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RESOURCE CENTER

MODEL PRODUCTION SYSTEM FOR LAMINATED WOOD PRODUCTS

by

Marlen J. Kemmet

A Thesis

Submitted to the Graduate Faculty

of the

University of North Dakota

for the degree of

Master of Science

Grand Forks, North Dakota

December

1980

This thesis submitted by Marlen J. Kemmet in partial fulfillment of the requirements for the Degree of Master of Science from the University of North Dakota is hereby approved by the Faculty Advisory Committee under whom the work has been done.

(Chairman)

This thesis meets the standards for appearance and conforms to the style and format requirements of the Graduate School of the University of North Dakota, and is hereby approved.

Dean of the Graduate School

Permission

Title Model Production System for Laminated Wood Products

Department Industrial Technology

Degree Master of Science

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TABLE OF CONTENTS

LIST OF FIGURES vi

LIST OF TABLES vii

ACKNOWLEDGMENTS viii

ABSTRACT. ix

Chapter

I. INTRODUCTION 1

Statement of the Problem 4
Need for the Study 4
Limitations of the Study 5
Definition of Terms 6

II. REVIEW OF LITERATURE 8

Introduction 8
Production Management 8
Production System 10
Models 11
Wood Lamination 12
Summation 14

III. METHOD OF THE STUDY 15

Obtaining the Data 16
The Model Design 16
Product Selection 17
The Comparison 17

IV. ANALYSIS 18

Survey Responses 18
Application of Variables 27
Modeling 28
Traditional Lamination Method 37
The Comparison 44

V. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS 48

Summary 48
Conclusions 49
Recommendations 51

TABLE OF CONTENTS
(continued)

APPENDICES 52

Appendix A. Surveyed Companies and Individuals 53
Appendix B. Survey Instrument 57
Appendix C. Taylor Clamp 60

BIBLIOGRAPHY 62

LIST OF FIGURES

Figure		Page
1.	Typical Production System	1
2.	The Management of a Production System	3
3.	A Simple Description of an Operating System	10
4.	Laminated Cutting Board Design	29
5.	Model Process Layout.	34
6.	Model Break-Even Chart	36
7.	Traditional Method Process Layout	41
8.	Traditional Method Break-Even Chart	43

LIST OF TABLES

Table		Page
1.	Returned Surveys and Their Products	19
2.	Process Chart Symbols	30
3.	Schematic Model Cutting Board Lamination Process Chart	32
4.	Traditional Cutting Board Lamination Process Chart.	38
5.	Process Chart Comparison	44
6.	Process Layout Comparison	45
7.	Break-Even Analysis Comparison	46

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ABSTRACT

The purpose of this research was to investigate and experiment with the use of a designed model production system in comparison to a traditional system. It was the intent of this study to develop an efficient model production system for producing laminated wood products.

This research included: (1) review of the literature pertinent to wood lamination, (2) survey of companies and individuals involved with wood lamination, (3) design and testing of a model lamination system, and (4) comparison of the designed system to the traditional method of laminating a wood product.

Methods

The variables and procedures relating to wood lamination were identified through the review of literature and returned surveys. The variables and procedures deemed important were used to design the schematic, mathematical, and physical models of a lamination system. The designed model system was compared to the traditional method of producing a laminated wood product. This was done through a comparison of production times, process charts, process layout diagrams, and cost analysis.

Conclusions

The primary conclusions obtained from this study were: (1) the designed model layout resulted in less material movement than the traditional layout, (2) the designed model process required fewer

production activities than the traditional process, (3) the designed model process required less production time than the traditional method, (4) the designed model proved to be more economical in producing the same quantity of products than the traditional method, and (5) the quality of the laminated wood product proved higher using the designed model system in comparison to the traditional method.

Recommendations

It is recommended that: (1) a designed layout be used in lamination production runs, (2) a designed process should be incorporated in lamination production runs, (3) break-even analysis should be used to compare the economics of two production methods, and (4) models should be used to compare two or more competing systems.

CHAPTER I

INTRODUCTION

A production system can be viewed as a structural framework of activities within which the creation of value can occur. Production systems transform or convert such inputs as raw materials, labor skills, management skills, and capital into some product that may then be sold.

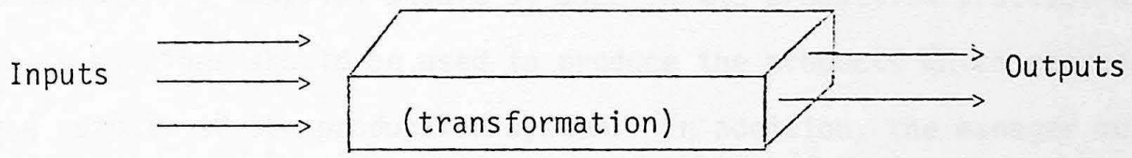

Figure 1: Typical Production System

Outputs of the system are usable products, wages that flow into the economy, environmental effects, social influences, and other less obvious factors. Connecting the inputs and outputs are a series of processes, storages and inspections. The design of a productive system is an activity which occurs before a firm begins production and recurs intermittently when redesign is necessary.

