IDEAS, for integral logistics

in centralized wood processing

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STELLINGEN

(1)

De logistieke keten, zoals die voorkomt in de centrale houtverzagende industrie, is te beheersen met behulp van een hiërarchisch produktiebesturingssyteem.

(Dit proefschrift)

(2)

Bij het gebruik maken van een hiërarchisch produktiebesturingssysteem dienen de operationele (locale) optimaliteitscriteria getoetst te worden aan de strategische (globale) doelstellingen.

(Dit proefschrift)

(3)

Bösch toonde in 1987 aan dat integrale optimalisatie nog niet bereikt was voor de centrale houtverwerking. Onterecht echter concludeerde hij dat dit in de toekomst ook niet mogelijk zou zijn.

(Bösch, B., Die Anwendung von Methoden der Unternehmensforschung in der Sägeindustrie, 1987)

(4)

Door in de recurrente betrekkingen van het dynamisch programmeringsalgoritme, ter optimalisatie van het verzaagprobleem,

$$G_{zx}(l_z, f_{zx})$$

te bepalen met

$$YF(l_z, f_{za})_{zay^{d}(f_{za})}, \text{ waarbij } a = Nx_z - x + f_{zx}$$

en vervolgens

$$YF(l_z, f_{zx})_{zx}$$

te bepalen met

$$YF(l_z, f_{zx_1})_{zx_1 y^{d}(f_{zx_1}) - y^{d}(f_{zx_2})}$$

is dit algoritme geschikt voor on-line toepassingen.

(Dit proefschrift)

(5)

Een toename van de aantasting van bosareaal, zowel in kwantitatieve als in kwalitatieve zin, gaat gepaard met een toenemende betrokkenheid vanuit de maatschappij. Maximale betrokkenheid is niet gewenst.

(6)

Hoewel ontbossing reeds in het Bronzen Tijdperk (Meiggs, 1982) een groot probleem was, realiseren weinigen zich dat de huidige ontbossingsproblemen die van toen overtreffen.

(Meiggs, R. Trees and timber in the
Ancient Mediterranean World, 1982)

(7)

Bosbouwers dienen innovatief met (kwantitatieve) besturingsmethoden om te gaan teneinde houtproduktie en overige functies van het bos, zoals natuurbescherming en recreatie, met elkaar in balans te brengen.

(8)

Eén van de aspecten van OPT (Optimized Production Technology) is het accepteren en waarderen van geplande stilstand in het belang van de onderneming. Alvorens toepassing van deze filosofie in de samenleving als geheel te overwegen dienen de sociale implicaties zeer wel in kaart gebracht te worden.

(9)

Het jargon waarvan de specialisten in Operations Research zich bedienen heeft zich ontwikkeld tot een zelfstandige wetenschap, met een nieuw type beoefenaars.

(10)

De verhouding van de inspanningen, geleverd ter realisatie van dissertatie enerzijds en stellingen anderzijds, is niet altijd te achterhalen tijdens de promotieplechtigheid.

M.P. Reinders
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M.P. Reinders

IDEAS, for integral logistics in centralized wood processing

Proefschrift

ter verkrijging van de graad van
doctor in de landbouwwetenschappen,
op gezag van de rector magnificus,
dr. H.C. van der Plas,
in het openbaar te verdedigen
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Abstract

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A decision support system (DSS) is developed to improve the quality of decision making in wood processing companies. Wood processing companies are businesses that import (buy, harvest) raw materials, stems and logs, and export (deliver) products, assortments and boards, after a multi-step conversion process.

The DSS, called IDEAS (Integral Decision Effect Analysis System), supports the operational, tactical and strategic level of decision making, by providing a range of tools of varying complexity.

Various analyses have been made for validating the underlying models. A case study was performed to test the impact for the relevant business chain.

Possible other fields of application can be the oil-industry, slaugther-houses, and in general cutting-stock performing industries. All these industrial circles share the package-production problem in common.

Management descriptors: Wood processing, Operational pattern optimization, multi-period, multi-product tactical production planning, strategic "what-if" simulation.

Technical descriptors: Nested dynamic programming, knapsack problems, multiple goal programming, dual interpretation, column generating procedure.

Tool descriptors: Menu-driven software, SCICONIC/VM, PRODUCER, FORTRAN, modular programming, SAS.

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To my mother and father

PREFACE

This thesis is concerned with the integral logistics for wood processing companies. Wood processing companies are defined for this thesis as businesses that are supplied with raw materials (trees and logs), and that produce assortments and boards by means of a multi step conversion process.

The conversion of stems on a central conversion site is a complex process due to a number of reasons. Firstly the conversion itself can only be carried out by a sequence of strongly interconnected decisions.

Moreover, the optimization of the production process must be performed according to a set of goals. For instance value recovery is considered of importance, because it determines the efficiency of the conversion process.

However, a company also strives for a sound financial base, and thus also profit making is of importance. Hence, also the effectiveness of the plant is of interest.

The goal of this research was to design a blue-print, and build a prototype, for a decision support system (DSS). This DSS, denoted IDEAS (Integral Decision Effect Analysis System) consists of three main components.

A database, containing corporate data. A model-base, consisting of a hybrid production planning system, combining both pull (demand orientated) and push (supply orientated) elements. And a menu-driven user interface, to control the communication between decision maker and the decision support system.

From a managers point of view, IDEAS consists conceptually of three interconnected shells, coinciding with the three levels of a decomposed management model. In the kernel of IDEAS the operational production planning is supported. The tools provided in this shell are fully directed towards efficiency maximization.

The second shell, supporting the multiperiod tactical planning, balances efficiency and effectiveness aspects of production control. Value recovery, service rate, inventory policy, and aspects such as package production are dealt with at this planning level.

The outer shell, supporting the aggregated strategic planning, is equipped with "what-if" simulation tools.

IDEAS was tested with real-world data, provided by a company in the Federal Republic of Germany. Although models and data were not equally tuned in on each other for all planning levels, interesting results were obtained.

The research was carried out at two departments, the department of Mathematics (section Operations Research), and the department of Forest Technique and Forest Products from the Agricultural University in Wageningen.

This dissertation is a reflection of efforts, made by many people, over many years. I would like to acknowledge my debt to them here.

First of all I would like to express gratitude to my mother and father. From my early years, they supported me together, with love, patience and advice. Later my father performed this essential task under his own power.

Furthermore I had the luck to grow up in a great, and strong family, that has expanded in recent years.

I thank my dear parents-in-law for their sympathy, and their "Kurort" management that gave me the moments of rest I needed.

I wish to thank Prof. Ir. M.M.G.R. Bol for having the vision to initiate this research, and for giving me the opportunity to write this thesis. Moreover his contacts in the relevant industrial circles turned out to be very important.

Prof. Dr. P. van Beek supported this research from the Operations Research point of view. His attention to integral logistics, and the emphasis put on hierarchical production planning were valuable supports. Furthermore he created a stimulating working climate, in which I had all possibilities to carry out this research.

I am much obliged to Ir. Th.H.B. Hendriks, my colleague and mentor during the years of this research. We had many hours of fruitful and enthusiastic discussions, concerning mathematics and more personal subjects, often resulting in new ideas and motivation.

Special thanks to Ir. W. Hey, for his contributions with respect to forest engineering subjects, for his realism, and for his support and interest.

Thanks to Dr. W. Duffner, from the "Fuerstlich zu Waldburg-Wolfegg'sche Forstverwaltung" (FRG), for his helpfulness with respect to the practical validation of the models, and for the valuable data he provided.

I would also like to thank Dipl. Ing. K. Döhrer, from the "Forstbetriebsgemeinschaft Kreis Waldeck" (FRG) for his interest and co-operation.

I would like to thank my friend Dr. Ir. P.J.M. Wijngaard. He performed the essential job of converting the original printer version of this work into a camera-ready thesis.

Much appreciation is due to A. Pols Msc, without his help the graphical representations would not have been what they are now.

I would like to thank my colleagues of the section Operations Research, and all other members of both the Departments of Mathematics and of Forest Technique and Forest Products, for their sympathy with this research.

Thanks to the Drawing-office of the "Biotechnion", they made the figures, sometimes based only on sketches, and they provided the materials needed for the graphics.

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H. van Holland and P. Hendriks performed the original typewriting of the most difficult parts of this dissertation, I thank them for their helpfulness.

Thanks to my friends, I cannot mention you all by name, but I am obliged to all of you that were interested, sympathized with me and the research, and for whom I sometimes gave too little attention to in the past years.

Desiree, my dearest comrade and wife, you did not only play the role of the sometimes wronged lady, but you actually helped me when the implementation phase took place. Already now the nights we spent at the Department, pouring our eyes out at the source-code, debugging the software, drinking too much coffee, seem to be romantic when looking back.

M. Peter Reinders

Wageningen
May 1989

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Chapter 1

INTRODUCTION

1.1. WHY THIS RESEARCH?

Forests possess many, in some cases partially conflicting, functions. Besides nature and nature conservation, soil protection, and recreation, forests have another function, namely the production function. By the latter we mean forests as a procreator of forest-products. The term forest-products denotes wood as well as the so-called minor products.

Wood, as one of the many forest products, is of great importance for mankind. In our life we are almost daily confronted with applications of wood. It is for example successfully used as a construction material, as raw material for fibre-boards, as a component for paper production and in many other industrial and non-industrial fields of application.

Trees in general grow only slowly compared with the velocity with which the main product of trees, wood, is used. It is therefore an absolute necessity to use forests in a very well-considered way, in order to be able to cope with present and future demand for forest-products. In other words, forestry has a very large responsibility with respect to the strategic impact of the pursued policy.

A well balanced forestry policy however is not enough to obtain longterm assurance for the availability of wood. Also the industrial chain, using wood as a raw material, has a responsibilty and, in our opinion, therefore a function, to obtain strategic stability for forests and forests products industries.

Many decisions have to be made for the conversion from tree to boards, in this thesis called final products. All these decisions are related, and the results of the distinct decisions heavily interact with each other. Harvesting can be mentioned with its clear effects on both business profit and environment.

Furthermore crosscutting (merchandizing) both in the forest and on a processing yard has a micro-economic component, in a way that the efficiency of this process influences the added value for the company. However merchandizing-efficiency also partly determines the strategic inventory status of the raw material wood.

In a system with a complex network of relations, and interacting decisions, many interests, both with macro (e.g. environmental) and micro (e.g. business) importance meet.

It turns out that (commercial) companies, both private and owned by government, need tools and systems to control the decision-sequence in order to convert their business interests into money, a typical micro oriented goal. Furthermore to assure longtime profitability, which clearly has equally directed parts with more macro oriented goals they need tools that enable them to analyse the behaviour, of both the ecological ,and technical parts of the production system, as a result of various policy scenarios.

Concluding it can be stated that a need exists for advanced decision support systems that help decision makers to improve the quality of their decisions. These decision have both commercial, business directed, and more macro-economic, for instance environmental, aspects.

1.2. GOAL OF THIS RESEARCH

In this research the conversion from raw material (stems) to semi-products (roundwood assortments) and final-products (boards) is regarded. Main emphasis will be laid on the conversion on a so-called centralized conversion site. The basic technology for these conversion sites is not new. In this research the conversion from stems into assortments, and the sawing from assortments into boards will be considered integrally. Moreover this thesis will deal with the integral optimization of the logistics as they come with centralized processing.

The integral approach of production planing and control can be considered as the result of new insights.

When starting this research it was self evidently not clear what methods and techniques we had to use in order to solve all kinds of problems as they arise during the decision-sequence from tree to boards. However what we did know was what the targets of this research should be.

A range of tools should be developed, a coherent set of decision support functions, that enable the decision maker to improve and evaluate his decisions.

From now on we will call this whole set of inter-related functions a decision support system (DSS). A more formal introduction of the concept of DSS will be made in chapter four.

The DSS to be developed should have a logical structure, that links up with the process to be supported, the management process of the logistics from raw material via semi-products to final-products.

This management process can be looked upon as consisting of three, interconnected shells.

The outer shell can be thought of as formed by the strategic planning. At this level of management the creation of capacity in terms of facility design for the business is considered. The DSS should be able to support the process of evaluating investment policies, new layout configurations and many other long-term policy making aspects. Most important will be the effectiveness.

The tactical planning forms the next shell to be considered. At this level the main purpose of the management process can be regarded as optimizing the usage of the capacity created at the outer shell, the so-called aggregated capacity planning. The DSS must be able to optimize and support the evaluation of different medium term production plans. Aspects as efficiency, added value and turnover must be taken into account.

As the kernel of the management process functions the operational planning. Our DSS should be able to support the process of optimizing the various production phases, such as merchandizing, sawing, sorting etc.

In other words it can be stated that the main goal of this research is to develop and build a blueprint of a DSS that can serve as a decision aid on all three levels of management. This decision support system (DSS) should enable the policy makers to carefully balance long-term, medium-term, and short-term aspects using wood as a raw material for conversion.

The emphasis of this research will be laid on the industrial part of the total system, associated with the conversion of stems into roundwood assortments and boards.

1.3. METHODOLOGY

The first phase of this research was studying previous scientific work. Then the first attempts were made to model the centralized conversion sites. A blueprint for a DSS was designed.

However this DSS will be primarily developed with the purpose to build a prototype for future systems that can function in a practical situation. In order to obtain this applicability the DSS has to be developed in a setting of frequent contact and relationship with possible future users of the systems.

Therefore contact with the relevant line of business was considered as a necessity for a successful project.

Particularly in the Federal Republic of Germany, Sweden and the USA, researchers in forestry and the woodprocessing-industry use techniques out of the operations research. Therefore scientific contacts with these countries are usefull, and were thus realized.

During our project there were intensive contacts with researchers and managers specially in the southern part of the Federal Republic of Germany. These contacts have helped us to direct the research towards a practical use.

The next phase of this research was the implementation of the system IDEAS (Integral Decision Effect Analysis System) on a computer system. After testing and validating the system, a case study was performed. Again the contacts with managers turned out to be useful.

1.4. OUTLINE OF THE THESIS

This thesis has been written based on a philosophy of stepwise refinement. New terms, principles, models, and algorithms are introduced step by step on a more and more advanced level during the thesis.

Moreover, different types of readers should be enabled to find their own way throughout this writing. As a result the thesis has the following structure.

This thesis consists of three parts. In part one various concepts of processing trees to boards are discusssed. This part of the thesis demands no typical skills from the reader. Part one contains chapters two and three.

In the second part new models and algorithms are introduced, all within the framework of DSS. Some sections, especially chapter five and six, ask insight in mathematical techniques and methods. Chapters four to seven form the second part.

The third part describes possibilities of a DSS for centralised processing by means of a case study, and can be of interest for all readers. The third part contains chapters seven to nine.

Let us now take a short look at the contents of the various chapters forming this text.

Chapter two : Centralized processing

In chapter two the basic concepts of centralized processing are introduced. After an introduction in which the definitions are given of typical forestry conceptions, the relevant wood-processing steps are explained in the second paragraph.

The relations between centralized processing and vertical integration are made clear. In this chapter concepts of the system theory are used.

Chapter three : Integral logistics

Isolated optimization of parts of the decision sequence will lead to a suboptimum situation with respect to the system as a whole. Therefore the concept of integral logistics is introduced in chapter three.

Moreover the concept of a decomposition of the management function into three interconnected shells is further explained in this chapter. A first introduction of a preferable system is given.

At this point all processing related concepts necessary for this research are introduced more or less. The second part of this writing contains solution methods, models, algorithms and aspects of implementation, all explained within the theory of DSS.

Chapter four : Decision support systems

Chapter 4 gives an introduction to DSS as a concept. The three main components of a DSS in general, being the database, the modelbase, and the user interface are discussed. This chapter is considered essential for readers interested in chapters five and six. More management oriented readers, interested purely in the potential impact for practise of this research, can skip this chapter at first reading.

The components, modelbase, database and user interface, in a DSS are further elucidated and explained with respect to the system IDEAS. IDEAS stands for Integral Decision Effect Analysis System. All functions are described implementation independently, in other words conceptually. One is guided through this chapter by the shells of the management process as described in chapter three.

Chapter five : The modelbase

Because in this project much emphasis has been layed on model development, a whole chapter, chapter five, is devoted to the modelbase. In chapter five techniques as dynamic programming (DP) are used for optimizing the process of merchandizing (crosscutting) a tree into logs. DP is also used for the conversion of an assortment into boards, a process called sawing.

Goal programming (GP) is used in this chapter to construct a multi-period, multi-item production plan. The relations between sawing strategies, DP and GP are discussed in depth.

The described models are extended by means of a column generating procedure, a well-known procedure in the field of linear programming. This procedure constructs new crosscutting and sawing patterns based on adjusted product values as a result of interpretation of the dual problem. This chapter is rather technical in depth. Therefore we suggest that readers with little mathematical background, or interested readers that are more management oriented skip this chapter when first reading this writing.

Chapter six : IDEAS, technically

As mentioned before the result of this project had to be a prototype for a DSS. For this reason we had to tackle many problems of information theory nature.

In chapter seven technical requirements and solutions are described from a more computer science point of view. This chapter can be of great interest for the technically interested reader, and is of less importance for the conceptually oriented reader.

Chapter seven : Analysis, using IDEAS

A DSS would have no value at all if it could not be used for all a whole set of problems varying from an operational, via a tactical, to a strategic nature.

Hence this thesis contains a chapter devoted to possibilities for analysis using the developed system. Chapter eight will deal with investment analysis, marketing policy, and personnel policy.

Chapter eight : Case study

Chapter eight is entirely dedicated towards a case study. In this study possible practical meanings of the support system are regarded.

Chapter nine : Conclusions, further research

Of course there is still research to be done. This research will merely be of a practically orientated nature. Suggestions for improvements, increasing accuracy and applicability will be regarded in this chapter. Figure 1.1. illustrates the outline of this writing, and can be used as a readers aid.

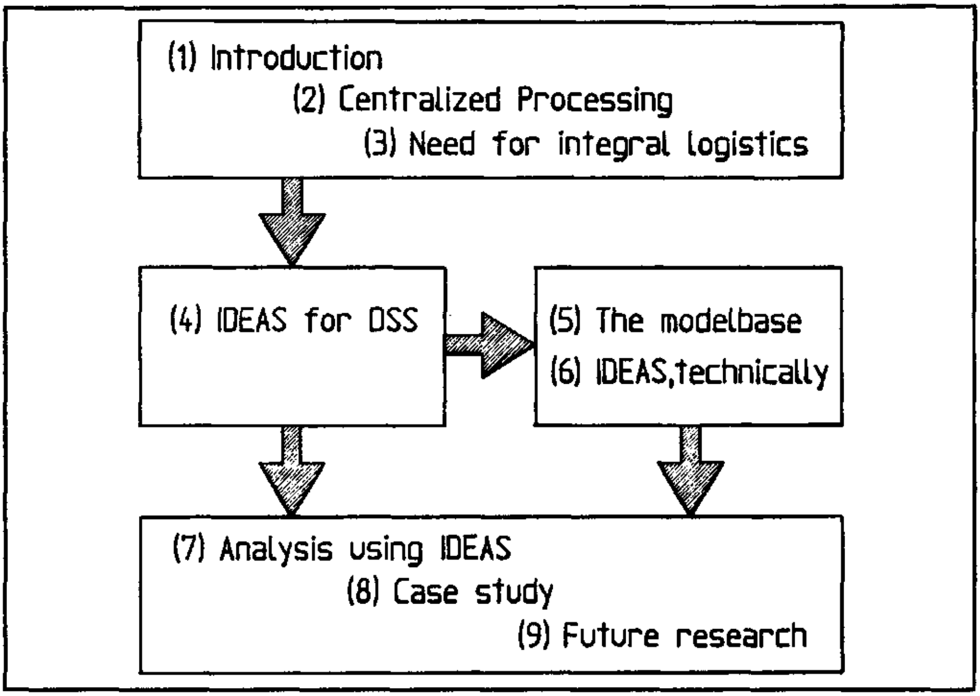


Figure 1.1. Structure of the thesis.

Chapter 2

CENTRALIZED PROCESSING

As all disciplines forest engineering and woodprocessing industries use their own jargon. In the introduction of this chapter the reader will be informed about terms and conceptions used in these fields of research and the line of business regarded. Moreover an overview will be given of developments in harvesting and processing systems.

The second paragraph describes all processing steps and the corresponding decision sequence for the conversion of trees into final products.

The third section deals with the relationship between centralized processing and vertical integration, two conceptions with a strong relationship. This research is not limited to conversion sites, centralized both with respect to place and time. In fact, activities performed on different locations, interconnected by means of information exchange, can be optimized integrally.

Processing centres are regarded as systems. Hence the parts of a processing centre, the system components, will be discussed in the fourth paragraph. Functional design will be emphasized.

All functions are carried out by physical components, a relation that is shown in paragraph five.

2.1. INTRODUCTION

In general the following steps can be considered when discussing the process from forest to forest products. Roughly there is a harvesting part, a processing part (consisting of two main steps) and a distribution part. Figure 2.1. displays these three functions.

Although in every harvesting and processing system these functions have to be carried out in order to produce products that can be sold, there are many possibilities in performing the operations in practice. It can be stated that there are

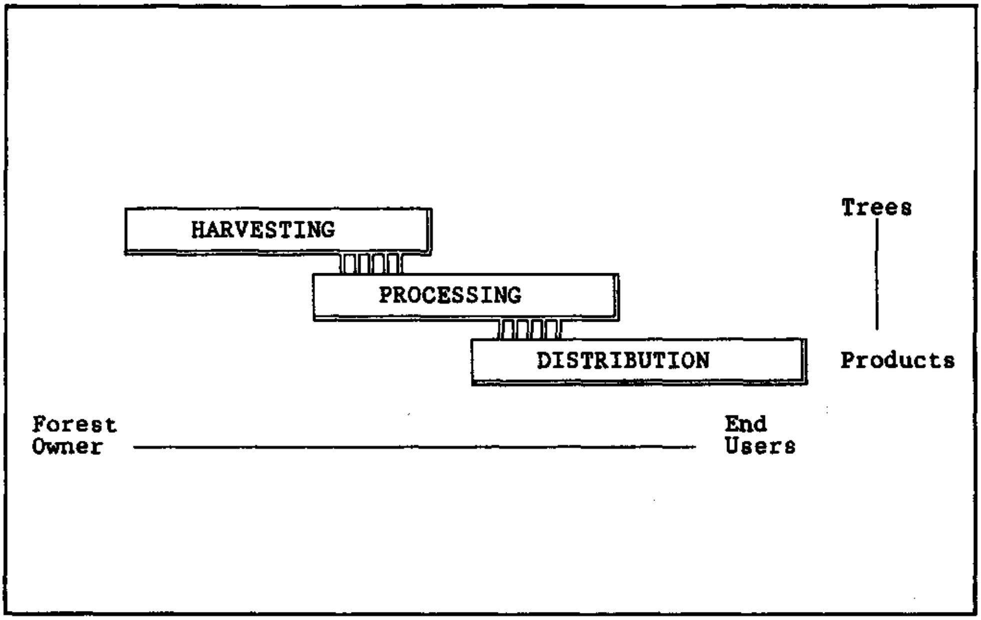


Figure 2.1. The three main functions.

certain advantages for centralized processing on so called central conversion sites (CCS).

Before discussing CCS, a brief overview will be given in order to position the CCS in the whole set of possible harvesting and processing systems.

In traditional systems (in this section we mean the system of harvesting and processing) most of the activities were performed in the forest.

Harvesting, i.e. felling, delimbing, debarking and skidding to the forest road were for the most part carried out manually in the forest (Bol, Tromp 1967). After these actions the stems (timber) were measured and bucked (sawn into logs) at the forest road. This part can be called the processing part. The parts of the tree resulting from the bucking, called assortments, where then loaded on a truck and distributed to the users.

The described organization is called a tree-length system, because the delimbed stems are skidded to the forest road. If the trees are sawn to assortments at the stump, and then transported to the forest road, the system is called a short-wood system. The users of the assortments can be sawing mills, paper mills, mines etc. The process of felling, delimbing, debarking and bucking, in relation with the relevant systems is illustrated in table 2.1.

Table 2.1. The systems in relation with the activities to be performed (+ = takes place, - = takes not place, CCS = central conversion site).

	System	
Activity	*Shortwood*	*Treelength*
Felling	+	+
Delimbing (at stump)	+	+
Skidding (to forest road)	-	+
Crosscutting (at stump)	+	-
Forwarding (to forest road)	+	-
Transportation (to CCS)	-	-, +
Crosscutting (at forest road)	-	+,-
Transportation (forest to user)	+	+,-
Crosscutting (at CCS)	-	-, +
Transportation (CCS to user)	-	-, +

The systems, shortwood and tree-length with crosscutting at the forest road, have some serious drawbacks (Bol, Tromp 1968). These minuses are from both organizational as ergonomic nature.

Because of the relationships between operational cost on one hand, and terrain conditions, weather, treetypes and shapes, roadnetworks, and many other influencing factors on the other hand, scheduling the operations is a large problem (Grammel, 1979).

Moreover, forest labour is very heavy work and from an ergonomic point of view it would be better if forest operations could be simplified and lightened.

In addition, special sylvicultural aspects and the non-productional functions of the forest, such as recreation and protection ask for shorter, and less intensive periods of disturbance of the ecosystem forest (Grammel, 1984).

All these reasons can be considered as key factors driving towards a system of harvesting and processing (tree-length with crosscutting at the CCS), which is displayed in figure 2.2. This system can be called centralized processing and is performed mainly on central conversion sites (CCS).

In this writing emphasis will be layed on tree-length systems.

A result of working at CCS is the effect of labour concentration (Platzer, Wippermann, 1970). Planning and automation are thus far more easy to implement compared to the traditional short-wood system, and the tree-length system, with crosscutting at the forest road.

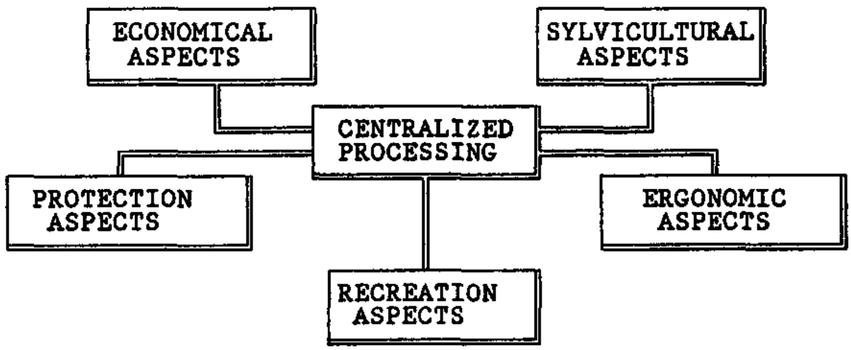


Figure 2.2. Key factors driving towards centralized processing.

For the purpose of this research the definition of CCS will be extended. After the conversion of stems into assortments, the latter are further processed into boards. These boards will be called final products, the assortments are called semi products.

As a result of this widening of the term CCS, centralized processing is defined as the conversion of a tree into assortments, sawn wood, and material such as chips, carried out under integral control. In most cases this will mean a concentration at a central plant, yet this concentration with respect to location is not an absolute necessity for reaching integral control (see pp. 11,13).

This means that the number of actions to be carried out in the forest is reduced to felling and partial delimbing for transportation. On the processing site of the industry, partial delimbing, debarking, crosscutting (merchandizing) and conversion to sawn timber (lumber) is done. For the traditional CCS a market for valuable roundwood assortments is a necessity. As a result of the extended definition introduced in thesis, this market can be bypassed if necessary. Of course both definitions require typical stem properties, with respect to shape and quality. What can be the benefits of centralized processing on a CCS?

Harvesting and handling cost.

As a result of reducing the number of actions to be taken in the forest, the harvesting and handling cost in the forest are reduced to a minimum. Many of the scheduling and organizational problems are shifted from the forest to the CCS. The disturbance time in the forest is thus reduced. The intensity of the disturbance also needs to be mentioned. Various authors state however that tree-length systems, whether related or not to centralized processing cause more damage to the remaining trees. Hence, additional care for damagecontrolled harvesting is needed, in particular for tree-length skidding.

Economy of scale.

The processing centres process high volumes and hence a high return on investments, necessary for efficient production equipment, can be gained.

Improved value recovery.

The bucking operator as well as the sawing operator are able to make decisions with far less uncertainty than working in the forest, because of the use of partly computerized decision support systems. As a result of this development higher recovery and service rates can be obtained. The use of automization, and optimization of the control is a new aspect of the conversion of trees.

Better tree utilization.

A processing centre can also convert non-grade material, i.e. chips. This is more difficult when dealing with systems performing the conversion steps in the forest.

Centralized wood processing can be considered as a way of organizing a business column, with its own typical characteristics. The different actions to be taken to process a tree into sawn timber are functionally arranged.

Note that we have not discussed the matter of ownership yet, nor have we made assumptions about the location for the conversion. Because the design of the chain of production is rather independent on ownership of the business units that carry out the production stages, the next paragraph will give an explanation of the various stages to distinguish when dealing with centralized processing.

2.2. THE DECISION SEQUENCE

A distinction can be made between the following tree conversion and handling steps, when dealing with centralized processing.

Harvesting.

Harvesting can be carried out in many ways by many techniques. The choice of a specific technique depends on economic, technical and ecological factors. What trees to harvest, from a specific area in a certain period of time strongly depends on the result of a trade-off to be made between short time and long time effects of a typical policy (Duffner, 1980).

Flexibility and as a result a high service rate may result in high turnover at short notice. On the other hand a company also needs long time raw material assurance, in other words continuity. Hence operational actions must be consistent with strategic goals (Barros, Weintraub, 1982).

Conversion for transportation.

After felling, the branches and the tree-top are removed from the trunk. This action can be done in the forest. As a result of this action, combined with off the road transportation, a transportable stem is obtained at the forest road.

All decisions concerning optimal tree processing can be made more or less integral on the processing centre, because the number of degrees of freedom is maximal (Duffner, 1983; Christensen, 1986).

Transportation.

Further transportation of the stems can be performed in various ways. Dependent on local infrastructure, transport by truck, railroad, and by water can be mentioned.

The choice of a transportation system is made after evaluating the topographical conditions, the volumes to be transported, and the available infrastructure (Fronius, 1982). The evaluation leading to a choice for a typical system is beyond the scope of this research.

Storage and handling.

Storage of raw material, on the CCS, is from our point of view a very important phase in the total chain of production. The organization of the storage yard, and the adherence to a specific technical system have great impact on both efficiency and effectiveness of the further production process (Fronius, 1982).

High-volume, small-log conversion on one hand, and low-volume, large-log conversion at the other, ask for different organised storage yards and different systems of material handling. Techniques to put a functional design into practice are summarized by Williston (1981).

Delimbing, debarking, crosscutting (merchandizing), and sorting.

During this stage the stem is converted into logs (assortments), top-end, stump-end, and waste material. The stem is firstly measured and checked for decayed spots. This function can be performed by manpower or fully automated.

The very great importance of the conversion of a tree into roundwood assortments should be emphasized, for once produced assortments are only limited applicable. In other words the crosscutting step (merchandizing) sets the framework for the sawing phase. Due to its importance, many research has been done to optimize this production step. Without being complete on this subject Duffner (1973), Glueck and Koch (1973), Faaland and Briggs (1984), and Naesberg (1985) can be mentioned.

Besides this research with a mathematical background, also training support tools have been developed, merely based on graphical software (Lembersky, Chi, 1984).

Distribution.

By distribution is meant the tranportation of assortments, boards, and waste material from the CCS to the customers. Although one must realize that physical distribution is very well suited for optimization, it will not be a major subject of interest in this research.

2.3. VERTICAL INTEGRATION

So far centralized processing has been discussed as a result of various driving forces. Emphasis was laid on the fact that only an organisational structure was regarded. However, in practice the matter of ownership is also important. Why can CCS be discussed without regarding ownership? To answer this question, let us first look at the impact of ownership on managing the conversion process.

2.3.1. OWNERSHIP AND ORGANIZATION

In the business column, a set of tasks has to be carried out in order to meet a demand for forest products. These tasks can be considered as more or less distinct phases in the chain of production. For every single task the effficiency and effectiveness depends on each preceding phase.

Every production step can be taken care of by distinct companies. Or a cluster of steps, for instance harvesting and transportation, can be executed by a typical company while further processing is carried out by another firm.

A form of organization can be co-operative companies, with their own harvesting policies, but with joint-ventures taking care of the industrial processing of the wood. In fact it can be stated that a whole spectrum exists consisting of all types of combinations of ownership and collaboration. The matter of ownership for a specific situation depends on available know how, harvesting volumes, economic situation and thus availability of capital, and many more factors.

One of the possible ownership scenarios can be that of a single company covering many functions of the chain. An enterprise like that will be called vertically integrated. Vertical integration can be defined as the combination under a single ownership, of two or more stages of production or distribution, or a combination of the two (Buzzell, 1983).

It is clear that a tree-length system as discussed before is extremely well suited for use by a vertically integrated company. The vertically integrated company is also able to structure the planning and control function resulting in an integral logistics policy. This subject will be considered in chapter three.

Roughly two basic forms of vertical integration can be distinguished, namely forward and backward integration. Let us explain these two forms, starting with backwards integration.

Company management is often confronted with so-called "make or buy" questions concerning products, components, materials and services. Backward integration can be considered as an alternative in favour of the first choice, make

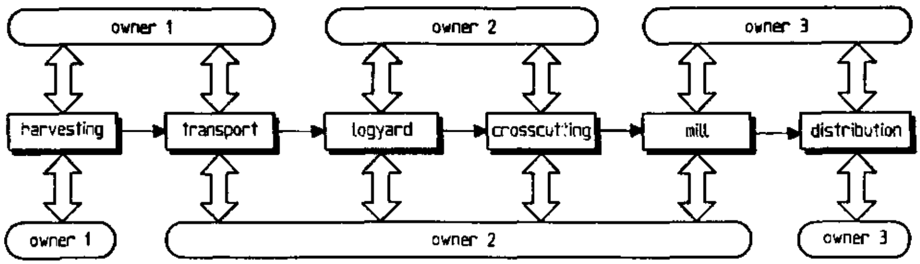


Figure 2.3. Ownership and the chain of production. Owner 1 is forward integrated, when comparing the lower structure with the upper structure.

instead of buy. In wood processing industry this could mean a transportation company becoming forest owner, or a papermill getting ownership of a conversion site.

In a more or less similar way forward integration can be seen as an answer to the "use or sell" trade-off. In a situation where a processing firm becomes owner of a distribution system one can speak of forward integration. The same is true when the firm decides to a further processing of logs instead of selling them to a mill working under different ownership. Figure 2.3. visualises the aspects production stages and ownership.

In this figure the chain of production is represented by the bars in the centre, the lower and upper bars represent two examples of distinct forms of ownership.

2.3.2. PLUSSES AND MINUSES OF VERTICAL INTEGRATION

In the previous sections the concepts of CCS and vertical integration have been introduced. In this section both positive and negative aspects will be regarded.

Several analyses have been made, and it turns out that besides many pluses (Christensen, 1986), the strategy of tree-length systems combined with vertical integration has some serious drawbacks (Duffner, 1980; Buzzell, 1983). Let us first discuss the advantages of CCS combined with vertical integration.

Reduction of transaction costs

Buying and selling cost are dramatically reduced as a result of vertical integration. In a situation of a company selling all its sawlogs on a free market, it needs market resarch, promotion, and sales support for this specific product-market combination. Of course this problem is partly shifted to the final products division, however when integrating towards end-users the effects of increased added value may out balance the cost of further processing and selling the final products.

Supply assurance

CCS are faced with huge investments for processing and handling equipment. Shortages of raw material can lead to low usage of very expensive facilities. Eventually this can damage the continuity of an enterprise. Vertical integration can be an answer on these problems in terms of supply assurance. This benefit of vertical integration has a direct negative counterpart which will be dealt with later.

Improved coordination

Vertical integration may permit cost reductions through improved scheduling and controlling of both production and inventory. Integral control can be applied well in a vertically integrated enterprise (Monhemius, 1985). Optimization techniques, such as operational research tools, can be fully exploited (Duffner, 1983). The company is able to exploit the possible synergy among the various business units. This review would not be complete without mentioning other constructions of organisation and ownership like co-makership. This last example represents a whole set of constructions aiming to combine advantages of both integral planning and control on one hand, and independency and specialisation on the other.

Technological capabilities.

Because vertically integrated firms by definition participate in many production and distribution activities in which improvements can be made, they are best equipped to innovate (Buzzell, 1983).

The combination of centralized processing and vertical integration has also a number of drawbacks. The most important are mentioned here.

Capital requirements

Because of high volume production, expensive investments can be made in high productivity equipment. However, the investment intensity may step across the productivity increase. The investments in automation are especially very high (Wippermann, 1985).

Unbalanced througput

Every production stage in vertically linked functions has its own optimum scale of operation. This might lead to unbalanced throughput. In forest operations one is dependent on all kinds of ecological factors. A result of adapting to these conditions can have a negative influence on sawmill performance. For example, the mill operates optimally when making large series without change over. However, because of sylvicultural continuity different diameter and length classes are supplied from the forest.

Reduced flexibility

In our case vertical integration means commitment to the centralized processing strategy and its technology of high capital demanding stationary equipment. It is because of practical problems often difficult to up-grade the system, resulting in decreased flexibility. Innovation will be very important to overcome these problems (Christensen, 1986; Wippermann, 1985).

Loss of specialisation

The distinct stages of production and distribution may require different managerial skills, that might be lost as a result of vertical integration (Buzzell, 1983; Duffner, 1980). The forest management may lose, or not develop, its selling skills and the saw-mill its purchasing skills.

2.4. CCS AS A SYSTEM

In the description of CCS concepts of system theory (in 't Veld, 1975) will be used.

In analysing processing centres as production systems a blackbox approach will be used, in a way that during the course of this section we will descend to lower levels of abstraction and aggregation. Consecutively the blackboxes will be examined further, partly by discussing previous research.

2.4.1. THREE MAIN SYSTEM COMPONENTS

At a high level of aggregation the first entities to be distinguised coincide with the main logistical functions.

1) Input: Purchasing, harvesting and transportation.
2) Production: Raw material handling and conversion from tree to boards on CCS.
3) Output: Physical distribution.

The input providing function, is performed by the system entity, the subsystem, concerning the purchasing , harvesting and handling of the raw material, trees. The suppliers will partially consist of company owned forest divisions, as a result of vertical integration, and partially of firms operating on the raw material market. This split function of the entity can be a result of tapered vertical integration (Harrigan, 1984). With purchasing a whole set of activities is meant containing harvesting, buying, requirement planning, and transportation to the CCS.

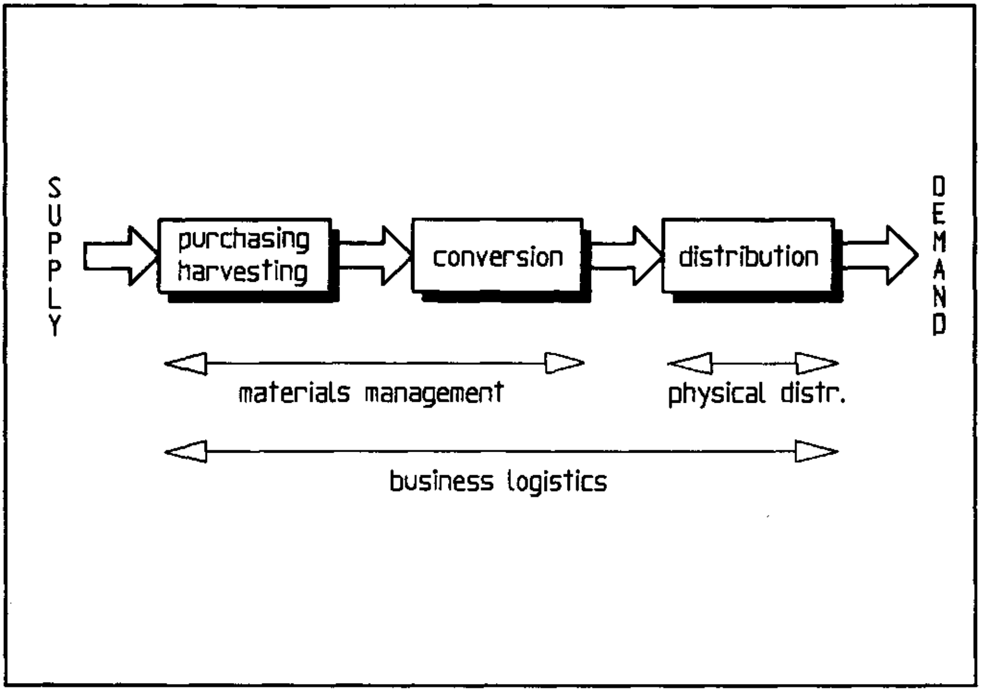


Figure 2.4. The logistical system.

The production unit is regarded as a combination of handling and conversion activities. Receiving, inspection, storage and handling are examples of the first aspects of this entity, called handling. The second aspect is the transformation process from trees, possibly via assortments, to boards, the final products, a process called conversion.

The physical distribution unit includes the process of providing customer service. It requires the performance of order acceptance, and relate these orders with the available inventory of final products and semi products (logs). The transportation of finished products is part of the distribution function. The physical distribution function will not be considered explicitly further during this thesis. Figure 2.4 displays the distinct functions.

2.4.2. INPUT SUPPORT

Wood processing companies (WPC) can both buy trees and logs or obtain them from their own forests. When getting the trees from the company owned forests the WPC is confronted with many problems of planning and controlling nature.

To produce lumber and minor-products with great flexibility to the market demand, the WPC wants the right trees, at the right time, at the CCS. Moreover this process has to be carried out at minimum possible cost. If the market for final products asks for heavy lumber, the CCS will need heavy dimensioned raw material (logs and stems). On the other hand when only small boards are asked for, the crosscutting and sawing of large trees would be a destruction of capital.

Hence it is of great importance to schedule harvesting and thinning activities in a way that optimally satisfies the CCS needs for raw material in order to produce logs and lumber. Optimal forest management would imply an instantaneous delivery of trees that fits exactly to the current demand for final products (lumber) and logs (assortments).

This however is a rather oversimplified approach. First of all the harvesting must be placed within a strategic framework. If harvesting was performed with flexibility, and as a result short time profits, as a single goal, continuity of the company could become uncertain. The raw material resources would be exploited without realising that todays young trees are tomorrows capital base.

One should realise that the supply of raw material is of absolute key importance for the business column as a whole, and thus continuity has to brought into balance with short term management. Of course management has to have enough room for manoeuvre within this framework.

A second point of attention should be the set of ecological factors. These ecological factors reduce the possibilities for planning the sylvicultural measures.

Some timber areas might only exploited without damage to soil and standing trees in certain seasons (Barros, Weintraub, 1982), this will of course influence the scheduling possibilities for forest operations. Another sylvicultural factor is the relationship between management of timber lands and development of trees. Harvesting and planting has an obvious impact on future growth, but also thinning has its influence in a way that it accelerates the diameter growth.

To overcome problems and difficulties as considered in this section various researchers have been working on these fields.

A detailed, sylvicultural approach is given by Broadie and Kao (1979). Their system, based on dynamic programming, can be used to analyse the cost and management regime for alternative thinning and harvesting techniques in various terrains. The main advantage of their approach is the possibility of the model for simultaneous analysis of various sylvicultural techniques and their interactions.

Some research has been done to optimize the forest management in relationship with processing plants, such as paper and lumber mills. Barros and Weintraub (1982) developed a system, supporting the planning of a vertically integrated WPC. The model captures several characteristics of the industry, such as quality of the logs, access problems due to terrain conditions, and market conditions. The underlying model is based on linear programming (LP). Restrictions as the area availability, timber production, timber requirements, and budgetary limitations were taken into account.

Road building, plant expansion, and land acquisition can be called operations from a strategic nature. These actions are characterized by their typical long term effects on WPC and environment. To support decision makers involved with planning strategic activities, Weintraub (1986) developed a system based om aggregated data and models. The approximations carried out in the process of aggregation where validated by the fact that strategic investment decisions basically depend on aggregated variables, rather than on detailed variables.

2.4.3. PRODUCTION

This logistical function covers a set of sub-functions. When opening the black box, representing production at the CCS, two new boxes occur. One of them representing the materials handling, the other containing the conversion from tree to boards.

The first box, raw materials handling, consists of three new boxes, the raw material storage yard, the handling facilities and the employees.

The conversion unit, represented in the second box, contains a debarker, a metal detector, measurement equipment, merchandizer, assortment storage yard, sawmill, a final products storage yard, employees, and a controlling system. Figure 2.5 displays the blackbox approach.

It will be clear that the components as described here differ in level of aggregation and abstraction. For example the sawmill is in fact a complete plant, but considered here as an entity on the same level as a debarker. A discussion of relevant research is presented later in more detailed sections of chapter three.

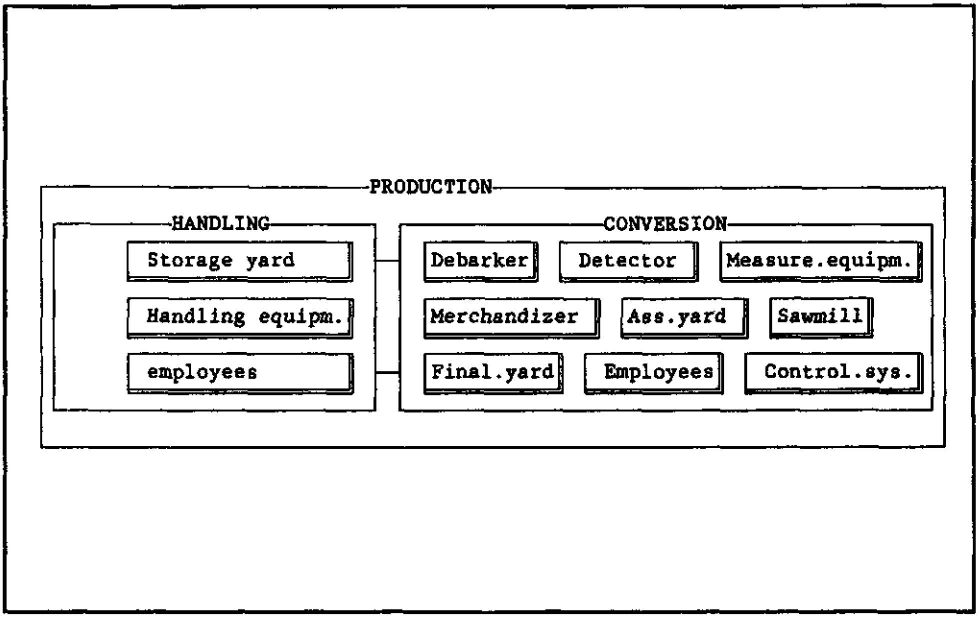


Figure 2.5. The black box approach.

2.5. SITE LAYOUT

In the preceding sections the CCS as a system has been discussed. The concept of vertical integration has also been introduced. In our opinion the models (optimization models) and systems (decision support tools) developed during our research, and discussed in the following chapters, can be relevant for far more situations then just for a CCS performing in a situation of vertical integration.

The concepts introduced will be workable in any situation where from an organisational point of view a coherence exists between the distinct production stages. Integration with respect to ownership, and concentration with respect to location is not an urgent necessity.

Therefore, from now on the concept of vertical integration will not be dealt with explicitly anymore. Although integral control is not limited to concentration with respect to location, the basic ideas of a CCS will run through the thesis like a thread.

During the course of this research a standard plant layout configuration will be used. This configuration reflects the system boundaries as they will be used during the next chapters.

The purchasing and harvesting will not be dealt with explicitly. The physical distribution is not considered relevant for the research and therefore skipped. Summarizing it can be stated that emphasis will be put on the production part of the logistical chain, with attention both for raw material handling and conversion aspects of the processing of trees into assortments (semi products) and boards (final products). The resulting CCS layout is displayed in figure 2.6.

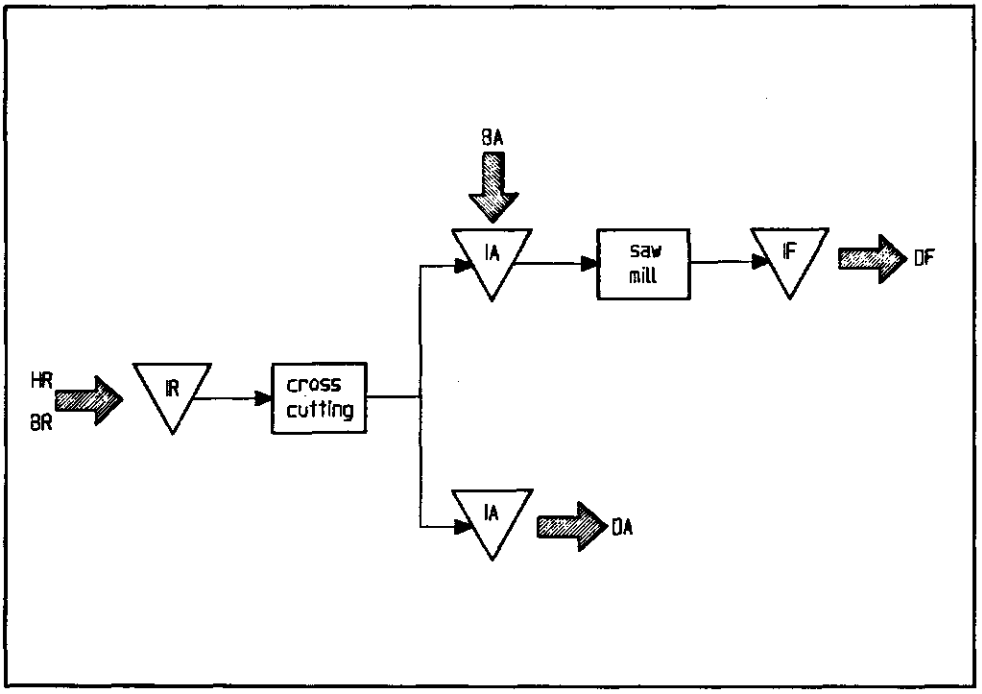


Figure 2.6. CCS standard layout configuration. HR = Harvested raw material, BR = Bought Raw material, IR = Inventory Raw material, BA = Bought Assortments, IA = Inventory Assortments, IF = Inventory Final products, DA = Demand Assortments, DF = Demand Final products.

Chapter 3

INTEGRAL LOGISTICS

A CCS has been described as a system. To attain specific, predefined, goals, the system needs controlling.

Roughly two different approaches can be regarded discussing the planning and controlling function. All components can be managed seperately; each functioning optimumly with respect to its local specifications and environment. Another approach can be the result of making a corporate plan, and stimulating the components to function within an overall framework. This framework should assure corporate optimality, and provide enough slack, provide enough room, for the components to react flexibly to local impulses.

This chapter starts with an overview of the research done on the two main components of the production function, namely the handling and the conversion steps. The latter will be split up in a) merchandizing, from tree to assortments (semi products), and b) sawing, from assortments to boards (final products.

After an introduction to decomposing the management process into three different levels of aggregation, the chapter will end with a discussion of the benefits of integral production management.

3.1. FROM TREES TO BOARDS

Trees, or in fact stems as they are topped and delimbed, are processed to boards in a number of conversion steps. In addition the handling of the stems on the raw material yard is of great importance.

3.1.1. INVENTORY CONTROL AND MATERIALS HANDLING

WPC seem to have a tendency to grow more end-user oriented. The handling of raw material has a very strong relationship with this issue.

The yard can be organised and equipped in many ways. Let us firstly consider the extremes of this whole spectrum of possible configurations. The first extreme to consider is the one representing a situation of no handling equipment placed at the yard. After regarding this situation the other extreme representing huge investments in handling facilities will be looked at.

No investments

When no investments were made in handling machinery, nor in logistical controlling facilities, all stems are delivered at the yard and stored without grading or sizing.

A direct result of this policy is a great pile of unsorted raw material. This means that site management has no insight into the number of stems of various types and size on the plant. Self evidently they also do not have an idea of the production potential, stocked up in these stems.

Indirectly this situation leads to inflexibility of the plant in responding to market demand for semi products (assortments) and final products (boards). Why inflexibility? Because operations management cannot pick specific trees, that fit best to demand for typical products, unless high operational cost are made. The latter is clear when thinking of a pile of stems, from which one specific stem has to be found. This requires expensively handling. Thus the picking of specific raw material is not likely to occur.

Hence the personnel controlling the merchandizer (the bucking operator) saws a stem into assortments (bucking, or crosscutting) without reference to the dimensions and quality of the next one. The bucking equipment faces thus different dimensions all the time. This situation leads to a log distribution, a frequency of assortments, that does not fit the demand pattern. A way to buffer the above problems, called results of uncertainty in raw material input for the merchandizer, can be investing in more flexible machinery. In doing this however the investment problems are passed down to a next phase in the chain of production.

High investments

The second extreme to consider is a situation in which investments in handling machinery have been made. Suppose a very advanced system exists for sizing and grading, in a way that all stems are classified and stored individually, before any conversion step has been made.
When coupling the merchandizer with this sorting system, the bucking operator can

be aware of all raw material types and dimensions available on the yard. Moreover management is able to have insight in the amount of capital hold in inventory. But of course a price has to be paid. This type of sorting requires enormous investments.

The result of these investments is the possibility to pick typical stems, that satisfy, after processing, the demand for semi products and final products best as physically possible. Hence the wanted product distribution can be reached as close as possible. Furthermore one can make clusters of raw material that give minimal change-over cost downstream in the logistical system. Thus, downstream a tendency towards less flexible, and as a result less capital intensive, equipment is possible by investing in raw materials handling machinery.

Trade off

Concluding it can be stated that plant management faces a trade off between low fixed cost, but high operational cost as a result of uncertainty on one hand. On the other hand cost of investments, but decreased uncertainty, and thus decreased operational cost can be placed.

Handling equipment, and sometimes space, is expensive, what will be the return on investment? How important really is flexibility in raw materials handling?

It is rather obvious that the problem of investment levels in the fitting-out of storage yards is suited for application of optimization techniques. With help of operations research tools, the organization and machinery of a storage yard can be optimized, with respect to both fixed and operational cost, and bearing in mind that production of goods should be customer oriented.

