Large	Large	Small	Large
Annual production ($m^3 \times 10^3$)	50	100	125	75	100
Capital cost (US$ x 10^6)	25	34	50	30	38
Number of employees	133	185	210	91	116
Manufacturing costs ($/$m^3$)					
wood	85		38	41	
adhesive	13		26	35	
labour	40	28	24	18	17
overhead	64	52	49-57	52	
Total	201	178	138-146	146	137
Selling price (FOB) factory ($/$m^3$)	220		210	200	
Remainder ($/$m^3$) for profit, tax, etc.	19	42	72-64	54	63
Interest on capital ($/$m^3$ 10%)	50	34	40	40	38
Labour productivity m^3/employee per day	1.1	1.6	1.8	2.5	2.6

[a] "Small" here is in relation to the range for industrialized countries. For developing countries, smaller plants may be appropriate as indicated in Table 3.2.

Table 3.4 Comparison of the three wood based panel plants of Table 3.3 using assumed costs for a developing country

Assume plant size, capital cost, manpower are the same as for Table 3.3, and that the factor costs, as a percentage of those shown in Figure 1.1, are:

Wood cost	change factor	0.6
Adhesive cost	" "	1.5
Labour cost	" "	0.2-(0.5)
O/H	" "	1.5

Manufacturing costs (US$/m^3)	Plywood Small	Plywood Large	Comply Large	OSB Small	OSB Large
Wood	51		23	25	
Adhesive	20		39	53	
Labour	8-6 (20)	(14)	5 (12)	4 (9)	
Overheads	64	52	49-57	52	
Total	143 (155)	127 (135)	116-124 (123-131)	134 (139)	
Price (assumed minimum)	180		170	160	
Remainder: profit, tax, etc.	37 (25)	53 (45)	54 46 (47)-(39)	26 (21)	
Interest on Capital $/m^3 10%	50	34	40	40	38
Price in developed world (e.g. US) $/m^3	220		210	200	
Sea freight costs $/m^3 approx.[a]	48-67		48-67	48-67	
Remainder: profit, tax, etc.	10-45		46-20	0-18	

Source: Brion 1982.

a/ Between South-East Asian ports and the USA, US$52-67
" " " " Europe US$58
" " " " Japan, Korea US$48

Table 3.5 Production costs in 1975
(for the same plants as in Table 3.3)

	Costs/m^3		
Item	Plywood	Comply	Particle Board a/
Wood	44	22	16
Adhesive	12	25	30
Labour	15	13	12
Overheads	39	26	23
Total	110	86	81

Sources: Moloney, unpublished, Koenigshot 1977.

a/ OSB and waferboards have similar costs but higher product value.

Table 3.6 Comparative costs in relation to scale for hardboard production[a/]

Annual Production (m^3)	7,500	11,000	33,000	51,000	75,000
Daily Production (m^3)	25	37	110	170	250
Unit Production cost (US$/$m^3$)	200	135	120	110	100
Unit capital cost ($/$m^3$)	50	30	30	25	23
Total unit cost ($/$m^3$)	250	165	150	135	123
Labour productivity (m^3/employee/day)	.7	.9	1.1	1.1	2.2

Source: UNIDO 1975.

a/ Conventional wet system.

Table 3.7 Cost of automation for wood based panel plants

Initial outlay (US$)	250,000	500,000	1,000,000
Annual depreciation and maintenance ($/year)	50,000	100,000	200,000
Annual plant production (m^3)	50,000	100,000	150,000
Cost of automation per unit product ($/$m^3$)	1	1	1.3
Cost savings $/$m^3$ For 7.5% material reduction			
Plywood	6	6	6
Composites	3	3	3
For 15% labour saving $/$m^3$			
Plywood	12	7.5	6
Composites	n.a.	6	4.5
Total cost saving $/$m^3$			
Plywood	18	13.5	12
Composites	n.a.	9	7.5

Source: From McNeil, 1981.