Competitive production requires an efficient production system to maximize the value created. Inputs must be converted efficiently and effectively into the desired outputs whether the organization is

profit or nonprofit, private or governmental, whether the output is tangible or intangible, a product or a service. All produced outputs involve processing operations which must be managed and operated. Efficient production involves input conservation and maximizing enhancement of the value added by processing. Efficiency can be optimized through a well designed and managed production system.

Effective and efficient production requires management. One type of management is production management. The role of the production manager is that of the decision maker in a production system. The production manager must plan the organization of resources, which materials and supplies should be used in the production process, and which machines should be used to produce the products which represent the outputs of the production system. In addition, the manager must plan for facilitative devices which accompany production activities, such as tools, jigs, fixtures, materials handling equipment, and so forth. After the production processes are started, they must be controlled.

Management control involves observing results and checking to see that the results conform to the original plans. This process of checking, in terms of a production system, requires the process known as feedback. During the feedback process, information is gathered from the production processes concerning how the processes are operating. The role of the production manager and feedback in the production system is depicted in Figure 2.

Decision making involves analysis, comparison, and determining alternatives. Models are used in the decision making process for

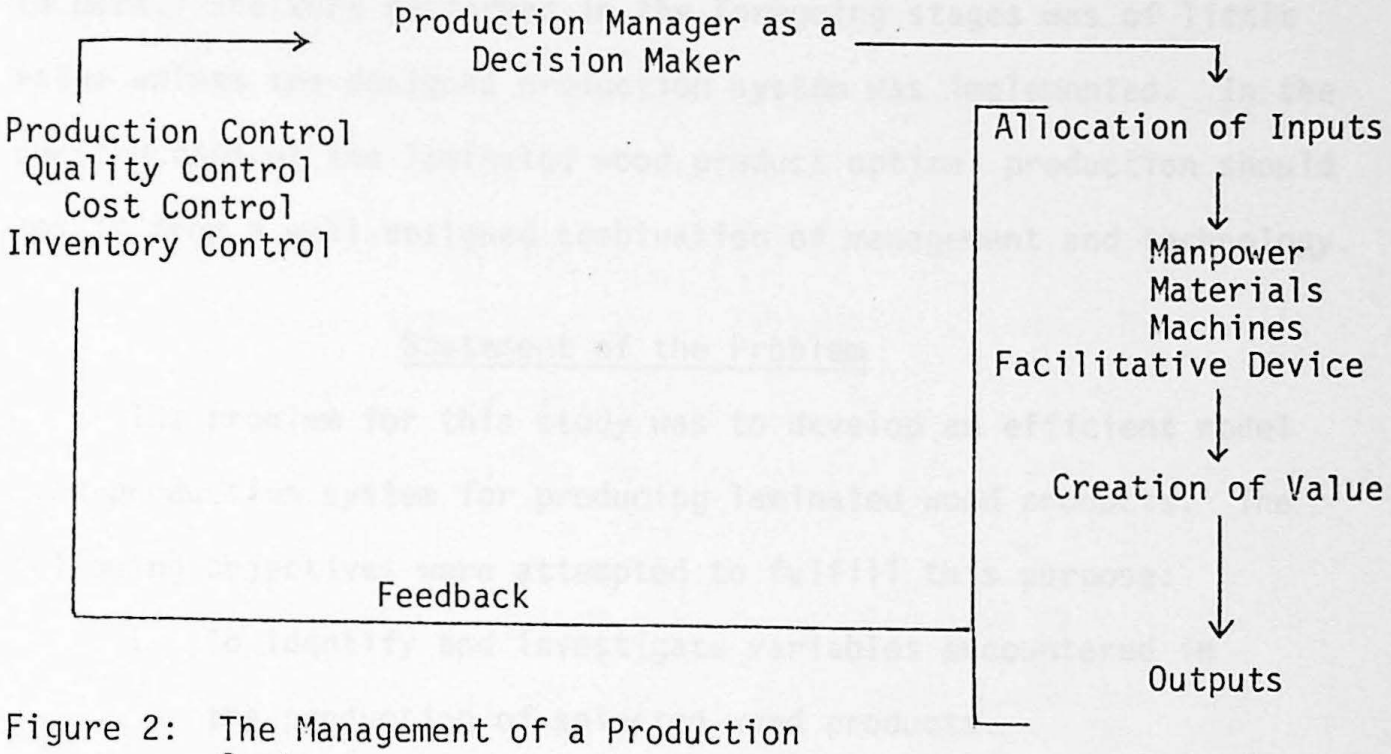

Figure 2: The Management of a Production System

depicting alternatives and in analyzing their performance. A model is an abstract representation of some real world process, system or sub-system. Models are developed when the need for a decision is recognized and when one seeks to understand how the real world works. A model is usually a simplification of the real world situation. The real test, using the principals of the production system and the processes of technology, is in their application.

This study used a combination of production system principals and the processes of technology in the production of a laminated wood product. The study attempted to utilize the following management processes: (1) planning, (2) organizing, (3) assembling, (4) directing,

and (5) controlling, in the operation and control of the production. The final stages in the management process were putting the variables to work. The work performed in the foregoing stages was of little value unless the designed production system was implemented. In the construction of the laminated wood product optimal production should result from a well designed combination of management and technology.