3.1.2. Merchandizing (crosscutting)

The first conversion step in the processing of stems into boards is that of crosscutting the stem into assortments (logs). The logs function as semi manufactured products. Because both the market, for example the paper industries, and the sawmill, an internal demand for saw logs, ask for assortments, the WPC faces a desired log distribution.

To obtain this distribution as close as possible the plant has two major instruments. Firstly crosscutting the stems into logs, and secondly buying logs on the semi manufactured article market. Unless there exists a real shortage on this market, the only limits imposed on buying logs are of budgetary nature. Therefore our attention for the moment is primarily focused on crosscutting.

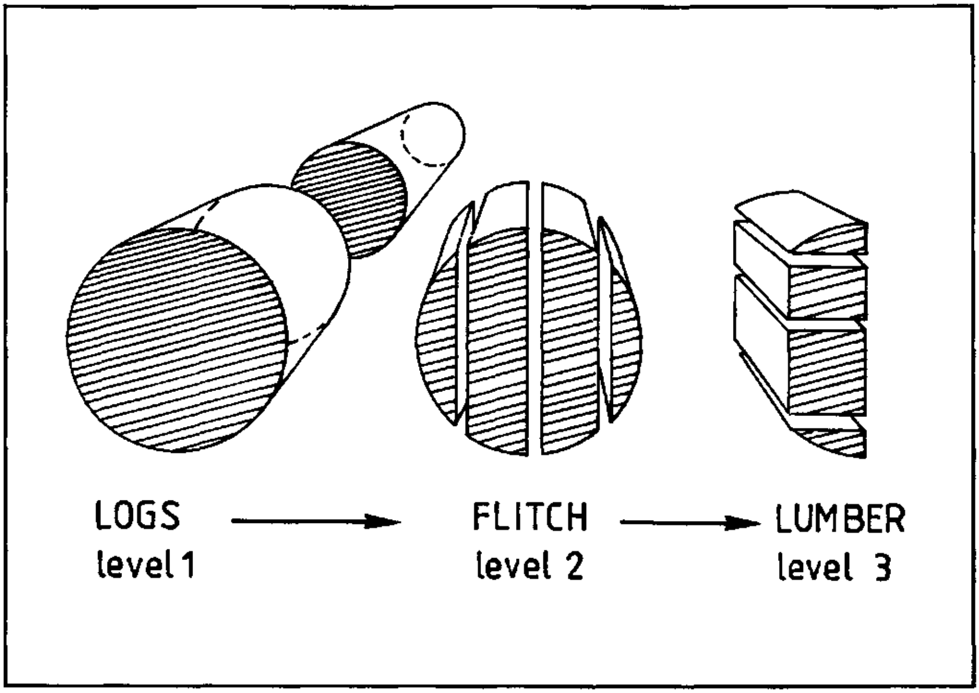


Figure 3.1. Logs, flitches and lumber, the three subsequent product stages.

Optimization

Crosscutting optimization is the problem of converting a stem into logs, the latter characterised by dimension and price, in a way that the total stem value is maximised. The stem value is defined as the sum of the log values produced out of this stem. The problem can be stated as choosing the most profitable combination of log lengths, diameters, and qualities, out of many alternative solutions. Figure 3.1. displays the relationship between logs, flitches and lumber.

On-line application

When all data describing a stem are available, and an off-line application would be considered, the optimal cutting pattern could be obtained by means of checking all possible patterns and chosing the optimum solution (complete enumeration).

However in practice productivity must be high, and due to the on-line application, the time for measuring a stem and making decisions is short. Therefore decisions have to be made very fast in order to be useful in an on-line application.

Stem defects

Another problem is caused by the presence of quality differences and defects in the stem. Crook, sweep, knots and rot influence the cutting patterns. Sweep and crook for example, impose limits on the possibilities of producing saw logs out of a stem.

Machinery

The quality of the machinery and controlling systems used at the merchandizer also play an important role. In a situation with inaccurate measuring and cutting tools, the extra effort made for optimizing the cutting patterns might lose its economical justification.

In this thesis only a brief overview of resarch done in this field of application is given, because thorough discussions have been supplied by various authors (Faaland, briggs, 1984; Bare, Briggs, 1984; Naesberg, 1985; Eng, Daellenbach, 1985).

Models

Models dealing with the merchandizing problem, also called marking for bucking problem, can be classified roughly into two classes. The first class of models is based on dynamic programming (DP). A technique described by Bellmann (1957). The second class of models is based on linear programming, also a well known instrument out of the operations research toolbox (Dantzig, 1948).

Both techniques have pluses and minuses. A main advantage of the use of DP is in the fact that no commitment has to be made to a commercial software package. DP can be put into an algorithm by developing relatively straight forward software. This means however that every application is in fact dedicated to a specific situation.

In models, based on dynamic programming two distinct movements can be described.

Firstly various authors choose for a one to one correspondence between decision stages and system states. This means that the decision, possible at various preset places on the stem, is defined as the length to cut off, and the state of the system is defined as the length of the stem already processed. Examples of this approach can be found in the work of Pnevmaticos (1972), Geerts (1979), and Naesberg (1985).

Other researchers use distinct definitions. Instead of fixed intervals and thus preset possible cutting positions, they use the number of cuts as decision stages. These can be positioned, by definition, on all possible distances from the stump-end. The

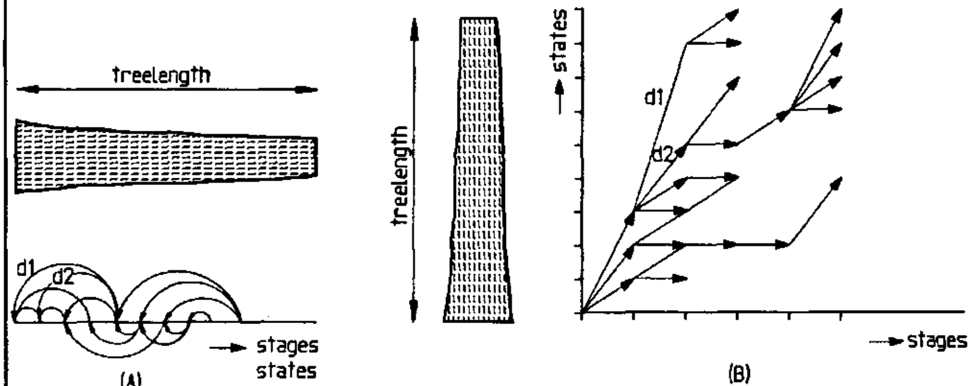


Figure 3.2. Two types of decision networks.

one to one correspondence between state and stage is now lost. Every decision stage can correspond to a number of states. For a state is defined as the stem-length allready processed, but this can be achieved by many decision sequences. Examples are the work of Strand (1968, indirect access via Naesberg, 1985), Glueck and Koch (1973).

The two possible decision networks are pictured in figure 3.2. For a more detailed description the interested reader is advised to study the works of the mentioned authors.

A different approach is given by Forster and Callahan (1968), and by Bare and Briggs (1979). They use linear programming for the solution of the crosscutting problem. An advantage of this method is the fact that margins for the amount of logs to be produced can be implemented rather easily. Yet the solution times are relatively long, and a linear programming package is needed for this on-line control.

In our research the problem of finding margins for the amount of logs is solved on a higher level of aggregation. The problem of finding optimal crosscutting patterns is dealt with by means of Dynamic Programming.

3.1.3. SAWING

Sawing is the process of converting a log (assortment) into lumber. Lumber can be boards, planks and laths, all of various sizes. Optimization is, for the purpose of this introduction, stated as searching for a breakdown pattern to convert a log into boards, in a way that the value of the log is maximised. The value of the log is defined as the sum of the values of the boards produced out of it.

Board dimensions defined, and sawing equipment used, depends on local conditions and historical developments. For example Europe and The USA differ in both applied machinery and the number of different board-sizes used.

In this research however optimization techniques and methods will be emphasized rather then technical aspects of lumber production.

The production of lumber out of logs, by means of sawing, is influenced by a number of factors. These factors are partly of a technical nature, such as productline design and the equipment used for production, and partly biologically determined, such as log dimensions and quality.

Logshapes

An important class of factors is formed by the logshapes. Lumber consists of straight pieces, rectangular in cross section and length. Lucidly, the bending of a tree out of its axis, called sweep, will decrease the lumber recovery compared to logs that more closely approximate cylinders or truncated cones. Also the gradual decline in diameter with increasing height in the tree, called taper, highly influences lumber recovery (Williston, 1981; Fronius, 1982).

Taking into account these aspects of log shape it is obvious that, in order to maximize lumber recovery, log geometry must be known. To bring this into practise all kinds of optical electronic devices have been developed (Williston, 1981; Fronius, 1982).

The logshape has also an indirect effect. It can augment the effects of feedwork on sawing efficiency. There is a relationship between the way a log is handled and transported through the processing system and the gross lumber recovery obtained. When designing a new mill one can handle this problem in terms of machinery design.

Machinery

Another factor of importance is the sawing equipment. When wood was a less scarce commodity, saws with widely spaced teeth became popular because they perform sawing with high feed speeds. These type of saws however result in products with very rough torn surfaces.

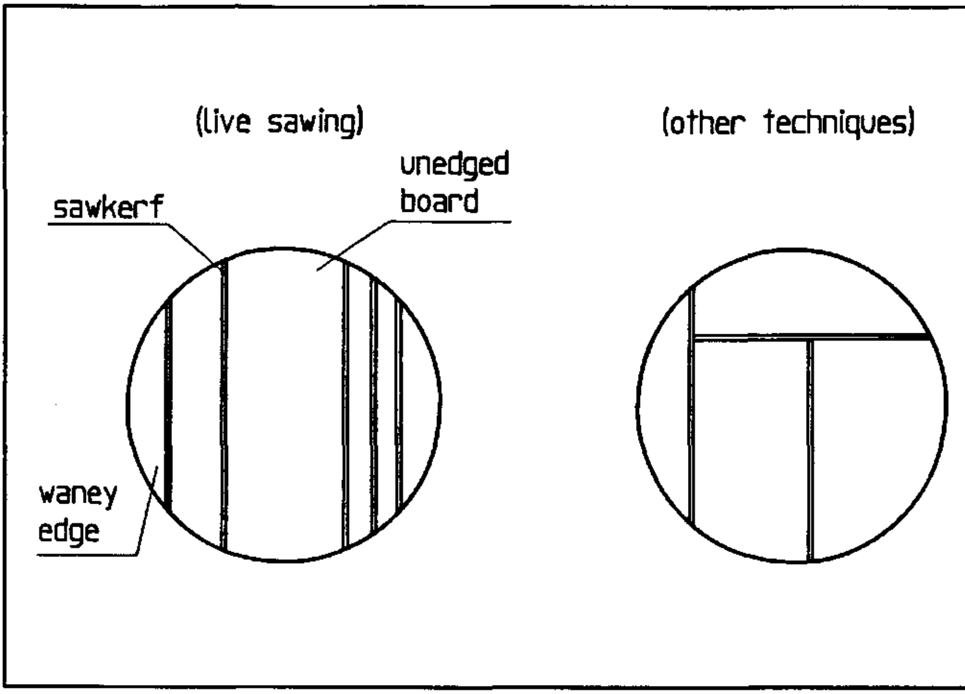


Figure 3.3. Concepts and terms of lumberproduction.

Nowadays situation is somewhat different. Large logs do not occur as frequently as they used to, and small logs lumber recovery is strongly affected by accuracy and smooth sawing (Williston, 1981). When using closer tooth spacing one must realize that horse power requirements increase.

Depending on the choice for specific equipment a number of sawing techniques can be used. In this research live sawing and cant sawing will be mentioned. Live sawing can be mostly performed with a headrig, cant sawing consists of a primary and secondary breakdown, and can be performed by several types of equipment. Figure 3.3. displays some terms of lumber production.

Cant sawing can be considered as the best when yield maximization is the objective (Hallock, Lewis, 1976). For a detailed description see Williston (1981).

Existing models

The process of breaking down an assortment into lumber is complex. Optimizing the sawing pattern of a log (assortment), using lumber of various dimensions, can be considered as a geometrical problem. In mathematical terms the problem can be stated as a two dimensional cutting stock problem (Gilmore, Gomory, 1969). However if lumber of lengths shorter than the log length are produced, for example if a full tree-length is optimized in one step, then the problem is of three dimensions.

The methods discussed here are based on dynamic programming. Faaland and Briggs (1984) worked on the problem of lumber production optimization. Although the production of logs out of stems was integrated with the conversion of logs into lumber, only the latter aspect will be dealt with in this section.

Faaland and Briggs (1984) used a routine to calculate the greatest value of boards sawn from the largest cylinder inscribed within a saw log. They assume circular cross sections, and a two dimensional tree profile measured by an electronic scanner. A system to handle different grades is implemented.

The authors of that work introduce a new algoritm to overcome the problem of inscribing the largest cylinder in a cone. The approach is restricted to live sawing, which simplifies the problem considerably. When live sawing is applied, the headrig, in their case with fixed inter-saw distances, makes a series of parallel cuts through the length of the log, resulting in two side-slabs and unedged boards. The resulting composite boards (unedged boards) must be ripped into single boards.

A code was written in FORTRAN for a VAX-11/780 computer. Two test problems are included. The authors of the article indicate that further reasearch is needed to optimize other sawing techniques, like cant sawing.

The model presented by Geerts (1984) is not limited to live sawing. His model is from a two stage guillotine cutting type. In the first stage all cuts go from one edge of the log to the opposite edge, and for the resulting flitches (mother boards) in the second stage the same is true with respect to these flitches.

The first level of the algorithm consists of a one dimensional dynamic programming algorithm that is used to break the log into flitches of various sizes. The value of the log has to be maximized, the width of the flitches the decisions to be made. The breakdown of the flitches into lumber with the value of the flitch optimized by means of optimal cutting of lumber products forms the second level of optimization. A comparable algorithm was proposed by Bösch (1987).

The algorithm deals with sawkerf, defect core, taper and different grades. The model is more broadly applicable then the one proposed by Faaland and Briggs (1984), but is has some serious drawbacks. Because of computational problems the waney edge is dealt with heuristically, and therefore not optimally. This is not decribed in the article (Geerts, 1984) however. The potential of the second model (Geerts, 1984; Bösch, 1987) is greater than that of the first model. Because of non optimal software, resulting in extremely long computer times, the model developed by Geerts (1984) is at this moment not applicable in real time, on-line, situations. The model of Bösch only determines symmetrical patterns. Of course they need not be optimal.

3.1.4. SALES

In this research sales will be a minor subject of interest. Wood processing companies (WPC) can have many different forms of organisation with respect to the sales unit. The function of this unit is interrelated with the production strategy imposed on the conversion phases. Whether the plant produces final product orientated, or more value recovery orientated, influences the sales unit.

The sales department is confronted with a characteristic demand pattern. Demand for specific products is often related to the demand for other products. For instance in the construction business the distinct products are often asked for in a predetermined rate. As a result package deals are quite normal in this line of business.

On the other hand, typical products can be replaced by others with some slightly different specifications. Therefore sometimes demand classes are defined.

In this thesis marketing, forecasting and other functions of the sales division will not be discussed explicitly. The aspects of this function, and the influence from the market will be considered integrated in the discussions of the other logistical functions in various sections.

3.2. MANAGEMENT

In this section, the management of the CCS will be the subject of interest.
Managerial activities can be aggregated into a group, and considered as one activity among various others. Other actvities in the total industrial undertaking can be of technical nature, commercial, financial, security, and accounting activities (Hussey, 1974).

Besides management there are many more important activities, however management is considered of great importance because it effects many other business aspects. The impact of management is great because the corporate goals are set by management (Garret, Silver, 1973).

The functions of management can be summarized (Garret, Silver, 1973) as:

1) Planning, involves the generation and identification of alternative courses of action and the selection of an optimum course from these alternatives.

2) Organizing, the structure of a company, and continuously reviewing this structure, to be able to adapt it when more effective alternatives show up.

3) Assembling resources, that constitute the company's input. Personnel, material and capital facilities must be provided.

4) Directing, which means initiating actions that need to be performed to achieve goals.

5) Controlling, checking whether the preset targets have been realized.

Hierarchical planning

In the previous sections it has been stated that wood processing companies (WPC) face problems of various kinds. Some of the problems occur every day. An example of such a problem is the choice of a specific tree to convert into lumber of various sizes.

Another question might be that of what sawlogs and how many of them should be bought on the market for semi products. This could be a problem recurring every week.

Also the issue whether to hire or fire labour forces occurs with a certain frequency. For instance seasonal extra labour force is needed a couple of times a year.

Futhermore a WPC can be confronted with a changing, dynamic, environment. New product dimensions are asked for and the production capacity might be insufficient to meet this new demand. Hence, a decision has to be made whether to leave this new market for what it is, or meet it by means of investments in new production equipment and logistical organisation improvements.

Of course these few examples are oversimplified. But a tendency of growing complexity and increasing span of time can be observed. These effects are not restricted to our line of business. It has been notified as a general aspect of planning and decision making.

In order to keep the process of management, and therefore the planning function, clearly structured, and conveniently arranged, it is decomposed in roughly three decision echelons. These echelons are strongly interrelated (Switalski, 1987).

Figure 3.4. Decomposed management process.

Figure 3.4 displays the stratified management model.

The process in the kernel of this stratified management model is called the operational management. As a direct result it is responsible for the operational planning. This operational planning is sometimes called day to day planning, and the corresponding management layer the operations management.
The next shell is formed by the tactical management. Its planning function can be characterised by increasing complexity and more planning periods involved.

The outer shell, or layer, is known as strategic management. The strategic management is concerned with long term planning, and it largely determines the course of the company in a dynamic environment, and the responses to be made on impulses coming from this environment, in which almost every aspect is considered variable.
Of course these layers in a decomposed management situation should communicate in order to obtain a consistent policy. There are two information streams to be regarded, the importance of which depend on the style of management, and thus the business culture. These two information streams also coincide with two distinct approaches of researching the management process.

From the inside out, in other words from operations management to the board direction, a stream called bottom up can be marked off. The opposite stream, from strategic management to day to day management is called top down.

Let us now look closer at the three management levels, focusing at the planning aspects of management.

Strategic planning

This part of the planning process takes place at the highest level of the planning hierarchy (Anthony, 1965; Garret, Silver, 1973). At this level of management the goals are set (Hussey, 1974). The overall purposes and objectives are set as a broad group of managerial plans.

Once these goals have been set, guidelines are formulated that will govern actions in pursuit of these objectives. The guidelines are called policies. These policies are formulated with respect to financial,marketing, personnel and research aspects of the planning process (Anthony, 1965). Because of the nature of strategic planning most time long term plans are made.

When planning over a longer period of time, say five years, the uncertainty is high (Hax, Candea, 1984). When dealing with a great amount of uncertainty, planning in detail seems less relevant. Therefore plans on this level are mostly based upon aggregated data. Emphasis is laid on the effectiveness of the company, also in future environments. Some examples of stategic planning issues are: the introduction of new products, the investments in a new layout, the decision on further vertical integration, the target market share within five years. Hence, capacity needs to be created (Kampfraath, 1988).

Tactical planning

The next step in the planning hierarchy is formed by the tactical planning, or management control (Anthony, 1965). On this level appropriate courses of action have to be taken to achieve the organisational goals according to the company policy. The planning period for this planning echelon is shorter than on the previous level (Hax, Candea, 1984). As a result the information has a more detailed, less aggregated, character. Moreover the tactical plan is in more detail and more tangible.

At this planning level the, non variable, production layout should be managed as efficient and effectively as possible. To make this planning and management stage efficient itself, the sequential steps that must be taken to accomplish tasks are put into procedures.

Some examples are working capital planning, inventory policy, formulating decision rules for operational planning, medium-term production planning. Thus, the available capacity needs to be turned into account.

Operational planning

In the nucleus of the planning process the daily actions have to be coordinated. The information to be used in the planning process at this echelon can be based on detailed data, because of the short term aspect.

The planning period is short, and as a result the amount of uncertainty to deal with has been decreased (Garret, Silver, 1973). Main emphasis is on efficiency.

At this planing level rules are used to enforce the specific company policy. Operational planning aims to actually control the inventory levels, to schedule the production, and measure the productivity and efficiency. This planning philosophy will be used to explain models and their application in the next section.

3.3. INTEGRAL PRODUCTION MANAGEMENT

In this section firstly the wood processing company (WPC) will be classified, following a standard procedure (Menipaz, 1982). After this introduction the problems arising with separate optimization of each production phase will be regarded. Opposite to this seperate optimization, integral production management will be discussed.

3.3.1. TAXONOMY

Planning and controlling the commodity flow over the various production units is one of the most important tasks of materials management. A great deal of effort is often attended to the control of production and inventory levels. Most classical algoritms will not be suitable for the problems we are dealing with when controlling the inventories of stems, logs, and lumber. This statement will become clear when looking at the following characterization (Menipaz, 1982) of the system of interest, the WPC.

1) The demand for product i does effect the demand for product j. This interdependence exists because the products are sometimes complimentary. Moreover a demand for specific lumber (final products)dimensions creates an internal demand for assortments (semi products)

2) The demand for product i is aggregated out of many orders, and partly unkown. Many customers ask for various products. The company faces the aggregated demand as a claim on the production capacity.

3) There exist a great variety in products. Wood processing companies (WPC) produce assortments and lumber in all kinds of combinations of dimensions, quality, and accuracy of the dimensions.

4) The lead time for an order is unknown and variable. This is a result from the fact that the frequency with which a typical product is produced, is a function of the demand for all other products.

5) Inventory levels are considered to be reviewed continuously.

6) The planning horizon is in fact infinite, however tactical planning will be regarded as a finite, multi period problem.

Concluding it can be stated that WPC need multi product, multi period models and algorithms to support decisions involved with successfully performing their tasks.

3.3.2. SEPARATE OPTIMIZATION

In section 3.1. some models have been discussed concerning the conversion of a stem into boards. In this section the effects of using these models as an optimization aid for each conversion step will be discussed. When applying the models for controlling, a situation of local optimization will be the result. Figure 3.5 displays this situation.

In order to obtain a clear sight of the possible problems, two somewhat charged examples will be subject of discussion. After discussing these extremes, a start will be made with the development of a third logistic policy.

The first example will be that of a company laying accent on value recovery with respect to the raw material. The stems available on the central conversion site (CCS) push the production system to produce typical products, in order to obtain high efficiency with respect to the use of the raw material. A production policy like this will hence be called, in this context, a push strategy.

Combining these ideas with the conceptions introduced in section 3.2. the inference can be made that the long-term aspects, the more strategic vision, is

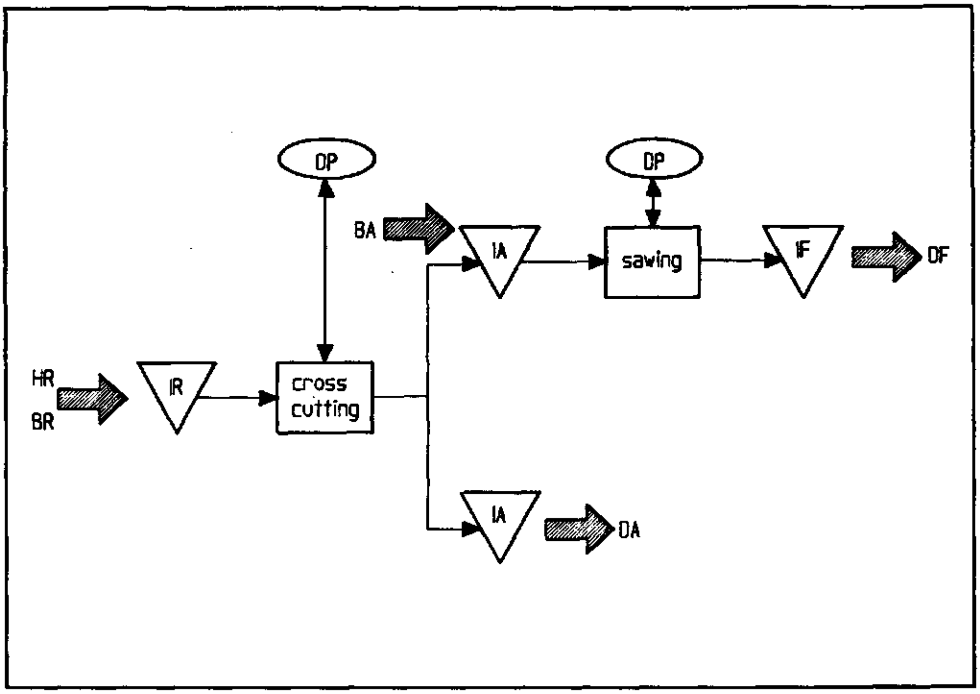


Figure 3.5. Local optimization.

overemphasized in this policy. The more short-term effects, like making profit, that should have been taken care of at the operational level, are made fully subsidiary to the higher levels of planning.

The second example is about a company that emphasizes the need to produce products that are asked for by the consumers. The demand from the markets for final products (boards) and semi products (assortments) pulls at the system to produce the goods that are being asked for. Therefore a wood processing company (WPC) with a purely market oriented production strategy will be denoted working in accordance to a pull strategy.

In this example, management is mainly interested in profit making. The strategic impact of a well-considered raw material usage is strongly underestimated in this policy.

Let us now consider the distinct policies in depth.

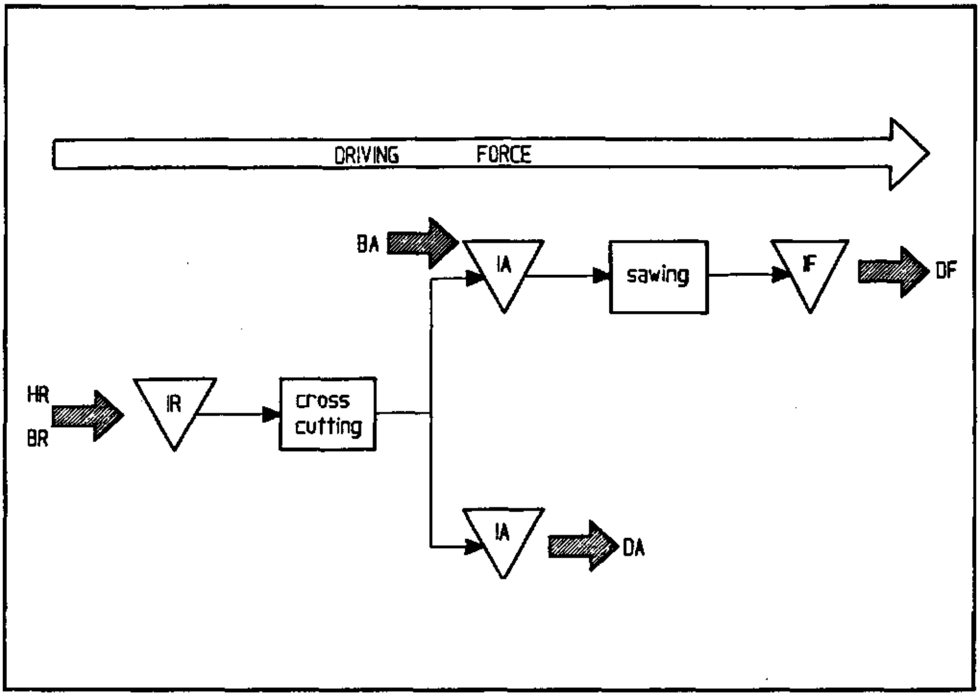


Figure 3.6. Push strategy.

a) Push strategy

The push strategy will be discussed moving from the input of raw material, towards selling of final products. Several problems will be tracked.

Harvesting

In a situation where trees are harvested with respect to purely ecological factors, a typical stem distribution will be the result. This specific distribution might have no relation at all with the demand patterns for both semi and final products. Thus a first tuning problem possibly arises. This problem among others is displayed in figure 3.6.

Sorting

A WPC, managed supply oriented, is not concerned with end user oriented production. As a result there is no need for sophisticated handling equipment, for sorting the stems (raw material). The only reason for investing in sorting machinery might be done to enable the conversion tools to make series, in order to lower the changeover cost. This adjustment however is not related to the market conditions.

The direct result of this management strategy is a typical log distribution that probably does not meet the market. Hence a second tuning problem arises.

Conversion

The distinct processing stages in the total chain of conversion can be optimized with the help of tools as discussed in section 3.1. After using a dynamic programming (DP) approach for optimization of the conversion of a shaft in logs, the result will be an inventory of assortments (semi products) as output from maximum value recovery directed conversion of trees. The log distribution has probably no relation with the demand for final products (boards). This can be regarded as a third tuning problem.

The process of breaking down logs into boards is not really optimized yet. However when applying the algoritms discussed in section 3.1.3. the emphasis again is laid on value recovery from log to boards. The resulting final products distribution may not meet the merket demand, and this will be the fourth tuning problem, which is directly related to the financial results of the company.

Concluding it can be stated that a company managed with a push strategy operates with high value recovery rates. However the directedness towards the market is low, in terms of responding at realized demand (Kamarkar, 1986), and hence the percentage of the orders that can be met will be relative low. This percentage can be called servicerate. Because of a low servicerate the amount of cash obtained from selling products, the turnover, will be low. A low turnover will threaten the financial basis of the company, and thus the continuity.

b) Pull strategy

Let us now consider the strategy with an opposite philosophy: the pull strategy. This policy is illustrated in figure 3.7. This strategy will be discussed starting at the demand side, moving towards the supply side of the system.

Conversion

The WPC is confronted with a market demand for both semi products (assortments) and final products (boards). The main object of the management is to

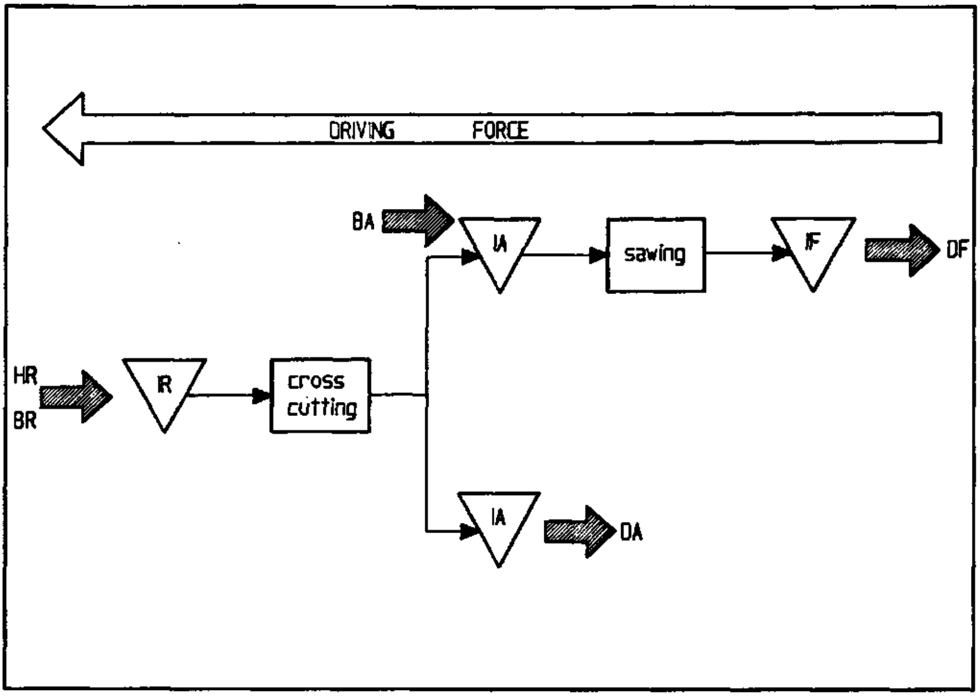


Figure 3.7. Pull strategy.

meet this demand, in other words to let the market pull the conversion process in the wanted direction.

The conversion of logs into boards will be controlled in a way that the desired final products are produced with a frequency high enough to meet the demand from the market. This can be achieved by using typical sawing patterns. However these sawing patterns may not be optimum with respect to the value recovery of the assortments. Hence a tuning problem occurs in the end of the chain.

Because of a demand for boards, an internal demand for assortments exists. To meet this demand, typical cross cutting (merchandizing) patterns are needed in order to obtain the log distribution asked for. The used patterns may not be optimum with respect to the maxium value recovery of the stem. As a result a second problem arises in tuning the conversion.

Handling

Stems are converted to final products. Preferably stems are selected that fit best for specific products. For example large trees for heavy lumber. To enable the picking of specific trees, investments made for grading and sorting machines have to be made. The choice for specific trees may cause however an unbalanced raw material inventory. Concluding it turns out that tuning problems may occur at the yard.

Harvesting

The final cause for possible low raw material recovery is the fact that in order to get a desired stem distribution the harvesting can be executed sub optimum with respect to sylvicultural aspects.

Concluding it can be stated that a company managed according to a pull strategy will probably perform badly with respect to raw material value recovery. The service rate will be high, which leads to a high turnover, and thus a relatively good financial result. However the raw material is taken care of poorly. From a strategic point of view it is of key importance that the raw material is used in a both effective and efficient way.

c) Integral logistical management

After looking at the two opposite logistial policies, two different ways of production and inventory management, it is clear that a need exists to combine the positive components of the two philosophies, a so-called hybrid system (Kamarkar, 1986). This can only be accomplished when evaluating the production system as a whole, taking into account the set of relations existing between the distinct conversion steps.

An approach using all these aspects, and taking into account the different layers of management, with their sometimes conflicting objectives, will be called an integral approach. The corresponding style of management will be called integral logistical management. A detailed discussion will be given in the next section.

3.3.3. INTEGRAL OPTIMIZATION

As an answer to the problems discussed in the previous sections, the concepts of integral logistics for a wood processing company (WPC) will be introduced.

Some researchers have been paying attention to the problems of an integral approach. In fact most of them focuse on sub problems, by means of taking into account only a subset of the possible variables (Glueck, Koch, 1973), or restricting themselves to heuristic approaches (Smith, Harrell, 1961), or neglect the multi period aspect of planning (Naesberg, 1985). Others conclude that an integral optimization is impossible (Bösch, 1987).

The goal of an integral logistical system is to balance both effectivity and efficiency, in a way that the production system functions optimally with respect to carefully determined targets. Hence to develop a system controlling concept that takes into account operational, tactical and strategic aspects. When formulating these goals, a decomposition increases the insight. When considering the aspects in accordance to a bottom up approach, this leads to the described blueprint for a system, supporting management in making decisions:

Operational level

Operational optimization of the conversion from a stem via assortments (semi products) into boards (final products). This part of the system is not concerned with the correctness of the given framework, its only objective should be optimizing its functioning within the given tasks.

This optimization must be equipped to accept information from the next level of aggregation, the tactical planning, and to pass back information to enable the tactical level to adjust the framework. Summarizing, the main goal for this level is doing the job best as possible.

Tactical level

Tactical optimization of the planning for a multiperiod, multiproduct production system, taking into account layout specifications, and a known and static environment is of interest at this level. In other words develop a production plan that determines what semi and final products have to be produced in what quantities, out of which types of raw material, for the various periods of time taken into account.

This plan should be constructed in a way that raw material is used optimally (efficiency), the impact of this claim balanced with a high servicerate (effectiveness), and that capacity is reserved to be able to anticipate on future orders. This tactical management system must be designed in a way that it can accept information from, and pass information to the strategic level. Also facilities must be built in to translate the tactical plan into operation by instructing the kernel of the system, the operational control, and to accept feedback information from the day to day planning and controlling layer.

Strategic

On this level, of more or less aggregated planning, effectiveness is emphasized. By means of simulating the effects of varous policy alternatives an optimal CCS configuration must be realized. This level is considered with the creation of capacity. Capacity is meant here in a broad sense. Personnel, equipment, logistic controlling strategy and corporate objectives are considered variable at this outer planning shell. Of course interfaces have to be designed to pass to, and accept information from the deeper nested planning levels.

A logistical management system, partly automated, with the variety of tasks as discussed above, cannot be developed and implemented in an arbitrary way. A systematic development and implementation according to typical rules is needed. The next chapter will deal with such a framework, called the decision support (DSS) approach. Before concerning the specific DSS needed for our line of business, the general concepts of DSS will firstly be discussed in the next chapter.

Chapter 4

DECISION SUPPORT SYSTEMS

The conception "decision support system" often causes confusion. What is a decision support system? What is it good for? The number of definitions of decision support systems (DSS) are almost as numerous as there are authors dealing with this subject.

In this chapter some workable definitions will be introduced. Whether these definitions fully answer the theoretical ideas behind a DSS is not considered of interest within the scope of this chapter.

After a short review of the concept in section 4.1., the various modules of a real-world DSS for wood processing industries (IDEAS) will be regarded in section 4.2. The basic modules will be discussed rather in depth in section 4.2.2. (the database), section 4.2.3. (the model base) and in section 4.2.4. (the user interface).

4.1. THE BUZZWORD DSS

In this section a "historical" overview will be given of systems that help decision-makers in improving the quality of their decisions. Historical is not exactly the right word because the systems that have been developed subsequently still function next to each other. The various systems have their own fields of application and all have different reasons for existing. Many researchers use as many different definitions. The complexity of the systems underlying these definitions is very diverse (Alloway, Umbaugh, 1986). As a definition for a DSS the following will be used (Sprague, Carlson, 1982; Sol, 1985) :

> *DSS are computer based systems helping decision makers to improve the quality of their decisions, by using data and models, for solving complex problems.*

4.1.1. OVERVIEW

Before discussing the functions and possibilities of a DSS, let us first regard the three main "phases" in systems supporting the decision making process (Reinders, 1988).

Electronic data processing.

Electronic dataprocessing (EDP) can be considered as the result of administrative automation. The increase of the efficiency of the dataprocessing task is the main purpose of the EDP system. EDP is directed towards the operational planning level. Much attention has been paid to develop efficient software, with short response times.

Due to the availability of high-quality low-cost computers, on-line applications, effective datacommunication technology in combination with intelligent work stations (decentralization of processing functions), many companies nowadays possess a well functioning EDP system.

Management information systems.

Instead of emphasizing the data-processing aspect (as in EDP) the information processing aspect is most important for management information systems (MIS) (Kanter, 1979). The aim of MIS is to improve the quality of information in terms of accuracy and timeliness. Collection, aggregation, retrieval and most of all presentation is of great importance.

Sometimes these systems have some primitive, or basic, tools for supporting the planning process itself. In these circumstances operations research techniques can be applicable.

Decision support systems.

DSS are equipped with interactive software and database systems. By using advanced information technology, in combination with operations research techniques, managers functioning on distinct levels in the organisation can be supported in making their decisions (De et al., 1985).

Emphasis is laid on improving the effectiveness (Keen, Morton, 1978) of the company, from a corporate point of view, and of the particular manager. It is considered as of importance to support decision-making on a strategic planning level, beside the tactical and operational level.

EDP , MIS and DSS have all their own functions in a company and exist next to each other (Klein, Hirschheim, 1985). There is a tendency to incorporate the distinct functions of all three systems in one large system, covering the production process from operational process-control via tactical production planing to the strategic planning. This is sometimes called computer integrated manufacturing (CIM) (Boaden, Dale, 1986). Of course the principles also be applied in non-manufacturing environments (i.e. routing).

4.1.2. DECISION MAKING WITH HELP OF A DSS

A company, or a part of a company, has a set of short-term and long-term goals. Furthermore planning procedures will exist to achieve these goals as close as possible. The result of the planning process, a (production) plan, is a set of rules and targets to achieve the goals. However such a plan is the result of a more or less continuous process of evaluating, interpreting and rejecting earlier plans and results.

The function of a DSS, as an implemented system, is to support this complex process. Emphasis is laid on the support of the decision making process instead of making the decisions. Quantitative techniques cannot subsitute the manager. His insight and experience however can be complemented with the power and precision , and hence high efficiency, of the algorithms (Anthonisse et al., 1988).

In a DSS, models play an important role. The models are often of a more or less mathematical nature. Operations research is an important science that provides many (mathematical) techniques and methods to build models. The models function as workable images of the real-world. In a model the decisions to be made are specified in terms of variables and relations between them.

Models can be of very different natures. On one hand simulation and spread-sheet models can be mentioned. These kind of models can be used to evaluate the choices of the decision maker. Several decisions may be tried before a satisfying response is given to tackle the problems. The main purpose of these models is to support what-if situations.

Moreover models can be used to generate decisions. Classical operations research techniques, such as linear programming, can be used to generate high quality decisions, among others like dynamic programming, queueing theory and many others.

When actually building a DSS for a specific environment, some design advises can be defined (Sprague, Carlson, 1982; Anthonisse et al., 1988):

1) Combine operations research models and methods with powerful data handling facilities.

2) Use tools that make the DSS user-friendly, such as interactive software, error prevention and graphics.

3) Design the system in such a way that changes in the planning environment can be accomodated.

These design goals lead to a number of functional requirements that will be discussed when considering the DSS named IDEAS, in the next section.

4.1.3. COMPONENTS OF A DSS

A user of a DSS is confronted with the system via the computer terminal. In fact the decision maker only faces the dialogue system by definition (figure 4.1). Let us look closer at the components of a DSS.

The user interface

The final user friendliness of a DSS is for a large part determined by the limitations of this component. When designing this component of the DSS a feedback is necessary with the users that have to work with the system. That part of the user interface in dialogue with the user is called the dialogue system, or dialogue management and generation software (DGMS).

The acceptance of the system in a company depends on the simplicity and consistency of the dialogue system. Therefore it is recommended to use logical function names, grahical representations, and when possible menu driven software. Of course one should realize that the hard- and software available partly determine the possibilities for implementing a dialogue system.

Moreover the user interface has more functions than the ones carried out by the dialogue system. Also contact with the database is considered as a function of the user interface. The sub-component of the user interface performing the translation of user commands into data handling activities is called the database management system (DBMS).

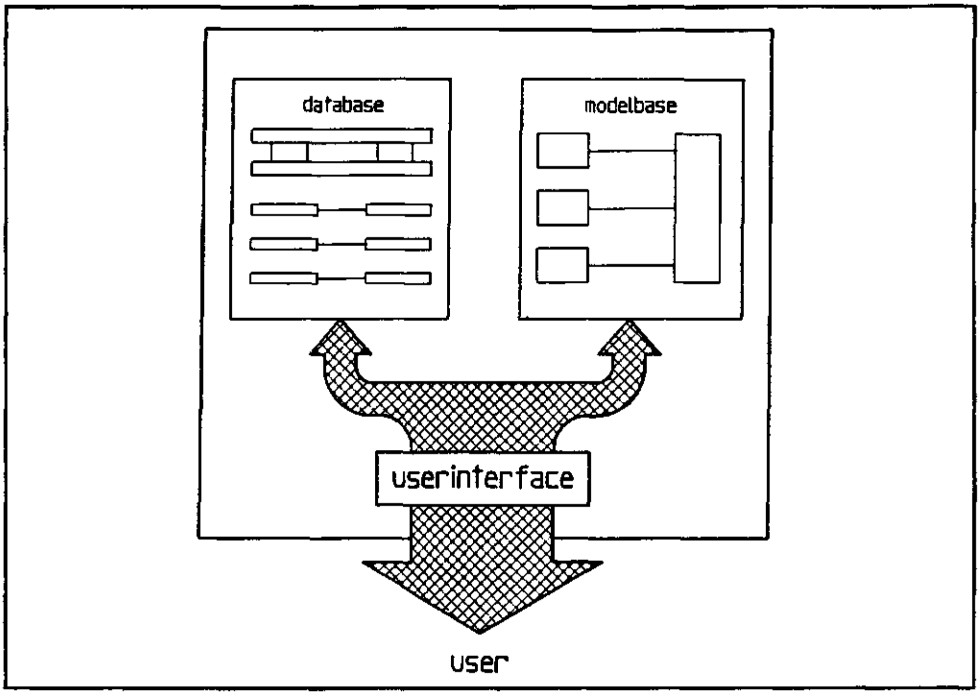


Figure 4.1. Components of a DSS.

Models and data interact with each other. This interaction is the result of a direct or indirect command or decision of the user. The part of the user interface performing the necessary activities is denoted the modelbase management system (MBMS).

The database

This part of the system is also of great importance for the functioning of the DSS. Its design imposes the limits and possibilities on the use of the total system. The design has two major counterparts. On one hand the data can be stored in many ways, using different techniques. On the other hand the possible operations allowed on the data in the database partly are a result of the design.

Management has to make decisions which have an impact on all levels of the organization. Therefore the data stored in the database must be accurate and of high quality. Some systems use a corporate database containing data concerning plant layout, financial parameters, logistical data, personnel data etc. For a specific problem environment a working database is formed as a subsystem of the corporate database.

In a database objects are described. Within the scope of this section it is not a necessity to know all about databases, yet a few key concepts are worth-while mentioning. In the following data objects will be discussed, as they are described by the datamodel.

For instance an employee can be a data object. This employee can be characterized by a number of data. These are called attributes. For instance name, age and function can be attributes of an employee. Johnson, 35, plant manager, are occurrences from these three attributes. The objects are described by means of a data model. The datamodel describes the technical storage rules (datastructure), the allowed operations on the data (valid operations), and the occurrences of the attributes that are considered valid (valid occurrences).

In chapter six these basic concepts will be used to give insight in the technical specifications of the DSS-prototype IDEAS.

The modelbase

The modelbase can be considered as a set of models describing the structure and the behaviour of the organization (or the relevant part of it). This model system will for instance partly consist of operations research models, and partly of knowledge rules.

Of course not all knowledge concerning the organistation and its behaviour can be structured in mathematical models. Therefore non mathematical heuristics and rules of thumb can be an important part of the modelbase.

The models implemented in the DSS should not be rigid. The models and the model handling facilities (MBMS) should be flexible in both controlling convenience and possible applications.

The decision maker should be able to model and remodel, structure and restructure, using different environments as a background for the organization or parts of it.

4.2. IDEAS BEHIND THE DSS IDEAS

After discussing the basic functions and components of a DSS in general, a start can be made to consider a real-life application of these concepts. As regarded in the first three chapters the design and prototyping of a DSS was the major subject of this thesis.

When building a DSS all kind of technical problems occur that have to be tackled. This section will not give an insight in these technical problems. Instead a conceptual view will be given how to build a DSS that can be used for central conversion sites, as an important part of a woodprocessing company. Hence the result of this section will be an understanding in the functional design of IDEAS (Integral Decision Effect Analysis).

4.2.1. IDEAS IN A NUTSHELL

When starting this research it was stated that IDEAS should be a DSS with a broad field of application. The system should be able to support decisions of diverse complexity. This range of complexity is a result of the hierarchical approach of the management process.

On a daily base problems occur in terms of production efficiency. These problems are of a complex nature because of the necessity to decide in a short period of time, a so-called on-line environment. On a tactical level, say a few weeks up to a few months, problems occur with respect to resource and capacity allocation. These problems are complex because of the many partly conflicting goals such as efficiency versus effectiveness. On the strategic level where for instance investment policies have to be evaluated, the dynamic environment can cause hard problems to solve.

Thus, a DSS with real-life potential has to deal successfully with a great variety of problems.

In this research the following approach was followed. Firstly an abstract overview of the conversion site and its relevant environment was made. This first model is in fact a list of characteristics and rules of behaviour, that are considered important to include in the final DSS.

Secondly an overview of important decisions was made. These decisions have an impact on the part of the system considered of importance, in the perspective of this research.

After executing these first two steps, a start can be made to model a centralized conversion site more formally in terms of mathematical relations structuring the decisions to be made, with the corresponding cost, and the behaviour of the system (the modelbase).

This step can be combined with an exact listing of the data necessary to build the models (the datamodel).

Now two of the basic modules of the system are available. To put the DSS into a workable system, a userinterface has to be build meeting all the claims described in section 4.1.

In the following sections the conceptual design of the three main modules of the system IDEAS will be discussed.

4.2.2. THE DATABASE

In the database the data objects are stored. For the purpose of this section a conceptual understanding of the database as a large chunk of memory is sufficient. In this memory the distinct data objects have their own place. The most important parts of the database will now be considered consectutively.

1) Plant layout.

A central conversion site (CCS) has a typical layout configuration. This configuration can be considered as a set of descriptors that describe the site. A CCS can be described as :

a) raw material both harvested and purchased.
b) raw material sorted in two piles .
c) semiproducts both sold and further processed .
d) non-integrated production process.

Of course more variables are used for a full characterization of the conversion site.

2) Machinery.

At the conversion site both saws for crosscutting and conversion to boards may be placed. The machinery can be described by a number of parameters :

a) Crosscutting speed	(cm/s)
b) Transportation speed (crossutting saw)	(cm/s)
c) Number of simultaneously made cuts (secondary saw)	(-)
d) Sawing speed (secondary saw)	(cm/s)

3) Personnel.

For controlling the machinery personnel are needed. The number of employees and the length of a dayshift influence the total cost of labour.

a) Number of employees (-)
b) Length of a dayshift (hours)

4) Raw material.

The raw material used by the company can be described by a number of representative stems (see chapter five). These stems can be characterized by a number of key descriptors :

a) Length of a stem (cm)
b) Diameter at 10 cm. from the stump-end. (mm)
c) Diameter at 10 cm. from the top-end. (mm)

Selfevidently a real stem has many more parameters for description (Glueck, Koch, 1973), however in this context these more accurate descriptions are not of great interest. For if an integral optimization can be obtained using these basic assumptions, also more real sub-models can be used (Reinders, Hendriks, 1989).

5) Semiproducts (assortments).

Semiproducts are not just stored as data objects. They are grouped into sets. A set consists of semiproducts that share some data in common. The most important is the steplength. All semiproducts in a (storage) set have a length that is an integer multiple of the steplength, defined for that specific set. Furthermore a maximum diameter and a minimum diameter is defined :

a) Assortment length (cm)
b) Maximum diameter at the top-end (mm)
c) Minimum diameter at the top-end (mm)

In a real-life situation also other characteristics (attributes) can be used such as quality. This aspect is not dealt with but can be implemented rather easily (Reinders, Hendriks, 1989). Moreover some overall data are defined :

a) Setname	(-)
b) Number of assortments in set	(-)
c) Steplength	(cm)

6) Final products (boards).

Like the assortments the boards are stored in sets. Besides the steplength along the axis, also a steplength at the circular cross-section is defined :

a) Boardlength	(cm)
b) Boardwidth	(mm)
c) Boardheight	(mm)

Furthermore some shared data are of interest :

a) Steplength along axis	(cm)
b) Steplength on circular cross-section	(mm)

7) Financial parameters.

To be able to distinguish between various decision alternatives, cost calculations must be possible. Therefore financial parameters are included in the datamodel. The most important are :

a) Variable cross-cutting machinery cost	(Dfl/hour)
b) Variable sawing machinery cost	(Dfl/hour)
c) Personnel cost for the crew	(Dfl/hour)
d) Overtime cost personnel	(Dfl/hour)
e) Storage cost for raw material	(Dfl/(m^3.week))
f) Storage cost for semi-products	(Dfl/(m^3.week))
g) Storage cost for final-products	(Dfl/(m^3.week))

8) Managerial parameters.

This set of parameters is a reflection of the managers insight into the production system and its behaviour.

a) Stockout cost for assortments	(Dfl/(m^3.week))
b) Stockout cost for boards	(Dfl/(m^3.week))
c) Number of week-equivalents safety stock	(weeks)

Although the above paramters look like cost they are in fact only controlling instruments for the manager. For if a typical demand can not be met, a penalty will result. This mechanism will be discussed in the next section and in chapter five.

9) Planning and scenario data.

To evaluate a company and its behaviour according to a specific policy an environment has to be created. The specific choice for an environment, containing the interactions between customers, suppliers and the conversionsite, will be called a scenario.

a) Demand for final-products every week	(1/week)
b) Demand for assortments every week	(1/week)
c) Supply of raw material every week	(1/week)
d) Initial inventory of stems when starting the planning	(1/week)
e) Initial inventory of assortments starting the planning	(1/week)
f) Initial inventory of boards when starting the planning	(1/week)
g) Planning horizon	(week)

10) Solutions.

After solving a typical problem, the solutions and answers must be evaluated. This is an important process, and it is carried out by means of (re)considering other solutions. Much data is stored, such as :

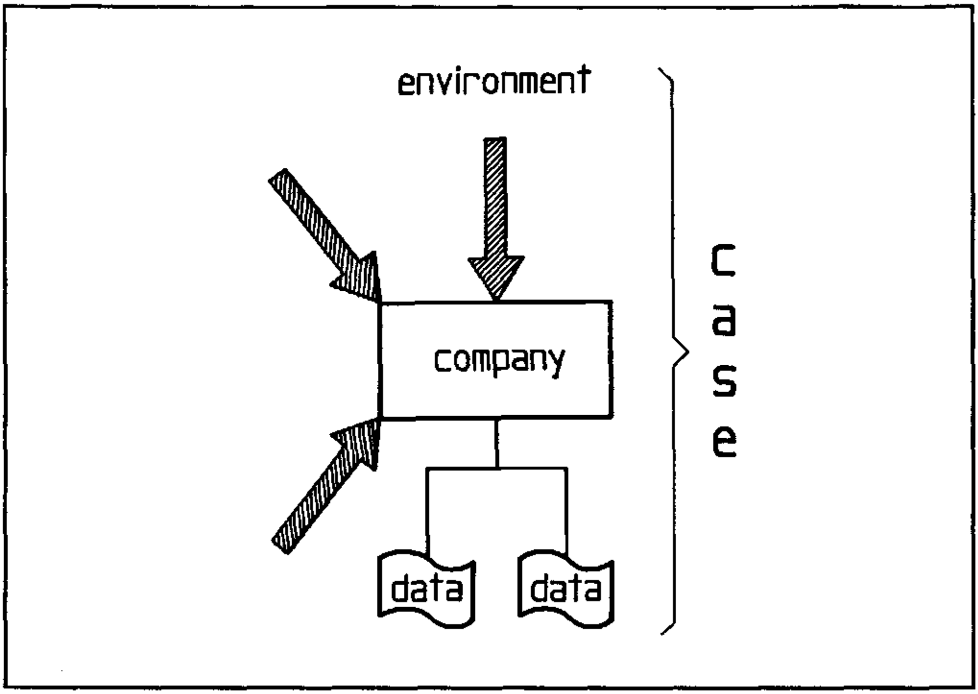


Figure 4.2. Datamodel concepts.

a) Production amounts
b) Financial results
c) Service rates
d) Used reaw material
e) Used assortments
f) Primary and secondary breakdown patterns
g) Machine usage

Of course many more parameters and descriptors can be discussed.