Table 3.8 Costs in relation to scale for plaster-fibre board production (1983 costs, Australia)

Annual production (m^3)	3,000	1,900	750
Daily production (m^3)	10	6.25	2.5
Production staff (labour)	7	5	3
Capital cost (US$)	200,000	150,000	100,000
Production cost $/$m^3$			
Glass fibre	80	80	80
Gypsum	20	20	20
Labour	60	70	90
Overhead	80	90	100
Total	240	260	290
Selling price ($/$m^3$)	400	400	400

Source: Private communication 1983.

Note: 1 m^3 = 100 m^2 of 10 mm board
125 m^2 of 8 mm board (normal use).

Table 3.9 Costs of producing various products in developed and developing countries

Item	Plywood	Comply	OSB	Plasterboard
Plant size	Large	Large	Large	Small
Technology	Medium	High	High	Low
Annual production (m^3)	100,000	125,000	100,000	3,000
Costs for year	1981	1981	1981	1981
Production costs %				
Fibre	48	26	28	33
Binder	6	18	24	8
Labour	16	16	13	26
Overhead	29	40	35	33
Total %	100	100	100	100
US$/$m^3$	178	146	146	184

Production costs in developing countries as % of total production costs in developed countries[a/].

Fibre	33	16	17	11
Binder	9	27	36	16
Labour	8	8	7	13
Overheads	29	40	35	33
Total %	79	91	95	73

[a/] Costs are assumed to be as shown in table 3.4, labour costs are assumed to be 50 per cent of those in developed countries.

Table 3.10 Energy requirements for various processes

Process plant	Existing technology (New Zealand)	New technology (Scandinavia)	Ratio new/old
Sawn timber (MJ/M^3)	4,380	2,450	.55
Stone ground Kraft newsprint (MJ/T)	17,860	15,030	.85
Kraft free newsprint (MJ/T)	20,480	11,880	.57
Bleached chemical pulp (MJ/T)	2,680	1,700	.63

Source: Smith 1982.

Note on abreviations: MJ = Megajoule, T = ton

Table 3.11 Input costs for various products in developing and developed countries

Region	Labour cost	Material cost	Capital cost	Intensively utilized resource	Product
Developing	Low	Low	Medium	Material	Sawn timber
			Low	Labour	Mineral fibre board
			Low	Labour	Construction
		Higher	Medium	Material	Sawn timber
			High	Capital	Plywood composites
			Low	Labour	Hand crafted furniture
Developed	High	Low (wastes)	High	Capital	Composites
		High	High	Capital	Veneers Sawn timber Machine made furniture.

Table 3.12 Levels of technology appropriate to different processes

	Large automated plant	Highly mechanized production	Partly mechanized production	Largely manual production
Sawn timber	X	X	X	X
Plywood	X	X	X	
Comply	X	X		
Oriented strand board (OSB)	X	X		
Medium density fibreboard (MDF)	X	X		
Hardboard	X	X		
Cement fibreboard		X	X	X
Gypsum fibreboard		X	X	X
Housing construction			X	X
Furniture	X	X	X	X

Table 3.13 Markets for products

Product	sawnwood	plywood	comply	OSB wafer	hardboard	gypsum board	cement board
Markets	export	export	export	export	export		
	domestic	domestic	domestic	domestic	domestic		domestic
End-uses	ext,int	ext,int	int	ext,int	ext,int	int	ext,int
	struct.	struct.	struct.	struct.	struct.	lining	lining
	nonstr.	nonstr.	nonstr.	nonstr.	nonstr.		
	furnit.	furnit.	furnit.	furnit.	furnit.	housing	housing
	housing	housing	housing	housing	housing		
	const.	const.		const.	const.		const.

Note on abbreviations:
const. - construction
ext - exterior
furnit. - furniture
int - interior
nonstr. - nonstructural
struct. - structural

Table 4.1 Fibre strength

Fibre	Ultimate Strength of Fibre (MPa)
WOOD	
PINUS RADIATA FIBRES	
Test tube preparation of fibre	1,100
Standard kraft paper fibre	600
ASPLUND	150
TMP	300
SOFTWOOD	
Klinki pine	240-340
EUCALYPTUS OBLIQUA	
Ordinary pulp	800
VEGETABLE FIBRES	
N.Z. flax	300-400
Copra (coconut)	133
Sisal	300
Water reed	70
Elephant grass	178
Plaintain	92
Muryamba	83
Manila abaca	500
Sanseviera	300
Sugar cane bagasse	500 a/
Lupine	500 a/
Barley straw	500 a/
Bamboo	240 a/
Peanut shells	140 a/
Rice Hulls	250 a/
INORGANIC	
STEEL	600
ASBESTOS	700-1000
FIBREGLASS	1,400

a/ Estimated from board properties.