To get an insight in various policies, investment alternatives etc. all relevant planning and solution data must be stored.

With this part of the datamodel, describing what type of data have to be collected, a characterization of a plant (conversion site) and its environment can be made. Figure 4.2. displays the definitions of the various concepts.

The following summarizes the use of the database. A company is described by its (1)layout, (2)machinery and (3)employees. The company processes (4)raw material via (5)semi products to (6)final products. This conversion process has a (7)financial counterpart. The company faces the (9)market demand and is supplied with (9)raw material. The process is partly determined by the parameters representing the (8)managerial activities. The results of the planning activitities, the (10)solutions, are stored.

4.2.3. THE MODELBASE

In chapter three the need for integral logistics was discussed in relation with the decomposed management process. It was stated that three interacting shells of management can handle the planning and control problems at a CCS.

This planning process however can be improved with respect to its quality by means of a DSS. In this section the modelbase will be discussed. When performing a division of the management process, it is extremely important that information exchange between the various levels is possible (Mears, 1978).

This modelbase contains a set of operations research models that support the decision making on operational, tactical and strategic levels.

Operational support : crosscutting process

The first real conversion step in the production process from stem to boards is the crosscutting step. The debarking step is not considered as a individual conversion step (chapter three). The problem of crosscutting a stem into assortments can be stated as :

> Cut a stem into assortments in a way that the total value of the stem, defined as the sum of the values of the resulting assortments, is maximum. This process can be regarded as a one dimensional knapsack problem.
>
> Goal: value maximization.
>
> Input: stem dimensions, assortment dimensions and assortments prices.

> Output: crosscutting pattern, product frequencies.

Optimizing this breakdown process can be achieved by using a technique known as dynamic programming (Bellman, 1957; van Beek, Hendriks, 1986). In the underlying research a DP algorithm has been implemented on a VAX/8600 minicomputer. The corresponding software was written in FORTRAN-77. A discussion of the details of the algorithm and the software is given in chapter five, section 4.2.

Operational support : sawing process

The second conversion step in the production process can be described as the sawing process. This is sometimes called the secondary breakdown. The problem of cutting an assortment into boards of various sizes can be stated as :

> Cut an assortment into boards in a way that the total value of the assortment, being the sum of the values of the resulting boards, is maximum. This problem can be stated as a two dimensional knapsack problem, and it can be visualized as fitting rectangles in a circular cross section.
>
> Goal: value maximization.
>
> Input: assortment dimensions, board dimensions and board prices.
>
> Output: sawing pattern, board frequencies.

This secondary breakdown process can be optimized by using an algorithm based on dynamic programming. In this research the problem, which is two- dimensional, was tackled by applying two nested one-dimensional DP routines.

Much attention has been paid to speeding up the basic algorithm because of its future on-line application. For in a real-life situation decisions must be made very fast. The resulting software was implemented on a VAX/8600 minicomputer, all code was written in FORTRAN-77.

Tactical support : production planning models

The previous two operations research models, based on dynamic programming (DP), were fully directed towards value maximization. In other words how to cut a stem into assortments, and these assortments into boards in order to maximize the value. Yet it was stated in chapter two and three that a more complex problem has to be solved. Not just optimizing a stem, but a whole population, and this process repeated every week. The decisions to be made are very complex and extremely numerous. In the models, insights of various control systems have been applied (Aggarwal, 1985; Fox 1982). Hence the DSS functions as an advisor (Anthonisse et al., 1988), and the manager uses his experience and typical skills to evaluate and control the process of decision making.

To support the decisions to be made on a tactical level, for instance a production planning for four weeks, more advanced tools have to be developed. The problems that occur on the tactical level (in a simplified way) can be described as :

> How many assortments of what type out of which stems should be made and purchased. And how many boards of what types out of which assortments should be made, in what week during which days? This according to a number of goals. Hence, in a way that value recovery is maximum, service rate is maximium, production cost, inventory cost and cost of labour are minimum, and in a way that the company anticipates on future demand.
>
> Goal: Multiple goal, integral optimization.
>
> Input: crosscutting and sawing patterns, all relevant company and scenario data.
>
> Output: Multiperiod production plan.

It will be clear that to tackle the problems occuring when optimizing the production planning asks for advanced tools and techniques. To support the decision-making with respect to the multi-period production planning, a multiple goal programming model was developed.

The goals formulated in the objective fuction of this model are described in the peceding paragraph. The restrictions, the constraints, among which the limited capacity, the directedness towards the customers and the limited raw material availability, are all softened where necessary. For instance capacity constraints may not lead to a situation not having a feasible solution for the production planning problem. In practice a manager will employ an extra shift instead of just stopping the production process, if an "infeasibility" occurs. In a real-life situation the plant has to work, whether optimally or not. This typical property must have a counterpart in the models.

After the model was formulated, it was implemented on a VAX/8600 computer, using the software package SCICONIC/VM.

Tactical support : extending the models

The production planning model as described in the above, uses the crosscutting patterns and the sawing patterns to determine the rates at which the various assortments and boards are produced. This is important in order to determine the usage frequencies of these patterns.

Suppose for every stem-type only one crosscutting pattern is allowed. Moreover for every assortment only one sawing pattern is allowed. Then the possibilities of finding a good production plan are limited (capacity constraints, package production etc.). In fact several cutting altenatives are needed for the distinct stems and assortments.

The other extreme is that all alternative cutting patterns are included in the production planning model. The result of this approach is that a very good, a well balanced, production plan can be made. A serious drawback of this approach is the fact that a very large model will be the result, which will take a long solution time on the computer, even on powerfull machines, and thus reduces the flexibility of the manager. Hence, a procedure is needed that uses just enough sawing patterns to optimize a specific plan, and minimizes the redundant information in the planning model.

To achieve this goal, a balance between amount of information (size of the matrix) and optimality, a so-called column generating procedure was developed. This procedure works as follows.

Suppose that for each stem and each assortment one cutting pattern is generated. These patterns are the result of using the stems in combination with the assortments and boards and their dimensions and market prices. The result is a set of cutting patterns that maximize the value recovery of the raw material and the semi products. This task is accomplished by using the optimization routines described earlier. The cutting patterns are used to form a linear model, describing the tactical planning.

The cutting patterns and all relevant data in relation to the company and its environment can be used to find an optimal production plan, using the tactical planning support system (multiple goal planning). This production plan however supplies more information than just a planning.

An interpretation of this first tactical production plan also provides an insight in the quality of the planning itself. There are two ways of looking at this plan. A more mathematically oriented view, described in chapter five, section 4.5., and a more managerial view. These two aproaches are in fact parallel. Let us now concentrate on the second approach, the managerial view.

After accomplishing the initial planning, an overview can be given of the cost. In fact, the solution of the tactical planning model can be projected on an economic model, the so-called financial business administration. This overview provides insight in the production cost, the cost of labour, the inventory cost of raw material, semi products and final products. Furthermore the out of stock cost can be considered, in combination with the overtime needed to produce and the possible standstill at the machinery.

All these parameters, results from the planning, tell the manager how good the planning is. Suppose that for a number of products the out of stock cost are high, this means that the service degree is low. In other words the demand for these products exceeds the production. Other products may be on stock for the whole planning period of several weeks. These products cause inventory cost and are apparently produced too much.

These considerations may cause the decisionmaker to upgrade the production plan. How can this be done?

By adjusting the production quantities of the various commodities. This can be done by using a fundamental characteristic of the pattern generating tools. It was stated in the above that dynamic programming was used to generate the cutting patterns. The ratios between prices and dimensions of the assortments and the products determine the patterns, and thus the frequencies the assortments and boards show up in the optimal crosscutting sawing patterns. This property can be used to improve the planning quality.

Those products and assortments produced too much should be produced less. This can be done by lowering the price of the product or assortment of interest. Nota bene, the price lowered is not the marketprice. It is just an internally used price, indicating the priority with which the product should be produced. After adjusting the prices for all assortments and all products, new patterns can be calculated with DP. These patterns will be different for the assortments or products that where produced unbalanced with respect to the market.

The new patterns generated are then added to the model, and the new, extended, problem can now be solved. After this , a production plan results, that is at least as good as the previous plan, but probably better. The procedure can be repeated until the decision-maker decides that the planning is good, or until no further improvements can be made. The latter can be true as a result of for instance physical boundaries. Heavy lumber cannot be produced from small dimensioned stems and assortments. Concluding the extension of the model can be formulated as :

> Interprete the current production plan, and improve this plan by adjusting the internal prices of both the assortments and the products. The prices will be adjusted by using the dual prices. These adjusted prices are in fact the priorities with which the production must be carried out.
>
> Goal: Improving the inital production plan.
>
> Input: Results of the current plan.
>
> Output: Adjusted plan, closer to the preset targets.

The tools to adjust the production plan are technically advanced. Firstly the current plan must be evaluated (see section 4.5.), and secondly new patterns must be calculated and added to the current plan. This means that advanced software, linking goal programming modules to dynamic programming modules must be developed. The technical aspects will be discussed in depth in chapter six.

Strategic support : Evaluation tools

Earlier in this thesis it was stated that on an aggregated planning level, the strategic level, the position of a company in a dynamic environment must be evaluated.

In the preceding explanations a system consisting of an operational control module (dynamic programming, value maximization) and a tactical planning module (goal programming, integral logistics) was regarded. The process of aggregation and further linking can be continued, resulting in a strategic support tool box.

On the strategic planning level the fitting out of the company must be designed and evaluated. The decision maker has to tackle a variety of problems, such as how important is an investment in raw material handling equipment? What influences has such an investment on value-recovery and servicerate? What are the effects of increased flexibility at the sawing mill? Or is just a capacity increase sufficient? How does a new product range coincide with the existent products, in relation with the capacity constraints?

The problems as mentioned above ask for a system that quickly evaluates the decisionmakers policies. Instead of real optimization or decision-generation, decision evaluation (Reinders, 1988) (simulation) is now emphasized. The system acts as a planning assistant (Anthonisse et al. 1988). This means that the system should place tools to the manager disposal that enable the him or her to make quick evaluations of various production and investment alternatives. Of course the response times of the system are at this level of management less bottleneck as on the previous levels. For the part of the DSS, supporting strategic level of decision making is by definition an off-line application. Concluding, the strategic decision support can be stated as :

> Strategic support can be seen as providing tools and techniques to enable the manager to evaluate distinct production, sales and purchase alternatives. The business is considered variable itself at this level because by means of investments and new policies adjustments as a reaction on a dynamic environment are possible.
>
> Goal: Tuning the company in on a dynamic environment.
>
> Input: Company and environmental data, alternative policies.
>
> Output: Product mix, neccessary machine capacity, investment analysis for raw material handling, personnel policy etc.

The modelbase of the system IDEAS can be regarded as a set of coherent models and tools to help the manager to tackle problems of various nature. Short-term problems as optimal sawing policies can be handled by the operational support system. Medium-term decision making can be improved by using the tactical support system, linked up with the operational tools. Long-term policy evaluations can be analysed with respect to their impact on planning and finance of the company by using the strategic support system.

4.2.4. THE USER INTERFACE

The user interface is of key importance for the DSS. Why? Because it ultimately determines the acceptance of the DSS by the decision maker. Developing a DSS that can be effectively used in many circumstances asks for a number of functional requirements. Whether the DSS possesses the claimed properties is realized via the user interface.

In order to implement a functional flexibility, a menu-driven outer shell of the user interface was developed. The decisionmaker can choose to use the system IDEAS on various modes. They are shown in table 4.1.

Table 4.1. The main parts of the system and their function.

	MAIN MODULE	*FUNCTION*
(1)	*Data analysis*	*Preparative*
(2)	*Operational optimization*	*Advisor*
(3)	*Tactical optimization*	*Advisor/assistant*
(4)	*Strategic optimzation*	*Assistant*

The difference between advisor and assistant is not always as clear as suggested in the table. In fact a broad spectrum of functions is applied. Also the second shell of this system is menu-driven. The decison maker should be confronted with a system that is simple and consistent in usage. If this is not the case, planners are not likely to use such a system. They must be enabled to fully concentrate on the planning problems instead of concentrating on how to work with the DSS. The first module considered is the data analysis module (see table 4.2.).

1) Data analysis

The first level of the data-analysis module is again menu-driven, and very easy to use. In this shell of the system there is still a distance between the presentation language, being the menu, and the action language, the machine understandable commands.

Table 4.2. The elements of the module data analysis.

	ENTITIES	FUNCTION
(1)	*Raw material*	*Raw material data analysis*
(2)	*Semi products*	*Semi products data analysis*
(3)	*Final products*	*Final products data analysis*
(4)	*Companies*	*Companies data analysis*
(5)	*Scenarios*	*Scenario data analysis*

By using the cursor up and down arrow key, an entity choice can be made. After making this choice the decision maker can choose a number of actions to perform on the data. After making a choice, the user can communicate with the system by means of dialogue. Presentation language and action language are now conceptually very close. For all entities roughly the following functions are implemented (see tabel 4.3.).

Table 4.3. The implemented functions of IDEAS.

	FUNCTIONS	USAGE
(1)	*Examine*	*Examine the existing data.*
(2)	*Adjust*	*Adjust the existing data.*
(3)	*Add*	*Add new data.*
(4)	*Delete*	*Delete existing data.*

These functions trigger a whole set of programs, designed for datahandling of all entities. To minimize the misunderstanding the system indicates the errors, and if possible handles them. The robustness of the system is therefore relatively large.

2) *Operational optimization support.*

The operational support has been discussed in chapter three and in the previous sections. To control the DSS when supporting the operational optimization the decisionmaker has the disposal of various tools. First of all a subset of the relevant data-analysis tools are also approachable from this module. In table 4.4. the whole set of functions is displayed.

Table 4.4. The set of functions usable in the operational support module.

	F U N C T I O N	*U S A G E*
(1)	*Data analysis tools*	*Data analysis during optimization.*
(2)	*Create/solve a problem*	*Link stem, assortment and board data, solve the problem.*
(3)	*Alpha numerical analysis*	*Analyse the optimization results.*
(4)	*Graphical analysis*	*Analyse the cutting patterns.*

With these functions decisionmakers can link the cutting optimizing models with the relevant data, and analyse the results. The result are stored in the database, and can be retrieved when necessary. In this operational support module both MBMS functions and DBMS functions are combined.

3) Tactical optimization support.

When choosing this mode, the advisor/assistant mode, production plans can be made and evaluated. The user has again a number of functions at disposal, the control of which is again in dialogue style. In table 4.5. the distinct functions are displayed.

Table 4.5. The set of functions usable in the tactical support module.

	FUNCTION	USAGE
(1)	*Data analysis tools*	*Data analysis during optimization.*
(2)	*Create/solve a case*	*Link company, scenario and management data. Solve the current problem.*
(3)	*Alpha numerical analysis*	*Analyse the optimization results.*
(4)	*Solutions*	*Make a comparison and evaluation of the solution, in relation to other solutions.*
(5)	*Tactical adjustments*	*Adjust and tune the company, as far as the tactical management is concerned.*

With the functions provided in the module operational optimization support, various data chunks can be coupled, and transported to the tactical planning model. The planning can be optimized by combining the underlying mathematical models. In the tactical support module both data management (DBMS) and model management (MBMS) functions are implemented.

4) Strategic optimization support.

When choosing this mode, the assistant mode, the strategic management decisions can be supported. This means that a number of functions are provided, with an emphasis on the strategic tuning of the company. At the strategic management level, company structure and environment are completely variable. The user has a number of functions at his disposal, the control of which is again in dialogue style. In table 4.6. the distinct functions are displayed.

Table 4.6. The set of functions useable in the tactical support module.

	FUNCTION	USAGE
(1)	*Data analysis tools*	*Data analysis during optimization.*
(2)	*Create/solve a case*	*Link company, scenario and management data. Solve the current problem.*
(3)	*Alpha numerical analysis*	*Analyse the optimization results.*
(4)	*Solutions*	*Make a comparison and evaluation of the solution, in relation to other solutions.*
(5)	*Strategic adjustments*	*Adjust and tune the company, as the strategic management concerned.*

With the functions provided in the module strategic optimization support, various data chunks can be coupled, and transported to the planning model. The impact of various strategic interferences can be analysed. In the strategic support module both data management (DBMS) and model management (MBMS) functions are implemented.

Of course one must realize that there is a difference between the conceptual design of the system IDEAS and the implementation. The technical realization is roughly a direct counterpart of the conceptual design. However in coupling the models and data the boundaries are not always as sharp as conceptually indicated. The functioning of the system is exactly as described here. In chapter six the technical requirements and implementation aspects will be discussed in depth.

Chapter 5

MODELBASE

This chapter deals with the model-base of the decision support system IDEAS. Main emphasis in this chapter will be put on the mathematical aspects of the models that enable a planning on operational, tactical and strategic level.

After a short introduction (section 5.1.) this chapter will continue with an explanation of the dynamic programming models supporting the operational planning (section 5.2. and 5.3.). The tactical planning is supported by means of a multiple goal programming model, discussed in section 5.4. A column generating procedure, to improve the implementation efficiency will be regarded in section 5.5. The strategic planning is supported by what-if simulation capabilities.

5.1. INTRODUCTION

In the preceding chapters an introduction has been given on the concept of hierarchical planning. This hierarchical planning is connected with the decomposition principle of management.

In this introduction the link between various models and a decomposed management process is discussed. The approach will be bottom up, which means that a start will be made with the model supporting the kernel of the management process: the operational planning. The operational planning is improved by using models and algorithms that enable the decisionmaker to employ optimal sawing and merchandizing patterns. In order to make a planning for multiperiod, multiproduct situations, a tactical production plan is needed. This tactical plan can be optimised by using multiple goal programming (MGP). The strategic planning will be supported by simulation like tools.

The various models, based on dynamic programming (DP), multiple goal programming (MGP) and simulation have to be linked.

An optimal sawing pattern will be optimal with respect to value recovery. However a company has to be end-user oriented, in order to become an acceptable turnover, that can lead to profit. Therefore optimal patterns are combined into an optimal tactical production plan. This plan balances production and inventory management, in all processing stages, regarding multiple goals. After constructing an optimal production plan, a company is able to produce at minimal overall cost.

A company however has to function in a dynamic environment. Customers may leave the market, or competitors may enter it. New products will be asked for, the marketprice of which has to be determined. Temporary or permanent shortages may occur. These problems require actions. All the mentioned problems share a distinguished mark. They are all of strategic nature. Therefore the company needs tools to face these problems. To analyse the effects of specific decisions and actions. Our decision support system (IDEAS) is therefore equipped with strategic decision support tools.

5.2. OPERATIONAL SUPPORT, CROSSCUTTING

Crosscutting can be stated as the problem of converting a shaft into logs, in a way that the total stemvalue is maximised, according to a given list of logdimensions, qualities and prices.

Crosscutting, or merchandizing, can thus be viewed as the problem of finding a set of assortments (logs) that can be produced from a tree, or tree section, with given dimensions, in a way that the added value of the logs, called the value of the tree, is maximised.

The approach for the solution of this problem is of the recursive fixing type (Naesberg, 1985; Geerts, 1979).

5.2.1. BASIC ASSUMPTIONS

In this section the general idea of the optimization algorithm is discussed.
Divide a tree, characterized by its length and diameter as function of the distance from the stump end, in fixed intervals with a unit length. Starting at the stump end, a stepwise movement can be made directed to the top end. Every interval, with unit length, can be considered as a phase where a decision can be made. A decision is characterized by the assortment to cut off at that specific distance from the stump end. The criterion for doing this will be the sum of the values of the log (assortment) to be cut off, and the value of the already processed part of the tree.

When following this procedure through, the top-end of the tree is reached finally. At the last interval, thus at the very top, again a de-
cision has to be made which assortment to cut off. After doing this, a part of the tree with length equal to the original tree length minus the length of the cut off assortment is left. For this piece of the original tree, the optimal decision is known, since the latter was determined in the first procedure at every single interval.

Accomplishing this second procedure will end with a tree of length zero, which means that the whole tree-length has been processed.

From a mathematical point of view this problem can be regarded as a multi-step, sequential decision problem. It can be viewed as finding the longest route in an acyclic directed network.

5.2.2 THE MODEL

In this section, the concepts as discussed in section 5.2.1., will be introduced more formally. Some of the ideas are not absolutely necessary to model the process of crosscutting. However, by introducing them now, this discussion will be consistent with the next sections discussing lumberproduction.

Consider a tree with total length L_{tot}. Call the axis the z-direction. Divide the tree into intervals of length δz along the z-axis. The total number of intervals is denoted with Nz. Thus,

$$Nz = [L_{tot}/\delta z] \tag{5.1}$$

If L_{tot} is not an integer multiple of the unit length, waste is formed at the top-end of the tree. The usable length of the tree, the effective length, is denoted L_{eff}. [.] means greatest integer $\leq$ (.). Hence

$$L_{eff} = \delta z . Nz \tag{5.2}$$

The diameter of the tree can be considered as a function of the distance from the stump, denoted as $D(z.\delta z)$, where z is the number of the unit interval. A unit interval is defined as an interval with a length equal to the steplength.

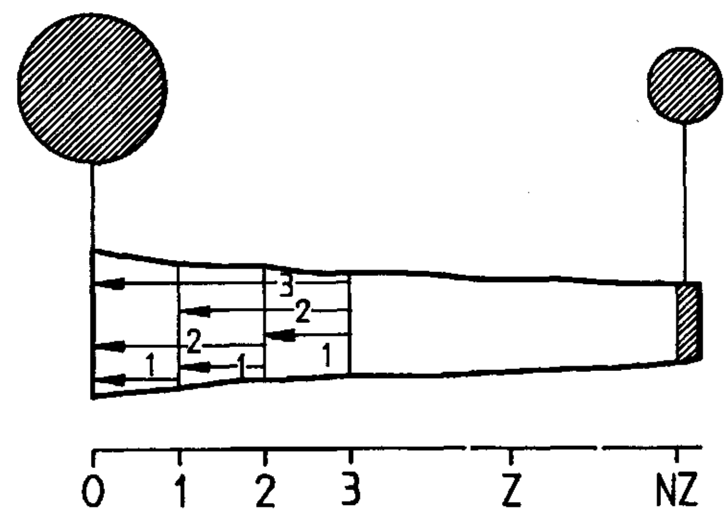


Figure 5.1. Relationship between stem and DP. At all stages 1 to Nz, decisions (numbered with 1,2,3) can be made.

The places where decisions can be made, are symbolized by z, and called the stages of the system. The states are the distances from the stump of the processed part of the tree, denoted as z.δz.

The decision is the assortment to cut off. To evaluate the quality of a decision, one has to know the value of the part of the tree to cut off at stage z. The assortments are numbered and the assortment numbered n, to cut off at stage z is called n_z. The value of n_z can be determined from a pricelist containing the dimensions of the assortments (logs) and the corresponding prices.

Figure 5.1. displays the relations between tree-dimensions, states and stages.

Let A be a set of assortments, semiproducts. Every element of this set represents an assortment. Each assortment $a(n) \in A$ is fully characterized by its dimensions and value,

$$a(n) := (l(n), d_{max}(n), d_{min}(n), v(n)) \tag{5.3}$$

The diameter at the top of the assortment, with length l, is called d. An assortment may have a tolerance for its top diameter, resulting in a maximum, d_{max}, and a minimum , d_{min}, allowed diameter. The value, denoted with v(n), of an assortment can be expressed in a relative way (Dfl/m^3) or absolute (Dfl).

The numbers n, ($n \in N$) are given to the assortments in a way that the logs are ordered lexicographically with respect to their length l(n). This means that for all numbers n_1 and n_2, given to assortments in A the length of n_1, $l(n_1)$, is smaller or equal than the length of n_2, $l(n_2)$. In formula this can be denoted as:

$$A := \{ n \mid (n_1 \le n_2)^1 \text{ HOLDS } l(n_1) \le l(n_2) \} \qquad (5.4)$$

In this formula ($n_1 \le n_2$) means for all n_1 and n_2 greater than n_1. Generalized this can be denoted as (.). In this formula, clearness was considered more important than mathematical correctness.

The reason for this ordering is of algorithmic efficiency. Once a decision n_z turns out to be impossible, because l(n) is greater than the part of the tree considered, all subsequent n greater than n_z are not worth trying.

A subset of A can be defined, containing all numbers of assortments that fit in the available tree section with respect to the diameter at stage z, D(z.δz), and the length z.δz. This subset of A, called A_z contains all assortment numbers in A, without the numbers corresponding to assortments that are too long, or which diameter range does not fit the tree diameter at stage z. Mathematically this can be stated as:

$$A_z := A \backslash \{ n \mid l(n) > z.\delta z \text{ OR } d_{min}(n) > D(z.\delta z) \text{ OR } d_{max}(n) < D(z.\delta z) \} \qquad (5.5)$$

In other words, A_z is the set of numbers, corresponding with logs worth while trying at stage z.

The original set A, is furthermore completed with an assortment always fitting at every stage z. This dummy assortment has a length equal to δz, and a diameter range always fitting at every D(z.δz).

[1] (.) denotes the all quantor.

Hence

$$a(1) := (\delta z, M, 0, 0) \tag{5.6}$$

M is a large positive number, the value of the dummy assortment is zero. The reason for introducing a(1) is the fact that at every stage z at least one possible decision must exist.
Summarized:

$$(z)[A_z = \text{not empty}] \tag{5.7}$$

Let us now discuss some extra concepts and definitions that bridge this application of DP to the general theory. (Van Beek, Hendriks, 1986).

$G_z(n_z)$: The value, added after a decision n_z has been made. It is the value of the assortment, with a length $l(n_z)$, and a top diameter $D(z.\delta z)$.

ZF_z: The value function of the system at stage z, if at all relevant previous stages, optimum decisions n_z have been made.
ZF_z can hence be considered as the maximum reachable value of the processed part of the tree.

$z.\delta z$: State of the system at stage z. The state is considered as the length of the part of the tree, already processed.

The recurrence function (Bellman, 1957; Van Beek, Hendriks, 1986) can be stated as:

$$ZF_z := \max_{n_z \in A_z} \{G_z(n_z) + ZF_{z-l(n_z)}\} \tag{5.8}$$

The model described in 5.2.2. has been put into an algorithm. The algorithm has been implemented by means of a FORTRAN-77 program. Because the model, nor the algorithm contains really new insights, the discussion of aspects of implementation is not given here. A recursive fixing approach was used (Naesberg, 1985).

5.3. OPERATIONAL SUPPORT, SAWING MODEL

The process of breaking down a log (assortment) into boards will be the main subject of this section.

The process of sawing, in other words the production of lumber can be considered roughly as a two-phase process: firstly the primary breakdown of the stem into assortments, followed by a secondary breakdown of the assortments into boards (lumber).

In this section the two processes mentioned, will be considered as one. The reason for this is of algorithmic nature. If a model, and an algorithm can be developed for the conversion of a tree into lumber, the conversion of a log into lumber can be considered from a mathematical point of view as of simpler nature.
The reason for searching for an integral optimization algoritm will be clear when bearing in mind that whenever strategic adjustments have to be evaluated, the decomposed productionproces can be point of discussion and perhaps replaced by an integral production control system.

The problem of finding an optimal sawing pattern for a tree can be stated as a three dimensional knapsack problem. Non-guillotine cuts across the tree are not considered as realistic, due to limitations of today's production technology. Hence, a split-up can be made into the earlier mentioned (section 5.2) one-dimensional knapsack problem, representing the primary breakdown, and a two-dimensional knapsack problem, modelling the breakdown of an assortment into boards.

The latter problem can be stated as fitting rectangles of various dimensions and values into a circle, in a way that the total value of the circle is maximized. The value of the circle is determined as the sum of the values of the products in it. Optimizing the sawing patterns has been a subject of interest to various researchers (e.g. Faaland, Biggs, 1984; Geerts, 1984; Hallock, Stern, Lewis, 1976).

As mentioned in chapter three, both efficiency and effectiveness are of importance when dealing with woodprocessing. In this section efficiency will be emphasized.

5.3.1. BASIC ASSUMPTIONS

A tree has to be cut into boards. The boards are fully characterized by their dimensions and value. The quality aspect is not dealt with, although it can be implemented by relatively small extensions.

A three-dimensional breakdown pattern has to be found, in a way that the tree-value is maximized according to a given final-products (lumber) list. A decomposition of the problems into three levels was stated. The decisions on each level interact to perform a global optimum.

On level one the problem is to find positions to break the tree down in a number of logs. The cuts are made perpendicular to the axis of the timber (cross-cutting). The prices of the saw-logs, are in fact the value of the logs when they are cut into lumber. This brings us to the next level of optimization.

On level two the logs are cut into flitches, the mother boards, in a way that the log is maximized according to the flitch values. The flitch values, however, are a result of the final products cut from it. Hence, to maximize the value of these flitches, we have to perform a level three optimization.

On level three, a one dimensional knapsack problem remains. How to cut a flitch into board in a way that the flitch value is maximized according to the product (lumber) values. The three levels are visualized in figure 5.2.

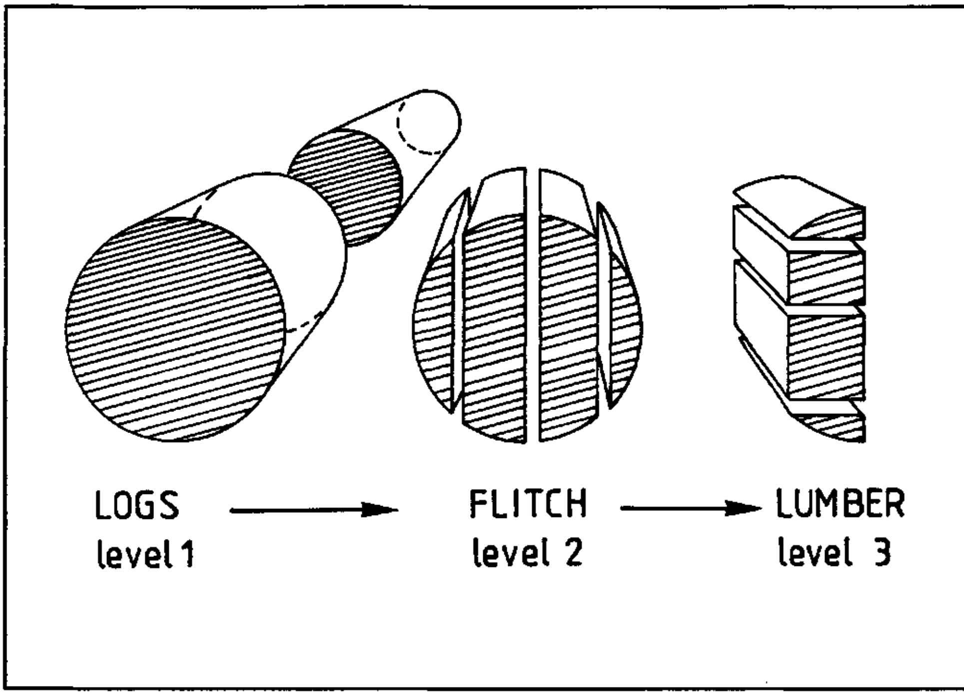


Figure 5.2. Conversion from tree into lumber.

When breaking up a log in this way, it must be realized that not all degrees of freedom coming with a three-dimensional knapsack problem are used. Let us explain this statement before discussing the algorithm.

Call the length along the axis, the z-direction, and along the width, horizontally, the x-direction. The direction perpendicular to these two, can be denoted the y-axis. Cuts perpendicular to the z-axis divide the tree into logs. It is impossible to produce final products longer then these logs. So, the guillotine character of these z-cuts, impose limits on the final products to be cut. Although, to our knowledge, a system with non-guillotine cuts perpendicular to the z-direction does not exist at this moment, it would possibly lead to higher relative recovery.

A second limitation occurs at the next processing step, cutting a log into flitches. The cuts in the y-direction are considered to be of a guillotine type, with respect to the cross-section. This type of cuts will be called parallel guillotine cuts from now on. Figure 5.3 illustrates this somewhat different approach from what is usually found in the literature (Gilmore, Gomory, 1969).

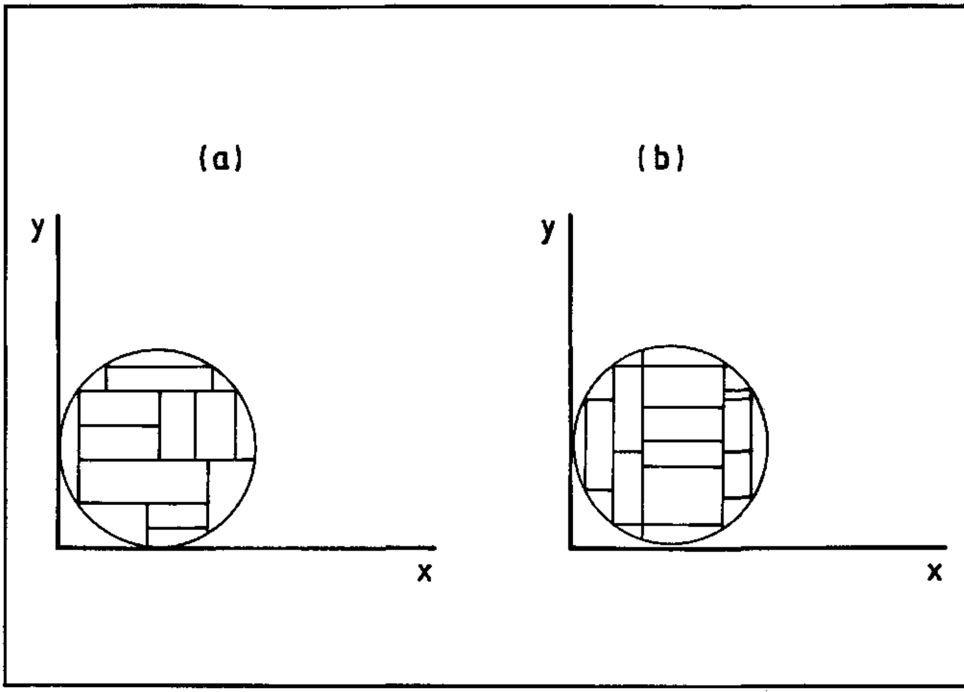


Figure 5.3. (a) Guillotine cuts, (b) Parallel guillotine cuts.

The first pattern, displayed in figure 5.3., can be made using classical production equipment, but only by means of a number of rotations. The second pattern can of course also be made with usual machinery. In this thesis, only patterns of type two will be allowed. This can be considered as a considerable extension to known models, presuming a fixed distance between cuts parallel to the y-axis (Faaland, Briggs, 1984).

To solve the three-level cutting stock problem, a model consisting of three, nested, one-dimensional, interrelated, dynamic programming formulations will be used. They will interact with each other for their value function and for the decisions to be made at the various stages. Stages are the moments (time, places) fit to function as starting points for a decision (Van Beek, Hendriks, 1986).

In the underlaying research, the effect of the waney edge, being the waney part of the cross-section, is fully used in the optimization algorithm, in contrast to the algorithm used by Geerts (1984) that dealt with the waney edge heuristically. A special problem is caused by the shape of the tree, a knotted cone, that does not allow us to make use of all the suggestions for speeding up as made by Christofides and Whitlock (1977), in optimizing the cutting of a rectangular plate.

5.3.2. SYMMETRY AND EFFICIENCY

When performing an algorithm, based on nested one-dimensional dynamic programming (DP) routines, effects of symmetry on one hand, and equality and similarity on the other hand, can be used to speed up the algorithms and thus save computer time.

In the developed algorithm, three distinct forms of symmetry, and equality and similarity, will be included. These effects will be denoted with "symmetry".

1) When crosscutting a tree, and thus cutting off a log at a specific distance from the stump end, the value of a trial log is already evaluated if the specific combination of diameter and length has occured before.

2) When sawing a log, and thus "slicing" a circle, the value of a typical trial flitch on the left has the same value at the opposite position at the right side. This holds only for uniform quality.

3) The third effect is that a flitch containing a part that has been optimized before, does not need a new calculation. For instance if a flitch contains a rectangle that has been calculated before, the calculation of the rectangle in the flitch can be skipped.

These so-called effects of symmetry are used to speed up the algorithm and have an input on the formulation in mathematical terms. This adjusted formulation will be dealt with in section 5.3.5.

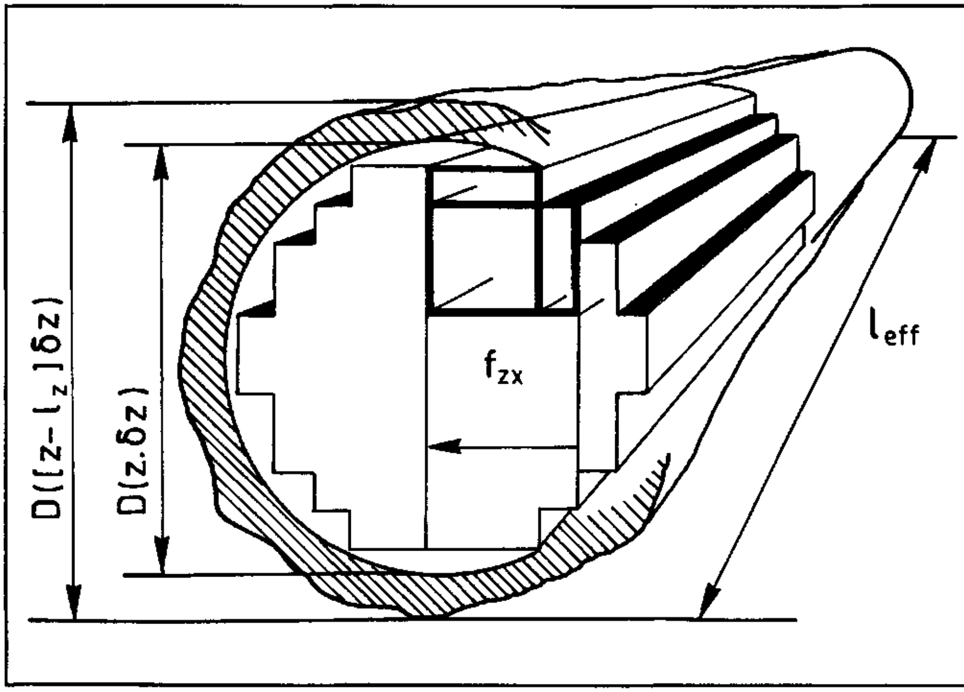


Figure 5.4. A stem, build up of unit elements, in relation with diameter and flitch decision.

5.3.3. GEOMETRY

A stepwize introduction to a mathematical formulation of the problem, starting from a geometrical point of view, will be provided in this section.

a) Z-level

Let L_{tot} be the length of a tree, divided into intervals δz along the z-axis. If L_{tot} is not an integer multiple of the unit length, then waste is formed at the top-end. The usable part of the tree is denoted with L_{eff}, the effective length. The diameter of the tree is a function of the distance from the stump, and can be denoted as D(z.δz), where z is the number of the unit interval. (see figure 5.4).

The moments, or positions when decisions can be made called the stages of the system, are symbolized by z. The states of the system are defined as the distances

from the stump-end of the processed part of the tree, and can thus be denoted $z.\delta z$. The decision at a typical stage z, is the length to cut off.
To evaluate the quality of the decision, one has to know the value of the part of the tree to cut off at stage z summed with the value of the processed part of the tree. The length cut off will be called l_z. The value of a part of the tree, an assortment, can be calculated by means of a dynamic programming (DP) algorithm solving the two-dimensional cutting stock (knapsack) problem.

b) X-level

At the x-level the stages are defined as the number of the unit interval, with numbering starting on the left side of the circular crossection. Hence the states of the system can be described, analogous to the z-direction, as the distance from the left-side of the cross-section. The distance from the left-side of the cross-section, can be considered as the cumulated width of a number of mother boards, called flitches. As a result of these definitions, again a one-to-one correspondence between stages and states has been constructed.

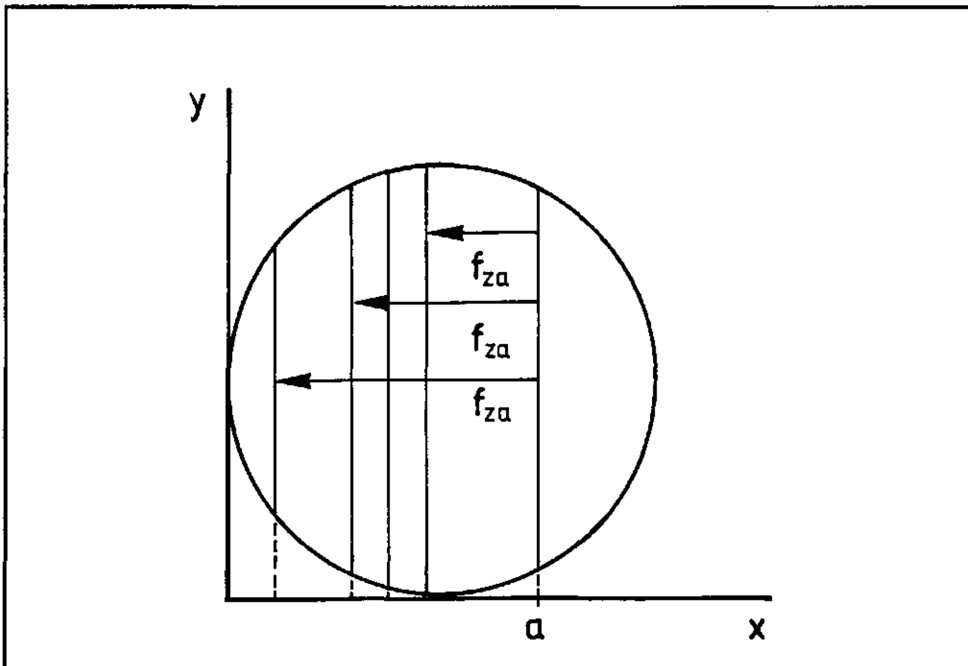


Figure 5.5. Relation between flitch and decisions.

The decision to be made at a stage x, is the width of the flitch to cut off. This flitch-width, at stage x, at distance z.δz from the stump end, will be called f_{zx}. If the diameter of the tree, and thus the diameter at the top-end of the assortment is not an integer multiple of the unit interval length δx, a small circle of waste is placed at the exterior of the cross-section, the thickness of which depends on the grid-width projected on the xy-plane.

The quality of a decision f_{zx} can be examined by the value of the flitch resulting from this decision. For the value of a trial flitch, is defined as the sum of the values of the lumber products produced from it. This statement brings us to a discussion of the deepest nested level, along the y-axis.

In order to maximize the flitch value, stages in the y-direction, are defined as the number of the interval unit with length δy, starting at the x-axis, hence, at y = 0. The decision to be made at each stage y, is the number of the product to cut off at stage y, at position (z,x,y). The decision is in fact two-dimensional itself, because a product can also be cut off rotated in the xy-plane. Hence a decision is denoted with $(n,r)_{zxy}$, where n is the product number, and r is the rotation factor, being 0 if no rotation occurs, and 1 after rotation over 90°.
The quality of a decision depends on the value of the product v(n), and the value of the flitch-part left after this decision $(n,r)_{zxy}$.

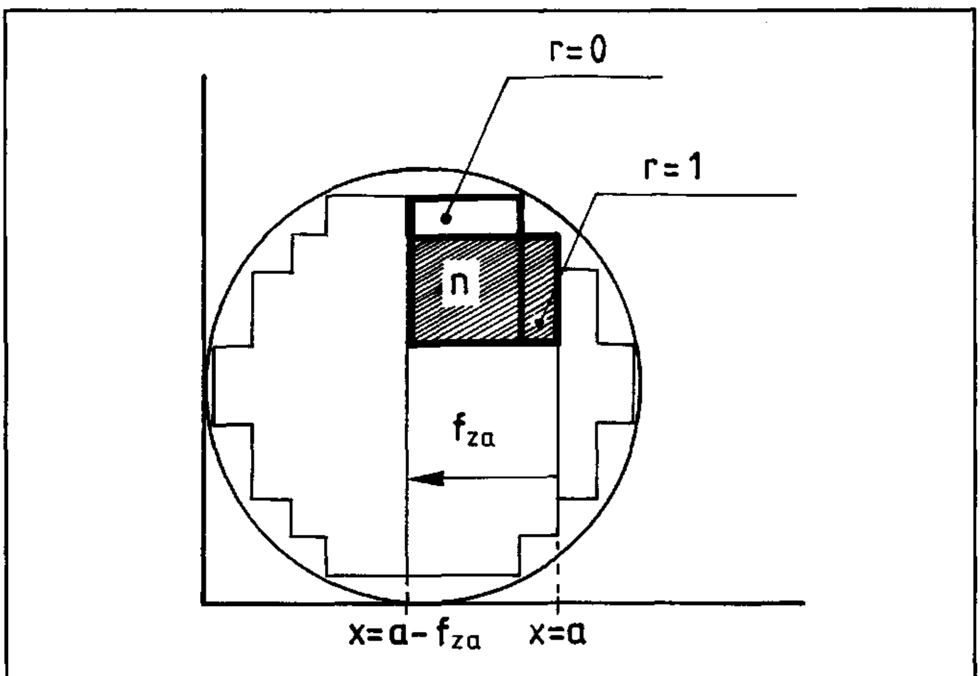


Figure 5.6. Relation between products and decisions.

After this brief introduction, it will be clear that the process of breaking down a tree into final-products (boards) can be decomposed itself into three levels. The first level, finding cross-cuts, is in fact discussed in earlier sections, let us therefore continue with the breakdown process of an assortment into lumber. Figure 5.7 will be used to visualize various definitions.

A tree can be viewed as built up out of unit elements δz, δx and δy. Consider the geometric aspects of breaking down a circle into rectangles.

If at a stage x, at z interval distances from the stump, the decision is made to cut off a flitch of width $\delta x.f_{zxy}$, then the functions as shown in figure 5.7 have to be considered.

In this figure two functions are of interest. Firstly the g-function is used for the calculation of the available flitch-height on a width x. Secondly, the h-function plays a similar role when calculating the flitch-width at a height y. The two functions can be stated as:

$$g(z,x) := \sqrt{}(R(z.\delta z)^2 - (x.\delta x - R(z.\delta z))^2) \qquad (5.9)$$

$$h(z,x) := \sqrt{}(R(z.\delta z)^2 - (y.\delta y - R(z.\delta z))^2) \qquad (5.10)$$

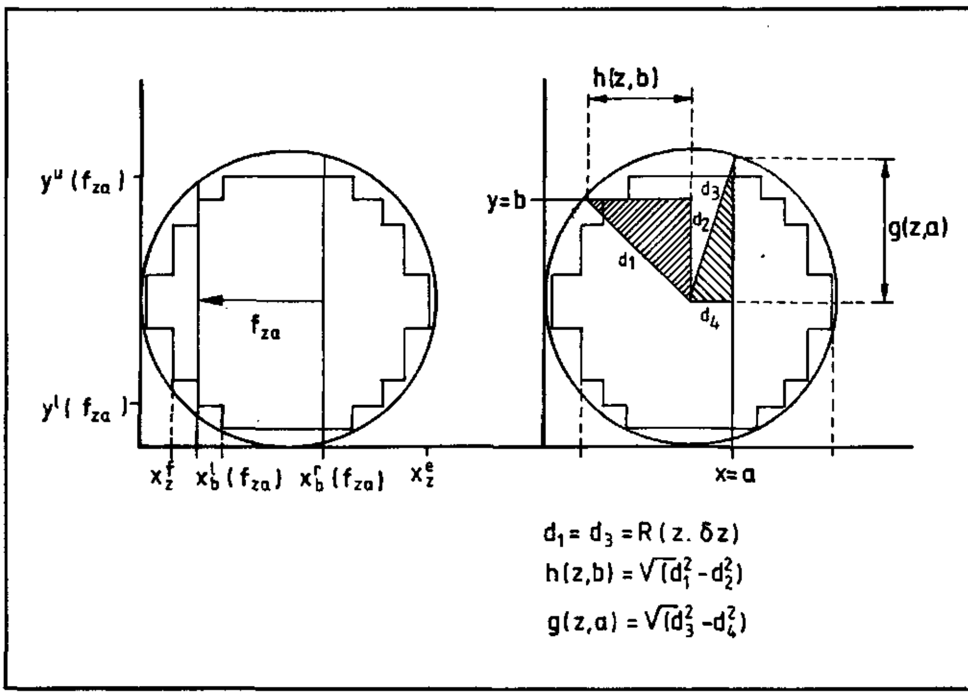


Figure 5.7. Geometric aspects of cutting-problem.

In this function the radius of the tree at a stage z is used, and denoted as $R(z.\delta z) = \frac{1}{2}D(z.\delta z)$. Furthermore let Nz be the number of intervals contained in the tree with length L_{tot}, in other words $Nz = [L_{tot}/\delta z]$. The number of unit intervals in both x and y-direction are defined as $Nx_z = [D(z.\delta z)/\delta x]$ respectively $Ny_z = [D(z.\delta z)/\delta y]$, where [.] means greatest integer value, smaller or equal than (.).

The variable x, denoting the stage of the system in the x-direction, is of course bounded. Only stages worthwile evaluating a decision are taken into account, x_z^f (x-first) is the first x stage where a flitch can be produced from, x_z^e (x-end) the last. In more mathematical form these two bounds can be formulated as:

$$x_z^f := \min_{1 \le x \le Nx_z} \{ x \mid [2g(z,x)/\delta y] \ge 1 \} + 1 \tag{5.11}$$

$$x_z^e := \max_{[Nx_z/2] \le x \le Nx_z} \{ x \mid [2g(z,x)/\delta y] \ge 1 \} \tag{5.12}$$

The effective height of the flitch is a function of the decision f_{zx} made at stage x.

If a trial flitch has a relatively large width, it is likely that the flitch has non-rectangular sides. Hence the variable y, denoting the stages in the y-direction is bounded, moreover these bounds are dependent from the flitch width f_{zx}. The lower bound (y-down) is denoted with $y^d(f_{zx})$, the upperlimit (y-up) with $y^u(f_{zx})$.
Hence,

$$y^d(f_{zx}) := \min_{x-f_{zx} \le a \le x-1} \{ [R(z.\delta z)-g(z,a)/\delta y] \} + 2 \tag{5.13}$$

$$y^u(f_{zx}) := \min_{x-f_{zx} \le a \le x-1} \{ [(R(z.\delta z)+g(z,a)/\delta y] \} \tag{5.14}$$

By now the x variable has a bound, dependent on the variable z and on δy, and the y variable has a bound, dependent on the variable z, and the decision f_{zx} made at z,x. However when evaluating a trial flitch, especially when large flitches are allowed, the x-range needs to be stated sharper.

Large flitches are often not rectangular, this means that the effective x-range is not $x\text{-}f_{zx}$ in most y stages. Therefore two new x bounds are introduced, as function of the "heigth" y, and the evaluated decision f_{zx} at position x,y. Therefore $x_y^l(f_{zx})$ and $x_y^r(f_{zx})$ are defined as the left and the right usable x-coordinates (stages) at position y, respectively, to determine the resulting flitch-width, if a decision f_{zx} is made.

$$x^{l}_{y}(f_{zx}) := \max \{ x-f_{zx}, [(R(z.\delta z)-h(z,y))/\delta x]+1 \} \quad (5.15)$$

$$x^{r}_{y}(f_{zx}) := \min \{ x, [(R(z.\delta z)+h(z,y))/\delta x] \} \quad (5.16)$$

c) Y-level

On the third level, a two dimensional decision has to be made. Firstly what product to cut off and secondly whether to rotate this product 90° or not. This decision can be stated as $(n,r)_{zxy}$. The decision influences the usable part of a flitch (motherboard). The part of the flitch, the usable flitch-width, when choosing a product with number n is denoted $W(f_{zx},(n,r)_{zxy})$. It can be stated as:

$$W(f_{zx},(n,r)_{zxy}) := \min\{ x^{r}_{y}(f_{zx})-x^{l}_{y}(f_{zx}), x^{r}_{y'}(f_{zx})-x^{l}_{y'}(f_{zx}) \} \quad (5.17)$$

In this definition y' denotes the stage y that is reached after a decision $(n,r)_{zxy}$. Hence

$$y' := y - ((1-r).ly(n) + r.lx(n))/\delta y \quad (5.18)$$

where lx(n) and ly(n) represent the lengths in the x and y direction respectively of product n, and $r=0$ if no rotation occurs, $r=1$ if rotation occurs.

5.3.4. THE MODEL

Based upon the geometric concepts introduced in the previous section the model can be stated formally.

Consider a set P of numbered products. A product p(n) is characterized by its dimension and its value.

$$p(n) := (lz(n), lx(n), ly(n), v(n)) \qquad (5.19)$$

The numbers are given to the products so that the products are ordered lexicographically with respect to their dimensions. Therefore,

$$P := \{ n \mid (n_1 \le n_2) \text{ HOLDS } lz(n_1) \le lz(n_2) \text{ AND}$$
$$(n_1 \le n_2)(lz(n_1) = lz(n_2)) \text{ HOLDS } lx(n_1) \le lx(n_2) \} \qquad (5.20)$$

The reason for this ordering is in algorithmic efficiency. This will be explained later.

Let us now introduce five sets, that restrict the possible decisions at stages z,x,y, and thus speed up the algorithm because of excluding non-relevant evaluations.

At the z and x levels, lengths and widths have to be cut respectively. These decisions are restricted because they are strongly related to the product-dimensions. Two ordered sets L and F containing the lengths and widths allowed to be cut off at the various z and x stages are introduced:

$$L := \{ l \mid {}^2(En)[l.\delta z = lz(n)] \} \qquad (5.21)$$

And,

$$F := \{ f \mid (En)[f.\delta x = lx(n) \text{ OR } f.\delta y = ly(n)] \} \qquad (5.22)$$

---

[2](E.) denotes the existential quantor.

When making a decision l_z in the z-direction, at a stage z, lengths $l_z.\delta z$ greater than the currently usable length $z.\delta z$ need no further evaluation.
Hence, only a subset of L is needed at stage z. This subset is called L_z, and can be denoted as:

$$L_z := \{ l \mid l \leq z \} \qquad (5.23)$$

On the same line of argument a restricted subset of F can be constructed. Consider a decision at stage x, at position z from the stump end. The decision has to be made about which width f to use, but values for f larger than the width of the cross-section at stage x are not worth evaluating. Also widths f that only occur with products having a length lz(n) larger than $z.\delta z$ at the current moment of decision are not usable. It can be stated:

$$F_{l_z x} := F \setminus ((F_1 \text{ AND } F_2) \text{ OR } F_3) \qquad (5.24)$$

with

$$F_1 := \{ f \mid (n)[lx(n)=f.\delta x \text{ OR } ly(n)=f.\delta y] \} \qquad (5.25)$$

$$F_2 := \{ f \mid (n)[lz(n) \geq l_z.\delta z] \} \qquad (5.26)$$

$$F_3 := \{ f \mid f \geq x \} \qquad (5.27)$$

The last decision level, the y-direction, the decision has to be made about which product to cut off, and whether to rotate the product or not, once decisions l_z and f_{zx} have been suggested. Similar to the previous two decision levels, also in this level some restrictions with respect to the decision space can be made.

Firstly only products that fit into the flitch height are of interest. Products satisfying this condition are contained in NR_1. Secondly the boards have to fit, rotated or not, into the available flitch width. The products satisfying this condition are denoted with NR_2.
Finally, only products with length equal to the cut off assortment are allowed. These products are contained in NR_3.

More formally, we can state:

$$NR_1 := \{ (n,r) \mid (y-(1-r).ly(n)/\delta y)-r.lx(n)/\delta x \geq 0 \} \quad (5.28)$$

$$NR_2 := \{ (n,r) \mid (1-r).(W(f_{zx},(n,r)_{zxy})-lx(n)/\delta x) + r(W(f_{zx},(n,r)_{zxy})-ly(n)/\delta x) \geq 0 \} \quad (5.29)$$

$$NR_3 := \{ (n,r) \mid lz(n) = l_z \} \quad (5.30)$$

Hence,

$$NR_{l_z f_{zx} y} := \{ (n,r) \mid (n,r)\in NR_1 \text{ AND } (n,r)\in NR_2 \text{ AND } (n,r)\in NR_3 \} \quad (5.31)$$

In order to give a DP-formulation of the knapsack problem, some extra variables and conceptions need introduction.

$G_z(l_z)$:= The maximum reachable value, after a decision l_z. Hence $G_z(l_z)$ can be interpreted as the value of a knotted cone of length l_z and a diameter at the top-end of D(z.δz). The diameter at the foot will be D((z.δz)'), where $(z.\delta z)' = (z-l_z).\delta z$.

Zf_z:= The value function of the system at stage z, if at all relevant, previous stages, optimum decisions l_z have been made. It can be considered as the value of the processed part of the tree.

$G_{zx}(l_z,f_{zx})$:= The maximum reachable value, after a decision f_{zx}. $G_{zx}(l_z,f_{zx})$ can thus be interpreted as the value of a flitch, cut off at a cross-section at distance z.δz, with length l_z, starting at position x.

$XF(f_z)_{zx}$:= The value function of the system at stage x, if at all relevant previous stages, optimum decisions f_{zx} have been made. $XF(l_z)_{zx}$ can be considered as the value of the part of an assortment, with length l_z, that already has been processed.

$G_{zxy}(l_z, f_{zx}, (n,r)_{zxy})$:= The value added after a decision $(n,r)_{zxy}$ at stage y. In the described case it will be the value v(n) of a product n. In other cases it will be a function of the location and the value v(n). (quality aspects).

$YF(l_z, f_{zx})_{zxy}$:= The value function of the system at stage y, if at all relevant previous stages, optimum decisions $(n,r)_{zxy}$ have been made.

When using these definitions in combination with the geometric reflections made in the previous section the model can be summarized.

Z - LEVEL

$$ZF_z = \max_{l_z \in L_z} \{G_z(l_z) + ZF_{z-l_z}\}$$

$$1 \leq z \leq Nz$$

$$G_z(l_z) = XF(l_z)_{zx_z^e}$$

X - LEVEL

$$XF(l_z)_{zx} = \max_{f_{zx} \in F_{l_z x}} \{G_{zx}(l_z, f_{zx}) + XF(l_z)_{zx-f_{zx}}\}$$

$$x_z^f \leq x \leq x_z^e$$

$$G_{zx}(l_z, f_{zx}) = YF(l_z, f_{zx})_{zxy^u(f_{zx})}$$

Y - LEVEL

$$YF(l_z, f_{zx})_{zxy} = \max_{(n,r)_{zxy} \in NR_{l_z f_{zx} y}} \{G_{zxy}(l_z, f_{zx}, (n,r)_{zxy}) + YF(l_z, f_{zx})_{zxy'}\}$$

$$y^d(f_{zx}) \leq y \leq y^u(f_{zx})$$

$$y' = y-((1-r).ly(n)+r.lx(n))/\delta y$$

$$G_{zxy}(l_z, f_{zx}, (n,r)_{zxy}) = v(n)$$

This dynamic programming formulation, can be used to design an algorithm. This translation results in a relatively straight forward programming code. No special requirements are needed, which means that FORTRAN, PASCAL or BASIC can be used. More or less independent from this model formulation both recursive fixing and forward reaching techniques can be applied (Naesberg, 1985).

5.3.5. SPEEDING UP THE ALGORITHM

In section 5.3.2. three different types of symmetry were introduced. In this section the first type of symmetry will not be dealt with. The impact on the DP-formulation is considered selfevident. Let us therefore start with the second effect, occurring when evaluating flitches at the right from the centre of the circular cross-section of a log (assortment).

Symmetry, unique flitches.

At a level x, suppose that different values for the decision variable f_{zx} have to be checked. For all x-values, greater than $[Nx_z/2]$, a chance occurs that the trial flitch has already been evaluated at an earlier stage x. In other words, if $x-[f_{zx}/2]$ is greater than $[Nx_z/2]$, the flitch has already been optimized at stage Nx_z-x+f_{zx}. More formally, it can be stated that,

$$(f_{zx})[x-[f_{zx}/2] \geq [Nx_z/2] \text{ HOLDS } YF(l_z,f_{zx})_{zxy^u(f_{zx})}$$

$$= YF(l_z,f_{za})_{zay^u(f_{za})}] \qquad (5.32)$$

with

$$a := Nx_z - x + f_{zx} \qquad (5.33)$$

and

$$f_{za} := f_{zx} \qquad (5.34)$$

Symmetry, rectangular flitch sections.

A second case of symmetry occurs, if a part of a flitch is rectangular, and has been optimized before. A flitch can only be a rectangle if the following two equations hold :

$$R(1): x^1_{yd}(f_{zx}) = x^1_{Ny_z/2}(f_{zx}) \qquad (5.35)$$

$$R(2):\ x^{r}_{yd}(f_{zx}) = x^{r}_{Ny_z/2}(f_{zx}) \tag{5.36}$$

Suppose x_1 and x_2, with $x_2 \geq x_1$, are both stages at which a decision $f_{zx_1} = f_{zx_2}$ can be made. If R(1) and R(2) hold, then at stage x_2 one can skip the calculations until $y - y^d(f_{zx_2})$ becomes greater than $y^u(f_{zx_1}) - y^d(f_{zx_1})$. Hence,

$$(x_1)(x_2 \geq x_1)[\ f_{zx_1} = f_{zx_2}\ \text{HOLDS}\ \ (y \leq b)[R(3)]\ ] \tag{5.37}$$

with

$$b := y^d(f_{zx_2}) + y^u(f_{zx_1}) - y^d(f_{zx_1}) \tag{5.38}$$

and

$$R(3):\ YF(l_z, f_{zx_2})_{zx_2y} = YF(l_z, f_{zx_1})_{zx_1 y^d(f_{zx_1}) - y^d(f_{zx_2})} \tag{5.39}$$

Implementing all these effects of symmetry, the adjusted model can be formulated.

Z - LEVEL

$$ZF_z = \max_{l_z \in L_z} \{G_z(l_z) + ZF_{z-l_z}\}$$

$1 \leq z \leq Nz$

$G_z(l_z) = XF(l_z)_{zx_z^e}$

X - LEVEL

$$XF(l_z)_{zx} = \max_{f_{zx} \in F_{l_z x}} \{G_{zx}(l_z, f_{zx}) + XF(l_z)_{zx-f_{zx}})$$

with

$G_{zx}(l_z, f_{zx}) = YF(l_z, f_{zx})_{zxy^u(f_{zx})}$, for

$x_z^f \leq x \leq x_z^e$, and $x - [f_{zx}/2] \leq [Nx_z/2]$

or

$G_{zx}(l_z, f_{zx}) = YF(l_z, f_{za})_{zay^u(f_{za})}$, for

$x_z^f \leq x \leq x_z^e$, and $x - [f_{zx}/2] \geq [Nx_z/2]$

$a = Nx_z - x + f_{zx}$

Y - LEVEL

$$YF(1_z, f_{zx})_{zx} = \max_{(n,r)_{zxy} \in NR_{1_z f_{zx} y}} \{G_{zxy}(1_z, f_{zx}, (n,r)_{zxy}) + YF_{zxy'}\}$$

for,

$y^d(f_{zx}) \leq y \leq y^u(f_{zx})$, AND NOT (R(1) AND R(2)).

$y' = y - ((1-r).1y(n) + r.1(n))/\delta y$

$$YF(1_z, f_{zx_2})_{zx_2 y} = YF(1_z, f_{zx_1})_{zx_1 y^d(f_{zx_1}) - y^d(f_{zx_2})}$$

for,

$y^d(f_{zx_2}) \leq y \leq y^u(f_{zx_1}) - y^d(f_{zx_1})$, and

$(x_1)(x_2)[f_{zx_1} = f_{zx_2}$ HOLDS (R(1) AND R(2))]

5.3.6. COMPUTATIONAL RESULTS

The model described in section 5.3.6. can be turned into a high performance algorithm. A technique of recursive fixing was implemented. The code was written in FORTRAN-77, and primarily developed for a VAX-computer. However, later a PC-version has been developed and implemented. The results displayed here all reflect the analysis on a VAX-8600 minicomputer. For displaying the results, the so-called sawing patterns, a routine was developed in SAS (Statistical Analysis Software). In fact SAS is overpowered for this application, however, because of programming convenience this tool was chosen.

Conversion of trees.

Before presenting and evaluating the computational results, let us first consider the assumptions made. The trees (timber) used in the experiments are only models of real stems. Real stems have all kinds of shapes that differ from the axis-symmetrical, knotted cones, used in the experiments. This however is not of importance when looking closer. Also non-model trees have a diameter as a (complex) function of the distance from the stump end (Glück, Koch, 1973).

The trees used in the experiments, are thus considered as knotted cones, with a diameter of 30 cm at 10 cm from the stump-end, and a diameter of 10 cm, at the top-end.

The three-dimensional grid, superimposed on the tree varies from 5 mm up to 20 mm for its unit-interval width. The products used for the computations are divided into two length classes of 50 and 100 cm respectively. Every class of products bounds consists of 21 products, the characteristics of which are displayed in table 5.1.

Table 5.1. Characteristics of the products, used in the computations(lz = z-length, lx = x-length, ly = y-length)

number	lz = 50	lx	ly	lz = 100	number
1	0.30	20	20	0.45	2
3	0.60	20	40	1.10	4
5	1.15	20	60	3.10	6
7	1.55	40	40	4.10	8
9	2.40	40	60	5.00	10
11	3.20	40	80	6.50	12
13	3.60	60	60	7.50	14
15	4.80	60	80	10.00	16
17	6.20	60	100	12.70	18
19	6.50	80	80	13.50	20
21	8.50	80	100	17.00	22
23	9.80	80	120	18.00	24
25	10.80	100	100	20.00	26
27	12.50	100	120	25.00	28
29	14.50	100	140	30.00	30
31	15.50	120	120	32.00	32
33	17.50	120	140	35.00	34
35	20.50	120	160	42.00	36
37	21.00	140	140	45.00	38
39	24.00	140	160	50.00	40
41	27.00	160	160	55.00	42

Table 5.2. Effectivity and efficiency as functions of tree length and grid-width. (Effectiveness is defined as percentage of largest profit, efficiency as the reciprocal of the percentage of the shortest cpu-time.

L_{eff}(cm)	δx(mm)	δy(mm)	profit(Dfl)	cpu(sec)	effectiv(%)	effic(%)
400	5	5	207.65	22.53	100	1.9
400	10	10	207.65	2.89	100	15.0
400	20	20	199.90	0.43	96	100.0
800	5	5	484.35	47.31	100	1.7
800	10	10	478.05	5.95	99	13.0
800	20	20	458.15	0.80	95	100.0
1200	5	5	763.95	73.91	100	1.9
1200	10	10	759.90	9.89	99	14.0
1200	20	20	727.85	1.41	95	100.0
1400	5	5	908.35	88.71	100	2.0
1400	10	10	891.70	11.40	98	15.0
1400	20	20	854.70	1.76	94	100.0

Other applications

Although not specially developed for the purpose, the algorithm can also be used in other fields of applications. For instance, the algorithm can be used to cut rectangular plates of material, such as steel and plastics.

To make a comparison with existing algorithms, the one suggested by Gilmore and Gomory (1969), including the speed-up suggestions made by Christofides and Whitlock (1976) was implemented.

The algorithm based on DP suggested in the previous sections can only make the so-called parallel guillotine cuts. The algorithm based on Gilmore and Gomory however can make general guillotine cuts, so it provides upper bounds to the effectiveness of our algorithm. In table 5.3 the used products for the experiments are given. In table 5.4 the results of some tests are displayed.

Table 5.3. Product dimensions and values (All lengths in mm).

number	length	width	value	length	width	value	number
1	10	40	0.60	20	20	0.40	2
3	20	50	1.60	20	110	3.50	4
5	30	30	1.10	30	50	2.50	6
7	40	20	0.90	40	30	1.50	8
9	40	40	2.45	40	50	3.20	10
11	40	130	8.00	50	50	3.25	12
13	60	50	4.40	70	20	2.05	14
15	80	40	5.10	80	80	10.75	16
17	90	50	7.80	110	60	9.50	18
19	120	130	12.00	160	110	15.00	20

Table 5.4. Computational results when cutting six different sized plates into rectangles of various values. (Board dimensions in cm, profit in Dfl, effectivity and efficiency in %) GG means Gilmore and Gomory, DPB means algorithm based on Dynamic Programming.

	GG				DPB			
board	profit	cpu	effec¹.	effic².	profit	cpu	effec¹.	effic².
10*10	16.40	0.03	100	100	16.40	0.02	100	149
18*18	53.95	0.09	100	100	53.60	0.05	99	200
28*28	130.80	0.25	100	100	130.15	0.08	100	321
48*48	387.00	0.94	100	100	387.00	0.09	100	1000
70*70	821.80	2.49	100	100	816.40	0.17	99	1428
100*100	1676.60	6.39	100	100	1695.10	0.19	100	3333

¹) Effectiveness as percentage of the maximum possible profit.
²) Efficiency as percentage of reciprocal of the cpu time.

Evaluation

As a first conclusion it can be stated that the developed algorithm is very powerful. A very high efficiency is coupled to a high effectiveness. When using a technique of life sawing, the patterns are optimal. In practice, as described in earlier sections, the process of converting a tree (stem) into final-products (boards) is performed in two stages. Of course our algorithm will also function in this situation, that is in fact a simpler (two-dimensional) problem. However, maximum recovery percentages are only reachable when using a three dimensional break down process.

Because of the combination of high efficiency and effectiveness, the algorithm and the corresponding software are useful for an on-line application. In cases where the need for efficiency dominates the need for effectiveness, the algorithm can be used for the cutting-stock problem as defined for rectangular plates.

5.4. TACTICAL SUPPORT, PLANNING MODEL

In section 5.3 the process of crosscutting and sawing a tree or a log into lumber of various dimensions has been discussed rather in depth. In this section 5.4. a continuation will be made with the problem of embedding a procedure for breaking down a tree, into a more overall tactical planning model.

5.4.1. GOAL

In chapter three the need for integral logistics has been emphasized. Let us now continue with the discussion of the exact goal for making a tactical planning. When sawing stems, with given dimensions, optimally in assortments, and these assortments into boards, a specific distribution of boards results. On the operational planning level, this production process is carried out using a list of board and assortment dimensions and values.

Depending on a push or pull strategy, several distinct tuning problems arise when planning the production. For instance service rate and value recovery on raw material may be conflicting issues.

On the tactical level a production planning needs to be made, that combines the advantages and disadvantages of both push and pull production strategy. In other words, goal of the tactical planning is to find production schedules, that both use the raw material efficiently, and effectivily (towards the customers). This production plan, made for several weeks (multi-period) must be translated to a sound operational policy.

5.4.2. MODULAR SYSTEM

When searching for planning models, a serious problem is encountered. Planning models are made for a typical plant, or conversion site, and thus are more or less specific. Our goal was however to find more or less general structures to support the process of tactical production planning. A direct result of this approach is the fact that a confrontation occurs with very many types of sites.

For instance the raw material stream differs from situation to situation. Some conversion sites are supplied out of company owned forests. Other plants get their input from both owned forests and from the market.

Furthermore the semiproducts situation may not be determined simply for all different types of companies.
Some companies have besides a production function, also a trading function, and therefore buy and sell semiproducts from and to the semiproducts (assortment) market.

Also layouts can differ both in terms of capacity and configurations.
All these aspects have driven this research towards a point of view from which distinct plants are considered as built up of standard components. Different sets of components can be made, and therefore distinct conversion sites can be considered. Briefly and to the point, a modular systems approach was adapted. Figure 5.8 displays the components.

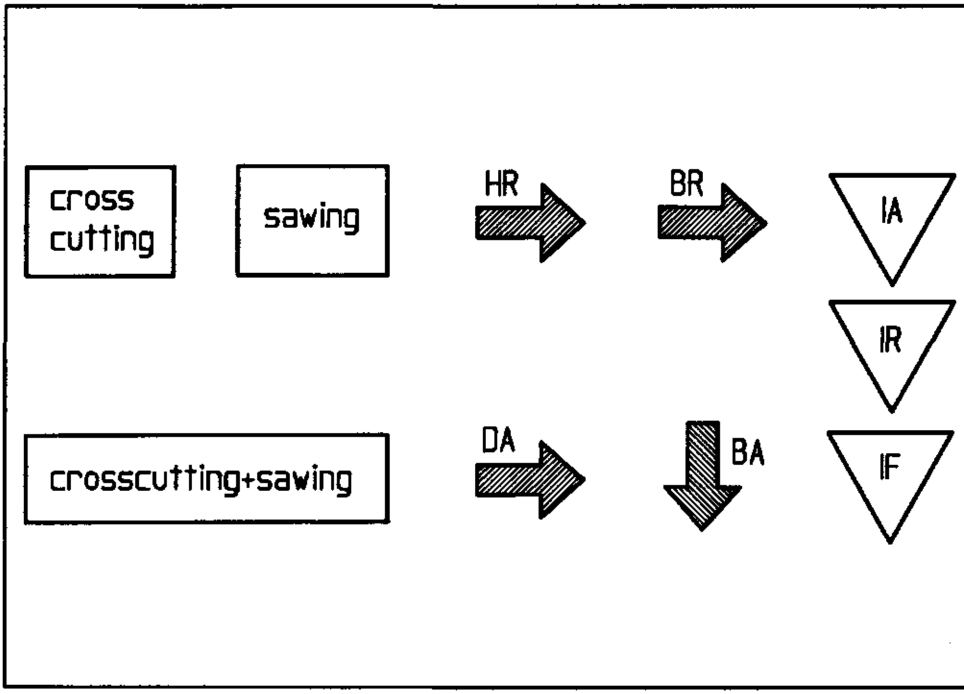


Figure 5.8. Conversion-site components, HR = Harvested Raw material, BR = Bought Raw material, DA = Demand Assortments, BA = Bought Assortments, IA = Inventory Assortments, IR = Inventory Raw material, IF = Inventory Final products.

In chapter six it will be explained that from a software development point of view this modular approach has substantial benefits. With the components-library it is possible to construct 16 different layout configurations, and of course within these basic types one can vary all numerical parameters (capacities, velocities, cost etc.).

In fact two really different sites are worth while when speaking in terms of mathematical modelling. The first plant is called traditional, the second plant can be called integrated with respect to the conversion technology (see figure 5.9.).

5.4.3. BASIC ASSUMPTIONS.

Before introducing the mathematical formulations of the tactical planning model, a discussion of the assumptions is needed.

The input for a plant are stems, which form its raw material. Trees have all kinds of properties. We can mention quality and dimensions. No two stems are exactly the same.

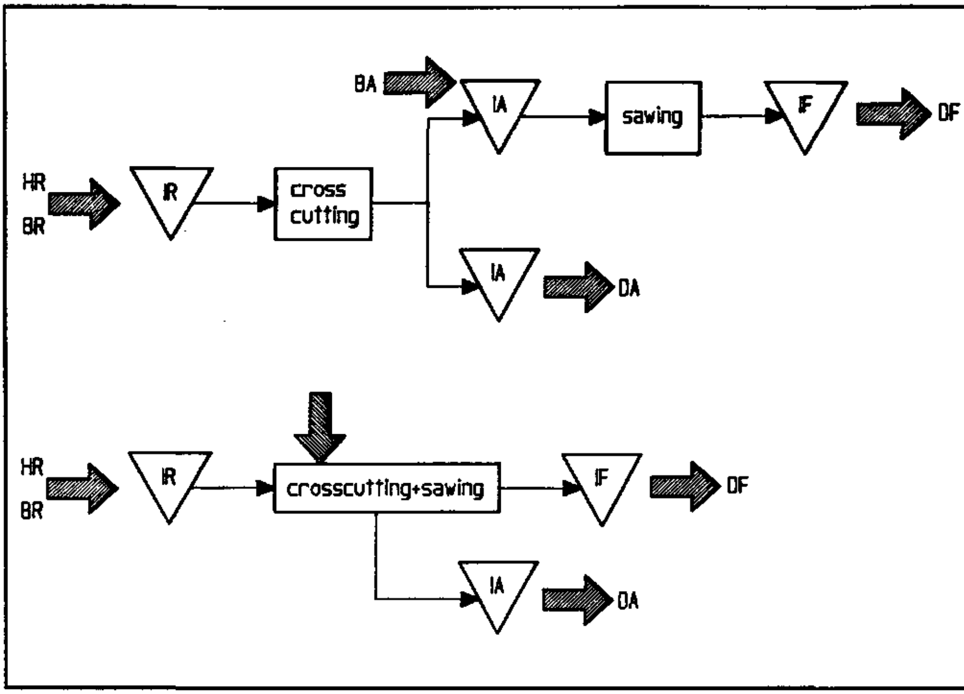


Figure 5.9. Two basic layout configurations.

When making a tactical planning, it will be clear that not all types of trees can be distinguished. A model of a stem needs to be made. To impose limits on the different occurrences of trees, classes can be defined.

A class is a set of trees, with limited variations in their different properties. This process of constructing classes can be called aggregation (Hax, 1986). Classes can be made with respect to e.g. length, diameter and quality.

Because every class consists of stems with relatively little variance in their characteristics, the class can be considered as a set of equal stems, all of a type called the representative stem. This representative stem has properties reflecting the properties of the class, without making too big an error.

Consider a population of stems, construct classes in a way that the interval width for each property is small. The population can now be considered as built up of many stems of a restricted number of types, being the representative stems. Each representative stem has for its properties the mean value of its class. A pile is a set of trees, belonging to one or more classes.

The stems are coming to the site whether debarked or not. In our model the debarking, reducing to circular cross-sections and other types of "conversion" steps where neglected. Hence, only crosscutting and sawing are considered as conversion steps.

When crosscutting a stem into assortments, waste is produced. The waste formed at the top-end, and the waste produced during the crosscutting process are taken into account. For many plants, also the saw-dust is considered as a secondary product. The amount of merchantable saw-dust however is not considered in the models.

The demand, from the market, for waste material will be realized in a demand for cubic meters of chips, waste prices etc. In the presented model, this demand is considered to be realized in pieces. The reason for this assumption is due to programming convenience.

After conversion of a stem into assortments, the logs have to be stored. It was assumed that enough space is available on the yard, to sort out all the different logs (e.g. in boxes). A direct consequence of this (realistic) assumption, is that the next processing step can make use of any type of assortment available, without a chance of picking the wrong (unsuitable) log to process. Hence, no extra risks are taken into account producing unwanted products from an assortment picked from inventory by accident.

The assortments are considered as semiproducts. These semi-products (logs) are cylindrical, and have a typical length, and a diameter at the top-end. In fact, most companies use a diameter tolerance for the diameter at the top-end. Equally to the situation of raw-material, the assumption was made that the assortments having a diameter within the diameter-tolerance, form a class. Therefore only a representative assortment is considered for each class. For most assortments the deviation from the representative assortment is only small, taking into account the fact that in practice often tolerances of one or two centimeters are used.

Also for the process of sawing an assortment into boards, some assumptions were made. A log can be sawn into boards with length lower or equal to the log-length. Only boards with lengths equal to the log-length were tolerated. Furthermore only acute-angled boards were taken into account. This means that boards having a waney-edge are considered waste in this model. Before introducing the model formally, let us introduce the symbols used.

5.4.4. SYSTEMATIC SYMBOL DEFINITION

When discussing large models, readers are often faced with the problem of translating the model into an understandable concept. This problem of translation cannot be avoided totally. However it can be reduced by using symbols that speak for themselves. When doing this we have to dilute our claims with respect to the beauty of the formulation, however the readibility will increase.

Every variable and parameter is defined in a way that its name is an acronym (as much as possible) of its function in the model. A variable or parameter name can be considered built up out of "describing characters". In table 5.6 the status describing characters are visualized.

Table 5.6. Status describing characters.

abbreviation	*meaning*
I	*Inventory*
O	*Out of stock*

In table 5.7. the characters pointing to the processor-type can be found.

Table 5.7. Processer describing characters.

abbreviation	*meaning*
M	*Merchandizer, or crosscutting saw*
S	*Saw for conversion to final products.*

A difference has to be made between the entities of the system. They are summed up in table 5.8.

Table 5.8. Entity describing characters.

abbreviation	*meaning*
R	*Raw material (trees)*
S	*Semiproducts (assortment)*
F	*Finalproducts (boards)*
a	*first class of a pile*
z	*last class of a pile.*

A number of decisions have to be made when performing a planning for the production. In table 5.9. the decision variables are displayed.

Table 5.9. Decision describing characters.

abbreviation	*meaning*
X	*Number of conversions from tree to assortment*
Y	*Number of conversions from assortments to boards*
Z	*Number of assortments to be purchased.*

Moreover some indices are used to indicate the process, action or phase on hand (See table 5.10).

Table 5.10. Indices.

abbreviation	*meaning*
n	*raw material class n*
p	*pile p*
c	*crosscutting pattern c*
s	*sawing pattern s*
a	*assortment a*
f	*final-product f*
t	*time-period t.*

Furthermore some general describing characters were used, as displayed in table 5.11.

Table 5.11. General describing characters.

abbreviation	*meaning*
T	*Time*
C	*Cost*
V	*Value*
N	*Number (amount)*
D	*Demand*
K	*Capacity*
P	*Production*
L	*Limit*
E	*Extra*
U	*Unemployed.*

With these describing characters the parameters and variables can be formulated as a sequence of describing characters. A difference is made between the distinct kinds of variables. Some variables are considered endogene, others exogene. Of course at this moment not all introduced variables can be interpreted fully by the reader. However this section must be considered as a reference for the further model explanations. In table 5.12. all variables refering to decisions made by the manager are reflected.

Table 5.12. Endogene decision variables.

variable	*dimension*	*meaning*
Y^t_{cn}	(-)	*Frequency for using crosscutting pattern c, for raw material class n, in planning period t.*
X^t_{sa}	(-)	*Frequency for using sawing pattern s, for assortment a, in planning period t.*
Z^t_a	(-)	*Number of assortments a, bought on the market, in time period t.*

After making decisions, the system moves to a typical status. This status is described by a set status descriptors, which are considered endogene (table 5.13.).

Table 5.13. Endogene status descriptors.

descriptor	*dimension*	*meaning*
IR_p^t	(-)	*Inventory of raw material, of pile p, at the end of time period t.*
IA_a^t	(-)	*Inventory of assortment a, at the end of time period t.*
IF_f^t	(-)	*Inventory of final-product f, at the end of time period t.*
OA_a^t	(-)	*Out of stock level, of assortment a, at the end of period t.*
OF_f^t	(-)	*Out of stock level, of finalproduct f, at the end of period t.*
EM^t	(hours)	*Extra hours worked at the merchandizer, in week t.*
UM^t	(hours)	*Unemployed hours at the merchandizer, in week t.*
ES^t	(hours)	*Extra hours worked at the saw-mill, in week t.*
US^t	(hours)	*Unemployed hours at the saw-mill, in week t.*

A third set of parameters is formed by the process descriptor. These parameters are considered fixed on the tactical level and can only vary on the strategic level, they are thus be denoted exogene (table 5.14).

Table 5.14. Exogene process descriptors.

descriptor	*dimension*	*meaning*
NA^t_{acn}	*(-)*	*Number of assortments of type a, when processing a stem of class n, using pattern c, in time period t.*
NF^t_{fsa}	*(-)*	*Number of final-products of type f, when processing an assortment of type a, using pattern s, in time period t.*
Nn	*(-)*	*Number of classes.*
Np	*(-)*	*Number of piles.*
Na	*(-)*	*Number of assortments.*
Nf	*(-)*	*Number of final-products.*
Ns	*(-)*	*Number of sawing patterns.*
Nt	*(-)*	*Number of periods.*
Nc	*(-)*	*Number of crosscutting patterns.*
WEEK	*(hrs)*	*Number of regular working hours in a week.*
BUD^t	*(Dfl)*	*Budget for purchasing assortments in period t.*

To enable the decision maker to distinguish between distinct planning policies, a financial analysis must be possible. Therefore financial descriptors are included in the model. They are displayed in table 5.15.

Table 5.15. Endogene and exogene financial descriptors.

descripton	*dimension*	*meaning*
CP	*(Dfl/hour)*	*Cost of production.*
CPM^t_{cn}	*(Dfl)*	*Cost of production using crosscutting pattern c, for raw material class n, in planning period t.*
CPS^t_{sa}	*(Dfl)*	*Cost of production using sawing pattern s, for assortment a, in time period t.*
VR^t_{cn}	*(Dfl)*	*Value of a stem out of class n, in period t, using crosscutting pattern c.*
VA^t_{sa}	*(Dfl)*	*Value of an assortment a, in period t, using sawing pattern s.*

Table 5.15 (continuation). Endogene and exogene financial descriptors.

descriptor	*dimension*	*meaning*
CIA_a^t	*(Dfl)*	*Cost of inventory for assortment a in time period t.*
COA_a^t	*(Dfl)*	*Cost of stockout for assortment a in time period t.*
CIF_f^t	*(Dfl)*	*Cost of inventory for final-product f in time period t.*
COF_f^t	*(Dfl)*	*Cost of stockout for final-product f in time period t.*
CIR_p^t	*(Dfl)*	*Cost of inventory for raw material, of pile p, in time period t.*

Every plant uses many machines and tools to process trees. Of course not all characteristics can, and have to be included in a tactical planning model. Instead, some general machinery descriptors, derived from more detailed specifications, are used to describe the process (table 5.16). The processing times are calculated in the dynamic programming modules.

Table 5.16. Machinery descriptors.

descriptor	*dimension*	*meaning*
TR_{cn}^t	*(hours)*	*Time needed to process a tree of class n, with pattern c, in time period t.*
TA_{sa}^t	*(hours)*	*Time needed to process assortment a, with pattern s, in time period t.*

A conversion site is economically related to its environment by means of incoming material, and demand for semi and final products. Therefore, a set of exogene, scenario descriptors is taken into account in table 5.17.

Table 5.17. Exogene scenario descriptors.

descriptor	*dimension*	*meaning*
DA_a^t	(-)	*Demand for assortments of type a in time period t.*
DF_f^t	(-)	*Demand for final products of type f in time period t.*
HR^t	(-)	*Harvested raw material in period t.*
BR^t	(-)	*Bought raw material, in period t.*
BS_a^t	(-)	*Bought semiproducts type a, in period t.*
β_n	(-)	*Percentage ratio of class n with respect to the total input of raw material.*

5.4.5. RAW MATERIAL

The material input for a CCS is formed by the stems, both harvested and purchased. Harvested and bought raw material are considered to be stored separately.

As a result of aggregation (section 5.4.3.), the total population of stems is considered to be a set of representative stems for the so-called classes. In the model the sorting and grading mechanism was one dimensional. Only the diameter at breast height (± 130 cm from the stump end) is used to grade the stems into classes. Nota bene, we are only speaking of aggregation of the raw material into classes, the actual physical sorting is not considered yet. (see figure 5.10).

Very often the raw material is not just stored on a large pile at the CCS. The stems are graded and sorted, and afterwards stored on separate piles. At the tactical planning level the decisionmaker has to work with a given number of piles. In other words a given site layout, with respect to raw materials handling, has to be used optimally. After sorting in physical piles, a situation as displayed in figure 5.11. can be viewed.

Hence, every pile consists of at least one, and probably more classes. For every pile p, a set of classes can be defined. In fact classes, used for different piles may overlap, however for this moment only disjoint classes are considered. Later, when discussing a case-study, also overlap will be looked at.

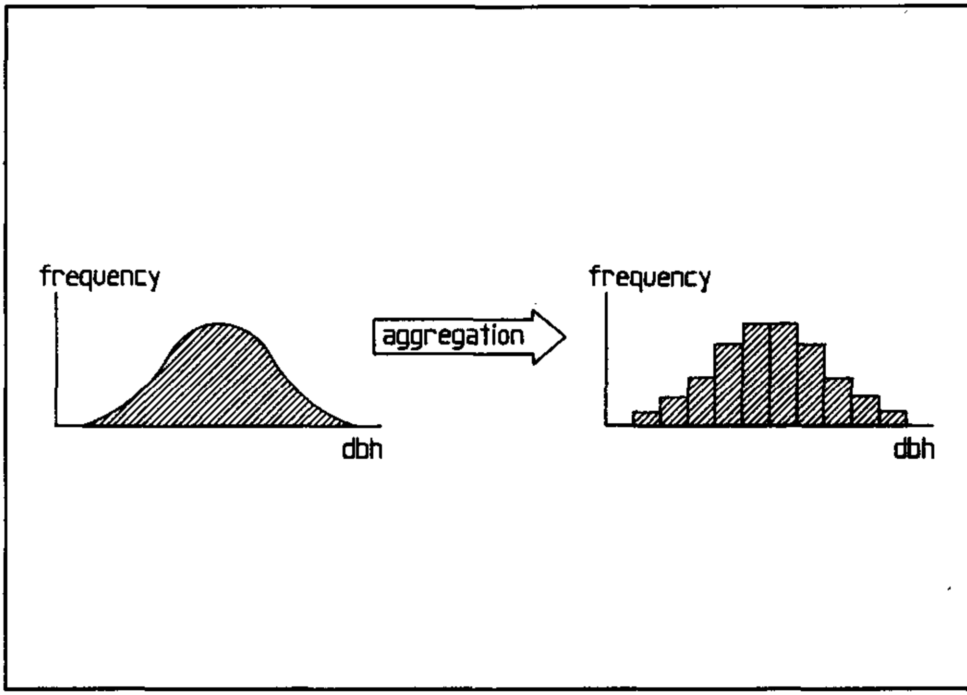


Figure 5.10. Raw material classes.

Thus, a pile p, can be described with classes n, such that $a_p \leq n \leq z_p$, where a_p and z_p indicate the lower and upper classes of pile p.

The number of stems of each class can be calculated from the scenario descriptors β_n, indicating the percentual share of class n in the total stem population. So, the number of trees coming in time period t, for class n, can simply be denoted with $\beta_n.HR^t$. The same is true for the extra bought stems, $\beta_n.BR^t$.

5.4.6. CROSSCUTTING, THE PRIMARY BREAKDOWN

In section 5.2. an algorithm was discussed to perform the breakdown of a stem into logs optimally. After crosscutting a stem optimally, assortments (semiproducts) are the result. Depending on dimensions and value, an assortment is produced more or less frequently from a stem. When using a crosscutting method, called a crosscutting pattern, denoted with c, the result is a mix of logs. Every log occurs a number of times, denoted with NA^t_{acn}. This is displayed in figure 5.12.

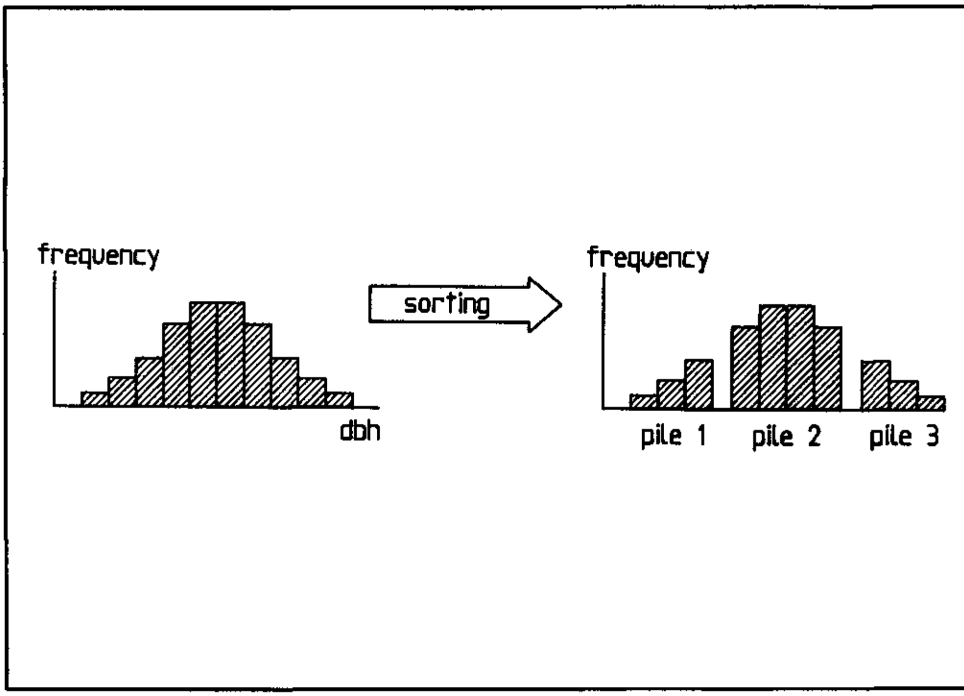


Figure 5.11. Classes and piles.

The assortments thus produced, can be used to meet a demand for assortments on the open market, or to be processed to boards. How much of each assortment should be produced? In other words, how many times should a stem of class n be processed into assortments?
When evaluating this decision it is clear that the number of times a tree can be processed with a specific pattern c (Y^t_{cn}) is bounded through a so-called material balance equation. When producing logs, a limit is imposed by the availability of trees. On the other hand when producing more then is asked for, an inventory of non-sold assortments will be caused.

What happens when production is less than is asked for? A shortage occurs! The result of this shortage is that later, when again assortments have been produced, the earlier caused shortages must be met. This is called a situation with backorders .

A situation of physical shortages can only exist for those assortments produced for the semiproducts market. Selfevidently, assortments used for further processing can be asked for in a desired amount, however when not reaching this ideal amount, a physical shortage will not occur. Simply because final products cannot be produced out of non-existing semiproducts. Instead of a physical shortage, a stress on the constraint representing the limited availability of the assortment of interest will result. This will be discussed in depth in section 5.5.

After discussing the effects of producing assortments, let us now formulate the relations more mathematically.

- *Limited availability of raw material.*

$$\sum_{c=1}^{Nc} \sum_{n=a_p}^{z_p} Y_{cn}^t + IR_p^t = \sum_{n=a_p}^{z_p} \beta_n (HR^t + BR^t) + IR_p^{t-1} \qquad 1 \le t \le Nt;\ 1 \le p \le Np$$

This set of equations can be considered as balance equations with respect to the raw material. It says that the amount of trees processed from a pile, summed with the amount of trees not processed, is equal to the amount of trees in the pile summed with the number of trees left from the preceeding week. The variable IR_p^{t-1} will be the initial stock when starting the optimization in case $t=1$. Hence

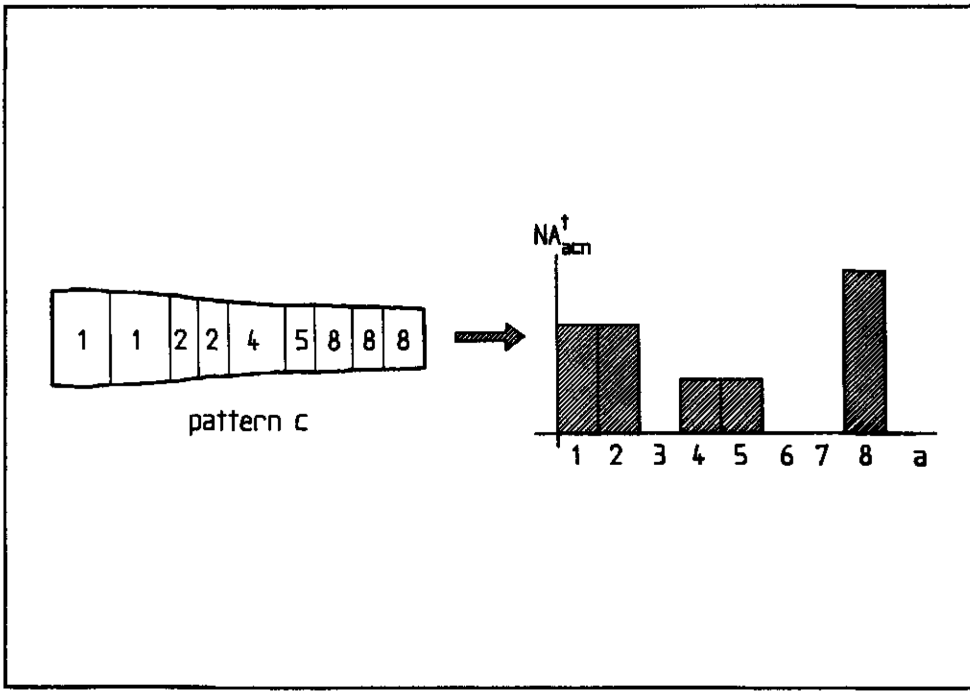


Figure 5.12. Crosscutting.

the initial number of trees in a pile when starting the planning is denoted with IR_p^o.

- *Constraints due to limited sorting.*

$$\sum_{c=1}^{Nc} \beta_n Y_{cn-1}^t - \beta_{n+1} Y_{cn}^t = 0 \qquad 1 \leq t \leq Nt;\ 1 \leq p \leq Np;\ a_p \leq n \leq z_p$$

In section 5.4.6. aggregation was discussed as a way of imposing limits on the dimensions of the model. In practice a company also sorts the stems (raw material) more or less.

If all representative trees are labeled and stored, the decision variables are limited only by the available amount of stems for each class. However, sorting will probably not be done to such an advanced manner.

In a case of none maximum sorting, in other words if the number of piles is less than the number of classes, this extra set of constraints occurs. For the decision to select a specific tree out of class n_1 is now limited because probably a stem of class n_2 is chosen, because both classes are in the pile of interest. In other words, not investing in sorting equipment, or logistical organisation, means increased uncertainty in selecting specific trees for typical purposes.

- *Directedness towards demand for semiproducts.*

Again, a balance equation can be formulated. All assortments produced or bought on the semi manufactured products market, summed with the inventory left from the preceding period, is equal to the demand for semiproducts, either for further processing, or for the open market, summed with the inventory.

$$\sum_{c=1}^{Nc} \sum_{n=1}^{Ns} NA_{acn}^t \, Y_{cn}^t + IA_a^{t-1} + OA_a^t + Z_a^t =$$

$$(1-\Phi_a) \sum_{s=1}^{Ns} X_{sa}^t + \Phi_a \; DA_a^t + IA_a^t + OA_a^{t-1}$$

$1 \leq t \leq Nt; \; 1 \leq a \leq Na$

In this set of equations the function Φ_a, having values 1 or 0, indicates whether the assortment is used for further processing ($\Phi_a = 0$) or for direct sales ($\Phi_a = 1$). When starting the planning, the initial inventory for assortment a is denoted with IA_a^0.

- *Capacity constraint, due to limited merchandizer capacity.*

Crosscutting stems into assortments requires production time on the crosscutting equipment (merchandizer). The amount of time required is a direct function of the number of cuts to be made, and the local diameter of the tree. Of course the available time on the merchandizer is limited. Time consuming, "complex", patterns may fit best to a demand distribution, but may be costly because of the production time required. Therefore,

$$\sum_{c=1}^{Nc} \sum_{n=1}^{n=Nn} TR_{cn}^t \; Y_{cn}^t - EM^t + UM^t = WEEK \qquad 1 \leq t \leq Nt$$

The extra time used in overtime, is of course more expensive than the production during the regular shifts.
Not working has no influence on the production cost in the model. For the crew has been paid for, whether they work or not. This approach can be considered as part of the Optimized Production Technology (OPT) (Gelders, Wassenhove, 1984; Jacobs, 1983), the so-called throughput maximization.

- *Budgetary limits.*

If available, extra assortments can be bought on the semimanufactured products market. The only limit imposed on the amount of assortments bought is of budgetary nature.

$$\sum_{a=1}^{Na} v(a).Z_a^t \leq BUD^t \qquad 1 \leq t \leq Nt$$

5.4.7. SAWING, THE SECONDARY BREAKDOWN

Earlier in this thesis, section 5.2., the use of DP to optimize the sawing of a log into boards has been discussed. After breaking down a log, a frequency distribution is the result for the boards. Some boards are produced many times, others less, and some not at all (see figure 5.13.).

Every final-product f, is produced NF_{fsa}^t times, when using pattern s, for assortment a. Different patterns s can be used in distinct weeks t.

The final-products produced, can be used to meet the market demand. How much of each product should be produced? Or, how many times should pattern s be used for an assortment a, in week t, to make a profitable contribution to the inventory?

Of course, final-products can only be produced from assortments available. Hence, the possible production-quota is limited by the amount of assortments produced.

If the total production of a product f exceeds the demand, inventory will be the result. On the other hand, if production can not meet the demand, a shortage occurs. This inability to serve the customers, might lead to a loss of goodwill. The latter can reduce future sales. To model this effect, stockout cost are introduced. These cost are not directly economically interpretable. However, for the time being, all that is of interest is the fact that not meeting demand has a negative effect. This discussion will be continued in section 5.5.

- *Directedness towards demand for final-products.*

A set of equations for all finalproducts f, describes the balance of material for boards. It says that all final products produced summed with all products left from the preceding week, must meet the demand for boards.

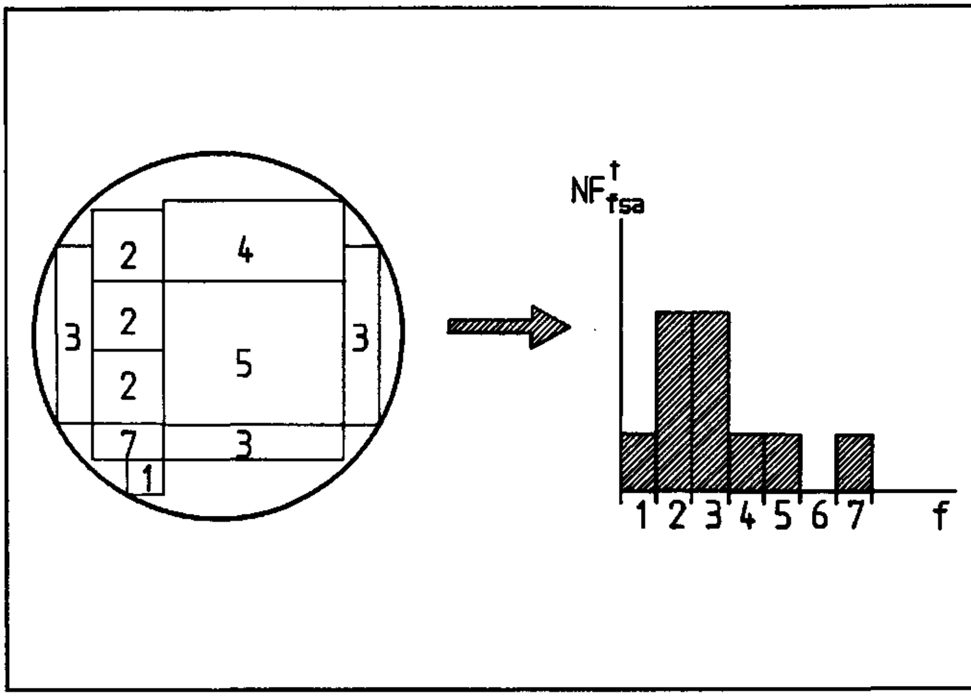


Figure 5.13. Sawing.

$$\sum_{s=1}^{Ns} \sum_{a=1}^{Nc} NF^t_{fsa} X^t_{sa} + IF^{t-1}_f + OF^t_f = DF^t_f + IF^t_f + OF^{t-1}_f \quad 1 \leq t \leq Nt;\ 1 \leq f \leq N$$

When starting the planning, the initial inventory is denoted with IF^0_f, or the initial shortage with OF^0_f. Shortages as well as inventories propagate in time, a situation of backorders is the result.

- *Capacity constraint, due to limited saw capacity.*

Processing assortments into boards requires production time on the sawing equipment. Complex sawing patterns, perhaps leading to high value recovery rates, may asks a lot of handling and sawing time. More simple patterns may be less optimum with respect to value recovery, but more attractive nevertheless because of their lower capacity demand.

$$\sum_{s=1}^{Ns} \sum_{a=1}^{Na} TA_{sa}^{t} X_{sa}^{t} - ES^{t} + US^{t} = WEEK \qquad 1 \le t \le Nt$$

5.4.8. REFORMULATING THE OBJECTIVES

A discussion of the objectives of the model can best be introduced by discussing the financial impact of making decisions for a CCS production planning. Firstly the possible revenues of producing boards and assortments will be regarded. Secondly the possible cost arising for instance with inventory and labour will be discussed.

- *Producing assortments*

After processing a tree into assortments, the number of logs will be NA_{acn}^{t} for each log of type a. The possible revenues, the "value" of a stem of class n, will thus be the sum of the values v(a) of all assortments produced out of it. Hence

$$VR_{cn}^{t} = \sum_{a=1}^{Na} v(a).NA_{acn}^{t}$$

However, producing assortments implies use of capacity at the crosscutting machinery. If the time needed for processing a tree from class n, with crosscutting pattern c takes TR_{cn}^{t} hours, then a correction on VR_{cn}^{t} can be made for the production cost.

$$CPM_{cn}^{t} = CP.TR_{cn}^{t}$$

Hence

$$VR_{cn}^{t} = \left(\sum_{a=1}^{Na} v(a).NA_{acn}^{t}\right) - CPM_{cn}^{t}$$

After calculating VR^t_{cn}, the frequency of using pattern c for a stem of class n is of interest. The total value of the assortments, added after processing all trees can be denoted as

$$\sum_{t=1}^{Nt} \sum_{c=1}^{Nc} \sum_{n=1}^{Nn} VR^t_{cn} . Y^t_{cn}$$

- *Producing boards.*

Processing an assortment into boards, the number of boards will be NF^t_{fsa} for each board of type f. The possible revenues, the "value" of an assortment of type a, will hence be the sum of the values of all boards produced out of it. Thus,

$$VF^t_{sa} = \sum_{f=1}^{Nf} v(f) . NF^t_{fsa}$$

Producing final-products means taking up capacity at the sawing equipment. For every assortment processed with a sawing pattern s, an amount of time of TA^t_{sa} is needed. Therefore the production cost are,

$$CPS^t_{sa} = CP . TA^t_{sa}$$

Hence

$$VA^t_{sa} = (\sum_{f=1}^{Nf} v(f) . NF^t_{fsa}) - CPS^t_{sa}$$

Furthermore, the total contribution to the financial results of producing boards is of interest.

The summed values of the boards (v(f)), after processing assortments can be regarded as

$$\sum_{t=1}^{Nt} \sum_{a=1}^{Nc} \sum_{s=1}^{Nn} VA_{sa}^{t} . X_{sa}^{t}$$

- *Purchasing Assortments.*

Extra assortments can be bought on the semimanufactured goods market. The cost made for purchasing are

$$\sum_{a=1}^{Na} \sum_{t=1}^{Nt} v(a) . Z_{a}^{t}$$

- *Inventory and shortages.*

This subject, cost related with inventory and shortages needs a more fundamental discussion.

Consider a company, trying to meet the demand for both assortments and boards. Suppose that all orders, placed by various customers, are considered aggregated. This means that the company faces a total demand for each product in each planning period.

Furthermore, assume a planning horizon of six weeks. This means that the company plans its production six weeks ahead. In week one, lots of orders have been booked. All these orders will occur with certainty.

However for the second week, most orders are certain, but also a small number of orders is indeed expected, but they are not absolutely certain to occur. The third, fourth, and fifth week give similar expectations, although the part of the orders becoming uncertain increases (fig 5.18). Finally, week six is booked with orders that are expected only. The amount of orders predicted can be estimated by using a variety of forecasting techniques.