Table 4.2 Fibre properties

Fibre type	Tenacity P (mm x 10^6)	Elongation ε	Stiffness (= P/ε) (mm x 10^8)
Sisal	39.0	0.027	14.2
Coconut bristle	8.0	0.25(+)	3.3
Manila abaca	62.0	0.028	22.2
Sansevieria	40.0	0.027	14.7
Glass fibre	50.0	0.02	25.0

Table 4.3 Comparison of fibres - cost effectiveness

Fibre type	Tenacity P (mm x 10^6)	Length (mm)	Cost C (US$/ Tonne)	Strength cost ratio		
				a	(P/c)10	(aP/c)10
Sisal[a/]	39	400	500	.94	.78	73
Coconut[a/]	8	200	350	.88	.23	20
Elephant grass[a/]	25	400	400	.94	.62	50
Softwood kraft fibre	75	2.5	500	.15	1.5	22
Softwood TPM	39	2.5	300	.3	1.3	40
Softwood asplund	20	2.5	300	.45	.67	30
Glass fibre	50	∞	1,600	1.0	.31	31
Asbestos	50	-	500	.3	1.0	30

[a/] Vegetable fibres are comprised of fibre bundles. Individual fibres are similar in geometry to those of wood.

Table 6.1 Regional production compared with growing stocks roundwood (millions m^3)

	Production			Growing stock		Ratio of growing stock to production/yr (yrs)
	1969	1980	% of world production in 1980	Total in operable forests	% of world stock	
DEVELOPED	779	811	26.9	55,900	21.7	68.9
N. America	455	484	16.0	36,400	14.1	75.2
W. Europe	238	251	8.3	14,100	5.5	56.2
Oceania	22	26	0.9	1,300	0.5	50
Other developed	54	51	1.7	4,000	1.6	78
DEVELOPING	1,107	1,467	61.4	161,600	62.8	110.2
Africa	280	380	12.6	38,800	15.1	102
Lat. America[a]	262	362	12.0	79,800	31.0	220
Near East	76	76	2.5	41,700	16.2	57.6
Far East	494	641	21.2			
USSR	374	356	11.7	40,000	15.5	112
WORLD	2,561	3,020	100	57,500	100	85.3

Source: FAO 1982.

[a] Latin America = South America + Central America.

Table 6.2 Production, imports, exports, and apparent consumption
(Thousands of m^3 per year)

	Production	Imports	Exports	Apparent Consumption
	INDUSTRIAL ROUNWOOD, 1980			
DEVELOPED	751,942	93,114	51,011	794,000
N. America	463,958	6,599	26,174	445,000
W. Europe	221,882	35,974	16,646	241,000
Oceania	24,092	4	8,046	16,000
Other	42,010	50,537	144	93,000
DEVELOPING	220,894	9,658	41,738	189,000
Africa	38,966	428	6,698	32,000
Latin America	76,879	179	1,250	76,000
Near East	15,075	548	5	15,000
Far East	88,069	8,498	32,894	63,000
Other developing	1,894	4	902	1,000
	WOOD BASED PANELS, 1980			
DEVELOPED	71,354	11,754	9,224	73,000
North America	32,548	2,323	1,746	33,000
West Europe	26,972	9,009	7,215	29,000
Oceania	1,160	88	142	1,000
Other developed	10,675	335	122	11,000
DEVELOPING	11,291	2,214	3,838	9,000
Africa	883	318	273	1,000
Latin America	4,194	270	590	4,000
Near East	832	887	25	2,000
Far East	5,348	721	2,936	3,000
Other developing	34	17	16	0

Source: FAO 1981.