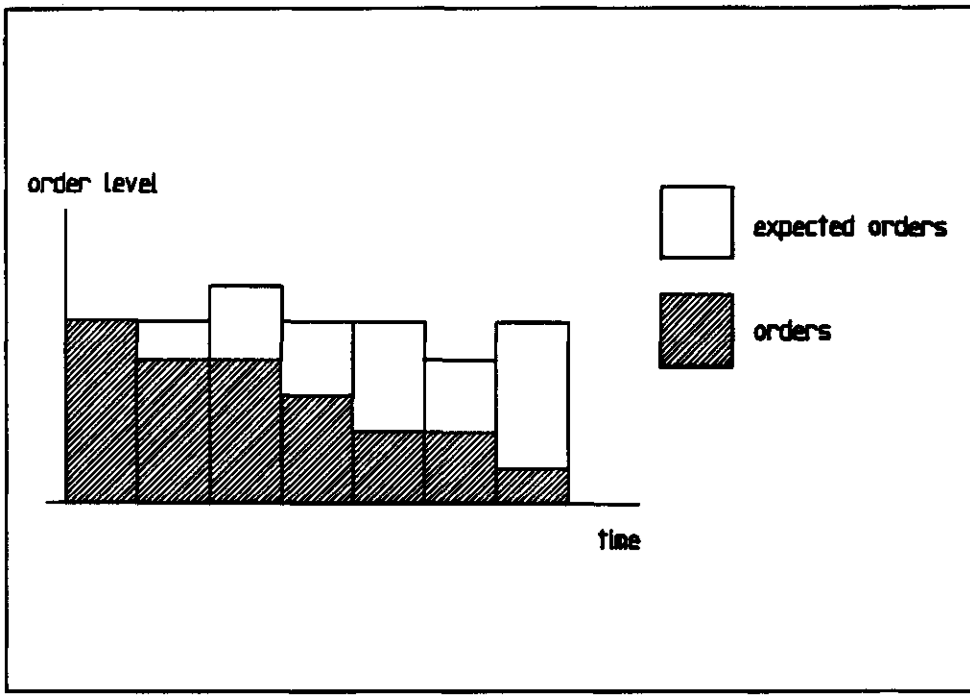


Figure 5.14. The order level for product f for various weeks.

The increasing uncertainty in order levels should influence the controlling of the model. Orders for next week are all realistic, and should be met as well as possible (if making profit is the goal of the company). Orders for timeperiods further ahead are uncertain, and it is thus not very realistic to make a planning in week one, which forces the system to meet demand for the weeks ahead. Is it very important to meet a yet uncertain demand level in week five? In our opinion, the delivery in future periods is of less importance than on the actual moment. A consequence of this reasoning is that for future weeks, the aspect of maximum value recovery is of more interest than the possible realisation of profit.

Because every few weeks, or perhaps every week a planning is made for say, six weeks, future demand becomes more certain in every subsequent plan. On the other hand new weeks are considered in the plan. This way of planning is called a rolling horizon planning (figure 5.15.).

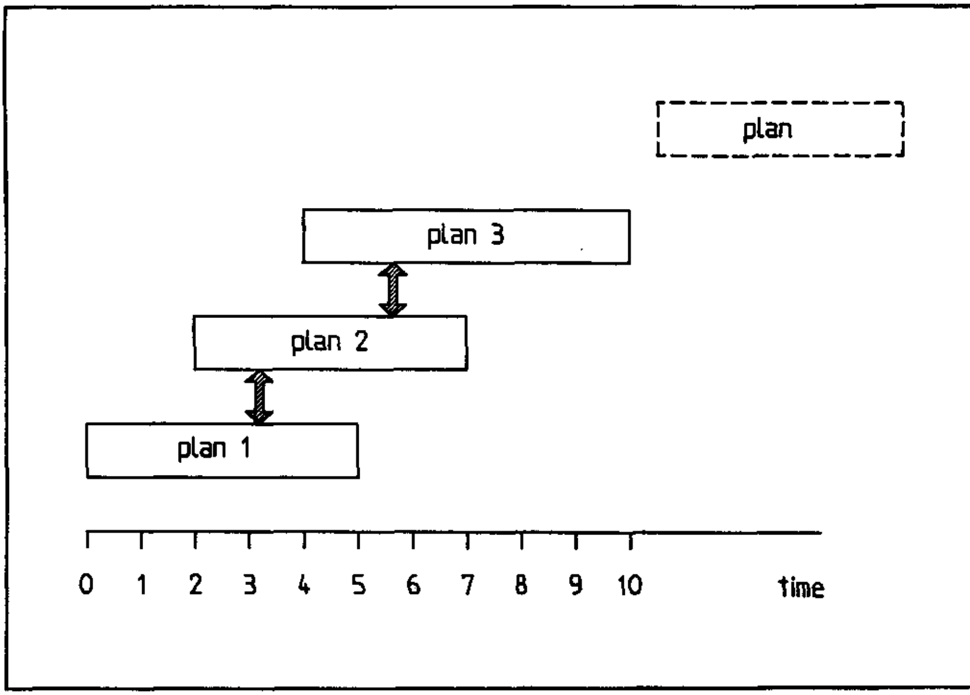


Figure 5.15. Rolling planning horizon.

Hence, the penalty incurred for not servicing the customers is a function of time. Expected disability for supplying future orders, is penalized less than not servicing next week. This is visualized in figure 5.16.

Nota bene that the decreasing out of stock cost are not the result of just imposing a discount rate. For this discount rate would effect all financial parameters in the model, instead of only the out of stock penalty.

If a positive inventory is the result at the end of the week, inventory cost will be the result. The inventory cost can be considered as a function of the time. This is accomplished by using a discount rate. A decreasing function from time resulting from a same point of view as discussed for out of stock cost is not regarded. This means that for planning periods further ahead the value recovery effect outbalances the profit aspect of production.

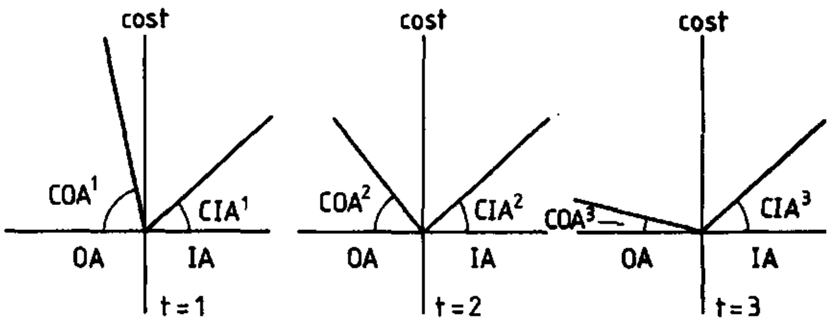


Figure 5.16. Inventory and out of stock cost as function of time.

Mathematically these reflections lead to the following contribution to the financial object function,

$$\sum_{t=1}^{Nt} \sum_{a=1}^{Na} (CIA_a^t . IA_a^t + COA_a^t . OA_a^t)$$

for the assortments. For the final products, these relations are,

$$\sum_{t=1}^{Nt} \sum_{f=1}^{Nf} (CIF_f^t . IF_f^t + COF_f^t . OF_f^t)$$

- *Raw material inventory.*

Production means in this case raw material usage. If the amount of stems in the system, combined with the inflow of stems exceeds the usage, an inventory occurs. The cost of this inventory is

$$\sum_{t=1}^{Nt} \sum_{p=1}^{Np} CIR_p^t . IR_p^t$$

- *Cost of labour.*

On the tactical level, the possibilities for flexible personnel management are restricted. It is considered unlikely that hiring and firing occurs within a period of days or weeks. Therefore the number of labourers is considered to be constant. This assumption results in the conclusions that salaries have to be paid, whether the crew is working the complete shift or not. In other words stand still does not result in extra cost. Moreover trying to achieve full usage of the shift-length might be undesirable in the framework of integral optimization. The crew is present, and they cost money working or not.

A different approach is made when working in the normal day shift is not enough to satisfy the demand for assortments and boards, or to anticipate for future demand. In this situation overtime might be profitable, in spite of the extra overtime rate. Of course the number of hours working in overtime should be minimized by scheduling the activities as well as possible. The contribution of labour cost can be denoted with,

$$\sum_{t=1}^{Nt} (CEM.EM^t + CES.ES^t)$$

- *Multiple goal.*

The goal of this model can now be stated as finding production and purchasing rates for raw material, assortments and boards, in a way that the raw material and the semi-products are used as efficiently as possible (value recovery), and also as effective as possible (servicerate). This production planning implies that an answer has to be found to what semi and final products must be produced in what quantity during which hours on what machine out of what raw material in what week. And this with respect to multiple goals, thus in a way that service-degree is maximum, raw material is optimally used, and capacity is reserved in order to anticipate for future demand.

Summarizing, the model supporting the tactical planning can be stated as:

$$\max \{ \sum_{t=1}^{Nt} (\sum_{c=1}^{Nc} \sum_{n=1}^{Nn} VR_{cn}^{t}.Y_{cn}^{t} + \sum_{s=1}^{Ns} \sum_{a=1}^{Na} VA_{sa}^{t}.X_{sa}^{t})$$

$$- (\sum_{a=1}^{Na} CIA_{a}^{t}.IA_{a}^{t} + COA_{a}^{t}.OA_{a}^{t})$$

$$- (\sum_{f=1}^{Nf} CIF_{f}^{t}.IF_{f}^{t} + COF_{f}^{t}.OF_{f}^{t}) - (CEM.EM^{t} + CES.ES^{t})$$

$$- (\sum_{a=1}^{Na} v(a).ZA_{a}^{t} + \sum_{p=1}^{Np} CIR_{p}^{t}.IR_{p}^{t}) \}$$

Subject to

$$\sum_{c=1}^{Nc} \sum_{n=a_p}^{z_p} Y_{cn}^{t} + IR_{p}^{t} = \sum_{n=a_p}^{z_p} \beta_n(HR^{t}+BR^{t}) + IR_{p}^{t-1} \qquad 1 \leq t \leq Nt;\ 1 \leq p \leq Np$$

$$\sum_{c=1}^{Nc} \beta_n Y_{cn-1}^{t} - \beta_{n+1} Y_{cn}^{t} = 0 \qquad 1 \leq t \leq Nt;\ 1 \leq p \leq Np;\ a_p \leq n \leq z_p$$

$$\sum_{c=1}^{Nc} \sum_{n=1}^{Ns} NA_{acn}^{t} \ Y_{cn}^{t} + IA_{a}^{t-1} + OA_{a}^{t} + Z_{a}^{t} =$$

$$(1-\Phi_{a}) \sum_{s=1}^{Ns} X_{sa}^{t} + \Phi_{a} \ DA_{a}^{t} + IA_{a}^{t} + OA_{a}^{t-1} \qquad 1 \leq t \leq Nt;\ 1 \leq a \leq Na$$

$$\sum_{c=1}^{Nc} \sum_{n=1}^{n=Nn} TR_{cn}^{t} \ Y_{cn}^{t} - EM^{t} + UM^{t} = WEEK \qquad 1 \leq t \leq Nt$$

$$\sum_{s=1}^{Ns} \sum_{a=1}^{Na} TA_{sa}^{t} \ X_{sa}^{t} - ES^{t} + US^{t} = WEEK \qquad 1 \leq t \leq Nt$$

$$\sum_{s=1}^{Ns} \sum_{a=1}^{Nc} NF_{fsa}^{t} \ X_{sa}^{t} + IF_{f}^{t-1} + OF_{f}^{t} = DF_{f}^{t} + IF_{f}^{t} + OF_{f}^{t-1} \qquad 1 \leq t \leq Nt;\ 1 \leq f \leq N$$

$$\sum_{a=1}^{Na} v(a).Z_{a}^{t} \leq BUD^{t} \qquad 1 \leq t \leq Nt$$

All variables continuous, and ≥ 0.

The size of this model, the number of constraints is

$$Nt(Np + Na + Nf + \sum_{p=1}^{Np} (z_{p} - a_{p}) + 3).$$

In special cases, this expression can be further simplified. Suppose that all piles, use disjoint classes. In this case,

$$\sum_{p=1}^{Np} (z_p - a_p) = Nn - Np.$$

Proof,

$a_{p+1} = z_p + 1$, furthermore $z_{Np} = Nn$, and $a_1 = 1$. Hence

$$\sum_{p=1}^{Np} (z_p - a_p) = \sum_{p=1}^{Np-1} z_p - \sum_{p=2}^{Np} a_p - 1 + Nn$$

$$= \sum_{p=1}^{Np-1} (z_p - a_{p+1}) - 1 + Nn$$

$$= (N_p-1).(-1) -1 + Nn = Nn - Np.$$

Therefore, the number of constraints equals

$$Nt(Nn + Na + Nf + 3)$$

if disjoint classes are used.

5.4.9. NEAREST DISCRETE SOLUTION

In the previous section the tactical planning model has been formulated mathematically. It was stated that all variables were positive, and continuous.

However, decision variables indicating production frequencies cannot be continous. Hence after solving the problem, formulated as a linear, multiple goal programming, model, the nearest, discrete (integer) solution has to be tracked. This way of searching for the integer solution implies a risk of finding a solution, not satisfying all constraints, because of rounding the activities of the variables in the continous solution. Is this a hard problem to solve?

A special software tool was developed to find the nearest integer solution. This module performs a number of iterations to find an integer solution, that is "physically" possible. Hence, no boards are cut from non-existent assortments. And the assortments are only produced from available raw material.

This routine however does not tackle the problem of satisfying all constraints, including the capacity constraint. Yet, by the nature of the model this is not a serious problem. If a variable is rounded "incorrectly", then only small inconsistences can occur. For instance, if a variable indicating the frequency for using a specific pattern is rounded incorrectly, the maximum error is 0.5 for that activity.

Hence the time needed for this erroneous use of the merchandizer is 0.5 times the time needed for the particular pattern. Thus an error of say two minutes is made in a whole production week. We feel that this problem is not worth further research.

5.5. EXTENDING THE MODELS

In the previous section, the sets of constraints related to the production of assortments and boards all had a parameter s or p, denoting the pattern number. In the model, the possibility for using different patterns for a stem or an assortment were used. Why use more than one pattern per stem or assortment?

In a situation where only one pattern for a typical stem is possible, the distribution of assortments is rather fixed. A tuning problem may be the result when producing assortments that are not required. Shortages, or high inventory may result. It is therefore clear that more patterns, giving production alternatives, need to be included in the model. How are desired alternative patterns generated?

When performing DP for the conversion of a stem into assortments, or an assortment into boards, the optimal sawing pattern will not be the omly result. Also various cutting alternatives can be deduced. The problem is that no tools are available to distinguish between the set of alternative cutting patterns. Hence, another methodology is needed to provide alternative sawing patterns to the model.

Using many distinct cutting patterns for both the primary and the secondary breakdown will result in a too large model. For many patterns will imply many columns in the multiple goal programming matrix, every pattern represents a part of a matrix column, and many rows. Therefore a column generating procedure was developed. The basic idea of this procedure will now be the subject of discussion.

Firstly for all classes only one pattern is generated. Afterwards the multiple goal model is solved by means of linear programming. The problem will always have a feasible solution, because all constraints are "buffered" with slack variables. These slack variables cause soft constraints, in which the deviation fromthe preset targets is pictured.

After solving this initial problem, the solution can be interpreted (by means of the dual problem). The production of the semiproducts and final-products can be adjusted after interpretation of the service rate, the inventory levels etc. This results in a new set of prices, reflecting the degree of "eagerness" for each commodity. The dual variables indicate the imposed pressure on the primal constraints.

With this new set of prices, the so-called local prices, new patterns can be calculated. These new patterns are added to the initial problem, and represent processing alternatives. Again the adjusted problem can be solved. This cycle can be repeated until a satisfying (a stopping rule can be reaching a specific service rate, profit or else) solution for the problem is formed. In section 5.5.1. the dual problems, needed for the price adjustments are introduced. In section 5.5.2. the columns generating procedure is introduced formally.

5.5.1. THE DUAL PROBLEM

In general, a linear programming problem can be formulated as,

$\max\{c'x\}$ *primal problem*

subject to:

$Ax \leq b$

$x \geq 0$

In this model c represents the cost vector, x represents the variable vector. Furthermore A is the problem defining matrix, and b is the so-called right hand side. The closely related, dual problem can be stated as min{b'u} *dual problem*

subject to:

$A'u \geq c$

$u \geq 0$

The dual problem related to the formulated model in section 5.5. can be stated as:

$$\min \{ \sum_{t=1}^{Nt} ((\sum_{a=1}^{Na} \Phi_a DA_a^t - \Phi_t IA_a^{t-1}) g_a^t + \sum_{f=1}^{Nf} (DF_f^t - \Phi_t IF_f^{t-1}) u_f^t$$

$$+ \sum_{p=1}^{Np} ((BR^t + HR^t) \sum_{n=a_p}^{z_p} \beta_n + \Phi_t IR_p^{t-1}) v_p^t + WEEK(k^t + h^t) + BUD^t 1^t)$$

subject to

$$\sum_{a=1}^{Na} NA_{acn}^t \; g_a^t + v_p^t + (\beta_{n+1} - \beta_{n-1}) 1_n^t + TR_{cn}^t . k^t \geq VR_{cn}^t$$ $1 \leq c \leq Nc;\ 1 \leq p \leq Np$; $1 \leq t \leq Nt;\ a_p \leq n \leq z_p$

$$(\sum_{f=1}^{Nf} NF_{fsa}^t . u_f^t - g_a^t + TA_{sa}^t . h^t \geq VA_{sa}^t) . \Phi a$$ $1 \leq t \leq Nt;\ 1 \leq a \leq Na$; $\Phi_a = 1;\ 1 \leq s \leq Ns$

$-COF_f^t \leq u_f^t - u_f^{t+1} \leq CIF_f^t$ $\quad 1 \leq t \leq Nt;\ 1 \leq f \leq Nf$

$v_p^{t+1} - v_p^t \leq CIR_p^t$ $\quad 1 \leq t \leq Nt;\ 1 \leq p \leq Np$

$k^t \leq CEM^t$ $\quad 1 \leq t \leq Nt$

$h^t \leq CES^t$ $\quad 1 \leq t \leq Nt$

$g_a^t \leq CIA_a^t$ $\quad 1 \leq t \leq Nt;\ 1 \leq a \leq Na$

$g_a^t + v(a) 1^t \leq v(a)$ $\quad 1 \leq t \leq Nt;\ 1 \leq a \leq Na$

In this dual model, u,g,v,l are the variables. Moreover Φ_t indicates whether preceding time periods must be included or not ($\Phi_t=1$ if $t=0$, else $\Phi_t=0$). The same is true for Φ_a, indicating whether the current assortment a is used for boards production or not.

5.5.2 INTERPRETATION OF THE DUAL PROBLEM

In the model-formulation in section 5.4. two sets of constraints represent the connection between the production process and the demand for assortments and boards from the market. The production process can be primarily managed by the controlling variables Y^t_{cn} and X^t_{sa}, and secondly by the purchasing variable Z^t_a.

The dual variables, related with these two sets of constraints are g^t_a and u^t_f, for the assortments and the boards respectively. To understand the role of both g^t_a and u^t_f some fundamental insight in the mathematical background is needed.

The relative cost coefficients of the columns in the primal problem, related to the (artificial) slacks, are equal to the dual variables associated with the (a+f) constraints in the primal problem.

In the primal problem, the slack variables, that soften the constraints, represent the surpluses and shortages that occur after production. Hence the relative cost coefficients of these variables indicate the marginal object function increase or decrease resulting after changing the (slack) variable. In other words, the dual variable associated with the relevant constraint, indicates the maximum prize one is willing to pay in order to loosen or tighten the corresponding demand restriction. This willingness can be called the "stress" superimposed on the constraints involved with the market demand.

This fundamental characteristic of the dual problem can be used for controlling the production planning, formulated in the primal problem.

A positive dual variable g^t_a indicates that the production process would be better tuned in on the (market) demand for assortments if less assortments of type a in week t would be produced. A negative dual variable g^t_a indicates a stress on the constraint, more production would imply more "profit". Profit is here between quotation marks because an increase in the object function is not necessarily a profit increase (see also chapters 7 and 8).

5.5.3. A COLUMN GENERATING PROCEDURE

The insights as described in section 5.5.1. and 5.5.2. can be used to increase the efficiency of the implementation of the production planning model.

In the model proposed in section 5.4. various patterns could be used to perform the tactical planning. How to obtain the distinct sawing alternatives can now be explained formally.

Positive values for the dual variables g_a^t and u_f^t indicate that too many products f and assortments a are produced in period t. The opposite proposition holds for negative values.
If a product is produced too frequently, this is a result of its price, and dimensions, relative to the other products. Hence, when decreasing its "price", or "value", relative to the other products, the typical product f will be less interesting to use in the DP solution proposed in section 5.3. Its frequency will be lower, and thus an alternative cutting pattern can be obtained, by adjusting the products and assortments prices based on an interpretation of the dual variables.

If a typical model is called the i^{th} model, then the next formulation including crosscutting and sawing patterns based on adjusted prices can be called the $(i+1)^{th}$ model formulation. The "local" (not market) prices can be regarded as a function of the prices in the i^{th} model and the dual variables after solving the i^{th} problem by means of linear programming (LP).
Hence,

$$(v(f)^t)^{i+1} = F((v(f)^t)^i,\ (u_f^t)^i) \qquad 1 \leq t \leq Nt,\ 1 \leq f \leq Nf$$

With $v(f)^t$, the "value" of product f in period t, and,

$$(v(a)^t)^{i+1} = F((v(a)^t)^i,\ (g_a^t)^i) \qquad 1 \leq t \leq Nt,\ 1 \leq a \leq Na$$

With $v(a)^t$, the "value" of assortment a in period t, and. Various functions can be used to calculated adjusted prices, for instance,

$$(v(f)^t)^{i+1} = \max\{\ 0,\ (v(f)^t)^i - (u_f^t)^i\}$$

$$(v(a)^t)^{i+1} = \max\{\ 0,\ (v(a)^t)^i - (g_a^t)^i\}$$

or,

$$(v(f))^{i+1} = (v(f)^t)^i .\ e^{-(\alpha(u_f^t)^i)}$$

$$(v(a)^t)^{i+1} = (v(a)^t)^i .\ e^{-(\alpha(g_a^t)^i)}$$

For the adjusted prices a lower bound of zero is included because the negative effects of non-desired products are already represented in the object function by the cost for inventory and out of stock.

After the previously discussed price-adjusting step, new cutting patterns can be calculated. However, not all cutting patterns, representing processing alternatives, will improve the solution of the planning problem. Only patterns with a positive marginal contribution will cause improvement. A positive marginal improvement will be obtained in case of a negative relative cost coefficient (Van Beek, Hendriks, 1986).

A negative relative cost coefficient for both assortments and boards will be obtained if the following two conditions hold,

$$\sum_{a=1}^{Na} (NA_{acn}^t)^{i+1}(g_a^t)^i + (v_p^t + (\beta_{n+1} - \beta_{n-1})l_n^t + TR_{cn}^t.k^t)^i - VR_{cn}^t < 0$$

and,

$$\sum_{f=1}^{Nf} (NF_{fsa}^t)^{i+1}(u_f^t)^i - (g_a^t - TA_{sa}^t.h^t)^i - VA_{sa}^t < 0$$

All new patterns for iteration (i+1) fulfilling this criterion will lead to an increase of the object function. However, checking this criterion asks for rather complex operations from a software development point of view. The maximum number of new pattern is $Nt(\Phi_a.N_a + Nf)$. In the implemented version of this algorithm, all new patterns are included. The result of this procedure is a somewhat larger simplex tableau, but more straight-forward software on the other hand. In chapter six the computational consequences will be discussed. Figure 5.17 displays the procedure.

STEP	ACTION
1	Solve the current MGP problem.
2	Check the dual variables.
3	Let the decisionmaker decide to continue or not.
4	IF continue THEN adjust prices. $(v(f)^t)^{i+1} = F((v(f)^t)^i, (u_f^t)^i)$ $(v(a)^t)^{i+1} = F((v(a)^t)^i, (g_a^t)^i)$ ELSE GOTO STEP 8.
5	Calculate new patterns, use adjusted prices.
6	Revise the current matrix, use new patterns.
7	GOTO STEP 1
8	STOP.

Figure 5.17. The column generating procedure.

The next chapter will elucidate the various analysis possibilities of the model.

Chapter 6

IDEAS, TECHNICAL ASPECTS

In chapters four and five the basic concepts of the system IDEAS were discussed. To put a blue-print for a DSS into a working system, in terms of a prototype, many technical problems must be tackled. The purpose of this research was to develop a prototype for a DSS to support the planning for centralized conversion sites. Yet it is considered not within the scope of the thesis to discuss all problems and solutions of computer science in depth. Instead the main approach will be explained in this chapter.

After a discussion of the technical requirements (section 6.1.) the database will be discussed with respect to its technical design (section6.2.). The model-base will be regarded in relation to the software tools used in the implementation (section 6.3.). In section 6.4. the important subsystem called the user interface will be covered.

6.1. TECHNICAL REQUIREMENTS

In chapter four the concepts of the DSS called IDEAS were considered. In order to implement a real-world system, using the basic ideas of these concepts, many problems of a computer science nature have to be tackled. What are the requirements for a such system? What are necessary utilities?

To answer these questions a list of requirements can be made (Alter, 1980; Anthonisse e.a. 1988). Some of these claims can be mentioned, such as flexibility (with respect to functioning), ease of use (simplicity, consistency and completeness) and robustness. Furthermore short response times, and the possibility of controlling the decision-making are considered to be of importance. To meet these requirements a typical technical design has been pursued.

The ease of use, the so-called user friendliness has been realized by developing a menu-driven outershell for IDEAS. This means that the user can make a set of decisions and choices by using relatively straight forward menu oriented software.

Moreover a system-style was used, consistent over the system as a whole. The robustness is assured by using a dialogue "language" in the inner shells of IDEAS. This method of conversation enables the user to employ the system in an easy way. Errors are reported, and handled where possible.

Short response times have been achieved by using advanced models and software packages, with an emphasis on computational efficiency. By using separately developed and executable modules, a system has been built that gives the user full control, even during the optimization itself, over the decision-making process.

In the next chapter all three main modules of the system IDEAS will be discussed.

6.2. THE DATABASE

In the database all relevant data are stored. In chapter 4 the main data objects were regarded. Data about raw material, semi-products, final products, companies and scenarios are stored.

Database systems can be used in many forms and based on various technologies. The proposed system was to be developed and implemented in a VMS (VMS is a VAX operating system) environment. In this environment the database system s1032 is available among others.

However when designing a prototype with the purpose to develop a system that can be used in practice, a minimum linking up should be aimed for with large existing packages. Taking into account these aspects, the decision was made to develop a "tailormade database". This means that a database was made specially for the purpose of this research.

The input data related to the main entities, raw material, semi-products, finalproducts, companies and scenarios are stored in five separated files (see figure 6.1, the icon for files, from the Window Icon Mouse Pointer System is used as a base for the pictures).

The datafiles consist of records, describing the data-objects, such as trees, semi-products, final products, machines, personnel etc. These records have a fixed length for each file. The record fields, used to store occurrecies for the various attributes are of variable length.

The raw material data are all of the same structure, therefore the corresponding datafile is filled with fixed-length, fixed-field records. All other files have a more complex organization. These datafiles consist of, besides a data chunk reserved for the overall data, and the data descriptors, a number of data chunks all corresponding with a dataset.

A dataset is for instance a set of assortments, with a typical set name, or a typical scenario. Within such a set there are fixed-length, variable-field records stored.

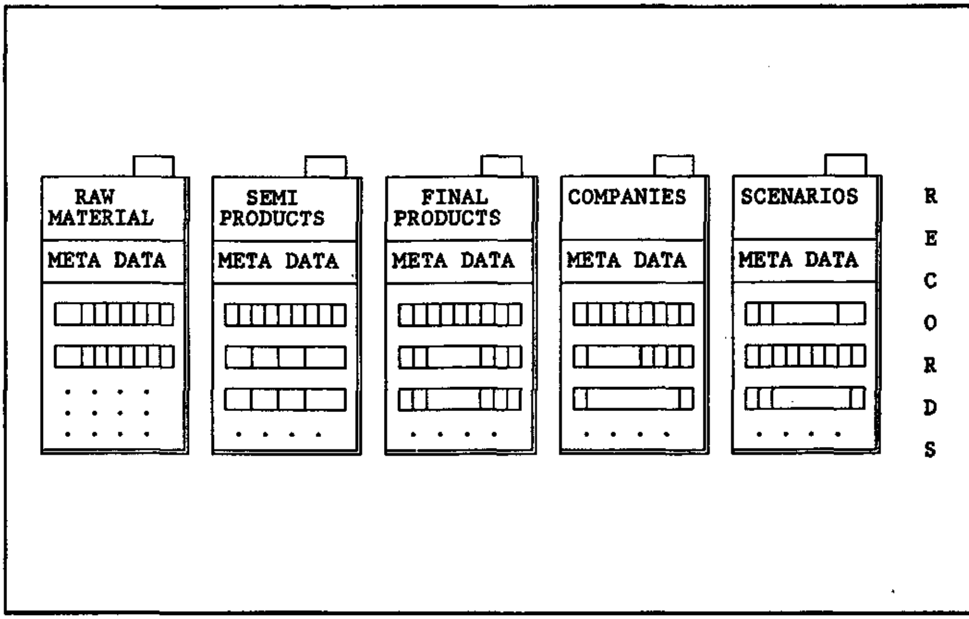


Figure 6.1. Datafiles and records.

A company is described by many different parameters (chapter 4). For instance a set of parameters indicates the type of machinery, its capacity and operational cost. Other data are used to link the datafile consisting of company data with other files.

For instance the company uses a specific type of assortments. In a special record, one of the fields contains an attribute describing the assortments setname that is used. This special attribute is called a key-attribute. In the same way many other links are established . The general structure of this database can be called hierarchical.

6.3. THE MODELBASE

After a brief discussion of the technical aspects of the database, now an overview will be provided of the techniques used in the modelbase.

6.3.1. CROSSCUTTING MODEL

The process of optimizing the crosscutting patterns is implemented using the dynamic programming technique. The code is written in FORTRAN-77, and implemented on a VAX-8600 computer. The forward and backward directed iterations make use of arrays. By storing all subsequent decisions and relevant information the backward iterations are very compact and straightforward. This program has very short response times, because of the relative simple problem to be solved and the efficiency of the programmed recursive fixing algorithm. The program combines various input sources to construct the problem (see figure 6.2).

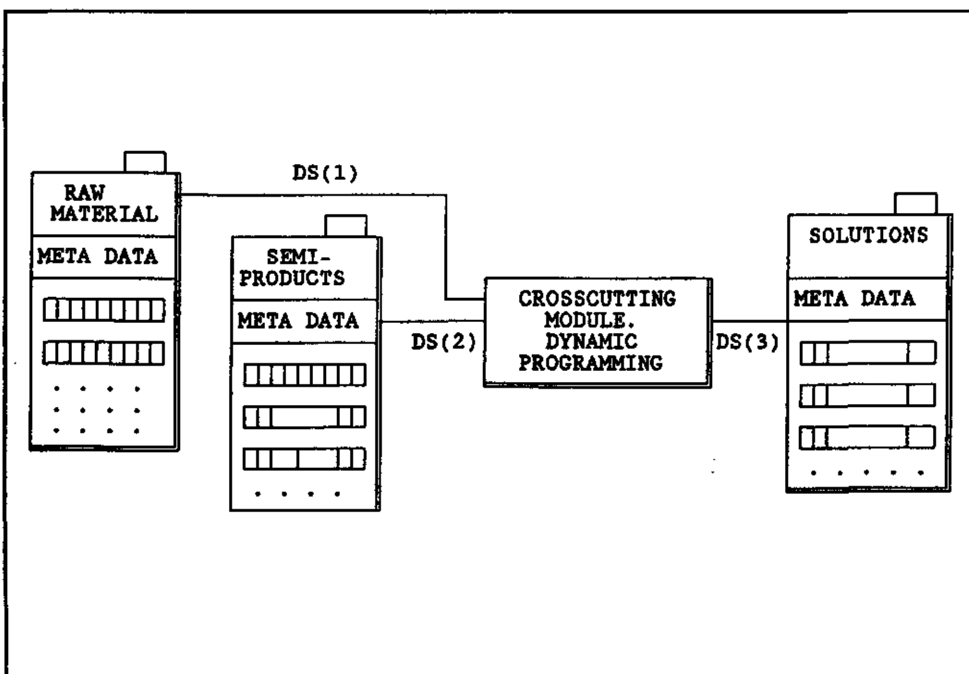


Figure 6.2. Input, optimization, output diagram. DS(i) are the datastreams.

6.3.2. SAWING MODELS

The process of breaking down a stem (in an integrated layout), or an assortment (in a non-integrated layout), into boards is referred to as the secondary breakdown or the sawing process. This process is optimized using two or three-dimensional dynamic programming. The optimization module used is capable of handling both two and three dimensional problems. The first problem, can be considered as a three dimensional problem, using products (boards) with a length equal to the stem length.

The software is developed in FORTRAN-77 (see figure 6.3). The basic algorithm can be regarded as three nested, interconnected dynamic programming shells. Much effort has been made to speed up the algoritm.

In the algoritHm, the speeding up techniques by-pass a number of possible decision evaluations on both z, x, and y level (chapter 5). The applied algorithm is again recursive fixing.

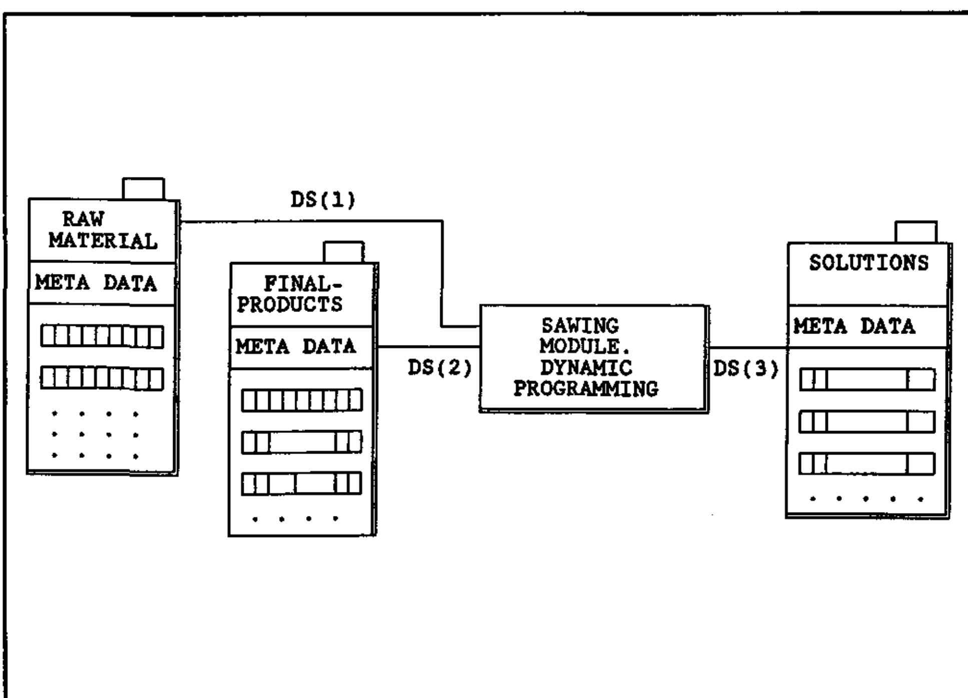


Figure 6.3. Input, optimization, output diagram. DS(i) are the datastreams.

6.3.3. TACTICAL PLANNING

The tactical planning can be considered as an extra shell enclosing the operational planning level. This is reflected in the technical design of this planning process. The optimization of the tactical planning is carried out by means of multiple goal programming. To develop and implement the necessary Linear Programming (LP) solving software which is totally tailormade would ask too much time and effort. To speed up the prototyping, the software package SCICONIC/VM was used.

The package SCICONIC provides many tools to develop and test models based on linear programming. In fact various modes for using this package are possible. The batch mode and the interactive mode are the most straight forward ways (see figure 6.4.).

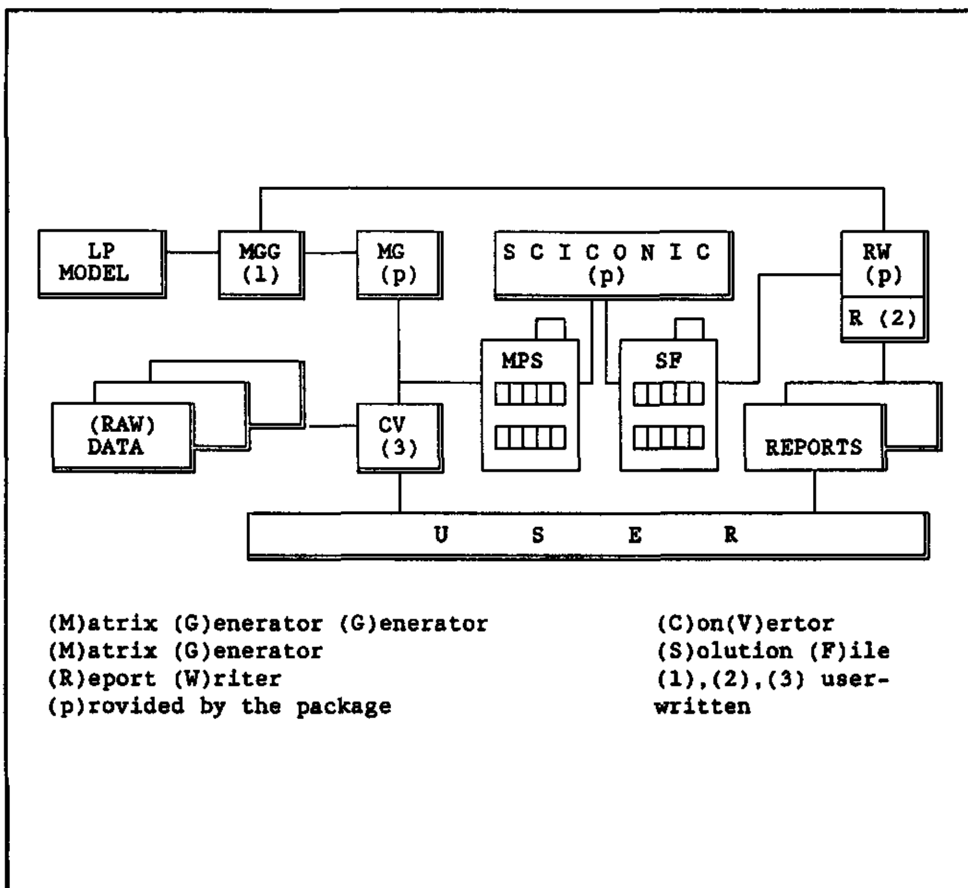


Figure 6.4. Linear programming solving system.

The user constructs a model, representing the relevant components and relations of the real-world system. This model can be formulated in terms of functions, corresponding to the mathematical formulation. With help from the Matrix Generator (MG) and the user-written Converter (CV), the raw data are transformed from their logical grouping (in the database, or the datafile) to the form required in an Mathematical Programming (MP) matrix. The MG will read the raw data and write it out in the required form, so that a linear programming package can solve the problem. However, it is a labourious task to modify the MG each time the problem formulation (the model) is adjusted.

To overcome this problem a Matrix Generator Generator (MGG) is provided. MGG is designed to simplify the task of preparing MG-programs, by automatically generating them from a description of the problem formulation and a description of the raw data available. Moreover routines are generated to read the Mathematical Programming (MP) solution file and to prepare the results for use in a report writer program. This report writer is partly provided by SCICONIC, the module RW, and partly user-written (R).

The description above is restricted to the standard interactive, and batch usage of SCICONIC. The solution procedure itself (a revised Simplex method) is a black box, and hardly interactive. Moreover the environment is not at all specific for a typical user.

In the previous chapters it has been emphasized that the solution process, the planning, should be controlled fully by the decision-maker. This claim results in a technical requirement for interactive decision-making. How can this requirement be met? By modular programming and implementation.

SCICONIC/VM was also designed to be implemented in a highly modular fashion, so that extensions and enhancements can be incorporated in a user directed system. When doing this, SCICONIC/VM is used as a collection of relocatable object files. This set of files is called a SCICONIC Algorithmic Tool Library (SATL). Hence, all modules normally constructing SCICONIC/VM, can also be used separately. The library can be linked with user-written routines, to form a "home-grown" system.

There are two ways of using SATL. The first method uses a provided single "gateway" from the control language interpreter to the user written code. This means that the user develops his own SCICONIC command. In this research a second method was used. This method dispenses with the control language entirely, and uses SATL directly from the user-written code. In figure 6.5. the system is displayed.

The tactical planning modules (TACT) are together with the operational planning modules (OP) and the column generating module (CG) incorporated in the modelbase. The modelbase management system (MBMS), as part of the user interface controls the modelbase, and thus establishes the necessary connections between the various planning levels. The MBMS is itself a library of FORTRAN-77 routines.

The database, containing all relevant data about various companies is connected with the database management (DBMS) part of the user interface. The same is true for the report data and the optimization results.

Both MBMS and DBMS are directly connected with the SATL. This means that the decision-maker controls the optimization process itself, by directly intervening the control of SATL via the dialogue system (DS) (see section 6.4).

The optimzation results can be illustrated by using the graphics utilities of IDEAS. To picture the optimal cutting patterns SAS has been used. SAS is incorporated in the user-interface and is directly controlled via the DS.

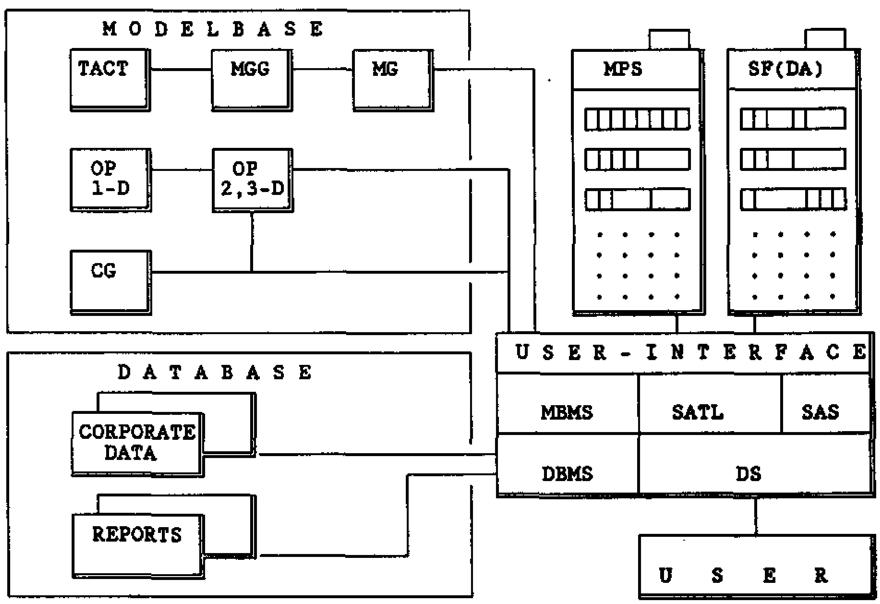
6.4. THE USER-INTERFACE

In figure 6.5 the user-interface is pictured as a set of modules. The technical realization of these modules, and their impact with respect to the earlier formulated technical requirements will be regarded in this section. In fact the system IDEAS can be considered as a set of shells. The outershells will be the first subject of discussion.

6.4.1. THE OUTER SHELLS

The direct contact of the decision-maker with the DSS starts after entering a short sequence of commands into the operating system (VAX/VMS). After the correct sequence of commands IDEAS starts. In chapter 4 the conceptual design of the system was described. The outer shell of IDEAS was described as menu driven. Menu driven software can be developed using distinct programming languages. Specially in a personal computer environment tools exist to develop menu driven applications. In a VAX environment these tools exist as well. A package called VAX-PRODUCER (VP) offers tools and techniques to create application software.

VAX-PRODUCER itself consists of two main modules, called DESIGN and DRAW. DESIGN can be regarded as a general purpose programming language, having a set of features that enables the programmer to speed up prototyping. DRAW is a development environment (Screen management, editor, library etc.).



(TACT)ical models
(OP)erational models
(C)olumn (G)enerator
(M)athematical (P)rogramming (S)tandard
(S)CICONIC (A)lgorithmic (T)ool (L)ibrary
(D)ialogue (S)ystem
(S)tatistical (A)nalysis (S)oftware
(D)irect (A)ccess
(M)odel (B)ase (M)anagement (S)
(D)ata (B)ase (M)anagement (S)
(S)olution (F)ile

Figure 6.5. The technical configuration of IDEAS.

By using DRAW, module screens, or forms, can be designed that give the developed software a very user friendly character. A set of screens can be stored in a library in an executable form.

When examining a DESIGN program, calls to the various screens can be detected, that ask to display a specific form (DRAW) on the terminal. This form can be used for instance for data collection, animation, or figures. (see figure 6.6.)

The described mechanism is used in the outer shells of the user interface, the dialogue system. Menu screens are stored in a library (DRAW), and called from the DESIGN program. In a menu, choices can be made triggering new forms (DRAW) and new menus (DESIGN).

The decision-maker is not just interested in a huge stream of alpha numerical results. Graphical elements are also of interest. Therefore two main utilities were built in.

Firstly a company can be considered to be built up out of standard modules (chapter 4). These standard modules are separately stored in a DRAW library, as screens. A specific company can now be displayed as a sequence of overlays, pictured on the screen.

Secondly the optimum sawing patterns are of interest. When sawing is performed by means of a numerically controlled device, coordinates and corresponding decisions (what product to be produced, rotated or not) give sufficient information about the patterns. The decision-maker however should be enabled to interprete

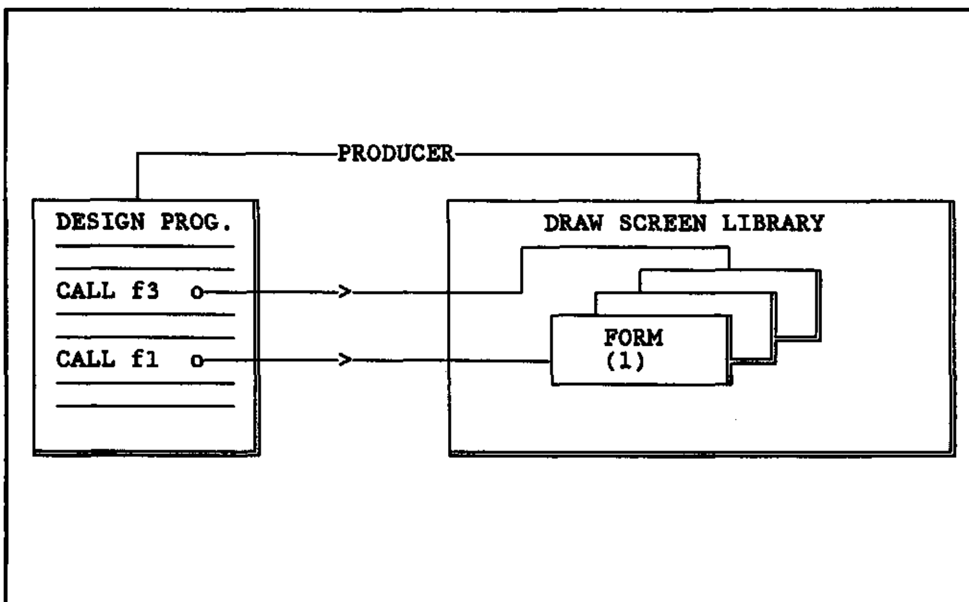


Figure 6.6. A DESIGN programm calling screens from a DRAW library.

typical patterns within seconds. Therefore some SAS utilities were used to display the patterns on the screen. Self-evidently a graphical terminal is needed whenever this possibility is wanted.

6.4.2. THE INNER SHELLS

After the exact choices are made, using the menus, a dialogue occurs. The programmes supporting the data handling, the sorting and the optimization are all written in FORTRAN-77. These FORTRAN routines are called via the outer shells, which are discussed above.

To obtain maximum flexibility, both in development as in use of IDEAS, the FORTRAN routines are used as so-called spawned processes. This means that the routines are developed modularly, and executable separately. All FORTRAN routines are again stored in a library. In figure 6.7 the mechanism is displayed.

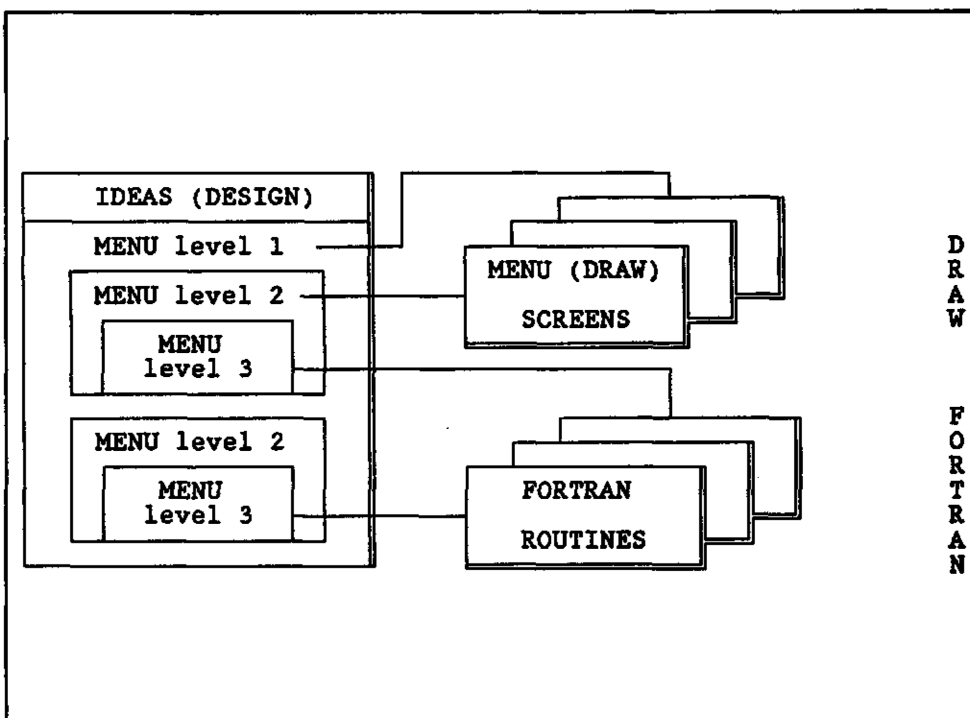


Figure 6.7. Menus connected with two libraries.

The parameter transport between DESIGN menus and FORTRAN routines is established by a special mechanism, called the "blackbox" mechanism. This mechanism is not very efficient, and has very limited capacity (only a limited number of strings can be passed). Therefore the outer shells are thin, this means that the parameter handling is limited, and merely left for the FORTRAN inner shells.

So far the dialogue system (DS) of the userinterface has been discussed. What about the MBMS and the DBMS?

The MBMS is very close to the dialogue system. The routines establishing the connection with the decision-maker, also provide utilities to control the model-base. Technically this means that the FORTRAN routines of the DS also submit control to routines communicating with the dynamic programming routines and SATL.

The latter routines are working as spawned processes of the inner FORTRAN dialogue system routines. Why use this mechanism? To avoid too big a executable image. Suppose all routines from the DS and the MBMS were linked, then all memory claims would be summed up. This means that storage used for SATL and for MBMS should be within the technical boundaries of the VAX/VMS system. By spawning the processes this problem is solved. Of course the dimensioning of the SATL system is still of importance, and should be taken care of with caution.

The DBMS is also relatively close to the DS. To minimize the response times some extra handling mechanisms are built in. The database is of relatively simple structure as was discussed in the above. When for instance choosing to examine a set of boards (final products) many data have to be passed from the database, via the DBMS to the DS.

When developing software in FORTRAN, no dynamic memory allocation can be made. This means that all memory considered to be useful during a session must be claimed when designing the software. One possibility is to declare a large chunck of storage space, hoping the user stays within these bounds.

For the development of IDEAS a different approach was used. When dividing the sets of data-objects into sections, and these sections are the memory units that can be accessed and passed, then both response times and memory space needed in the calling routines can be minimized. Of course this mechanism can have many forms in the different routines.

Concluding, it can be stated that IDEAS gives a decision-maker a powerful environment to handle planning problems effectively, and efficiently. Large parts of the system ask only for a FORTRAN compiler, and are thus rather portable. Other parts are dedicated to the specific VAX/VMS environment, and need to be reconsidered when other computer systems are used.

The operational planning, especially the optimization part can easily be implemented on a micro-computer. Also the data handling can be implemented for a micro computer, although a different approach (for instance using the commercially available data handling packages) might be favourable when speaking in terms of portability and compatibility.

The tactical and strategic planning can be carried out using a linear programming package that gives the system developer access to the main optimization routines. The latter is claimed because a column generating routine requires a direct intervening in the optimization process.

Hence micro computer applications of the basic concepts of IDEAS are likely to be possible, and thus give the developed prototype a greater potential.

Chapter 7

BUSINESS ANALYSIS, USING IDEAS

In the previous chapters, the decision support system IDEAS has been discussed. In this chapter a small number of possible applications of IDEAS will be the subject of discussion. One should realize that the total set of analysis possibilities are almost unbounded. Only some main subjects will be evaluated.

In section 7.1 the various applications will be mentioned. All analysis examples will be illustrated using a model plant. This model plant will be described in section 7.2. Distinct analysis examples, so-called policies, will be subject of discussion in section 7.3.

7.1. INTRODUCTION

The decision support system IDEAS was designed and built as a prototype for DSS. The main characteristics of IDEAS are its potential to support decisionmaking for various planning levels, combined with its user-friendliness.

The effectiveness of the system is partly determined by the technical possibilities of the system (as a result of its conceptual design), but also by the managerial insight and knowledge of the decision-maker using the system. Hence, discussing all analysis aspects is impossible, because they vary for the typical situation.

Instead, we will concentrate on regarding some important aspects of the DSS, associated with the three levels of planning.

Operational planning

IDEAS can give the manager insight in various problems associated with processing trees to boards. Efficiency is the main subject of interest, and therefore steplength, assortment set, final products set etc. play an important role. In the following sections this operational planning (analysis) will not be dealt with explicitly. In chapter five some results were given and displayed. At this stage tactical and strategic analysis are discussed in dept.

Tactical planning

The planning support on the tactical level, is an important utility of IDEAS. The main subject of analysis will be the optimization of the CCS, with terms as integral, end-user oriented, service degree and value recovery playing an important role. In section 7.3. attention will be paid to the tactical planning.

Strategic planning

The process of optimizing the design of a CCS is considered of great importance for the company. Therefore much effort is put into the construction of tools to support this planning. Examples that will be looked at will deal with investment analysis, layout alternatives and changes in the product-mix. Also various other managerial insights will be discussed.

7.2. A MODELPLANT

To illustrate the various analysis possibilities a model-plant will be introduced. This model-plant has all the typical characteristics inherent to a wood processing company (WPC). In the following the numerical data will be described.

The first subset (section) of the dataset describing the model-company has reference to the layout configuration. (table 7.1)

Table 7.1. The layout of the model-plant.

number	*description*	*logic state*
1	*Sorted raw material*	*true*
2	*Raw material harvested*	*true*
3	*Raw material purchased*	*false*
4	*Integrated production*	*false*
5	*Semi-products sales*	*true*
6	*Semi-products purchased*	*false*

The second subset (section) describes the raw material (table 7.2).

Table 7.2. The raw material.

number	*description (attribute)*	*occurrency*
1	*Number of piles*	*2*
2	*Number of classes*	*4*
3	*Smallest dbh input (cm)*	*20*
4	*Species*	*Pinus*
5	*Class width (cm)*	*5*

In table 7.3 the third section is displayed, describing the raw material representative stems. The section contains key-attributes, refering to the raw material file.

Table 7.3. The representative stems.

class	pile 1	pile 2
1	PN-DUF	-
2	PN-ASQ	-
3	-	PN-BNM
4	-	PN-WUZ

Table 7.3 displays that disjoint piles are used both represented by two stem-types. Disjoint piles means that each pile consists of classes, not used in other piles. In practice (chapter 8) also non disjoint piles can occur. Table 7.4 describes the

stemtypes. These stems have been modelled in order to obtain straight forward patterns, and are not chosen to be realistic.

Table 7.4. The used stem-types.

class	stem	length (cm)	dbh (cm)	dtop (cm)
1	PN-DUF	456	22	10
2	PN-ASQ	666	28	10
3	PN-BNM	723	34	10
4	PN-WUZ	888	40	10

Section four contains the crosscutting information (table 7.5).

Table 7.5. Crosscutting information.

number	*description (attribute)*	*occurrency*
1	*Crosscutting speed (cm/s)*	*20*
2	*Transportation speed (cm/s)*	*40*
3	*Variable crosscutting cost(Dfl/hr)*	*60.50*
4	*Semi-products set for conversion*	*PN-ST1*
5	*Semi-products set for sales*	*PN-ST2*
6	*Inventory cost (Dfl/(m^3.week))*	*6.00*
7	*Stock out cost (Dfl/(m^3.week))*	*80.00*

The record-fields 4 and 5 are references to the semiproducts datafiles, described in table 7.6 and 7.7.

Table 7.6. Semi-products (set = PN-ST1).

number	D min (cm)	D max (cm)	L_{tot} (cm)	Price (Dfl)
1	10	15	150	3.00
2	16	20	150	3.75
3	21	30	150	5.50
4	10	15	250	4.60
5	16	20	250	6.75
6	21	30	250	7.50
7	31	40	250	12.50

Table 7.7. Semi-products for direct sales (set = PN-ST2).

number	D min (mm)	D max (mm)	L_{tot} (cm)	Price (Dfl)
1	1	45	50	0.00
2	10	20	100	2.00
3	21	30	150	5.00

The fifth section describes the boards production parameters (see table 7.8).

Table 7.8. Boards production information.

number	*description (attribute)*	*occurrency*
1	*Sawing speed (cm/s)*	*20*
2	*Simultaneously made cuts (-)*	*2*
3	*Sawing cost (Dfl/hr)*	*75.50*
4	*Final products set*	*PN-ST3*
5	*Inventory cost (Dfl/(m^3.week))*	*7.00*
6	*Stock out cost (Dfl/(m^3.week))*	*80.00*

Record field 3 is a reference to the final-products information file (table 7.9).

Table 7.9. Final products set (set = PN-ST3).

number	z len (cm)	x len (mm)	y len (mm)	Price (Dfl)
1	150	0	20	0.00
2	150	20	80	0.50
3	150	40	140	1.25
4	150	60	180	3.25
5	250	0	20	0.00
6	250	20	80	0.80
7	250	40	140	3.00
8	250	60	180	7.00

Product 1 and 5 are the dummy products, assuring a possible decision at every stage (z,x,y).

In section six the personnel information is stored. This information is displayed in table 7.10.

Table 7.10. Personnel information.

number	*description (attribute)*	*occurency*
1	*Length of a day shift (hr)*	*8*
2	*Crew (persons)*	*4*
3	*Salary (Dfl/hr)*	*25*
4	*Overtime cost (+50%)(Dfl/hr)*	*37.50*

After a full description of the WPC, this company has to be related to in a specific scenario. This scenario is stored in the scenario describing data file, and divided into a number of sections.
The first section describes the contributing ratios of the classes, and the raw material describing parameters. (see table 7.11)

Table 7.11. Raw material scenario data, ratios as % of total input trees, initial stock in number of trees per pile.

		pile 1	pile 2
1	ratios	15, 35	35, 15
2	initial stock	210	250

The raw material inflow, in number of trees, as a result of harvesting, is described in table 7.12.

Table 7.12. Raw material inflow, in number of trees.

week			
1	2	3	4
900	980	800	1200

The second section describes the scenario as far as the semi-products are concerned (table 7.13).

Table 7.13. Semiproducts scenario data, numbers 8, 9, 10 correspond to the assortments of set PN-ST2.

	initial	demand in week			
assortment	stock	1	2	3	4
1	40	-	-	-	-
2	60	-	-	-	-
3	55	-	-	-	-
4	80	-	-	-	-
5	100	-	-	-	-
6	12	-	-	-	-
7	80	-	-	-	-
8	66	230	560	440	810
9	123	800	710	800	600
10	100	540	520	600	740

In section three the final products scenario is displayed. (see table 7.14)

Table 7.14. Final products scenario data.

board	initial stock	demand in week 1	2	3	4
1	32	2100	2300	2400	3600
2	67	4100	3200	4200	2490
3	6	2900	330	800	250
4	125	656	480	440	960
5	5	2080	4120	3220	6140
6	40	3130	1130	2340	2210
7	3	290	270	320	430
8	35	920	820	610	710

7.2.1. THE OPTIMIZATION

To find an optimal tactical production plan for this model-plant, IDEAS is used. Firstly for all classes optimal crosscutting patterns are determined. These patterns are displayed in appendix A, table A.1. For instance a stem out of class 1 is cut into three assortments, and a piece of waste. This piece of waste is called assortment 8. Assortment 8 has a default length of 50 cm. However, if at the top a length is cut off with length lower then 50 cm, this will be also called assortment 8. The value of a tree cut in assortment 1, 2, 3 is Dfl 11.19. The conversion time needed for this pattern is 0,16 hours, when using the machinery described in section 7.2.

The real value of the tree is 1*3.00 + 1*3.75 + 1*5.50 + 1*0.00 = Dfl 12.25, the crosscutting cost are Dfl 1.06, hence the resulting value is Dfl 11,19. In table A.1 only the patterns for period 1 are included, the patterns for the other semiperiods are equal when starting the optimization.

After crosscutting the stems into assortments, these assortments are cut into boards. In table A.2 it is shown that assortment 1 is processed into 2 boards of type 1, and 3 boards of type 3. The resulting value is 1,41, the processing time needed is 0,02 hourson the saw. Again only the patterns for time period 1 are given, because initially these patterns are all equal.

At this moment all initial patterns are generated, and the optimization can start. It turns out that pile 1, containing classes 1 and 2, is not used. For all 4 weeks class 3 and 4 are used 202 and 87 times respectively (table A.3). Table 7.15. shows the resulting inventory for stems.

Some assortments (1 to 7) are used for conversion, others (8 to 10) are directly sold. Table A.10. indicates that specific patterns are used with a typical frequency to convert the first seven assortments into boards. For instance assortment 2, was converted into boards 224 times in week 1, using pattern 1. The resulting material balance is displayed in figure 7.1. for week 1. The other weeks are displayed in figure 7.2. and figure 7.3.

Table 7.15. Material balance for stems.(IR = Inventory, H = harvested, U = used, R = Raw material).

		pile 1			pile 2	
week	IR	HR	UR	IR	HR	UR
1	210	450	-	250	450	290
2	660	490	-	410	490	289
3	1150	400	-	611	400	289
4	1550	600	-	722	600	289

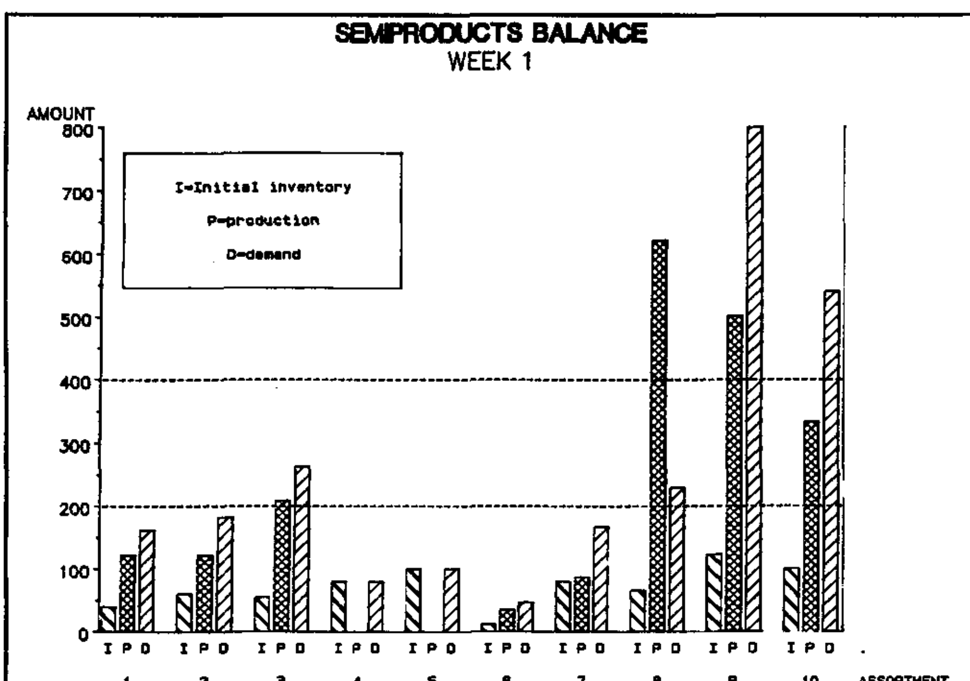


Figure 7.1. Semi-products balance for week 1.

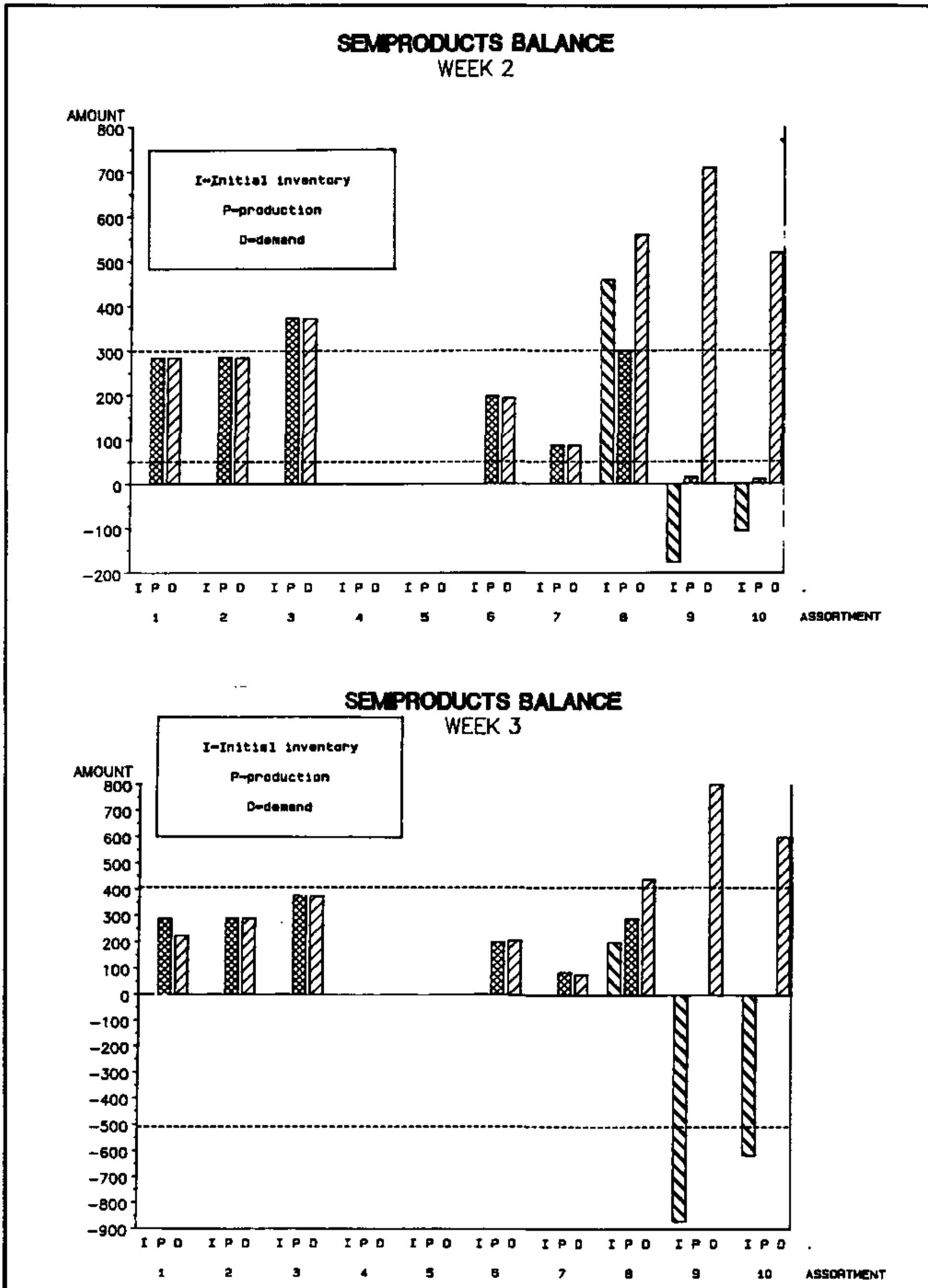


Figure 7.2. Semi-products balance for week 2 and 3.

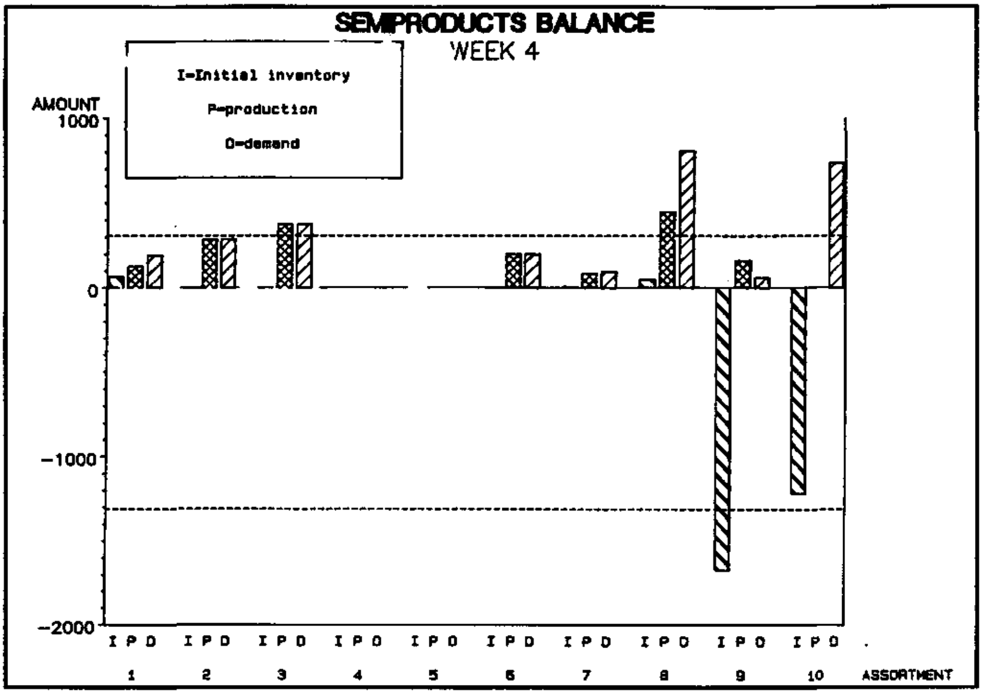


Figure 7.3. Semi-products balance for week 4.

The assortments are converted into boards. The already available inventory, summed with the new production, can be used to meet the demand for boards. The production, inventory and sales of final products results in a materials balance.

This balance can be made for all board types, for all four weeks of the planning horizon. In figure 7.4. the balances for the first two weeks are displayed. In figure 7.5. the materials balancec for boards with respect to week three and four are visualized.

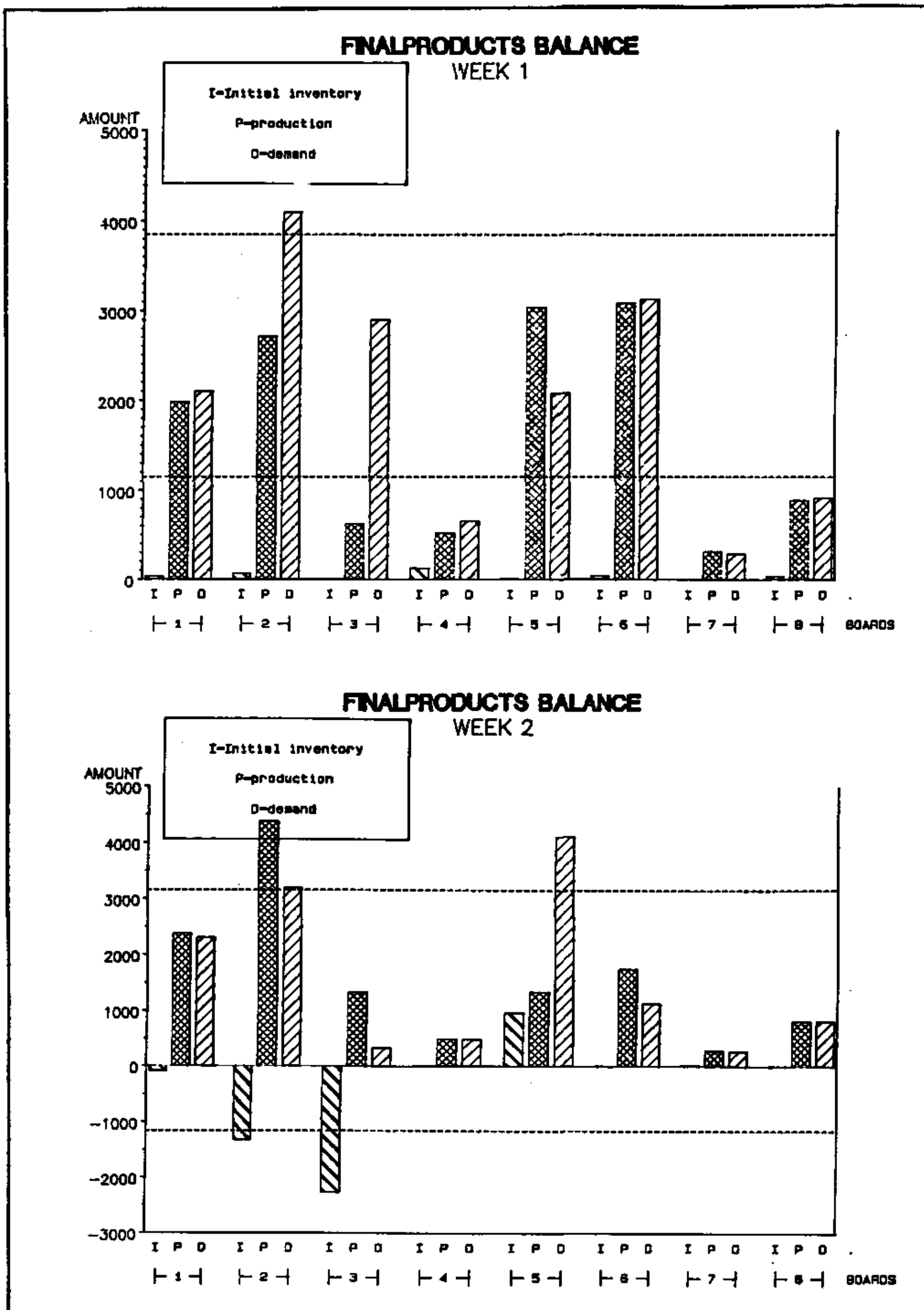


Figure 7.4. Final-products balance for week 1 and 2.

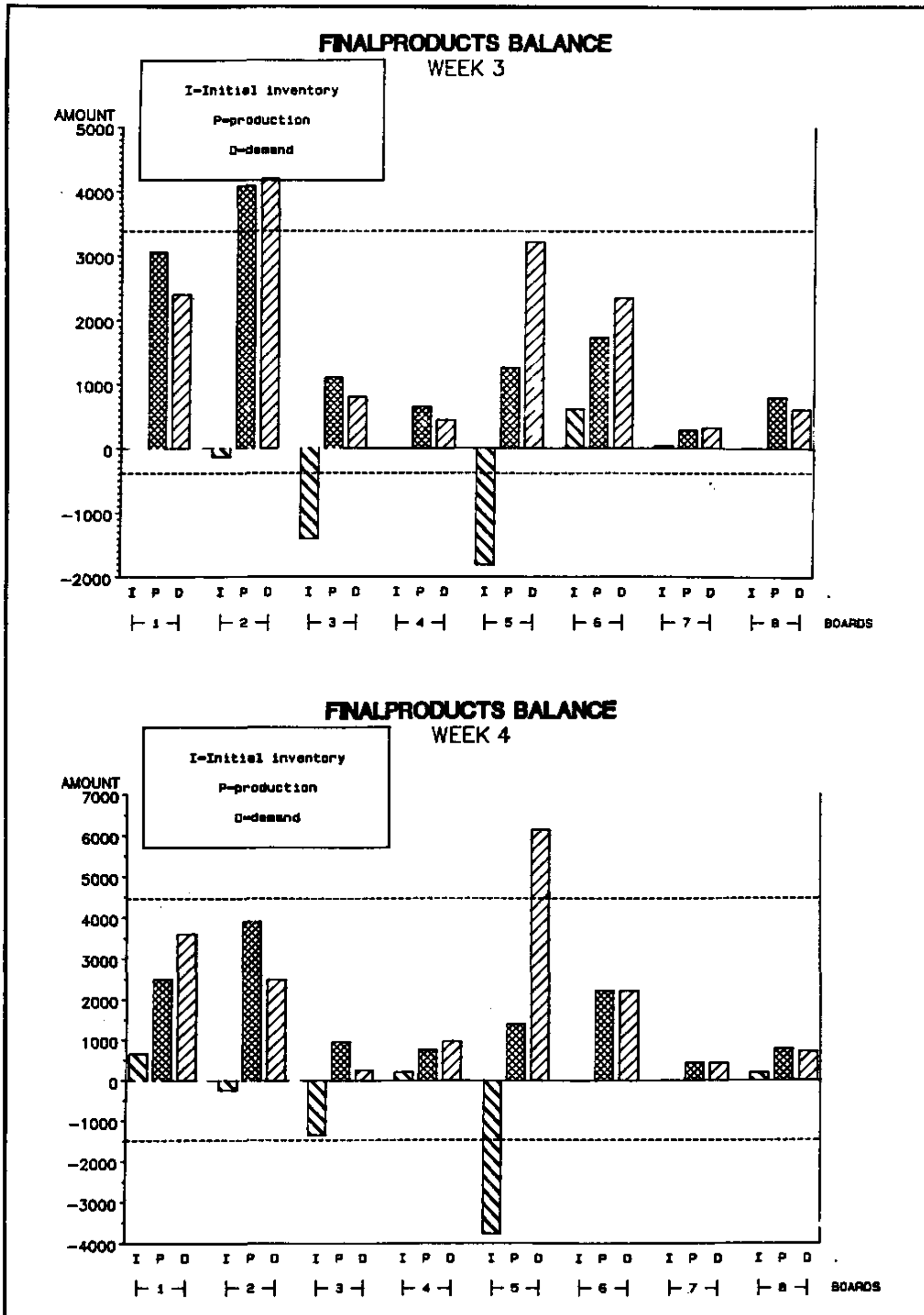


Figure 7.5. Final-products balance for week 3 and 4.

After this first optimization step, the financial result as displayed in table 7.16 is obtained.

Table 7.16. Financial result after the first optimization.

abbreviation	*description*	*value (Dfl)*
PV	*Produced value*	*87730.85*
TO	*Turnover*	*40312.75*
CIA	*Cost of inventory (assortment)*	*445.41*
COA	*Penalty for stockout (assortments)*	*45600.23*
CIF	*Cost of inventory (final products)*	*2412.16*
COF	*Cost of stockout (final products)*	*23527.81*
CIR	*Cost of inventory (raw material)*	*9795.64*
CL	*Cost of labour (regular shift)*	*16000.00*
CO	*Cost of overtime*	*6000.00*
CP	*Cost of production (variable cost)*	*2644.11*
RESULT	*Contribution to profit*	*3015.43*

This result can be improved by activating the column-generating procedure. So far, only one crosscutting pattern was used per raw material class, and only one sawing pattern per assortment. In chapter five it was explained that an interpretation of the dual problem can cause alternative cutting patterns, that are used for further improvement of the solution.

The adjusted prices, based on the dual problem interpretation, cause new patterns. These new patterns are included in the original problem. Table A.4. shows that in week 1 and 2, these new patterns (2) are used in the optimization from stem to assortments. Table A.10. shows that also in the assortment conversion the alternative patterns are used.

After two iterations, this means after optimizing the tactical productionplan, when two patterns are available for each class and each assortment, a somewhat changed result is obtained. (see figure 7.6)

Let us now examine the results, as displayed in figure 7.6 and table A.19.

The produced value has decreased, after using both the initial patterns, and the alternative patterns. However, because of using new patterns, the turnover, a measure for the service rate, has increased. How has this happened?

The initial pattern resulted in a typical assortments and boards frequency. However this frequency was purely a result of value maximization. The demand for final products and for semiproducts however may require a different frequency than the produced frequency. The stress on the constraints, indicating shortages and inventories cause internal price adaptions (chapter five). The result is a set of alternative patterns, better meet the market demand. The direct result is a turnover increase. In terms of the OPT philosophy this can be called throughput maximization. Self-evidently both stock out and inventory cost are lower after two iterations. The amount of raw material used is equal to the amount used in the initial problem. The contribution to profit however has increased dramatically.

After this second iteration, the process can be repeated. Tables A.4. to A.9. display the results of the next five iterations with respect to the raw material usage. It turns out that pile 1 is never used, which is quite understandable. The more large sized timber, in class 3 and 4 is sufficiently available, and thus the smaller timber is not used. Tables A.12. to A.16. indicate the results of the iterations 3 to 7 with respect to the assortment usage. After 7 iterations, it turns out that the variables related to patterns 1, 2, 3, 4, 5 are active.

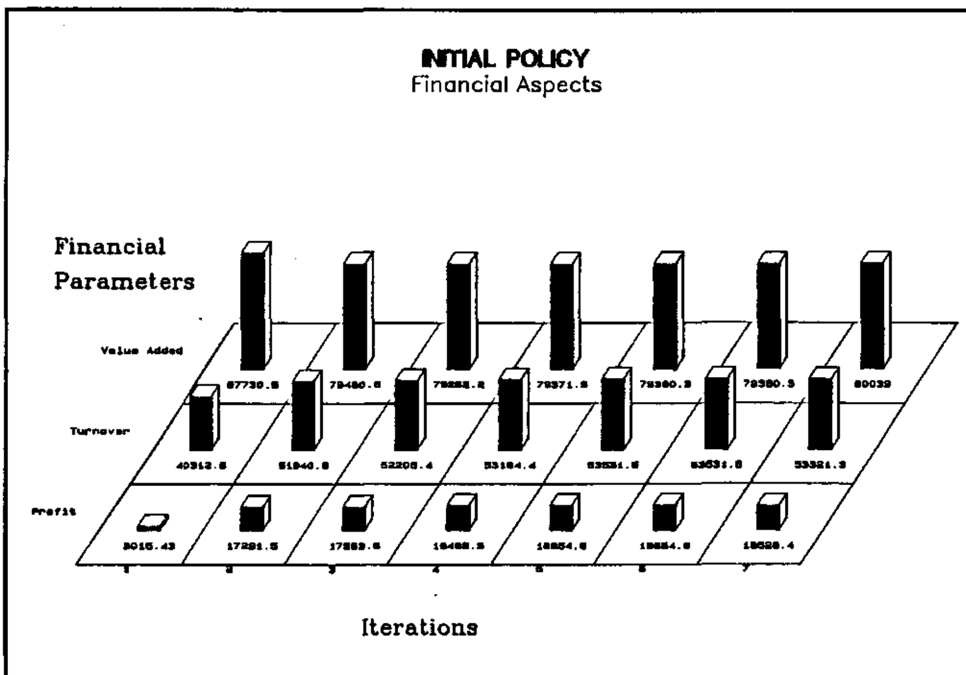


Figure 7.6. Produced Value, Turnover, and Contribution to profit as function of the number of iterations.

The total value produced increases, every time new patterns are generated. Turnover and contribution to profit however are maximized after 5 iterations. Hence, produced value and turnover are not exactly equally directed. This is a logical consequence of the economic model in relation to the objective function of the multiple goal problem.

The stock out cost for both assortments and final products, penalize the deviation from the preset target, specifically producing exactly what is asked for. If the market value, and the out of stock cost for the various commodities differ only little, then the above situation likely occurs.

The added value per cubic metre is increasing, which means that after the iterations the value recovery maximization outbalances the force that directs the system to the market demand. However, in this specific case, value recovery maximization and service rate maximization are equally directed during 5 iterations. (see figure 7.7.)

For the last two iterations, the value recovery maximization turns out to be the dominant force. The next section will explain how to handle and exploit this characteristic.

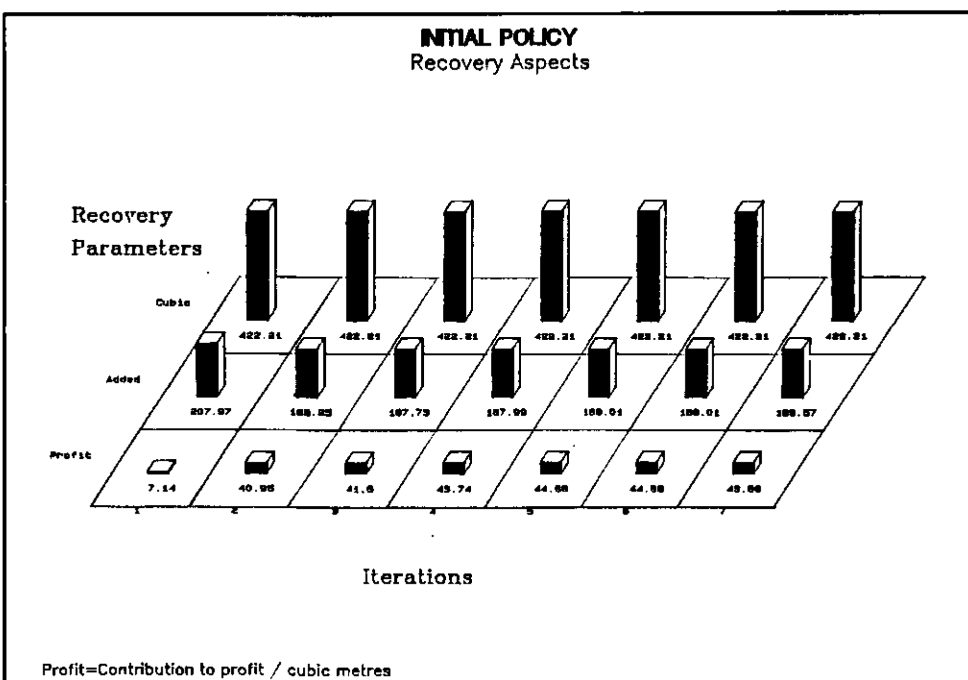


Figure 7.7. Result/m^3, Produced value/m^3, used m^3 as function of the number of iterations.

After seven iterations, the financial results are as displayed in figure 7.8. (table A.19.).

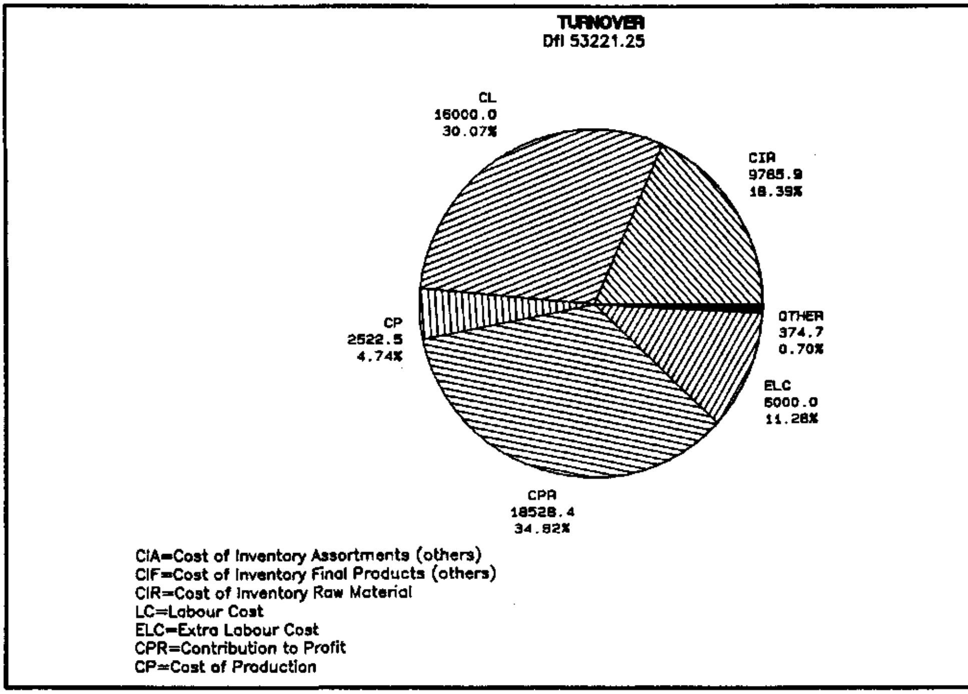


Figure 7.8. Financial results after 7 column-generating iterations.

7.3. VARIOUS POLICIES

In this section various policies with respect to the tactical planning will be subject of discussion. Of course the discussion of the numerical results will not be as detailed as in the previous section. For every policy the problem in the above section was the initial strategy.

a) Investment in handling equipment.

Suppose that an investment is made in handling equipment. This means that the number of piles is increased.

Instead of 2 piles, the company uses now 4 piles. Because every class is now stored on a separate pile, a stem belonging to this class can be chosen, without the possibility that a stem in the same pile, belonging to another class is picked.

Hence, every time a specific stem is needed, the best fitting, available stem can be picked from the right pile. The results of extra sorting must be translated into increased produced value, and in increased service degree (turnover). Note that turnover is an indication for service degree, but a high turnover does not necessarily result in a high service degree, because only valuable products might have been sold, while less valuable products were not delivered. Figure 7.9. describes the total added value (value produced), the turnover and the contribution to the profit as functions of the number of iterations.

Figure 7.10. shows the used amount of raw material, the added value per cubic metre and the profit per cubic metre as a function of the number of iterations.

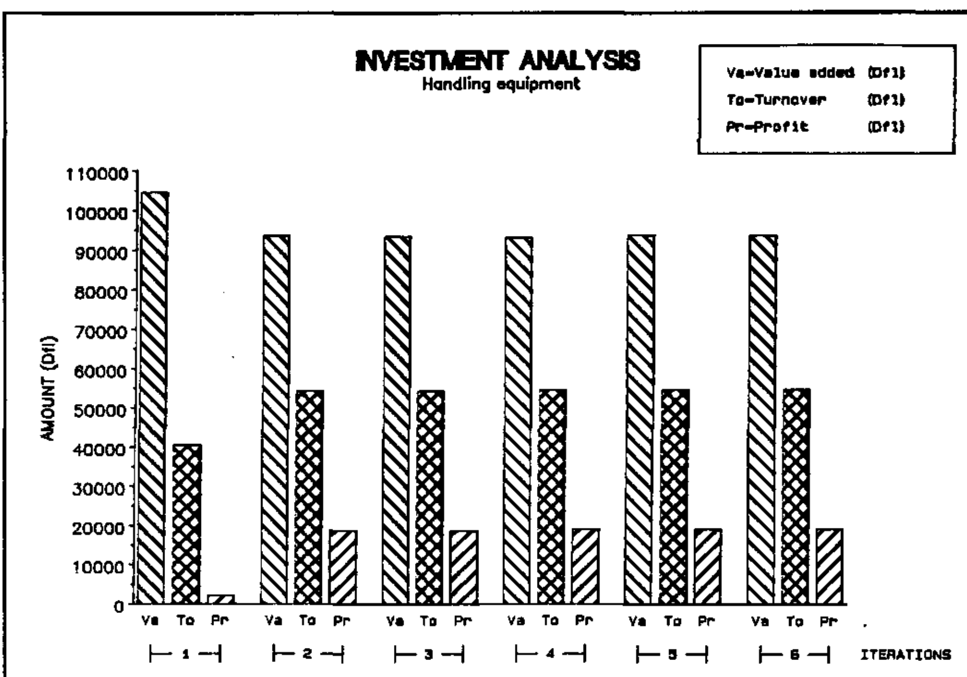


Figure 7.9. Value produced, turnover, and contribution to profit as function of the number of iterations.

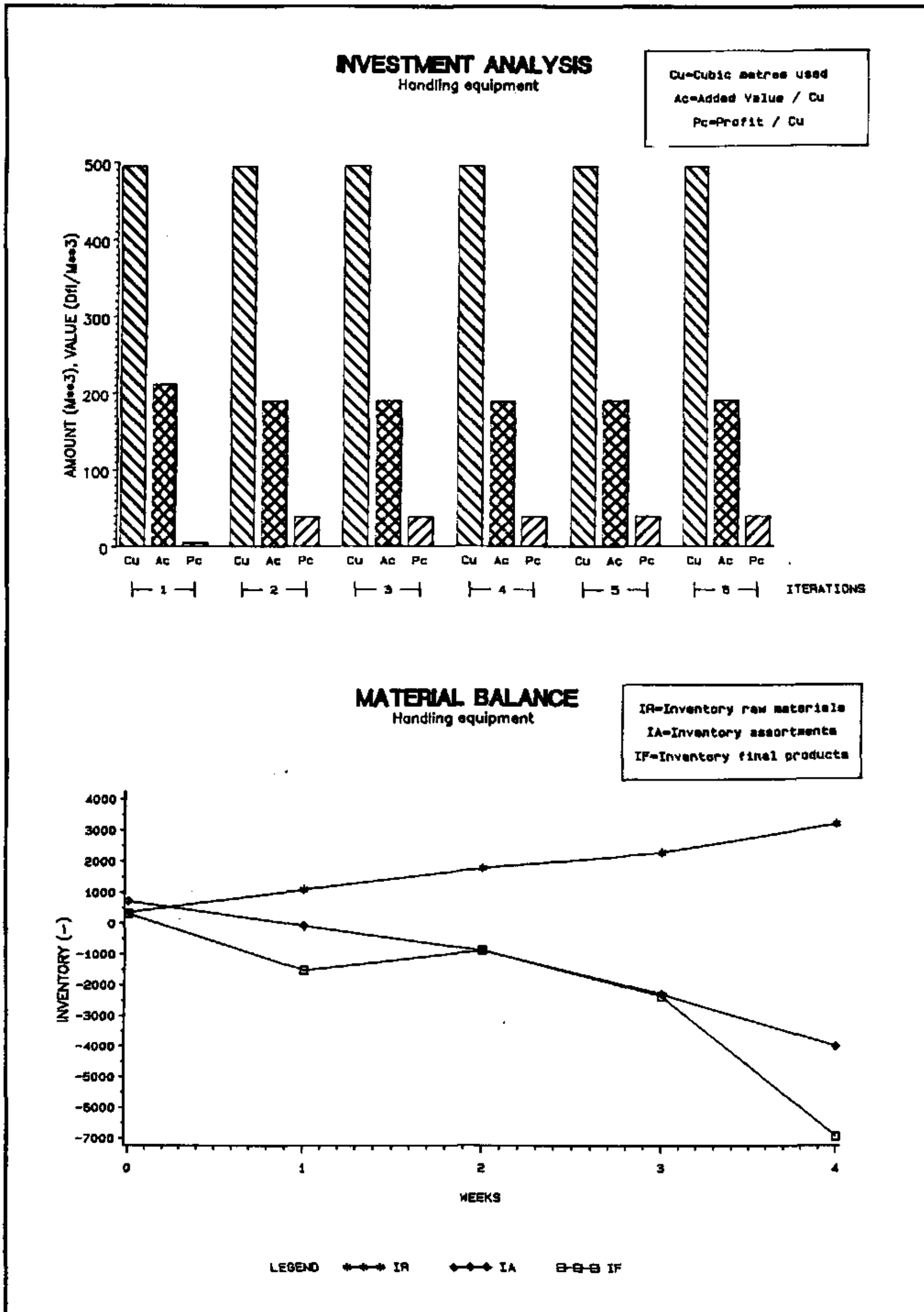


Figure 7.10. Relative recovery parameters, aggregated inventory levels.

The production has two major driving forces, value recovery maximization and service rate maximization. This leads to negative inventory in week 1 to 4, indicating shortages both for assortments and boards. The aggregated inventory for raw material, assortments and final products is displayed in figure 7.10. In table B.19. the financial aspects of this second policy are reflected. The total produced value, as well as the turnover has increased.

The added value per m^3 has also increased, which means that relatively better patterns could be applied as a result of the sorting. The increase in the contribution to profit is a result of the increased amount of raw material used, because the profit per cubic metre sold has decreased (table B.2).

Conclusion:
- more value produced
- higher turnover
- higher contribution to profit
- more raw material used.

b) Investment in crosscutting speed.

When investing in crosscutting machinery, the tactical planning takes a more demand orientated production direction, with respect to the semiproducts (pull effects). When increasing the crosscutting speed with 50%, produced value increases with ±47%. Hence, increasing the speed is very effective with respect to value recovery. The turnover increases with 19%, which means that less than a proportional increase is sold.

The stock out cost for assortments dramatically decrease, which indicates that as a result of speeding up the crosscutting, more assortments could be sold, and thus less shortages occured. However, the relative turnover increase is less than one might expect, because a part of the value is accumulated in inventory for final products (table B.9.).

The financial and recovery effects of speeding up the crosscutting process are displayed in figures 7.11 and 7.12 respectively. In figure 7.12 it is also shown that the aggregated assortments inventory has increased, and that overall shortages do not occur anymore.

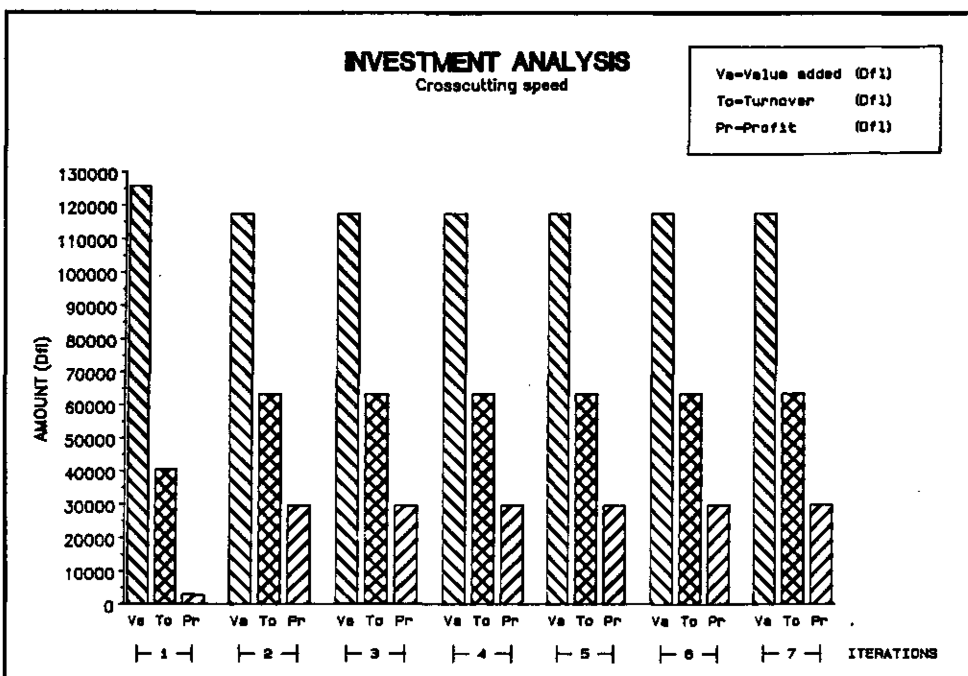


Figure 7.11. Financial parameters.

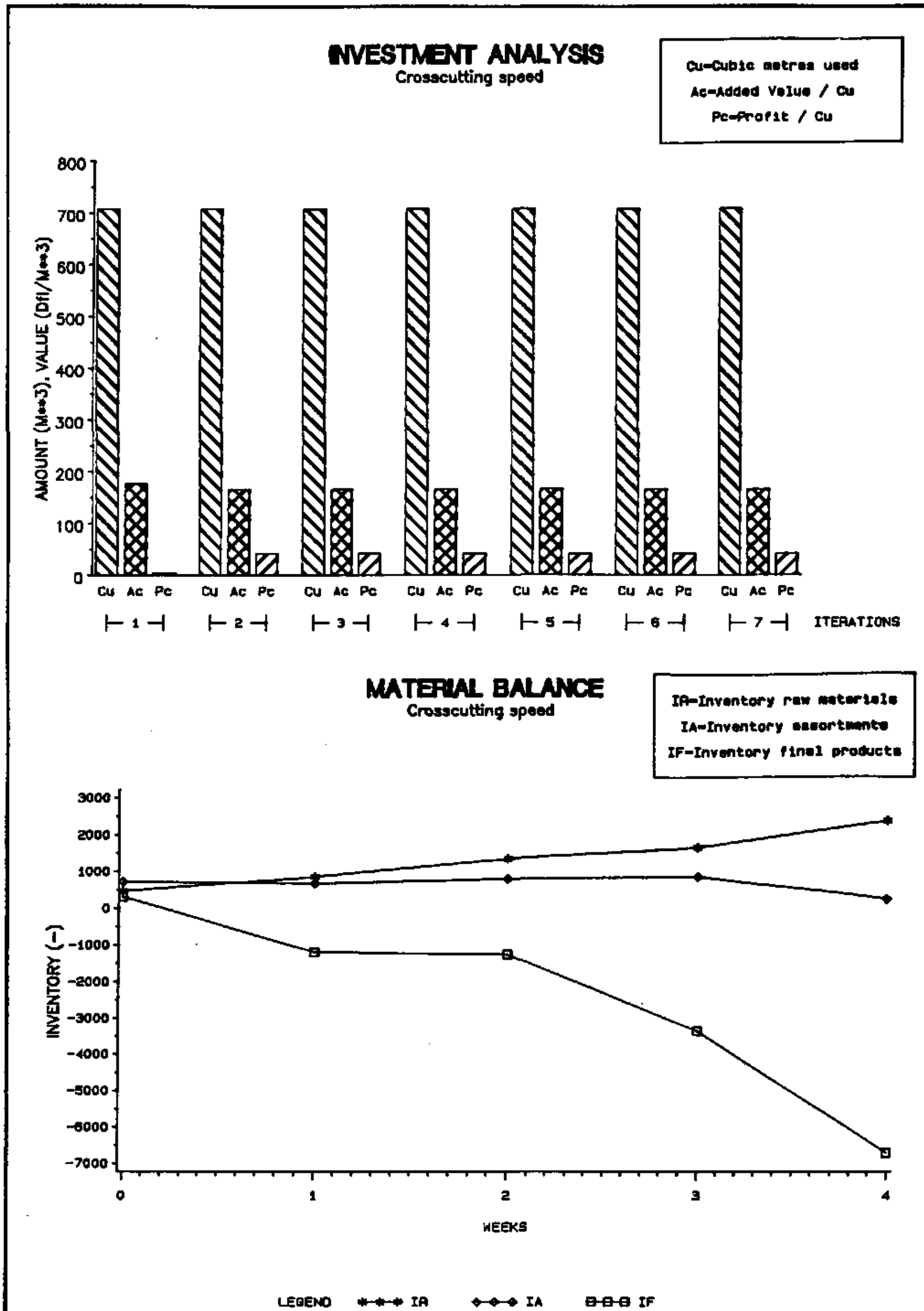


Figure 7.12. Relative recovery parameters, aggregated inventory levels.

Conclusion:
- more value produced
- higher turnover
- higher contribution to profit
- much more raw material used
- less relative value
- more relative profit

c) Both investing in handling equipment and crosscutting capacity

Suppose that both the raw material is sorted into four piles, and that the crosscutting speed is increased by 50% relative to the initial situation as described under policy a.

Evidently the speeding up effect is also exploited in this situation (see figure 7.13). Hence, both produced value and turnover are high. Moreover, because of the extra sorting, the out of stock cost for assortments and for final-products decrease. Because of the decoupling of classes 1 and 2 (both on a separate pile) now class 2 is used, in week 2.

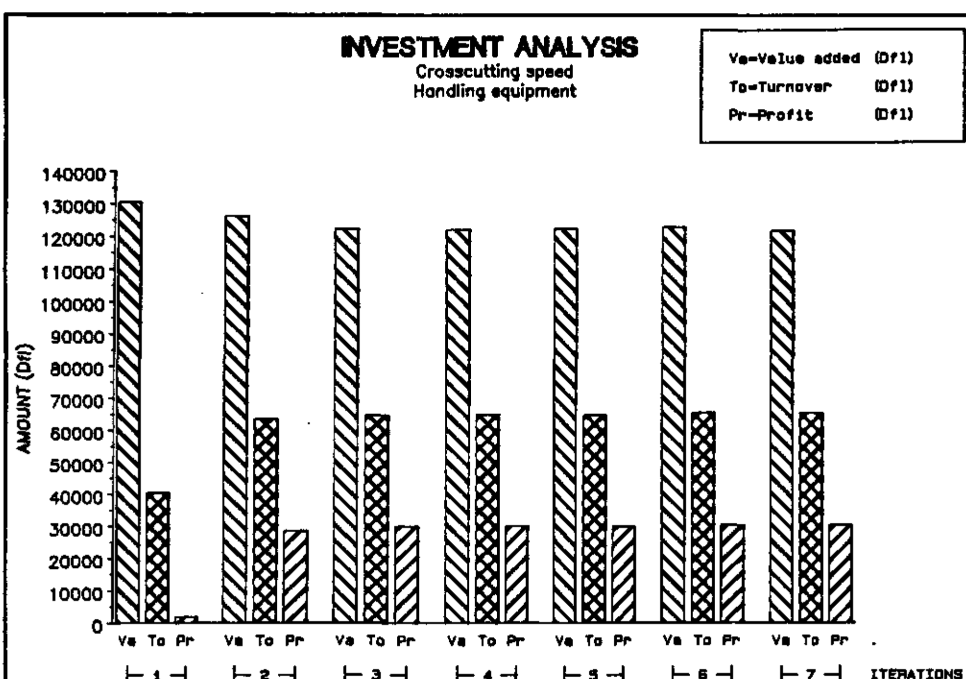


Figure 7.13. Financial parameters.

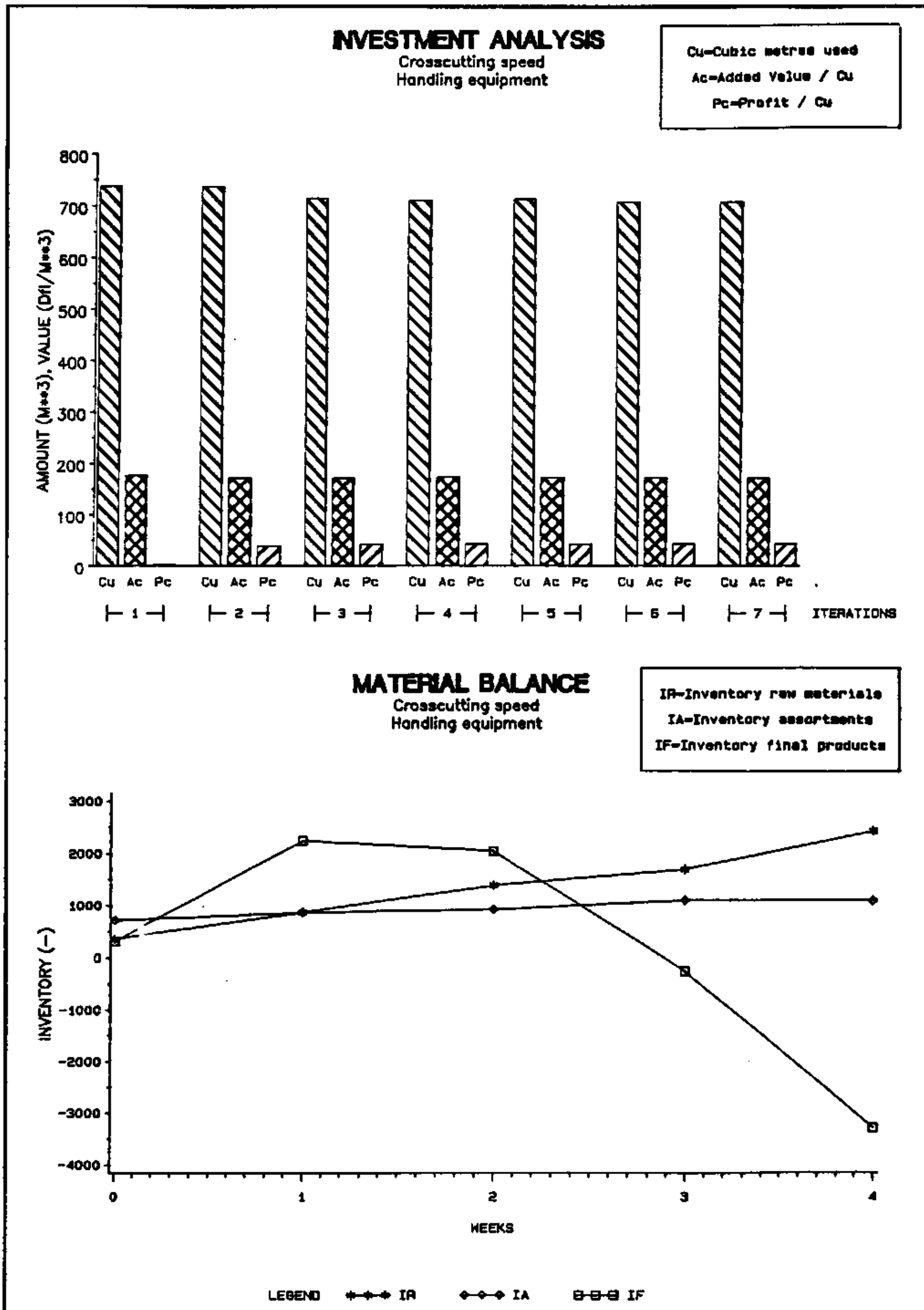


Figure 7.14. Relative recovery parameters, aggregated inventory levels.