Table 6.3 Potential for additional industrial roundwood production

(Millions of cubic metres per year)

Region	Production in 1980	Additional production potential (long term)	Projected production in the year 2000
DEVELOPED	752	400	
North America	464	200	642
West Europe	222	100	320
Oceania	24	50	58
Other developed	42	50	73
DEVELOPING	221	500	
Africa	39	100	60
Latin America	77	300	124
Near East	15	100	189
Far East	88		
Other developing	2		
USSR	278	200	531
Other planned economies			
WORLD	1,393	1100	2085

Sources: FAO 1976, 1981, 1982, Ferguson 1979 and Sutton 1981.

Table 6.4 Shares of population, forest resources, and roundwood production by region in 1980

(percentage)

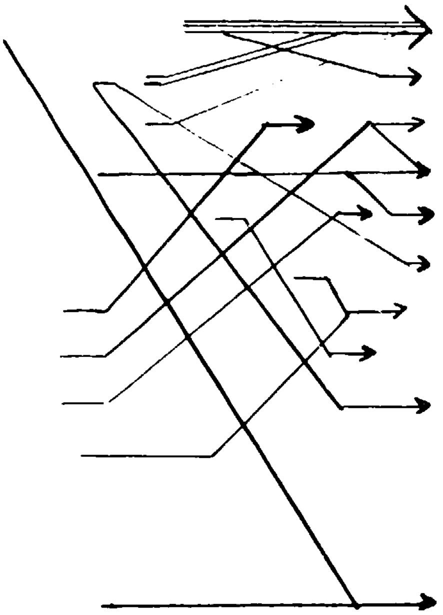
Region	Population	Growing stock	Total roundwood production	Industrial roundwood production	Sawlogs and veneer logs	Pulpwood
Developed	26	37	41	79	77	92
Developing temperate	32	5	12	7	6	3
Developing tropical	41	58	47	14	17	5
Developing total	74	63	59	21	23	8
World	100	100	100	100	100	100

Sources: FAO 1982, 1983.

Table 6.5 Saw logs and veneer logs - world trade

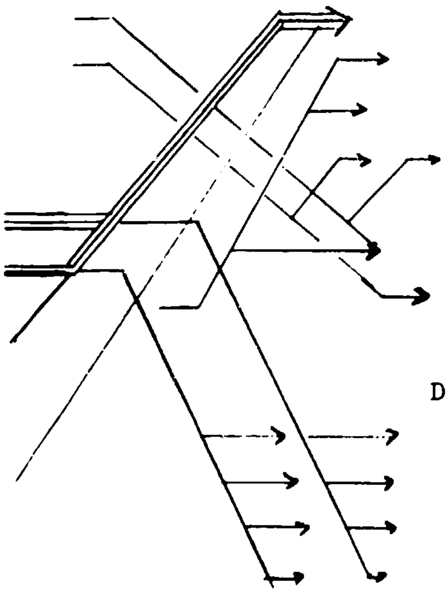
(1979 millions of m^3)

SOFTWOOD

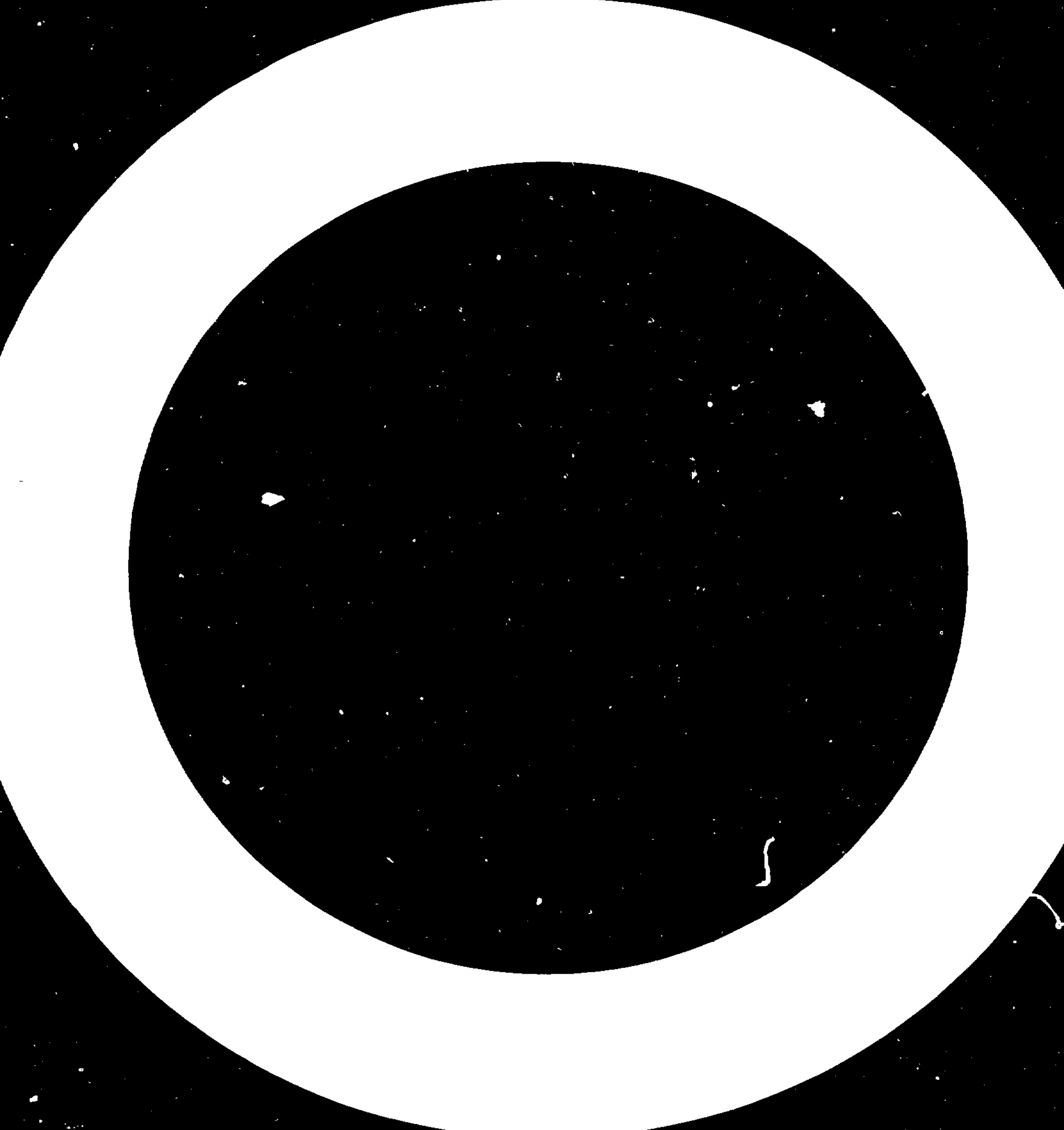


EXPORTERS		IMPORTERS	
DEVELOPED		DEVELOPED	
USA	17.1	JAPAN	22.0
USSR	7.7	CAN	1.9
NZ	1.2	ITAL	1.2
CZECH.	1.0	AUSTRIA	.9
CAN	.8	FRG	.7
FIN	.4	FIN	.6
SWITZ	.4	SWEDEN	.6
FRG	.4	USA	.5
BELG	.3	HUNG	.4
NORW	.2	OTHERS	.9
OTHERS	.8		
DEVELOPING		DEVELOPING	
CHILE	1.0	KOREA	2.1
INDON	.4	CHINA	.3
OTHER	.2	OTHER	.2

HARDWOOD



DEVELOPED		DEVELOPED	
FRANCE	.7	JAPAN	22.1
USA	.6	ITAL	2.7
OTHERS	1.8	FRANCE	1.8
DEVELOPING		FRG	1.3
INDON	17.8	AUSTRIA	1.0
MALAYSIA	3.2	SPAIN	.7
IVORY COAST	3.2	CAN	.4
PHILIPPINES	1.2	OTHER	2.2
GABON	1.2	DEVELOPING	
CAMEROON	.8	CHINA	7.1
PAPUA NG	.4	KOREA	7.0
LIBERIA	.4	SINC	1.5
OTHER	1.4	H.K.	.6
		OTHER	.9



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