A direct result is the fact that a little less raw material is now used , as shown in figure 7.14.

Conclusion:
- more value produced
- higher turnover
- higher contribution to profit
- the raw material is used both effectively and efficiently.

d) *Value recovery maximization*

What happens if the decision-maker decides to produce fully directed towards value recovery (push strategy). In other words only the production of valuable products is strived for, no matter whether there is a demand for these products or not. The produced value is very high (table B.9.), in fact this is the maximum attainable value recovery. Of course the turnover drops to a lower level, an effect that is accumulated in the financial results because the inventory cost for both assortments and final products increase. Hence the contribution to profit is substantially decreased. (table B.9.). The financial results are displayed in figure 7.15, the value recovery effects in figure 7.16.

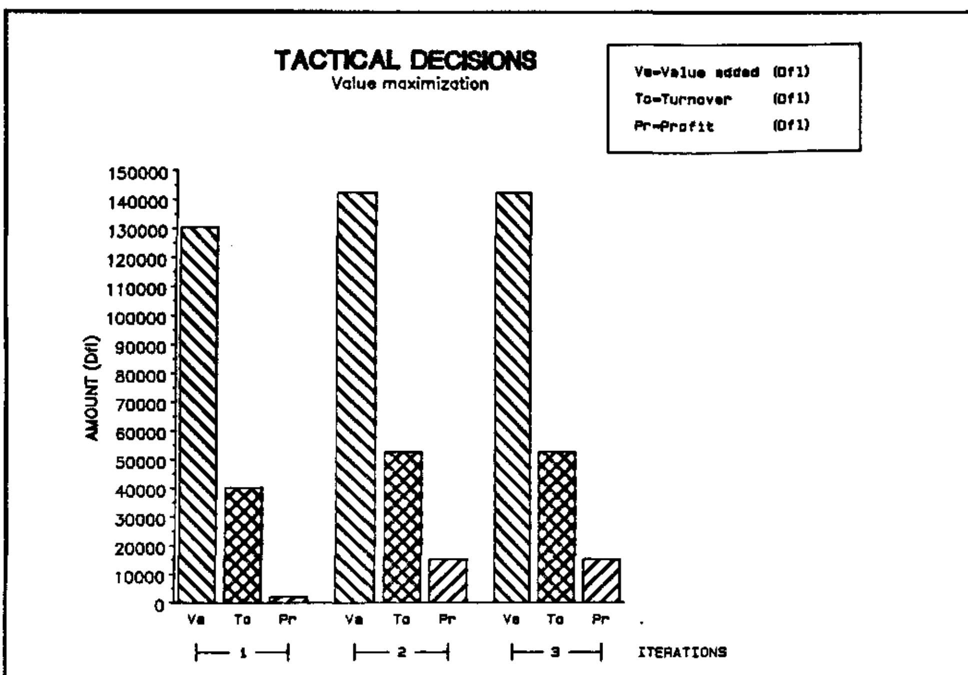


Figure 7.15. Financial parameters.

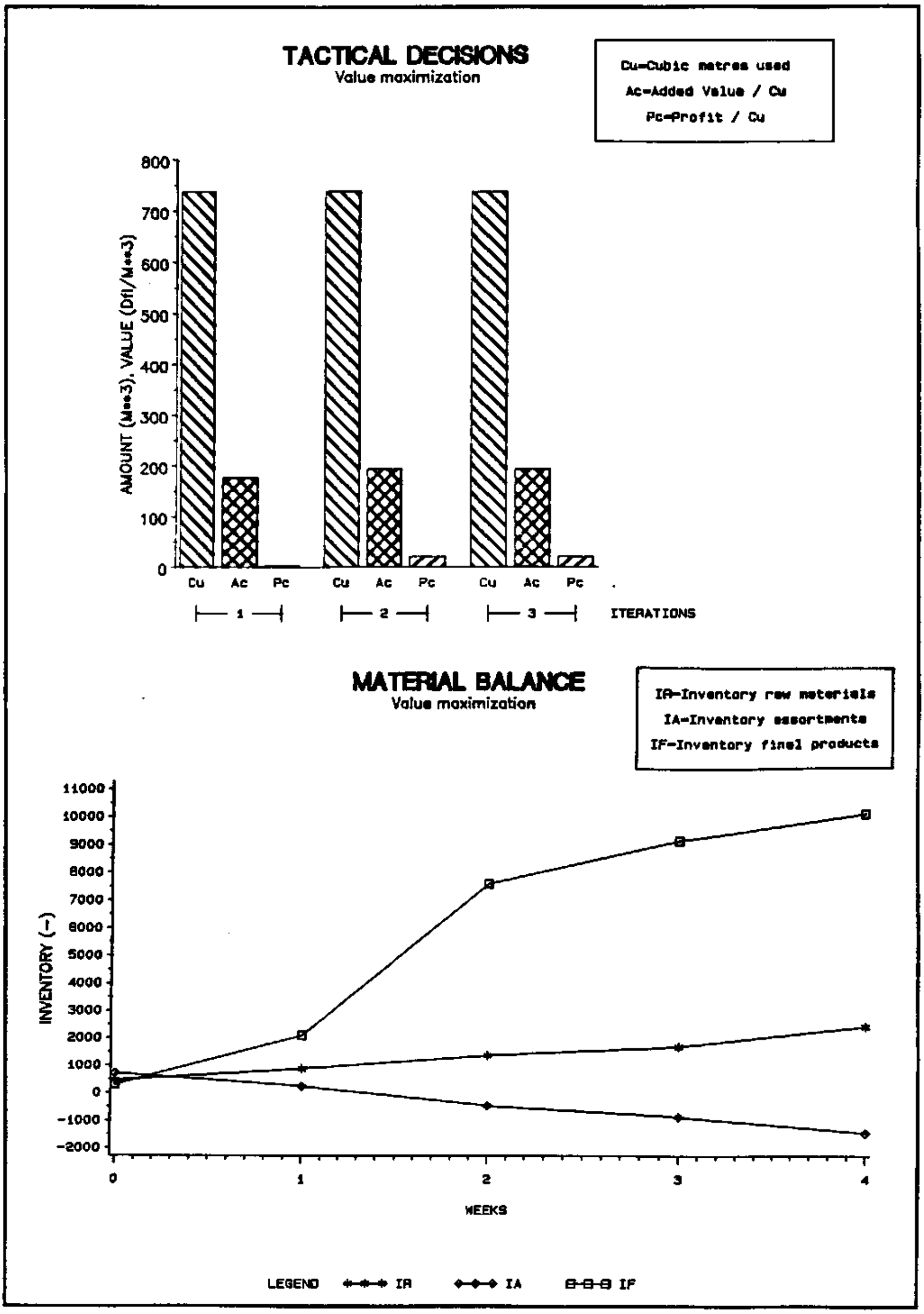


Figure 7.16. Relative recovery parameters, aggregated inventory levels.

e) Maximization of the contribution to profit

In this policy the profit making target has highest priority. Suppose that profit is considered of most importance, primarily products must be produced that are asked for.

Hence the planning must be controlled towards end user orientated production. A direct result is the fact that in this situation the service rate must be high, and thus the stockout cost must be high. For high stock out cost drive the system towards meeting the demand, because deviations from the preset target are penalized.

In table B.9. it becomes clear that this policy has indeed a very high turnover. Moreover the inventory cost for both semi-products and final-products are lower than in most other policies. It follows directly that the final result, the contribution to profit, is higher than for all other policies. (see figure 7.17.).

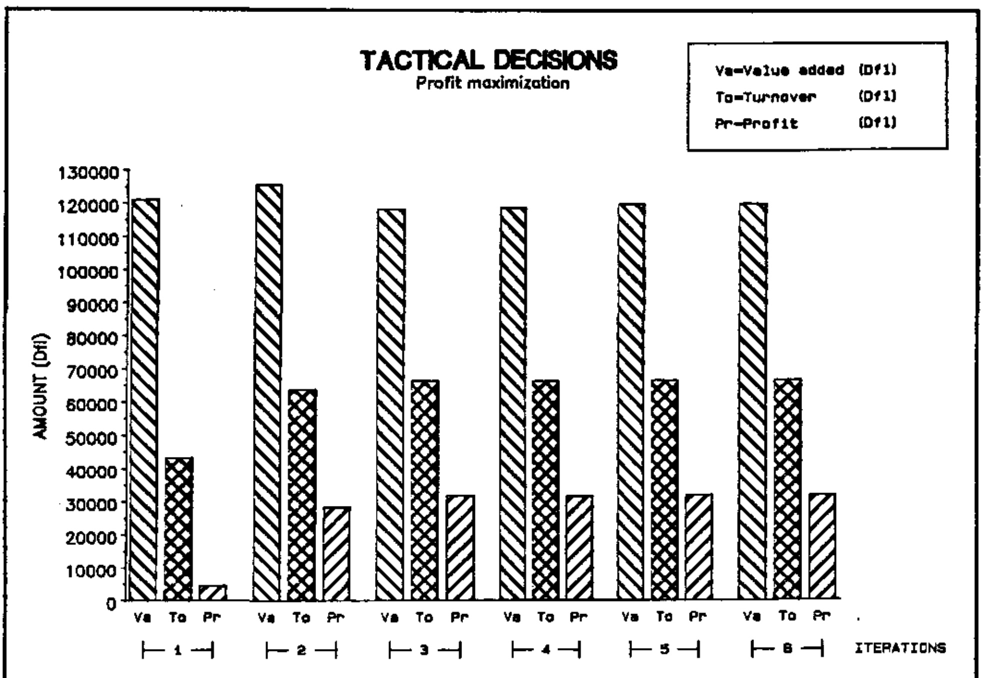


Figure 7.17. Financial parameters.

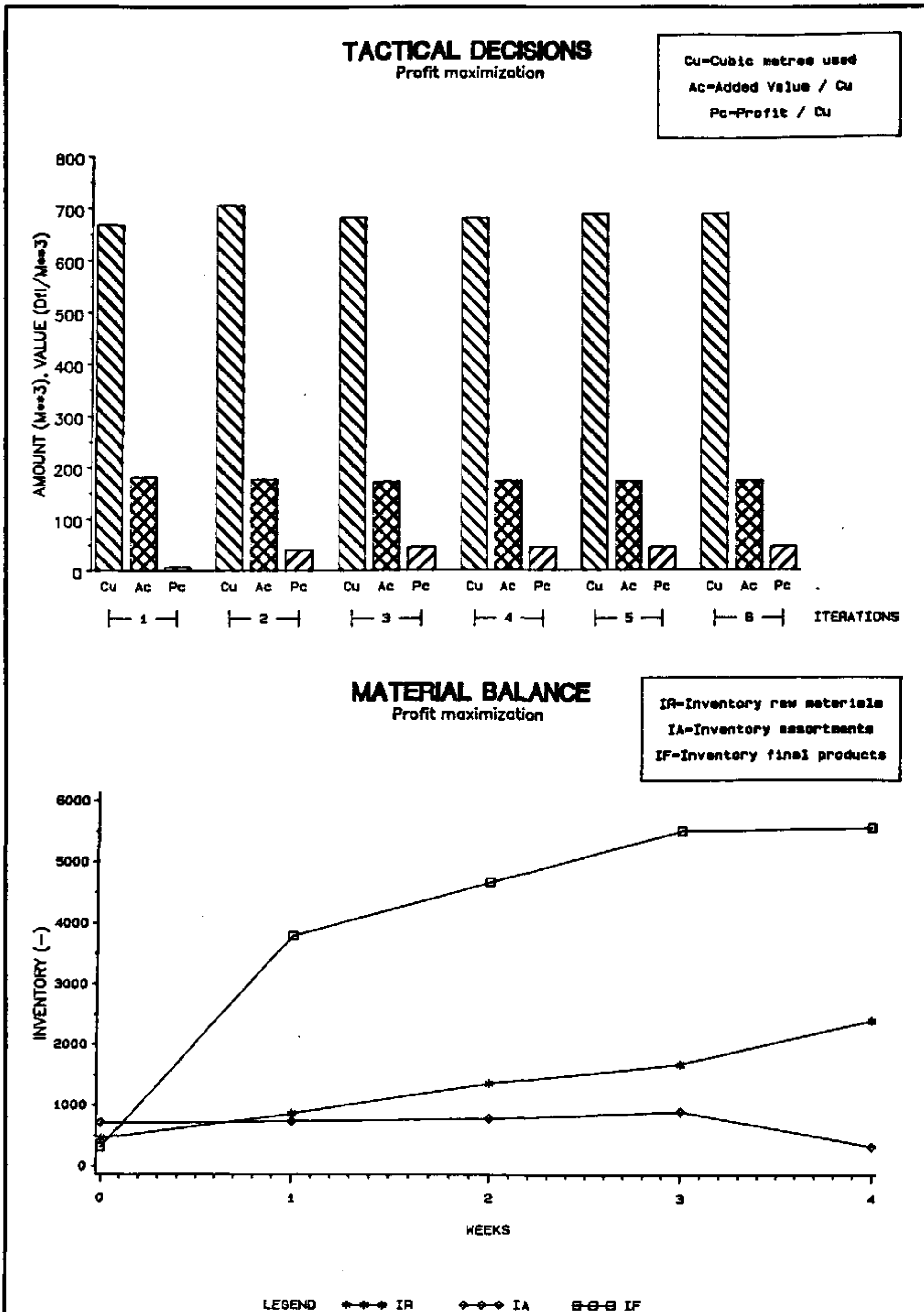


Figure 7.18. Relative recovery parameters, aggregated inventory levels.

Producing desired boards and assortments also causes production of unmarketable semi-products and final-products. This process is called package production. The total amount of raw material used is therefore lower than in other policies, because unwanted products cause inventory, which gives rise to inventory cost. Inventory cost has a negative influence on the contribution to profit. Therefore the added value per cubic metre is relatively high (less cubic metres) and the profit per cubic metre is for this policy maximum (see figure 7.18).

On an aggregated level, no shortages occur anymore, because shortage indicate a non maximum service degree. Using the described policy, all demand is met after four weeks, and thus a high turnover is the result. (see figure 7.18)

f) Adjusting the layout

Let us now examine what happens if a different layout is used for the conversion-site. Suppose that the primary and secondary breakdown are integrated, to give one integrated process. In this case the use of the earlier mentioned (chapter 5) three-dimensional dynamic programming model is needed. Moreover, the tactical planning model can be simplified.

The extra production-step, causing an inventory of assortments is not necessary anymore. The adjusted model asks for some re-definitions of some variables and parameters. Because most definitions are equal to the ones proposed in chapter 5, here only the adjusted definitions are given in table 7.17.

Table 7.17. Adjusted definitions.

descriptor	*dimension*	*meaning*
X^t_{sn}	(-)	*Frequency for using cutting pattern s for raw material class n, in planning period t.*
NF^t_{fsn}	(-)	*Number of final-products f, when processing a stem of type n, using pattern s, in time period t.*
CP^t_{sn}	(Dfl)	*Cost of production using sawing pattern s, for class n, in time period t.*
VR^t_{sn}	(Dfl)	*Value of a stem of class n, in period t, using pattern s.*
TR^t_{sn}	(hours)	*Time needed to process a stem of class n, using pattern s, in time period t.*

In chapter five all constraints and the object function have been discussed in depth. Because the basic assumptions have not been changed for this integrated model, the model will be stated without further explanations.
The model can be stated as:

$$\max\{ \sum_{t=1}^{Nt} (\sum_{s=1}^{Ns} \sum_{n=1}^{Nn} (VR^t_{sn}.X^t_{sn}) - \sum_{f=1}^{Nf}(CIF^t_f.IF^t_f + COF^t_f.OF^t_f) - CES.ES^t - \sum_{p=1}^{Np} (CIR^t_p.IR^t_p))\}$$

Subject to:

$$\sum_{s=1}^{Ns} \sum_{n=a_p}^{z_p} X^t_{sn} + IR^t_p = \sum_{n=a_p}^{z_p} \beta_n(NR^t+BR^t) + IR^{t-1}_p \qquad 1 \le t \le Nt;\ 1 \le p \le Np$$

$$\sum_{s=1}^{Ns} \beta_n . X^t_{sn-1} - \beta_{n+1} . X^t_{sn} = 0 \qquad \begin{array}{r} 1 \le t \le Nt \\ 1 \le p \le Np \\ ap \le n \le zp \end{array}$$

$$\sum_{s=1}^{Ns} \sum_{n=1}^{Nn} TR^t_{sn} . X^t_{sn} - ES^t + US^t = WEEK \qquad 1 \le t \le Nt$$

$$\sum_{s=1}^{Ns} \sum_{n=1}^{Nn} NF^t_{fsn} . X^t_{sn} + IF^{t-1}_f + OF^{t-1}_f = DF^t_f + IF^t_f + OF^{t-1}_f \qquad \begin{array}{r} 1 \le t \le Nt \\ 1 \le f \le Nf \end{array}$$

All variables continuous, greater or equal than zero.

In this model the first set of constraints describes the limited availability of raw material, usable for boards production. The second set of constraints is a result of the piles and the interconnected classes within the piles. The next set of constraints indicated the capacity limits. In the last set of equations the connection between production of boards and demand for boards is described.

To optimize the tactical planning, the same procedures are used as described in chapter five.

Let us now look at the optimization results. Because no assortments are produced the total produced value is substantially lower than in the previous production policies (fig 7.19.). The turnover however is still relatively high. At the end of the planning, after 4 weeks, all demand for finalproducts has been met, and a relatively large inventory for final-products (see fig 7.20.) is the result.

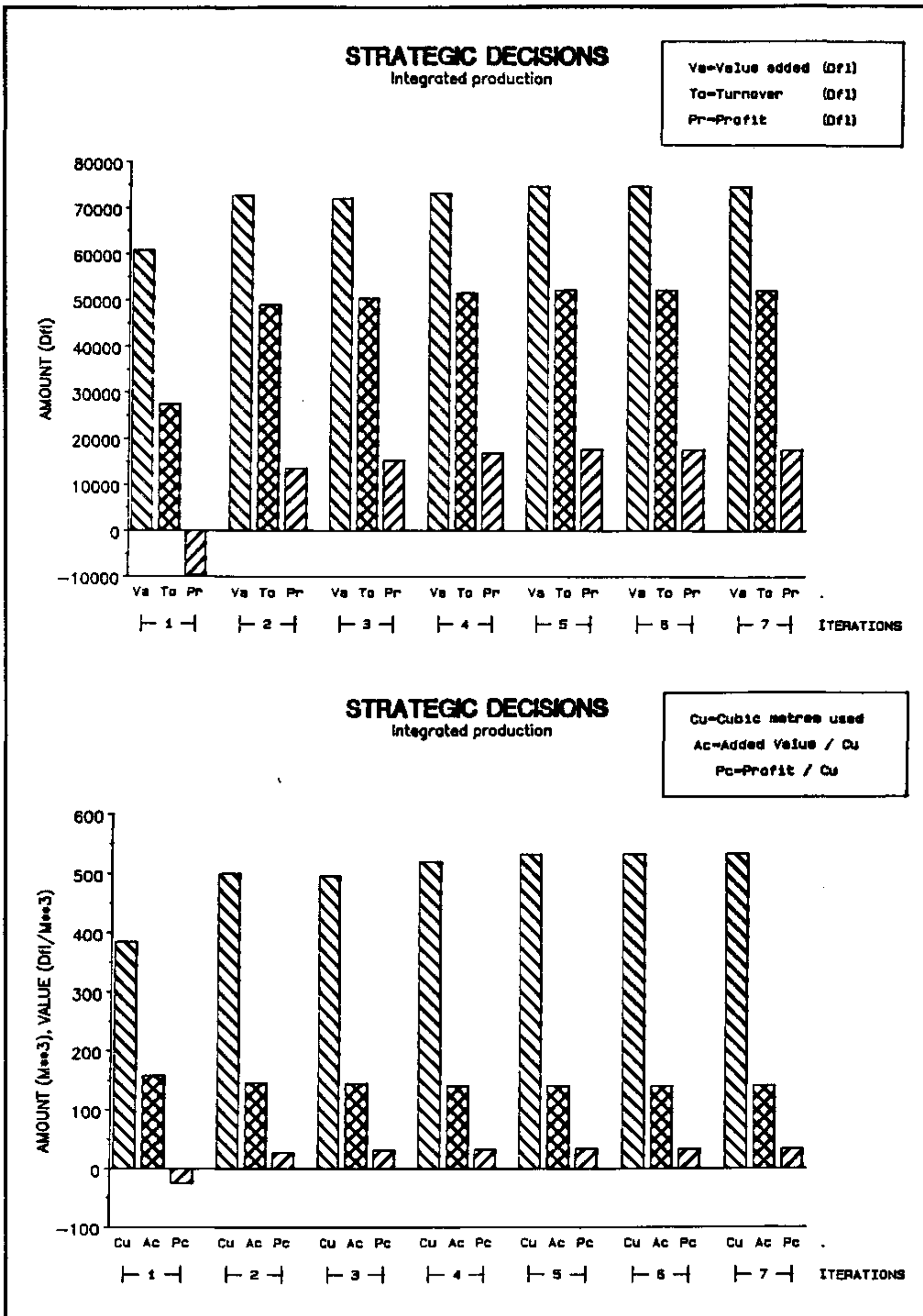


Figure 7.19. Financial parameters, relative recovery parameters.

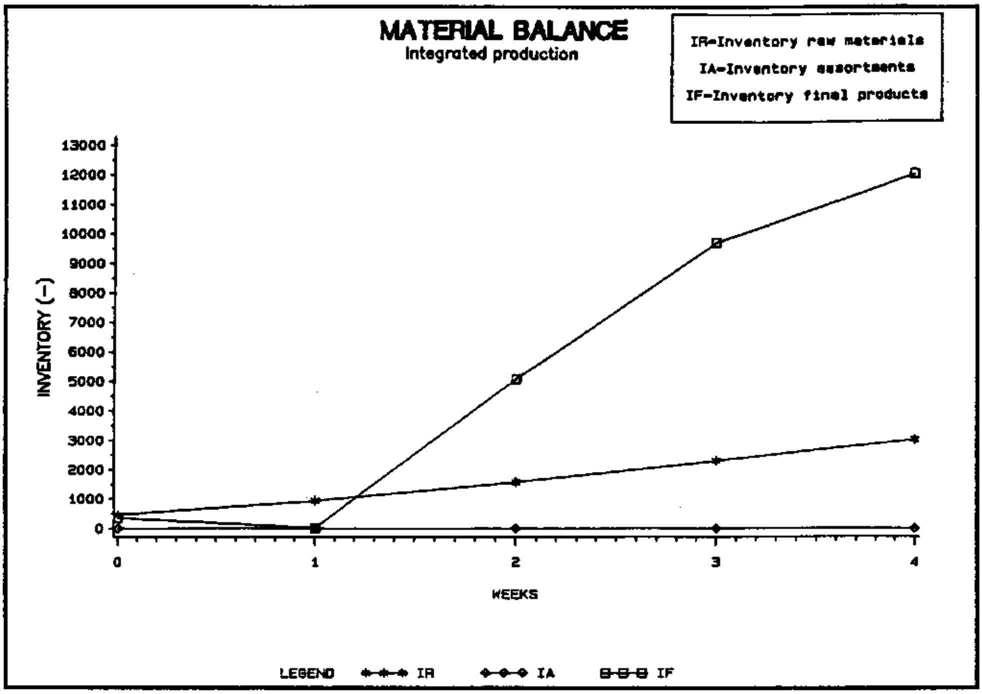


Figure 7.20. Aggregated inventory levels.

h) A new product-mix

In the previous policy, the production process was integrated. Hence, all degrees of freedom, usable for the conversion of a stem into boards were kept in the planning system. A direct comparison however was not possible, because all other policies sold also assortments. Therefore, look back at the conventional, two-step conversion-site.

Now the production of assortments, needed for the dynamic programming algorithm is used for direct sales. This assortment is supposed to be sold for a price of Dfl 0.00, because otherwise extra revenues would be possible, making the comparison with the previous policy unfair.

The results are displayed in figures 7.21, and 7.22.

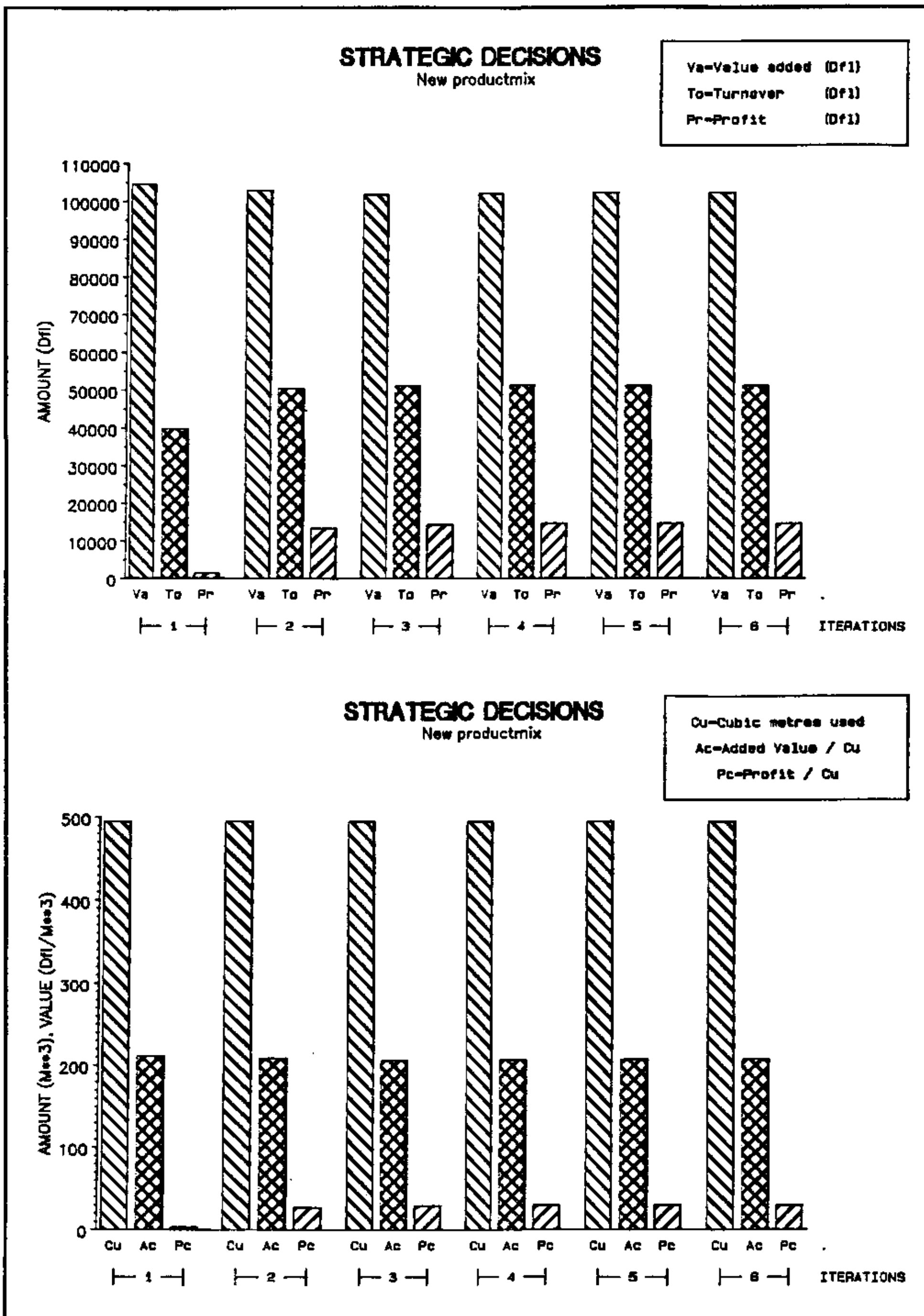


Figure 7.21. Financial parameters, relative recovery parameters.

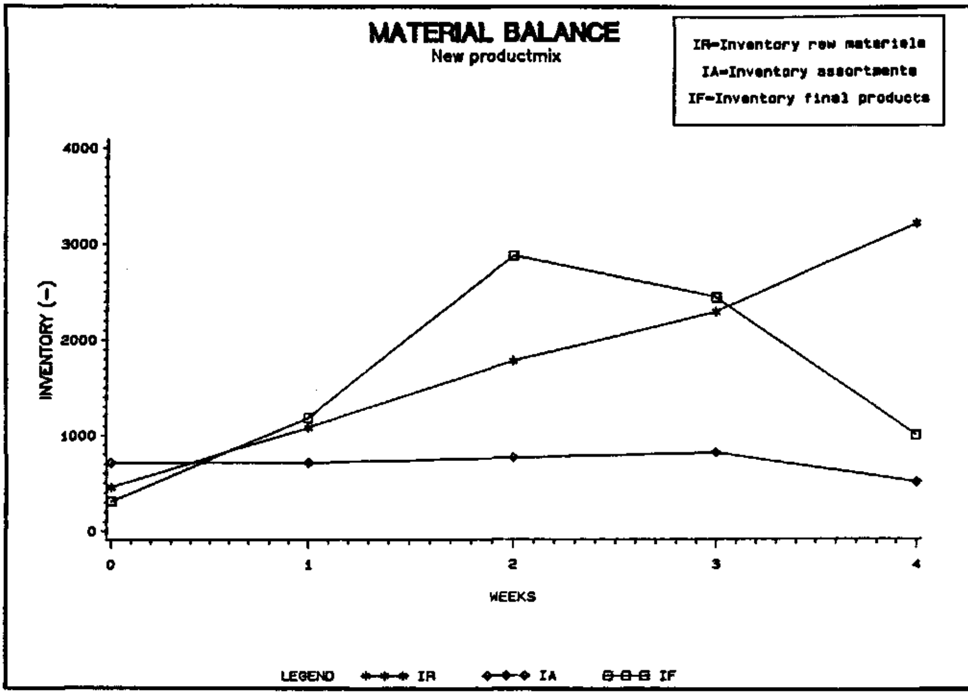


Figure 7.22. Aggregated inventory levels.

When looking closer at table B.9. some aspects illustrate the difference between the two policies (g,h). Because of integrating the production, policy g is more directed to the demand for final-products. As a result the turnover is higher, and because of the accumulation effect of the inventory cost, the contribution to profit is substantially higher for policy g.

Conclusion:
- Production integration leads to higher service degree.
- As a direct result higher contribution to profit.
- Lower cost of production. Yet the actual processing cost will be higher, because more advanced tools are used.

Chapter 8

CASE STUDY

In this chapter the system IDEAS will be tested in a real-world situation. A plant in the Federal Republic of Germany (FRG) is used to model a conversionsite. After a short introduction (section 8.1.), the model plant is described (section 8.2.). In section 8.3. various production planning alternatives are evaluated.

The conclusions drawn from the test results are summed up in section 8.4.

8.1. INTRODUCTION

In chapter seven various test runs were discussed. All data used for these tests were fictitious. To analyse the decision support system in a real-life situation, a case study was carried out.

Because during the research valuable contacts existed with various researchers and managers in the FRG, it is rather logical that the case study was directed towards a German company.

One of our most important contacts was the Fuerstlich zu Waldburg-Wolfegg'sche Forstverwaltung in Wolfegg. Wolfegg is a small place in the southern part of the FRG, in the state Baden-Wuerttemberg. Much data concerning this company were provided, and made it possible for us to make the underlying analyses.

Before discussing the data, some initial remarks must be made. The data obtained, and the models developed were not tuned in on each other at all detailed levels. Some data used as input in the analyses, are obtained by extrapolation of the available data. Other data are calculated and reshuffled from the original data, and thus not always easy to recognize from a practical point of view.

Moreover, the financial results, discussed in the following sections must not be interpreted literally. The relative differences, the shifting towards the various production strategies are considered to be of more interest.

The modelplant can be described as a two phase conversion-site. Firstly the stems are converted into assortments, secondly the assortments are converted into boards of various sizes. The company uses raw material both from company owned forests, and purchased from the open market.
The stems are sorted to some extent in piles. Roughly both large sized timber, and small dimensioned timber is used.

After final delimbing and debarking of the stems, they are measured electronic devices. Then the stems are crosscutted into assortments of various sizes and qualities. Some of these assortments are sold to other mills, yet most of the assortments are converted into boards in the company owned sawmill.

After sawing the assortments into boards of distinct dimensions and qualities, the final products are stored on the yard.

In the following section the conversion-site will be considered in terms of data description, used as input for the optimization.

8.2. THE MODELPLANT

The Wolfegg conversionsite was stored in the database of the system IDEAS. Therefore, it will be discussed in the same way as the model-plant in chapter seven.

The whole plant is stored in the database, distributed over the various datafiles, and partitioned in the distinct sections.

The first section of the dataset describing the Wolfegg company has references to the layout configuration. (see table 8.1)

Table 8.1. The layout of the Wolfegg conversion-site.

number	*description (attribute)*	*logical state*
1	*Sorted raw material*	*true*
2	*Raw material harvested*	*true*
3	*Raw material purchased*	*true*
4	*Integrated production*	*false*
5	*Semi-products sales*	*true*
6	*Semi-products purchased*	*false*

The second subset describes the raw material (table 8.2.).

Table 8.2. The raw material.

number	*description (attribute)*	*occurrency*
1	*Number of piles*	*5*
2	*Number of classes*	*8*
3	*Smallest dbh input*	*12*
4	*Species*	*Pinus*
5	*Class width*	*variable*

In table 8.2., eight classes are mentioned. These classes are used to constitute piles. Sometimes a class is used more than once. This means that for instance pile 1 and pile 2 both use class 1, 2, 3. Yet the contributing ratios for the classes in the two piles vary (table 8.11). Hence, no longer disjoint piles are used (see chapter 5) and thus the number of constraints in the linear programming model increases.

The relation between the various piles and classes is displayed in table 8.3.

Table 8.3. The representative stems.

	pile				
class	1	2	3	4	5
1	PN-WE1	PN-WE1	-	-	-
2	PN-WE2	PN-WE2	-	-	-
3	PN-WE3	PN-WE3	-	-	-
4	-	-	PN-WE4	-	-
5	-	-	PN-WE5	-	-
6	-	-	-	PN-WE6	-
7	-	-	-	PN-WE7	-
8	-	-	-	-	PN-WE8

Table 8.3. illustrates that piles are used with overlapping classes. In table 8.4. the stems, representing classes are described.

Table 8.4. The used stemtypes.

class	stem	length (cm)	dbh (cm)	dtop (cm)
1	PN-WE1	800	12	10
2	PN-WE2	1000	18	12
3	PN-WE3	1400	22	14
4	PN-WE4	800	12	12
5	PN-WE5	800	14	14
6	PN-WE6	600	18	18
7	PN-WE7	600	24	24
8	PN-WE8	600	28	28

Classes 6, 7, 8 are in fact not stems, but super-assortments, long parts of stems, used for further conversion. Classes 1 to 5 are real stems, partly bought on the open market.
Section four contains the crosscutting information (table 8.5.).

Table 8.5. Crosscutting information.

number	*description (attribute)*	*occurency*
1	*Crosscutting speed (cm/s)*	*33*
2	*Transportation speed (cm/s)*	*83*
3	*Crosscutting cost (Dfl/hrs)*	*37.00*
4	*Semi-products set for conversion*	*PN-WE1*
5	*Semi-products set for sales*	*PN-WE2*
6	*Inventory cost (Dfl/m^3.week)*	*0.20*
7	*Stock out cost (Dfl/m^3.week)*	*0.00*

The record fields also contain PN-WE1 and PN-WE2 respectively, two references to the semi-products sets, described in the corresponding datafiles. They are displayed in tables 8.6. and 8.7.

Table 8.6. Semiproducts (set = PN-WE1).

number	d min (cm)	d max (cm)	L_{tot} (cm)	Price (Dfl)
1	8	13	300	16.28
2	13	15	300	24.00
3	15	17	300	34.26
4	17	19	300	48.85
5	19	21	300	62.95
6	21	23	300	75.26
7	23	25	300	86.40
8	10	13	525	28.50
9	13	15	525	42.00
10	15	17	525	60.00
11	17	19	525	85.50
12	19	21	525	110.18
13	21	23	525	131.71
14	23	27	525	151.20

The prices are calculated from the available relative prices (Dfl/m^3).

Table 8.7. Semiproducts for direct sales (set = PN-WE2).

number	d min (cm)	d max (cm)	L_{tot} (cm)	Price (Dfl)
1	1	50	25	0.00
2	24	26	400	127.25
3	27	28	400	161.56
4	24	26	500	159.20
5	27	28	500	201.95
6	27	28	550	248.27

This set is completed with a dummy assortment (that enables a decision at every stage z).
The fifth section describes the boards production parameters. (see table 8.8.).

Table 8.8. Board production information.

number	*description (attribute)*	*occurency*
1	*Sawing speed (cm/s)*	*76*
2	*Simultaneously made cuts (-)*	*5*
3	*Sawing cost (Dfl/hr)*	*160.00*
4	*Final-products set*	*PN-WE3*
5	*Inventory cost (Dfl/m^3.week)*	*0.60*
6	*Stock out cost (Dfl/m^3.week)*	*0.00*

Record field 4 is a reference to the final products set, stored in the corresponding datafile. The products are illustrated in table 8.9.

Table 8.9. Final-products set (set = PN-WE3).

number	x len (mm)	y len (mm)	z len (cm)	Price (Dfl)
1	0	10	300	0.00
2	30	100	300	2.88
3	30	120	300	3.56
4	30	160	300	4.90
5	40	60	300	2.38
6	40	140	300	5.55
7	50	80	300	3.84
8	50	100	300	4.95
9	50	120	300	5.94
10	50	140	300	6.93
11	50	150	300	7.43
12	50	160	300	7.92
13	0	10	525	0.00
14	30	100	525	5.04
15	30	120	525	6.24
16	30	160	525	8.57
17	40	60	525	4.16
18	40	140	525	9.71
19	50	80	525	6.72
20	50	100	525	8.66
21	50	120	525	10.40
22	50	140	525	12.12
23	50	150	525	12.99
24	50	160	525	13.86

Products 1, and 13 are the dummy products, assuming a possible decision at every stage (x,y,z).

In section six the personnel information is stored. This information is displayed in table 8.10.

Table 8.10. Personnel information.

number	*description (attribute)*	*occurency*
1	*Length of a day shift (hr)*	*8.500*
2	*Crew (persons)*	*7*
3	*Salary (Dfl/hr)(7 à Dfl 30,-)*	*210*
4	*Total overtime cost (Dfl/hr)*	*262*

With the data, described in the tables above, the plant in Wolfegg is described sufficiently for our purposes. To test the company, in terms of optimizing its tactical production planning, a environment is needed. This environment, the scenario, is stored in the scenario describing data file. It is partitioned in a number of sections.

The first section describes the contributing ratios of the classes, and the raw material describing parameters. (see table 8.11)

Table 8.11. Raw material scenario data, ratios as % of total input.

pile	ratios	initial inventory (stems)
1	7, 12, 5	10309
2	3, 9, 12	3495
3	20, 20	12300
4	7, 3	7000
5	2	600

The raw material inflow, as a result of harvesting and purchasing is displayed in table 8.12.

Table 8.12. Raw material inflow, number of trees.

week			
1	2	3	4
1300	1080	1000	1200

The second scenario section describes the semiproducts, in relation with the demand, and initial amount.

Table 8.13. Semiproducts scenario data.

assortment	initial	demand for week 1	2	3	4
1	140	-	-	-	-
2	300	-	-	-	-
3	120	-	-	-	-
4	300	-	-	-	-
5	300	-	-	-	-
6	240	-	-	-	-
7	220	-	-	-	-
8	140	-	-	-	-
9	300	-	-	-	-
10	120	-	-	-	-
11	300	-	-	-	-
12	300	-	-	-	-
13	240	-	-	-	-
14	220	-	-	-	-
15	100	1230	1060	1040	1210
16	150	200	210	80	300
17	110	40	120	100	240
18	200	130	160	240	310
19	100	100	110	80	100
20	120	140	20	100	340

In section three the finalproducts scenario is displayed. (see table 8.14.)

Table 8.14. Final products scenario data.

board	initial	demand for week 1	2	3	4
1	1100	900	1200	1200	490
2	240	50	70	100	100
3	60	320	530	200	850
4	20	256	280	140	260
5	120	180	120	220	440
6	110	330	300	140	310
7	100	290	270	320	430
8	40	420	320	210	210
9	80	100	100	400	600
10	70	40	100	60	130
11	20	210	80	100	120
12	130	200	230	200	850
13	500	156	380	140	560
14	210	256	180	240	160
15	40	80	120	220	140
16	80	290	170	120	130
17	100	130	130	40	210

Table 8.14.(continuation) Final products scenario data.

board	initial	demand for week 1	2	3	4
18	40	290	670	420	430
19	90	50	20	90	310
20	30	320	420	510	410
21	250	120	220	110	360
22	60	420	420	330	610
23	90	120	70	80	180
24	100	320	130	440	512

In the next section this company and scenario will be examined further with respect to the optimization of the production.

8.3. ANALYSIS

In the following sections, the described company has been evaluated. Various policies were imposed on the conversion-site and the scenarios.

8.3.1. INTRODUCTION

In the analysis of the production planning for the Wolfegg plant several production policies were examined.

The current situation in Wolfegg has not been researched exactly. The main reason for this is the fact that optimizing the production process, on an operational level, is not performed in practice. The process of crosscutting a stem into assortments is indeed supported with a dynamic programming routine. Yet the secondary breakdown, the sawing, is not optimized, in the way we discuss in this thesis.

The sawing patterns are determined by physical possibilities for the typical assortments in combination with the available machinery. Moreover, the optimization of a population of trees is not performed, although the primary breakdown is controlled on population level with a mechanism called "adaptive price control". This means that "prices" (values) for individual assortments are adjusted based on intuition, related to inventory, demand and supply characteristics. This rule of thumb is not used for the secondary breakdown, because this process is not supported with a dynamic programming module.

The sawing patterns generated with mathematical algoritms, are not always of practical use (Bösch, 1987). The reason for this problem, that we encountered also, is that real-world plants use technology that only allow less advanced patterns. The system IDEAS also generates more complex patterns, that have no practical counterpart at this moment.

Bearing in mind the limitations discussed above, let us now consider the analysis results.

8.3.2. *RESULTS*

To get insight in the production planning five different policies were defined. The first policy comes most close to the situation in Wolfegg, because no advanced information controlling instruments are used in this policy. A short description of the policies follows:

1) The data as described in section 8.2 are used. This means that 5 piles are used, with 8 distinct raw material classes. This situation can be called limited sorting. Furthermore the stock out cost are 0.00, for all products. This reflects a situation where service rate is not considered very important for no penalty is set on a stock out situation. This situation is related with a push strategy. (chapter three)

2) This policy is a variation on the first policy. In this policy an attempt is made to balance the contribution to profit maximization, with the value recovery maximization. The stock out cost are set on 100 times the inventory cost for all products, both semiproducts for direct sales, and final products. This means that value recovery maximization has limited priority, and that also service degree, and thus contribution to profit, is considered of importance.

3) Also in this situation a balance is made between value recovery and profit (contribution to profit) maximization. Furthermore an investment in handling equipment is simulated. The result of this investment is that all raw material classes are stored on separate piles. This sorting lowers the uncertainty with respect to picking the right stem on the right moment, for the production of specific assortments.

4) This policy is directed to contribution of profit maximization. To obtain this "profit orientated" policy, the stock out cost are increased to the level of the product values. This means that every product not delivered, which is asked for, "costs" the company the market value of this product. Evidently, this policy has a very strong force driving towards high service degrees, low inventory cost, and thus high contribution to profit.

5) What happens if the company makes an investment in sawing equipment? Instead of five simultaneously made sawing cuts, now ten cuts are possible. This means that complex patterns require for no more time than less complex patterns. Hence, the overall goal, value recovery maximization, with service degree also considered of importance, must be more achievable.

In figure 8.1. and 8.2. the financial results of the five policies, and the effects on relative recovery are shown.

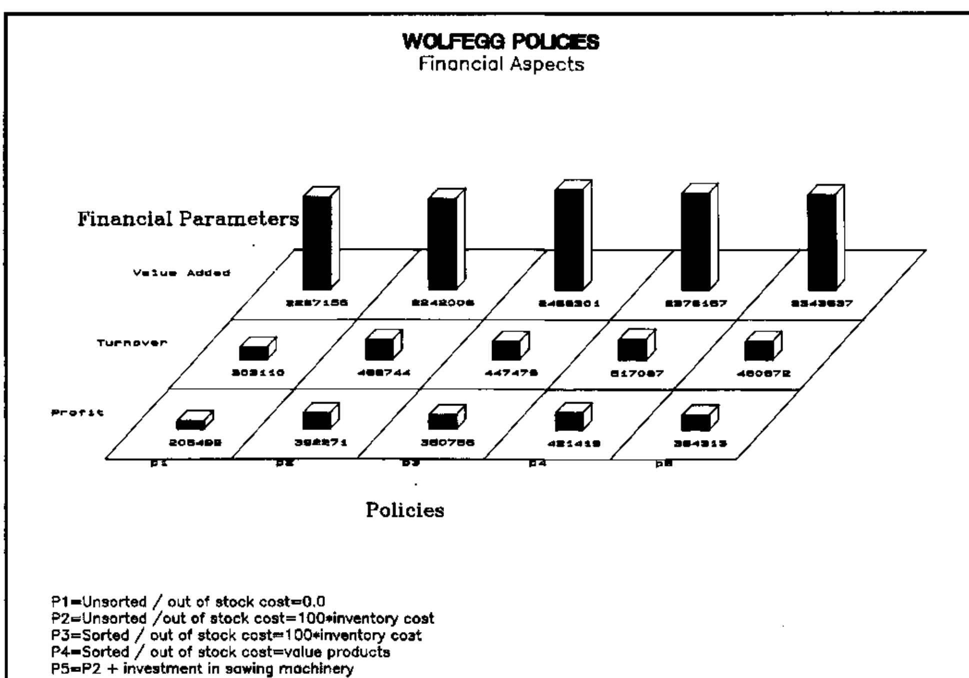


Figure 8.1. Financial results.

In appendix C, tables C.1. to C.5. the effects on some performance indicators are displayed, along with the variation of these parameters over the iterations required to obtain the optimum planning according to the typical policy.

In policy 1, 3369.79 m^3 raw material is used. Per cubic metre, Dfl 678.72 value is added (ADD/CUB). Of course the real value added is lower, because the raw material has an initial value when entering the conversion-site. The stock out cost for both assortments and final products are 0.00, according to the policy as described above.

When increasing the stock out cost (policy 2), what happens? A balance is made between value recovery, and profit making. This means that the system is forced to produce more demand orientated, a pull strategy in other words. Of course not an extreme pull strategy is obtained, because the value recovery still plays an important role.

The total value added is lower than for policy 1. This is a direct result of increasing the stock out cost. For the demand for products needs not to have a relation with the products distribution according to value recovery orientated sawing. However (see figure 8.1, table C.6) the turnover has increased dramatically. Moreover, to obtain this very good financial result, less raw material (figure 8.2) was needed. Of course the added value/m^3 is lower than for policy 1.

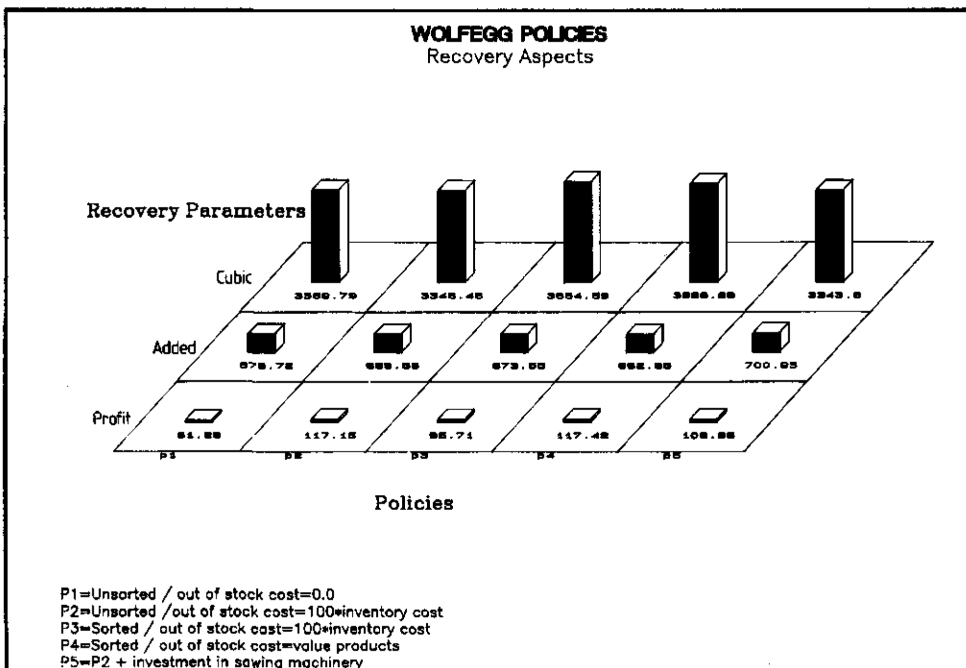


Figure 8.2. Recovery effects.

The raw material inventory cost are hence a little higher for policy 2 than for policy 1, because less material is used, thus more is stored on the yard. The contribution to profit for policy 2 is almost double compared to policy 1. N.B., no investments are made, only a managerial parameter, the stock out cost, have been altered.

The last parameter, called RESULT, is the contribution to profit. Cost like fixed cost for machinery, value of the raw material, have to be subtracted from this parameter to obtain the real profit. Because the necessary data for these calculations are not available, only the RESULT (the contribution to profit) is given in table C.6.

When sorting out the raw material, the preset targets can be more closely met. If the preset target is a mixture of value recovery maximization, with a little less priority given to profit making, than this should be reflected in policy 3.

For policy 3, the total added value is higher than in the previous policies. The turnover however is lower than in policy 2. To explain this result also figure 8.2. and table C.3. have to be included in the discussion. If the stock out cost are set on 100 times the inventory cost, than the main priority is laid on value recovery maximization.
The table C.3. shows that the turnover is lower, but the added value/m^3 is higher than for policy 1 and 2. This means that the sorting of the raw material indeed reduces the deviation of the preset targets, firstly value recovery maximization, secondly profit (RESULT) maximization.

Now look at a production strategy, where value recovery is regarded secondly to profit making (policy 4).

When looking at the results (table C.6.) a very high turnover is noticed. This turnover is higher than for all other policies. Yet this high turnover is combined with a high added value. True, this added value is lower than for policy 3, yet it is higher than for policy 1 and 2, both policies directed towards value recovery maximization. To obtain this result, less raw material was needed than in policy 3. Policy 1 and 2 used less m^3 than policy 4.

The turnover and the contribution to profit are substantially higher than in all other production strategies. The positive effects are accumulated in the RESULT, because both higher turnover, and lower inventory cost for assortments and boards work into the same direction.

What happens if both value recovery and profit making are considered of importance, and if instead of sorting the raw material (policy 3), an investment is made in speeding up the sawing machinery. The latter is achieved by increasing the capacity from 5 cuts made simultaneously up to 10.

It turns out that the added value is less than for policy 3, but the turnover, and the RESULT are higher. The turnover is lower than for policy 3, because the possibility of picking the exact stem for a specific purpose is not available, because the sorting is limited.

Yet the processing speed increased. This means that in the same processing time, more complex patterns can be sawn compared to strategy three. More complex patterns, indicate a system more directed to value recovery.

In this case the direction towards the values out balances the value recovery maximization. The inventory cost are shifted from assortments to boards, compared with policy 3. This is a direct result of the increased capacity for the secondary breakdown.

8.4. CONCLUSIONS

In the preceding sections various production strategies have been considered. One should realize that in fact a whole set of different policies are possible. All kinds of penalty levels can be combined with different layouts and machinery. Hence, the conclusions drawn in this section must be regarded bearing in mind that the policies only indicate tendencies. Neither the exact values for the distinct parameters, nor the differences between the policies may be interpreted as absolute margins.

Yet, several movements towards some sound policies can be observed. Moreover, tendencies can be perceived, into specific directions. Summarizing the above, the policy analyses give us more insight in the problems related to production planning on both tactical and strategic levels.

It turns out that planning the production, in a multiproduct, multiperiod environment is possible, using a variety of operations research techniques and managerial insights.

Moreover, multiple goals can be strived for simultaneously. The main goals researched in the above are the maximization of value recovery (production efficiency), and the maximization of profit (production effectiveness). The profit maximization finds expression in the parameter called result, the contribution to profit.

It becomes clear that one of the main managerial tuning tools, the stock out cost, are very appropriate in balancing between the main two goals. Policies 1, 2 and 3, 4 indicate clearly that by manipulating the stock out cost, the decision-maker can tune into the two main driving forces, profit making and value recovery.

When looking at the investments, sorting of the raw material could be the most interesting example. It became clear that when investing in sorting equipment, the preset target is best met. This means that the deviations from the goals are minimized, when investing in handling equipment. This is, in our opinion, an important conclusion, because nothing needs to be said about what the goals are! No matter whether the predefined goal is value recovery maximization, or profit maximization, or a balanced combination of the two, investing in handling equipment lowers the relative deviations from the targets.

The reason for this is that sorting decreases the uncertainty in the raw material handling. If the raw material is sorted in detail (for instance one class per pile) than for specific purposes, typical stems can be chosen.

Investing in speeding up the production, by increasing the sawing capacity, has a less tangible effect. In the specific example used in this section, profit making was stronger affected than recovery maximization.

This however is an effect that needs further research, because the direction of the changes in the parameters are a result of the combination of many data.

In tables C.1. to C.5. one can observe that for all optimizations, only a limited number of iterations are needed.

Three or four column generating iterations provide enough alternative cutting patterns to optimize the tactical planning. It is clear that if only one pattern for every assortment and stem was used, the results would be substantially worse.

Hence, when optimizing the tactical planning, one can not suffice with only one, overal, optimum pattern per stem or assortment. A set of alternatives is needed to create an overal optimum production planning.

Summarizing,

- The proposed column generating procedure is effective with respect to the generation of conversion patterns that fit best in the tactical planning.

- Stockout cost are very appropriate as a managerial tool, to balance recovery maximization and throughput maximization in the production system

- Detailed sorting of the raw material, as a result of investing in logistical control of the raw material, has a very tangible effect on the performance of the production system, according to the preset goals.

- Investing in sawing capacity has a less clear effect as the previous mentioned actions. Dependent on the preset targets, and many in fluencing factors (cost, service degree etc.) the emphasis of the effects can be more on value recovery or on throughput (turnover).

Chapter 9

CONCLUSIONS, FURTHER RESEARCH

In this last chapter some general conclusions, resulting from the research will be mentioned. Most conclusions imply a number of suggestions for further research. In section 9.1. the main conclusions will be presented.

In section 9.2. some suggestions for further research will be mentioned. Because the backbone for a DSS is designed and implemented in this research, most suggestions will be concerned with developing the prototype into a workable real-life system.

9.1. CONCLUSIONS

In this section the main conclusions, resulting from this research will be discussed. The conclusions will mainly be "conceptual", because we feel that more numerical results are needed to draw detailed conclusions with respect to specific companies. Hence the results regarded in this chapter will not give detailed, operational instructions to the decision-maker, instead trends and tendencies are indicated, and will be discussed.

The main goal of this research was to develop a blue-print, and build a prototype, for a decision support system for centralized wood processing companies. We feel that with the development of IDEAS this goal was reached. IDEAS gives the decision-maker a powerful set of tools to support the management process. Moreover, it gives an insight into how a future production control system can function, related to the production planning on both tactical and strategic levels.

In the sequel the results will be discussed. Although in practice the planning levels in a hierarchical planning systems are strongly interconnected, the conclusions will be regarded separately, for the sake of sim plicity.

9.1.1. DIRECT CONCLUSIONS

1) Operational support.

A module has been designed and built that has the potential to control the operational production process. The primary breakdown can be improved by using the proposed dynamic programming algorithm. in practice this algorithm is already used at several conversion sites.
The secondary breakdown can also be optimized, using an algorithm, based on dynamic programming. This module can be used for the conversion of assortments into boards (a two dimensional knapsack problem), and for the conversion of trees into boards (a three dimensional knapsack problem).

The algorithm is both computationally efficient, and gives a high value recovery, which is maximized when using a live sawing strategy. The software is tested with success on a mini-computer, and in a PC-environment. In the algoritm many speed up facilities have been built. Only minor adjustments are needed to implement this algorithm in a real-world situation.

2) Tactical support.

A main result of this research was a concept, and a prototype, for the optimization of the tactical planning. The tactical planning is the production planning for with a planning horizon of for instance four weeks and a planning period of one week, for all semi and final products.

Problems such as which patterns to use and in what frequencies for what stems and assortments, during what weeks, in a way that value recovery and profit making are both maximized, have been solved.

It turned out to be possible to balance multiple, partly conflicting, goals. Examples are the value recovery maximization and the profit making goal. The targets set for these goals may be difficult to reach simultaneously. Yet by using the developed tactical planning support module these goals can be balanced.

To support the tactical planning a multiple goal model was developed and implemented in the system IDEAS. The decision-maker has full control of the optimization process. In order to obtain a computationally efficient algorithm, a column generating procedure was designed. As a result of using this procedure the model size can be kept relatively small.

During the test runs and the case study it became clear that the stockout cost are a very powerful tool to control the planning process. By lowering or increasing these "cost", the earlier mentioned two main driving forces are tuned in on one another.

3) Strategic support.

The process of finding the optimal fitting out of a conversion site can be improved by using the strategic tools supplied by IDEAS. For instance various layout configurations, equipment, handling facilities and product mixes can be tested and evaluated.

All kinds of investments can be evaluated, and the effects on the conversion site performance simulated. The "what-if" approach is important on this planning level. Tactical and operational tools are used to simulate the effects on the various levels of aggregation when strategic decisions are made.

For instance a detailed sorting of the raw material seems to be a very effective way to improve the results of the conversion site, in accordance with the predefined targets. Both value recovery maximization and profit maximization are supported by better sorting of the raw material.

9.1.2. OTHER FIELDS OF APPLICATION

The system IDEAS has primarily been developed for application in the wood processing industry. However the tools incorporated in IDEAS can be applied in various other fields of application.

Many other industries have a divergent commodity stream more or less similar to the process described in this thesis. The operational support module of IDEAS is specific for wood processing companies. The tactical and strategic support however is directly applicable for other industrial circles.

Suppose that the sawing process is substituted by a slaughter process. This line of business is also divergent and package production is a typical characteristic. Only a new "column" (slaughter pattern) generating procedure has to be made to optimize the slaughter-house. Of course a number of business specific parameters have to be adjusted, but the main models can be used integrally.

Another example is related to the oil-industry. The operational process is now formed by the main conversion on a refinery. When a business specific module, generating feasible "refinery fractions" (columns) is clicked into IDEAS, integral logistics can be attained.

Of course all kinds of industries with a cutting-stock process can be optimized directly with the tools developed in this research.

9.1.3. LINKS WITH OPT

The system IDEAS uses tools from the Operations Research. Besides a number of algorithms, also parts of some philosophies have been used. One of these philosophies is Optimized Production Tecnology (OPT).

The three main components of the OPT strategy are 1) Inventory, 2) Throughput (profit), 3) Cost of operation. These three components play an important role in IDEAS.

In chapter seven, it became clear that there are two main driving forces, profit (throughput) maximization, and value recovery maximization. High stockout cost, direct the system towards a high service degree, low stock out cost can result in a high value recovery.

In order to obtain a high service degree (and thus a high throughput) relative simple conversion patterns may be used, that are less time consuming. This results in a drop of the cost of operation, but also in a lower value recovery. Throughput maximization may cause stagnation at the machinery. In this case the contribution of profit due to stagnation is higher than it would have been when production would have been continued.

In the opposite case, if a high value recovery is strived for, sometimes complex patterns are needed, and thus high cost of operation may be the result. As a result of this policy, the connection with the market is lost, resulting in a lower service degree.

9.2. FURTHER RESEARCH

In this section some suggestions for further research will be looked at. They all share the fact that the main emphasis is put on implementation effects. The state of the art at this very moment is that a prototype system called IDEAS runs at the university facilities. However, in practice a local system should be available. Before IDEAS can be really operational, some problems have to tackled. The problems will be discussed according to the decomposed management process.

1) Operational support.

The process of breaking down a log (tree or assortment) into boards has been optimized by means of a dynamic programming based routine. Stem curves were simulated by using knotted cones. Evidently real stems can posses complexer shapes. Further research to use more practice orientated shapes is necessary, although much literature already exists. The problem of using real stem curves can be dealt with rather easily. The need for this development goes along with the improvements of scanning equipment used in practice.

The quality aspect was not dealt with in the algorithm. However the necessary "infrastructure" for these improvements was already provided in the algorithm and the corresponding software. Every point of the three dimensional grid superimposed on the stem or the log, can be coupled to a statusvector.
At this moment, this vector contains only the stage and the state of the system. The vector can easily be extended using location dependent quality parameters.

The complexity of the algorithm does not increase with this extension. In other words the number of evaluations does not increase. Of course some used effects of symmetry will be less applicable, because quality can have a far from homogeneous distribution over the stem. Other stem properties can be used for further speeding up of the algoritm, like the symmetry effects along the axis.

2) Tactical support.

In the model supporting the tactical production planning only basic cost definitions were used. When implementing the prototype IDEAS in a real-world environment, perhaps more advanced cost models are needed.

For instance, when evaluating typical investments, in the described models the extra financial possibilities were calculated. Not the actual cost of this investment was taken into account.

Moreover, when calculating the financial parameters for a tactical planning, using a typical layout, only the variable cost are taken into account. This looks like a fair assumption, because only operational cost are interesting when evaluating distinct planning alternatives. However, the financial result is evidently not the ultimate profit!
To evaluate the real profit also the fixed cost are of importance, along with other cost like the mobile equipment (cranes etc.) supporting the production process. Moreover the value of the input materials (stems, assortments) should be subtracted from the added value. These extensions require a more detailed data acquisition than performed.

The description of the sawing machinery is simplified, in order to calculate the time consumption for the distinct patterns.

The crosscutting equipment is described with a parameter for the cutting speed, and a parameter for the transportation speed. A crosscutting pattern asks for a number of transportation activities, and a number of cuts on various diameters, perpendicular to the axis.

The sawing equipment is described using a parameter describing the sawing speed, and a parameter describing the number of cuts that can be made simultaneously. An assortment is cut into boards by making a series of cuts, perpendicular to the x-axis, and perpendicular to the y-axis. Hence the time consumption for a specific pattern can be calculated.

This approach however may be too straigtht forward. Other effects, as handling times, interruptions, and perhaps setup times can be used to model more practically oriented machines.

3) Strategic.

The strategic planning is not fully exploited in this research. The reason for this is that a large programming effort is needed to fully implement the tools needed to support the strategic planning.

When tuning a company in on its environment, many parameters are of interest. The demand for assortments and boards, the supply of raw material, disturbances and discontinuities at the input side, and the machines breaking down, or drops in the market demand can be mentioned. All these parameters interact and interfere with one another, and constitue a dynamic environment.

In chapter four and five it was shown that the production planning was confronted with a variety of parameters and variables, together shaping a scenario. A planning could be made for several weeks ahead, the uncertainty increasing each week from the initial planning week. The next tactical planning should then be made after say one week, including a new future week at the end of the planning. This is called a rolling horizon model.

However, all kinds of environmental properties can change during the planning. How will the controlling system react? Has it enough adaptive potential?

Answers on these questions can only be given when placing the production management system in a dynamic environment. This environment can be simulated by using special tools (SIMULA, GPSS etc.). We feel that placing a planning system in such a simulated environment gives extra power to a DSS.

Why does such a tool require such a large programming effort? In chapter six the technical design of IDEAS was regarded. The efficiency of the implemented software was improved by a so-called column generation procedure.
To implement this system, many information technological problems had to be tackled. The result is a system that enables the decision-maker to optimize a multi-period, multi-product tactical production planning.

When placing this system in a dynamic environment, all data had to be stored in the database, including the last multiple goal situation. Then the environment should be updated (simulated), and a new planning could be made. Technically this means that SIMULA (for instance), SCICONIC/VM, and user written routines all have to communicate, and execute depending on each others behaviour. Of course this can be built into the DSS, however for the scope of this research, we felt that a free adjustment on the scenario parameters would suffice.

4) Implementation aspects.

A DSS consists of a database, a model-base, and a user interface. For the prototype developed and implemented at the university, choices were made for specific available software tools. One should realize that without changing the concepts of IDEAS, other tools can also be used.

For instance the model-base was described in chapter six is rather primitive. Many database packages exist, some of them with good interface possibilities to user written code, or other software packages. The database of IDEAS can of course be exchanged for any other database package. The main advantage is that developing a user interface can be done almost simultaneously with the datamodel design (FOXBASE, DBASE etc). Perhaps a disadvantage can be that a commitment has to be made to a limited subset of the available computers, both for mini (VAX-like) and for micro-computers.

The model base can be developed using any general purpose language. The emphasis should be on fast numerical processing. Hence the choice for a specific language should be guided by the suitability for numerical processing.

SCICONIC/VM, the package used for the tactical planning can be replaced by any general linear programming package, that allows the system developer to intervene in the optimization process, or to use the package as a toolbox, to build a home-grown system.

The user-interface can be built using many commercial tools and packages, a complete list can not be given, however FORTRAN, turbo-PASCAL, C + VITAMINE-C, FOXBASE, DESIGN/DRAW can be mentioned.

SUMMARY

This doctoral thesis deals with integral logistics for centralized woodprocessing companies. Goal of the research was to design a blueprint, and build a prototype system of a decision support system (DSS). In general, a DSS can be considered as a computer based system, helping the decisionmaker to improve the quality of his decisions. Data and models are used to solve complex problems.

Chapter 1 gives an introduction to the problems that form the motivation for this research. The process of cutting a stem into boards can be considered as a two-phase conversion process.

Firstly the stem is cut into assortments, a process called crosscutting. The assortments can be characterized by their length and diameter at the top-end. The stem can be characterized by many parameters. In this research only stem length and diameter as a function of the distance from the stump-end are considered.

Secondly the assortments are sawn into boards of various sizes. The boards are described by their dimensions.

The processing of stems to boards can take place at centralized conversion sites. These sites ask for a sound production management. The decisionmaking, the management process, is considered as consisting of three, interconnected shells.

The outer shell, the long-term planning, is called the strategic planning. Within this shell, the tactical planning can be described, with a more medium term horizon. In the kernel of the management process the operational planning can be mentioned.

To assure a directedness towards the real-world business column, various relations were maintained with industrial managers.

Chapter 2 gives a description of the centralized conversion site as a system. A centralized conversion site is defined in this thesis as a site were all conversion steps from tree to boards are performed.

Roughly three main functions can be mentioned when regarding woodprocessing. Harvesting, processing, and distribution. In our research main emphasis was put on the processing function.

This processing function can be taken care of in many ways. Various forces drive towards centralized processing.

The benefits of centralized processing are for example a reduced number of actions in the forest, economy of scale, better ergonomic conditions, and possibilities for an improved value recovery.

Besides the functional organization of the business chain, also the matter of ownership is of importance. Every phase in the conversion sequence, can be carried out under different ownership.

Yet, many wood processing companies can be considered vertically integrated. Vertical integration is defined as the combination under single ownership, of two or more productionstages.

In this research functional aspects will be considered of more importance than ownership. Therefore, from now on the concept of vertical integration will not be explicitly dealt with.

Chapter 3 deals with integral logistics. Inventory control and raw materials handling are of great importance for the functioning of the conversion site.

Extremes of handling strategies can be regarded with respect to investments and operational cost. The two-types of cost have to be balanced carefully.

The crosscutting of a stem into boards is the next productionstep. Because the decision what assortments to produce out of which stems has to be made on-line, very fast optimization software is needed. Various models to improve the efficiency of the crosscutting process have been built. Most of these models use an algorithm based on dynamic programming.

The next conversion step of importance is the sawing of the assortments into boards. Again on-line decision support tools are required. At the time this research started, no real optimization algorithms were available.

The planning of this process is very complex. What products should be produced? How to handle the raw material? What productmix should be produced? What machinery is required? How important is a high servicerate? Is profit making inconsistent with high value recovery rates?

To answer all these questions a hierarchical planning model was used. This hierarchical planning model should assume integral optimization. Integral with respect to the production process from raw material to boards. And furthermore integral with respect to multi-periods.

To put this concept into work, a DSS has been built.

Chapter 4 is about decision support systems. Particularly IDEAS is of interest. IDEAS stands for Integral Decision Effect Analysis System.

DSS can be seen as a further development of Electronic Data Processing (EDP) and Management Information Systems (MIS).

A DSS consists roughly of three modules. The database, containing the corporate and environmental data. A model-base, containing Operations Research models to describe the production system and its behaviour. And finally a user interface, the module taking care of the communication between user and the first two modules.

IDEAS consists of a database containing all data about a conversion site and its environment. Moreover a modelbase exists. This module consist of set of operational models, optimizing the conversion process. Moreover a tactical planning model is stored. This plan describes a multiproduct, multiperiod production plan for a typical conversionsite. Furthermore a set of strategic what-if simulation tools is provided.

All models can be interactively connected, and the various optimization algorithm can be fully controlled, via the user interface.

In Chapter 5 the concepts described in the above are discussed mathematically in depth. The operational production process is described with help of a model, that can be evaluated by means of dynamic programming.

The tactical planning is performed with a linear, multiple goal model. Various alternatives are optimized by using the package SCICONIC/VM. A revised simplex method is used in the solution procedure.

The strategic planning is supported with simulation tools. No special packages are used, all software is developed by the author of this thesis.

Chapter 6 describes how IDEAS has been implemented technically. The use of FORTRAN in relation with the dynamic programming algorithms, the package SCICONIC/VM to perform the multiple goal programming, and the prototyping toolbase PRODUCER to build the user-interface are regarded in relation with the development of IDEAS.

After discussing the developed system IDEAS, the analysis possibilities are discussed in Chapter 7. Distinct policies are evaluated.

A policy is a specific way of managing the conversion of stems into boards. A manager can research the need for strategic investments, typical tactical planning alternatives, and the impact of various operational parameter settings.

To evaluate the policies, a set of performance indicators are provided. These indicators are both of financial and logistic natures.

In Chapter 8 the decision support system is tested in a real-world situation, as it appears at a company in the Federal Republic of Germany.

Although data and models where not 100% tuned in at one another, tendencies, could be detected.

It turned out that sorting the raw material has a very positive influence on site-performance, no matter whether the goals are directed towards value recovery or towards profit making.

Moreover, a decision-maker has a set of very powerful tools to evaluate distinct production strategies. One of those tools are the stock out cost. The driving forces can be controlled by tuning the stockout cost parameters.

High stockout cost mean a claim for high service rates, low stockout cost parameters give the site room to maximize the value recovery.

Chapter 9 describes the conclusions, and the suggestions for further research. We feel that the backbone for a real-world DSS has been designed and build during this research.

For instance, the influence of sorting the raw material, the impact of investing in crosscutting capacity, the results of integrating the layout, and the effects of a new product-mix were researched.

Future research should pay attention to further directedness towards practical problems. These problems must be tackled when installing IDEAS in a practical situation.

Although this research was primarily directed towards the wood processing industry, also other fields of application can be mentioned. IDEAS is build up of three main modules, supporting the operational, tactical and strategic planning.

The algorithms performing the operational optimization (cutting pattern generation) are fully orientated towards wood processing. The tactical and strategic planning however, are supported by tools that can be applied for other industrial circles, also dealing with a divergent production process combined with package production.

For instance oil-industry (refinery), slaugther-houses and in general cutting-stock performing industries (steel, plastics) can be mentioned.

For these industries IDEAS can be used, if the industry specific "patterns" are build into the system.

SAMENVATTING

IDEAS, voor integrale logistiek in de centrale houtverwerking

Deze dissertatie behandelt integrale logistiek voor centrale houtverwerkende bedrijven. Het doel van dit onderzoek was het ontwerpen van een blauwdruk voor, en het bouwen van een prototype van, een beslissing ondersteunend systeem (BOS).

Een BOS kan beschouwd worden als een op computergebruik gebaseerd systeem, dat de kwaliteit van de besluitvorming dient te verbeteren. Gegevens en modellen worden gebruikt om complexe problemen op te lossen.

Hoofdstuk 1 geeft een introductie van de problemen die de aanleiding van dit onderzoek vormden. De verwerking van een stam tot balken, planken en latten kan beschouwd worden als een twee-fase proces.

In eerste instantie wordt een stam tot sortimenten gezaagd, de primaire conversie. Deze sortimenten kunnen beschreven worden aan de hand van hun lengte en de diameter aan het top einde.

De secundaire conversie is de verwerking van sortiment tot balken, latten en planken.

Een stam kan beschreven worden met vele parameters. In dit onderzoek worden alleen de stamlengte en de diameter als functie van de afstand van het stronk-einde meegenomen. De planken, balken en latten, worden beschreven aan de hand van hun dimensies en marktwaarde.

Het verwerken van een stam tot produkten, kan plaats vinden op een centrale verwerkingsplaats. De centrale verwerkingsplaats is gedefinieerd als een locatie waar de industriele verwerking van stammen tot producten plaats vindt.

Deze industriële verwerking vraagt om een goed management. Dit management kan beschouwd worden als een systeem van drie, onderling communicerende schillen.

De buitenste schil, gericht op de lange termijn planning en effectiviteit, wordt het strategisch management genoemd. Binnen het kader van deze schil, vindt de middellange termijn planning plaats. Dit wordt het tactische planning niveau genoemd. De kern van het management proces wordt door de operationele, korte termijn planning gevormd, gericht op efficiency.

Hoofdstuk 2 beschrijft een centrale verwerkingsplaats als een systeem. Dit systeem heeft ruwweg de functies, inkoop, oogst, verwerking en distributie. Dit onderzoek is voornamelijk gericht op de (industriële) verwerking.

De verwerking kan op vele manieren worden uitgevoerd. Er zijn echter verschillende redenen om dit gecentraliseerd te doen. Met centralisatie wordt hier bedoeld een concentratie van de activiteiten naar plaats en tijd.

Voordelen van centrale verwerking zijn onder andere het geringe aantal operaties in het bos, de schaal effecten, en de potentie van hoge benuttingsgraad van de grondstoffen.

Behalve de functionele organisatie van deze bedrijfstak, is ook de eigendomsstructuur van belang. Elke stap in de logistieke keten kan door verschillende eigenaren uitgevoerd worden.

Toch zijn vele houtverwerkende (verzagende) bedrijven verticaal geïntegreerd. Onder verticale integratie wordt verstaan het combineren van een aantal activiteiten uit de logistieke keten, onder één eigenaar.

In dit onderzoek zal de functionele organisatie van de bedrijfstak meer aandacht krijgen dan de eigendomsstructuren. De concepten, zoals ontwikkeld in dit onderzoek zijn dusdanig dat in principe over eigendomsgrenzen heen geoptimaliseerd kan worden.

Hoofdstuk 3 behandelt de integrale logistiek. Voorraadbeheersing en materials handling van de grondstoffen zijn van groot belang voor het goed functioneren van het bedrijf. De verschillende investeringsalternatieven kunnen afgewogen worden in samenhang met de operationele kosten.

De volgende te optimaliseren stap is de productie van sortimenten. De beslissingen welke sortimenten uit welke stammen te produceren moet on-line genomen worden. Daarom zijn zeer snelle optimalisatie algoritmen nodig. In de praktijk zijn deze vaak gebaseerd op dynamische programmering.

De volgende conversie fase is die van sortimenten tot planken en balken. Wederom zijn snelle optimalisatie algoritmen nodig, die op dit moment nog niet bestaan.

De planning en besturing van het hele productieproces is zeer complex. Welke producten moeten geproduceerd worden? Hoe moeten de grondstoffen opgeslagen worden? Hoe belangrijk is een hoge service graad? Zijn winstmaximalisatie en afvalminimalisatie strijdig?

Om al deze vragen te beantwoorden is in het kader van dit onderzoek een hierarchisch planningsmodel ontwikkeld. Dit planningsmodel, gevat in een BOS, zorgt voor een integrale optimalisatie van de logistieke keten, dus van grondstof tot product. Ook in de tijd gezien, dus over meerdere perioden, wordt de productieplanning geoptimaliseerd.

Hoofdstuk 4 gaat over beslissing ondersteunende systemen (decision support systems). Met name het systeem IDEAS zal onderwerp van discussie zijn.

IDEAS staat voor Integral Decision Effect Analys System. BOS kan gezien worden als een verdere ontwikkeling van Electronische Gegevens Verwerking (EGV) en Management Informatie System (MIS).

In het algemeen bestaat een BOS ruwweg uit drie componenten. Een gegevensbank, die gegevens bevat van bedrijf en relevante omgeving. Verder een modellenbank, die operationele analyse modellen bevat die structuur en gedrag van het productiesysteem beschrijven. En als laatste een gebruikersmodule, die de communicatie tussen de gebruiker van het BOS en de eerder genoemde twee modulen mogelijk maakt.

Hiermee in overeenstemming bestaat IDEAS uit een databank, die alle gegevens bevat over de fabriek en de relevante omgeving.

De volgende module is de modellenbank. Deze module bevat een aantal modellen die op operationeel niveau het conversieproces optimaliseren. Verder zijn er tactische modellen. Deze helpen om in een multiprodukt, multiperiode situatie het productieplan te optimaliseren. Als laatste staan er voor het strategische niveau "what-if" simulatie modellen ter beschikking.

Alle modellen kunnen interactief worden gebruikt, en de optimalisatie algoritmen kunnen bestuurd worden vanuit het gebruikers interface.

De verschillende concepten zoals beschreven in het bovenstaande worden wiskundig beschreven in hoofdstuk 5.

Het operationele productie proces wordt beschreven met een model dat met behulp van dynamische programmering geëvalueerd kan worden.

De tactische planning wordt beschreven met een lineair multiple-goals (meerdere doelen simultaan) model. Verscheidene productie-alternatieven worden geoptimaliseerd met het pakket SCICONIC /VM, gebruikt als gereedschappen bibliotheek (tool library). De gebruikte oplossingsmethode is een gereviseerde simplex-methode.

De strategische planning wordt ondersteund met gereedschappen gebaseerd op simulatie. Alle software voor dit aggregatie niveau is speciaal voor dit onderzoek ontwikkeld.

De technische implementatie van IDEAS wordt beschreven in hoofdstuk 6. Het gebruik van FORTRAN voor de dynamische programmering, het pakket SCICONIC/VM voor de implementatie van de multiple goal programmering, en het pakket PRODUCER dat gebruikt werd bij de bouw van het user-interface, wordt besproken in relatie met de ontwikkeling van IDEAS.

Na deze beschrijving worden de mogelijkheden van IDEAS met betrekking tot analyses bekeken in hoofdstuk 7. Verscheidene strategieën worden geëvalueerd. Een strategie is een specifieke manier om langhout tot eindproducten te verwerken.

Een manager kan de noodzaak van het bedrijf aan strategische investeringen onderzoeken, specifieke tactische planningsalternatieven, en de gevolgen van verschillende operationele besturingskeuzen.
Om deze evaluatie mogelijk te maken, is een verzameling prestatie indicatoren ter beschikking gesteld. Zowel financiële als logistieke prestatie indicatoren zijn beschikbaar.

In hoofdstuk 8 wordt IDEAS getest met een praktijk probleem, zoals dat voorkomt in de Bondsrepubliek Duitsland.

Alhoewel deze test te summier is om absolute conclusies te trekken, konden wel bepaalde tendensen worden waargenomen.

Het bleek onder andere dat het sorteren van de grondstoffen een positief effect heeft op het functioneren van het bedrijf. Dit zowel in een situatie van waarde maximalisatie als in een situatie van winstmaximalisatie.

Verder heeft een beslisser de beschikking over een aantal zeer krachtige instrumenten om verschillende strategieën te evalueren. Een van deze gereedschappen zijn de buiten voorraad kosten voor zowel halffabrikaten als eindproducten.

De twee hoofddoelen, waarde en winstmaximalisatie kunnen bestuurd worden met deze parameter. Immers hoge buitenvoorraadkosten zijn een indicatie voor het belang van een hoge servicegraad, lage buitenvoorraadkosten geven het bedrijf de ruimte waarde gericht te produceren.

Hoofdstuk 9 beschrijft de conclusies en de suggesties voor verder onderzoek. Concluderend kan gesteld worden dat de ruggegraat van een practisch bruikbaar BOS is ontwikkeld en gebouwd.

In dit onderzoek werden onder andere de effecten van het investeren in grondstoffen handling faciliteiten, de impact van capaciteits verhoging in de zagerij, de invloed van een aangepaste productmix en de gevolgen voor het bedrijf van integratie van de primaire en secundaire conversie onderzocht.

Toekomstig onderzoek zal gericht moeten zijn op het verder operationeel maken van het nu ontwikkelde prototype.

Dit onderzoek was primair gericht op de houtverwerkende industrie. Toch zijn ook andere toepassingen mogelijk. IDEAS is opgebouwd uit drie modules, die de operationele, de tactische, en de strategische planning ondersteunen.

De algorithmen die de operationele planning ondersteunen, zijn gericht op de houtverwerkende industrie. De tactische en de strategische planning worden echter door tools ondersteund die inzetbaar zijn in andere takken van industrie.
Bijvoorbeeld de olie raffinage, slachthuizen, en in het algemeen de "versnijdende" industrie (staal, plastics), kunnen genoemd worden.

Voor deze bedrijfstakken kan IDEAS gebruikt worden, als de branche specifieke "snij patronen" in het systeem gebracht worden.

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Appendix A

BUSINESS ANALYSIS RESULTS

TABLE A.1. Initial patterns, from trees to assortment.

Period	diameterclass	value	processing time	frequencies									
1	1	11.19	0.16	1	1	1	0	0	0	0	1	0	0
1	2	17.65	0.17	0	1	2	0	0	0	0	1	2	0
1	3	18.64	0.17	1	1	1	0	0	1	0	1	0	0
1	4	29.11	0.18	1	1	2	0	0	0	1	1	0	0

TABLE A.2. Initial patterns, from assortment to boards.

Period	assortment	value	processing time	frequencies							
1	1	1.41	0.02	2	3	0	0	0	0	0	0
1	2	5.83	0.03	4	12	0	0	0	0	0	0
1	3	10.23	0.05	13	21	0	0	0	0	0	0
1	4	2.27	0.03	0	0	0	0	2	3	0	0
1	5	9.83	0.03	0	0	0	0	0	5	2	0
1	6	20.78	0.04	0	0	0	0	2	5	1	2
1	7	44.83	0.06	0	0	0	0	11	9	1	5

TABLE A.3. Crosscutting pattern frequencies after 1 iteration.

CLASS	WEEK			
	1	2	3	4
1	0	0	0	0
2	0	0	0	0
3	(1)202	(1)202	(1)202	(1)202
4	(1)87	(1)87	(1)87	(1)87

With (i)j : pattern number i, frequency j.

TABLE A.4. Crosscutting pattern frequencies after 2 iterations.

CLASS	WEEK			
	1	2	3	4
1	0	0	0	0
2	0	0	0	0
3	(1)33(2)169	(1)202	(1)202	(1)202
4	(1)36(2)51	(1)86(2)1	(1)87	(1)87

TABLE A.5. Crosscutting pattern frequencies after 3 iterations.

CLASS	WEEK			
	1	2	3	4
1	0	0	0	0
2	0	0	0	0
3	(1)34(2)168	(1)202	(1)202	(1)202
4	(1)60(2)27	(1)61(2)26	(1)87	(1)87

TABLE A.6. Crosscutting pattern frequencies after 4 iterations.

CLASS	WEEK			
	1	2	3	4
1	0	0	0	0
2	0	0	0	0
3	(1)36(2)167	(1)202	(1)202	(1)28(4)174
4	(1)87	(1)64(2)23	(1)87	(1)87

TABLE A.7. Crosscutting pattern frequencies after 5 iterations.

CLASS	WEEK			
	1	2	3	4
1	0	0	0	0
2	0	0	0	0
3	(1)35(2)168	(1)202	(1)202	(1)46(4)156
4	(1)87	(1)63(2)23	(1)87	(1)87

TABLE A.8. Crosscutting pattern frequencies after 6 iterations.

CLASS	WEEK			
	1	2	3	4
1	0	0	0	0
2	0	0	0	0
3	(1)35(6)168	(1)202	(1)202	(1)46(4)156
4	(1)87	(1)63(2)23	(1)87	(1)87

TABLE A.9. Crosscutting pattern frequencies after 7 iterations.

CLASS	WEEK			
	1	2	3	4
1	0	0	0	0
2	0	0	0	0
3	(1)35(2)167	(1)198(2)5	(1)202	(1)127(4)75
4	(1)87	(1)87	(1)87	(7)87

TABLE A.10. Sawing pattern frequencies after 1 iterations.

ASSORTMENTS	WEEK			
	1	2	3	4
1	0	0	0	0
2	(1)224	(1)414	(1)289	(1)289
3	(1)431	(1)376	(1)376	(1)376
4	(1)6	0	0	0
5	(1)100	0	0	0
6	(1)214	(1)202	(1)202	(1)202
7	(1)167	(1)87	(1)87	(1)87

TABLE A.11. Sawing pattern frequencies after 2 iterations.

ASSORTMENTS	WEEK			
	1	2	3	4
1	(1)109	(1)288	(1)289	(1)289
2	(2)129	(2)288	(2)289	(2)289
3	(2)160	(1)29(2)346	(1)51(2)324	(2)376
4	(2)80	0	0	0
5	(1)54(2)46	0	0	0
6	(1)45	(1)202	(1)197	(1)207
7	(1)159(2)8	(1)83(2)4	(1)83(2)4	(1)87

TABLE A.12. Sawing pattern frequencies after 3 iterations.

ASSORTMENTS	WEEK			
	1	2	3	4
1	(3)134	(3)263	(1)289	(1)230(3)59
2	(2)154	(2)263	(2)289	(2)289
3	(2)209	(1)29(2)296	(1)51(2)324	(2)376
4	(2)80	0	0	0
5	(1)58(2)42	0	0	0
6	(1)46	(1)202	(1)193	(1)211
7	(1)158(2)8	(1)83(3)4	(1)78(2)9	(1)87

TABLE A.13. Sawing pattern frequencies after 4 iterations.

ASSORTMENTS	WEEK			
	1	2	3	4
1	(3)163	(1)147(3)119	(3)213	(3)191
2	(2)183	(2)266	(2)289	(2)289
3	(2)264	(2)153(4)176	(2)273(4)103	(2)376
4	(2)80	0	0	0
5	(1)63(2)37	0	0	0
6	(1)26(2)22	(1)202	(1)186	(1)218
7	(1)167	(1)83(3)4	(1)87	(1)74(4)12

TABLE A.14. Sawing pattern frequencies after 5 iterations.

ASSORTMENTS	WEEK			
	1	2	3	4
1	(3)161	(1)144(3)122	(3)226	(3)195
2	(2)181	(2)265	(2)289	(2)289
3	(2)263	(2)156(4)174	(2)324(5)51	(2)376
4	(2)80	0	0	0
5	(1)60(2)40	0	0	0
6	(1)26(2)21	(1)202	(1)202	(1)202
7	(1)167	(1)83(3)4	(1)78	(1)74(4)12(5)10

TABLE A.15. Sawing pattern frequencies after 6 iterations.

ASSORTMENTS	WEEK			
	1	2	3	4
1	(3)161	(1)144(3)122	(3)226	(3)195
2	(2)181	(2)265	(2)289	(2)289
3	(2)263	(2)156(4)174	(2)324(5)51	(2)376
4	(2)80	0	0	0
5	(1)60(2)40	0	0	0
6	(1)26(2)21	(1)202	(1)202	(1)202
7	(1)167	(1)83(3)4	(1)78	(1)74(4)12(5)10

TABLE A.16. Sawing pattern frequencies after 7 iterations.

ASSORTMENTS	WEEK			
	1	2	3	4
1	(3)162	(1)241(3)43	(3)223	(3)193
2	(2)182	(2)284	(2)289	(2)289
3	(2)263	(2)242(7)129	(3)324(5)51	(2)376
4	(2)80	0	0	0
5	(1)61(2)39	0	0	0
6	(1)26(2)21	(1)193	(1)206	(1)202
7	(1)167	(1)87	(1)77	(1)75(4)12(5)10

TABLE A.17. Overwork (o) and standstill (s) (CROSSCUTTING)

WEEK	i=1		i=2		i=3		i=4		i=5		i=6		i=7	
	o	s	o	s	o	s	o	s	o	s	o	s	o	s
1	10.00	0	10.00	0	10.00	0	10.00	0	10.00	0	10.00	0	10.00	0
2	10.00	0	10.00	0	10.00	0	10.00	0	10.00	0	10.00	0	10.00	0
3	10.00	0	10.00	0	10.00	0	10.00	0	10.00	0	10.00	0	10.00	0
4	10.00	0	10.00	0	10.00	0	10.00	0	10.00	0	10.00	0	10.00	0

TABLE A.18. Overwork (o) and standstill (s) (SAWING)

WEEK	i=1		i=2		i=3		i=4		i=5		i=6		i=7	
	o	s	o	s	o	s	o	s	o	s	o	s	o	s
1	10.00	0	0	10.37	0	6.22	0	2.58	0	2.74	0	2.74	0	2.69
2	4.51	0	0	0.31	0	0	0	0	0	0	0	0	0	0
3	0.75	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0.75	0	0	0.77	0	0	0	0	0	0	0	0	0	0

TABLE A.19. Financial overview.

	ITERATION						
	1	2	3	4	5	6	7
PV	87730.50	79480.65	79262.20	79371.85	79380.30	79380.30	80039.00
TO	40312.75	51940.75	52205.45	53164.35	53531.50	53531.50	53221.25
CIA	445.41	117.95	125.84	137.26	134.91	134.91	147.21
COA	45600.23	29095.96	29519.64	30919.31	30915.44	30915.44	31847.02
CIF	2412.16	270.11	220.81	242.27	224.09	224.09	227.52
COF	23527.81	10724.02	9818.96	8307.71	8129.71	8129.71	8342.02
CIR	9795.64	9795.64	9795.64	9795.64	9795.64	9795.64	9795.64
CL	16000.00	16000.00	16000.00	16000.00	16000.00	16000.00	16000.00
CO	6000.00	6000.00	6000.00	6000.00	6000.00	6000.00	6000.00
CD	2644.11	2465.53	2499.60	2523.24	2522.22	2522.22	2522.51
RESULT	3015.43	17291.52	17563.56	18465.95	18854.64	18854.64	18528.37

Appendix B

POLICY COMPARISON

TABLE B.1. (a) Initial situation.

	ITERATION						
	1	2	3	4	5	6	7
VALUE ADDED(FL)	87730.50	79480.65	79262.20	79371.85	78380.30	79380.30	80039.00
TURNOVER(FL)	40312.75	51940.75	52205.45	53164.35	53531.50	53531.50	53221.25
RESULT(FL)	3015.43	17291.52	17563.56	18465.95	18854.64	18854.64	18528.37
RES/TUR(%)	7.48	33.29	33.64	34.73	35.22	35.22	34.81
RES/ADD(%)	3.44	21.76	22.16	23.37	23.75	23.75	23.15
CUBIC	422.21	422.21	422.21	422.21	422.21	422.21	422.21
ADD/CUB(FL/m^3)	207.79	188.25	187.73	187.99	188.01	188.01	189.57
RES/CU(FL/m^3)	7.14	40.95	41.60	43.74	44.66	44.66	43.88

TABLE B.2. (b) Investing in handling equipment.

	ITERATION					
	1	2	3	4	5	6
VALUE ADDED(FL)	104578.86	93698.80	93600.70	93293.60	94102.30	94102.30
TURNOVER(FL)	40552.75	54359.45	54305.00	54567.05	54773.05	54773.05
RESULT(FL)	2184.47	18910.02	18821.69	19188.02	19316.10	19316.10
RES/TUR(%)	5.39	34.79	34.66	35.16	35.27	35.27
RES/ADD(%)	2.09	20.18	20.11	20.57	20.53	20.53
CUBIC	494.91	494.91	494.91	494.91	494.91	494.91
ADD/CUB(Fl/m^3)	211.31	189.33	189.13	188.51	190.14	190.14
RES/CU(FL/m^3)	4.41	38.21	38.03	38.77	39.03	39.03

TABLE B.3. (c) Investing in crosscutting capacity.

	ITERATION 1	2	3	4	5	6	7
VALUE ADDED(FL)	125788.61	117397.36	117314.86	117487.36	117489.66	117702.11	117702.11
TURNOVER(FL)	40548.75	63305.25	63222.75	63219.75	63117.75	63430.75	63430.75
RESULT(FL)	2903.05	29684.23	29605.61	29606.95	29506.20	29775.25	29775.25
RES/TUR(%)	7.16	46.89	46.83	46.83	46.75	46.94	46.94
RES/ADD(%)	2.31	25.29	25.24	25.20	25.11	25.30	25.30
CUBIC	708.67	708.67	708.67	708.67	708.67	708.67	708.67
ADD/CUB(FL/m^3)	177.50	165.66	165.54	165.78	165.79	166.09	166.09
RES/CU(FL/m^3)	4.10	41.89	41.78	41.78	41.64	42.02	42.02

TABLE B.4. (d) A combination of increased capacity and handling equipm.

	ITERATION 1	2	3	4	5	6	7
VALUE ADDED(FL)	130439.95	126114.45	122161.70	121994.65	122347.40	121546.66	121546.66
TURNOVER(FL)	40548.75	63416.20	64594.20	64792.10	64565.05	65251.15	65251.15
RESULT(FL)	1835.56	28608.67	29941.50	30227.05	29941.58	30326.65	30326.65
RES/TUR(%)	4.53	45.11	46.35	46.65	46.37	46.48	46.48
RES/ADD(%)	1.41	22.68	24.51	24.78	24.47	24.95	24.95
CUBIC	737.66	736.73	714.83	709.26	712.25	707.30	707.30
ADD/CUB(FL/m^3)	176.83	171.18	170.90	172.00	171.78	171.85	171.85
RES/CU(FL/m^3)	2.49	38.83	41.89	42.62	42.04	42.88	42.88

TABLE B.5. (e) Directed towards value recovery maximization.

	ITERATION 1	2	3
VALUE ADDED(FL)	130447.40	142502.95	142502.95
TURNOVER(FL)	40196.95	52670.50	52670.50
RESULT(FL)	2004.14	15236.37	15236.37
RES/TUR(%)	4.99	28.93	28.93
RES/ADD(%)	1.54	10.69	10.69
CUBIC	737.66	737.66	737.66
ADD/CUB(FL/m^3)	176.84	193.18	193.18
RES/CU(FL/m^3)	2.72	20.66	20.66

TABLE B.6. (f) Directed towards profit maximization.

	ITERATION					
	1	2	3	4	5	6
VALUE ADDED(FL)	121020.40	125460.65	118194.45	118551.65	119455.66	119455.66
TURNOVER(FL)	43201.55	63739.45	66333.00	66134.41	66294.00	66294.00
RESULT(FL)	4535.22	28392.63	31825.31	31571.70	31759.60	31759.60
RES/TUR(%)	10.50	44.54	47.98	47.74	47.91	47.91
RES/ADD(%)	3.75	22.63	26.93	26.63	26.59	26.59
CUBIC	668.47	706.16	683.44	681.48	690.67	690.67
ADD/CUB(FL/m^3)	181.04	177.67	172.94	173.96	172.96	172.96
RES/CU(FL/m^3)	6.78	40.21	46.57	46.33	45.98	45.98

TABLE B.7. (g) Integrated production.

	ITERATION						
	1	2	3	4	5	6	7
VALUE ADDED(FL)	60700.00	72706.10	72125.80	73328.00	74911.86	74899.76	74899.76
TURNOVER(FL)	27491.75	49040.20	50517.40	51768.40	52305.60	52274.50	52274.50
RESULT(FL)	-9643.57	13643.89	15438.52	16971.68	17713.59	17679.38	17679.38
RES/TUR(%)	-35.08	27.82	30.56	32.78	33.87	33.82	33.82
RES/ADD(%)	-15.89	18.77	21.40	23.14	23.65	23.60	23.60
CUBIC	384.40	500.11	496.77	520.86	533.58	533.37	533.37
ADD/CUB(FL/m^3)	157.91	145.38	145.19	140.78	140.40	140.43	140.43
RES/CU(FL/m^3)	-25.09	27.28	31.08	32.58	33.20	33.15	33.15

TABLE B.8. (h) Adjusted productmix.

	ITERATION					
	1	2	3	4	5	6
VALUE ADDED(FL)	104578.86	102909.66	101916.95	102159.16	102363.91	102363.91
TURNOVER(FL)	39806.75	50515.10	51199.30	51391.55	51234.80	51234.80
RESULT(FL)	1438.47	13388.90	14393.50	14647.42	14613.42	14613.42
RES/TUR(%)	3.61	26.50	28.11	28.50	28.52	28.52
RES/ADD(%)	1.38	13.01	14.12	14.34	14.28	14.28
CUBIC	494.91	494.91	494.91	494.91	494.91	494.91
ADD/CUB(FL/m^3)	211.31	207.94	205.93	206.42	206.84	206.84
RES/CU(FL/m^3)	2.91	27.05	29.08	29.60	29.53	29.53

TABLE B.9. Financial results for different policies.

	POLICY						
	2	3	4	5	6	7	8
PV	94102.30	117702.11	121546.66	142502.95	119455.66	88184.01	102363.91
TO	54773.05	63430.75	65251.15	52670.50	66294.00	52274.50	51234.80
CIA	85.98	739.33	739.87	1831.28	585.32	-	863.73
COA	26868.40	6084.31	3536.95	0.00	4383.17	-	1859.84
CIF	1593.23	2453.13	2785.80	4312.39	2204.23	2206.89	2042.11
COF	7662.46	6690.35	5169.98	0.00	2909.90	986.21	2757.54
CIR	9237.74	5831.20	6761.26	6490.47	7106.05	8888.23	9139.24
CL	16000.00	16000.00	16000.00	16000.00	16000.00	16000.00	16000.00
CO	6000.00	6000.00	6000.00	6000.00	6000.00	6000.00	6000.00
CP	2540.00	2631.85	2637.56	2800.00	2638.80	1500.00	2576.31
RESULT	19316.10	29775.25	30326.65	15236.37	31759.60	17679.38	14613.42

Appendix C

CASE STUDY

TABLE C.1. (1) Policy related to push strategy.

	ITERATION 1	2	3	4
VALUE ADDED(FL)	2125184.50	2285111.25	2287156.00	2287156.00
TURNOVER(FL)	292430.66	297620.34	303109.53	303109.53
RESULT(FL)	196643.73	200954.80	206498.72	206498.72
RES/TUR(%)	67.24	67.52	68.13	68.13
RES/ADD(%)	9.25	8.79	9.03	9.03
CUBIC	3103.52	3369.79	3369.79	3369.79
ADD/CUB(FL/m^3)	684.76	678.12	678.72	678.72
RES/CU(FL/m^3)	63.36	59.63	61.28	61.28

TABLE C.2. (2) Policy balancing profit and value recovery maximization.

	ITERATION 1	2	3	4
VALUE ADDED(FL)	2125288.25	2241363.50	2242008.25	2242008.25
TURNOVER(FL)	293930.63	476841.38	488743.69	488743.69
RESULT(FL)	198124.33	379935.81	392271.03	392271.03
RES/TUR(%)	67.41	79.68	80.26	80.26
RES/ADD(%)	9.32	16.95	17.50	17.50
CUBIC	3103.52	3353.33	3348.46	3348.46
ADD/CUB(FL/m^3)	684.80	668.40	669.56	669.56
RES/CU(FL/m^3)	63.84	113.30	117.15	117.15

TABLE C.3. (3) Investment in handling facilities.

	ITERATION 1	2	3
VALUE ADDED(FL)	2384378.25	2468301.25	2468301.25
TURNOVER(FL)	295418.00	447478.75	447478.75
RESULT(FL)	199615.13	350755.69	350755.69
RES/TUR(%)	67.57	78.38	78.38
RES/ADD(%)	8.37	14.21	14.21
CUBIC	3487.76	3664.59	3664.59
ADD/CUB(FL/m^3)	683.64	673.55	673.55
RES/CU(FL/m^3)	57.23	95.71	95.71

TABLE C.4. (4) Profit oriented policy.

	ITERATION 1	2	3
VALUE ADDED(FL)	2378826.50	2378167.25	2378167.25
TURNOVER(FL)	299441.59	517086.56	517086.59
RESULT(FL)	203731.86	421419.19	421419.19
RES/TUR(%)	68.04	81.50	81.50
RES/ADD(%)	8.56	17.72	17.72
CUBIC	3487.76	3588.88	3588.88
ADD/CUB(FL/m^3)	682.05	662.65	662.65
RES/CU(FL/m^3)	58.41	117.42	117.42

TABLE C.5. (5) Investment in conversion capacity.

	ITERATION 1	2	3	4
VALUE ADDED(FL)	2196760.00	2298259.00	2343637.25	2343637.25
TURNOVER(FL)	295343.72	484178.31	460671.59	460671.59
RESULT(FL)	199273.63	387146.28	364313.00	364313.00
RES/TUR(%)	67.47	79.96	79.08	79.08
RES/ADD(%)	9.07	16.85	15.54	15.54
CUBIC	3103.52	3356.51	3343.60	3343.60
ADD/CUB(FL/m^3)	707.83	684.72	700.93	700.93
RES/CU(FL/m^3)	64.21	115.34	108.96	108.96

TABLE C.6. Financial results for different policies.

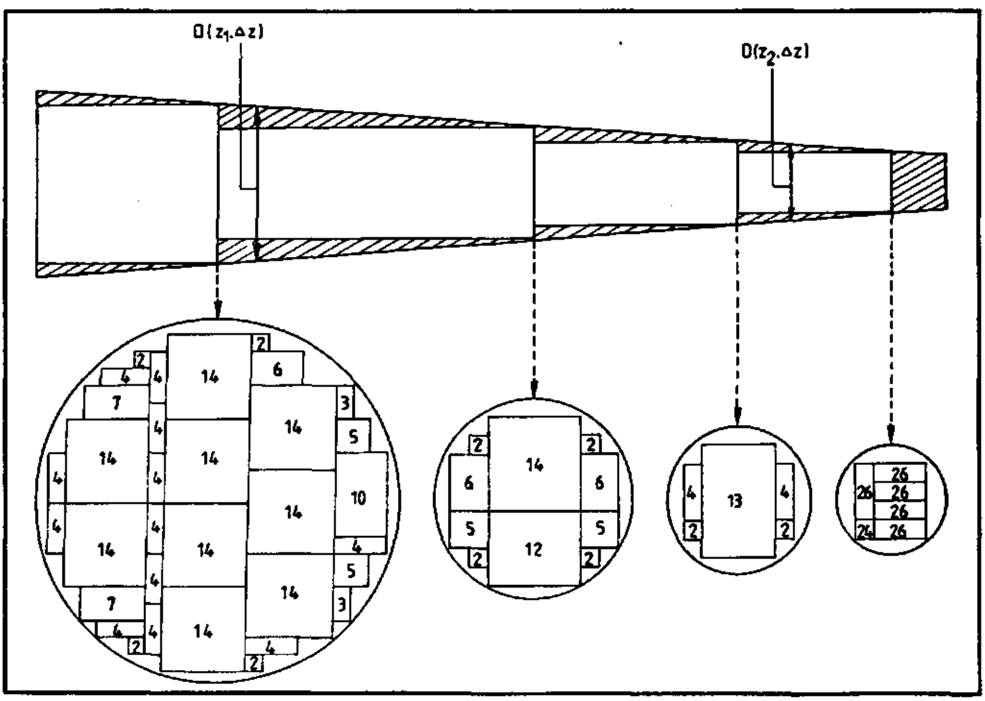
	POLICIES				
	1	2	3	4	5
PV	2285111.25	2242008.25	2468301.25	2378167.25	2343637.25
TO	297620.34	488743.69	447478.75	517086.56	460671.59
CIA	6850.52	6990.65	7402.80	6706.71	5931.49
COA	0.00	34216.20	40257.00	34475.00	37411.00
CIF	2407.24	1806.05	2055.51	1526.04	2847.42
COF	0.00	11162.85	16093.44	31691.82	11652.58
CIR	4447.80	4715.94	4304.75	4474.61	4619.69
CL	35700.00	35700.00	35700.00	35700.00	35700.00
CO	7860.00	7860.00	7860.00	7860.00	7860.00
CP	39400.00	39400.00	39400.00	39400.00	39400.00
RESULT	200954.80	392271.03	350755.69	421419.19	364313.00

Appendix D

OPERATIONAL OPTIMIZATION, OUTPUT

The conversion of trees into boards of various sizes is considered as a twophase process. In the algorithms, optimizing this production process, the conversion is optimized integrally.

This means that although in practice the conversion is considered as a combination of a one-dimensional and a two-dimensional cutting problem, in this research a three-dimensional model was designed (chapter 5).



The output of the optimization can be displayed (on a graphical screen) using the SAS-routines provided in IDEAS. The output after an optimization contains :

1) All distances from the stump-end, where cuts have to be made.

2) For all resulting assortments, the exact location of the optimal cuts along the y-axis, resulting in flitches.

3) All coordinates of the upper left angle from each product to cut off, and a logical indicating whether the product is rotated or not.

Furthermore some additional information is provided so that in future systems the cutting process can be fully automated, using these tools from IDEAS.

CURRICULUM VITAE

Martin Peter Reinders was born in Eindhoven on October 27, 1960. He received his elementary education in Eindhoven. In Eersel he took his school-leaving examination (VWO-B) at the *Rythovius College* in 1979.

In 1979 he started his study Forest Engineering at the Agricultural University in Wageningen. During his studies, he published an article about a research concerning extruder technology, and an article about forest-road networks optimization.

In January 1985 he graduated with honour, with Operations Research and Process Engineering as main subjects, and Forest Engineering as secondary subject.

He started his PhD-studies in March 1985 at the Department of Mathematics, Section Operations Research, and the Department of Forest Technique and Forest Products, both of the Agricultural University, Wageningen.

In January 1986 he became member of the staff of the Department of Mathematics. In this function he was involved in various researches for profit organizations.

During his PhD he visited several national and international congresses. Two of these occasions were used to report research results. Part of the results described in this dissertation, are reported in two articles in a national (Kwantitatieve Methoden, vol. 30, 1989) and in an international (European Journal of Operational Research, accepted for publication) scientific journal.