Statement of the Problem

The problem for this study was to develop an efficient model mass-production system for producing laminated wood products. The following objectives were attempted to fulfill this purpose:

1. To identify and investigate variables encountered in the production of selected wood products.
2. To design an efficient model system for the production of a laminated wood product.
3. To compare cost efficiency of the output from the designed production model system to a traditional hand produced laminated wood product.

Two major assumptions were tested in the study:

1. Variables and procedures relating to wood lamination could be identified.
2. A systematically developed model and process would result in a more efficient production system.

Need for the Study

Theories relating to production management are abundant, but, do the theories, when put into action, really work? Does production

become more efficient when ideal conditions and theories are used? This is the need for the study: to test the theoretical information in a real situation.

First, the study should discover specific data from companies involved with wood lamination comparable with previously learned production processes and theories. This technical data, when implemented into the theoretical model lamination system, should result in an efficient production system.

Groff (5) explained the need for such a study with the following statement:

> Theories and models can be valuable aids for explaining and predicting and, therefore for controlling a given system. Unfortunately, while there exist important theories and models that are useful for many problems within a complex operating or production systems, substantial gaps remain. If a set of theories from which to derive adequate means for dealing with a system does not exist, a reasonable alternative is to provide assistance for improving understanding of the problem (descriptive material and procedures for investigation and analysis) and for synthesizing and selecting desirable alternatives. (p. 5).

Limitations of the Study

Production, marketing, and finance are the three most basic functions of a business operation. The scope of this paper dealt only with the production function. Further limitations:

1. The selected product to be produced will be hardwood (oak and walnut) laminated cutting board.
2. The laminated product will be constructed on a specially designed custom made clamping device.

each other, by gluing edges in different arrangements, by combining edge and board surfaces, or by inserting veneers between the laminates.

Mass Production:

Done on a large scale; involving great numbers or large amounts, production for the sake of quantity.

Model:

A hypothetical representation of a real situation.

Moisture Content:

The total amount of moisture in a given piece of wood is expressed as a percentage of the ovendry weight of the wood.

$$\text{M.C., \%} = \frac{\text{wt. of wood with water - OD wt. of wood}}{\text{OD wt.}} \times 100$$

Procedure:

The act, method, or manner of proceeding in some process or course of action; the sequence of steps to be followed.

Process:

A continuing development involving many changes, generally involving a number of steps or operations.

Production Systems:

A network of structures and channels within which the creation of value or wealth by producing can occur.

System:

A complex of functionally related components designed to achieve a predetermined objective in the process of:

inputs ----> transformation ----> outputs

3. The production system will utilize appropriate equipment set up for a specialized task or purpose.
4. Three types of models will be used; mathematical, physical, and schematic.

Definition of Terms

Efficiency:

Producing effectively with a minimum of waste, expense, or unnecessary effort.

Feedback:

The transfer of part of the output of an active circuit or back to the input, either as an unwanted effect or in an intentional use, as to reduce distortion.

Fixture:

A device for holding and clamping a component in a predetermined position, it is clamped to the machine or is part of the machine, and any movement of the fixture is determined by the movement of the machine.

Jig:

A component holding device, in which the component is located and clamped in a prearranged manner. It is a tool which in use is held or manipulated by the operator; it is moved from station or tool to another station or tool; it is designed to provide accurate machinery and to guide the tool or tools.

Lamination:

The process of layering two or more pieces of wood in any desired manner, either by placing the board surfaces next to

CHAPTER II

REVIEW OF LITERATURE

Introduction

This chapter is divided into four sections. First, the review provided an explanation of the roles and objectives of production management. Second, the review indicated the function and conception of productive systems. Third, the review furnished a view of the use of models to design the actual production system. Fourth, the review indicated the processes and variables involved in wood lamination.

Production Management

At the core of production is the technology of transformations. Any production process can be viewed as an input-output system. A transformation process operates on inputs or resources and releases them in a modified form as outputs. The management of the transformation process is called production management. (5)

Efficient management is accomplished through well organized planning. The process of planning can be grouped into four distinct steps. Each step should be done as thoroughly as patience and time permits. In large companies, careful research and months of patient investigation are usually given to fact finding, which is the first step toward planning. Analyzing, which is the second step, usually requires much less time. Concluding means the selection of the most

desirable solution supported by the preceding steps; coordinating all conclusions with each other finally gives a plan and the methods for its fulfillment.

In organizing and managing production, the input-output system cannot be chosen arbitrarily or at random. It must be able to fulfill the tasks of producing the product as the plans require. Management problems can be solved by buying the best suited machines; setting them up to provide coordinated, efficient flow of the work; making them ready for utilization of the latest methods; and getting the best available men to do the work. (1)

A small plant committee research study expressed management as a series of thinking processes and of actions whereby the manager aims to make definite products or to render services in a definite way, in a definite volume at a definite time, at a price at which they can be sold and at a cost which leaves a profit to the enterprise. It is the main task of the manager to apply such thinking and actions as will fulfill these objectives. (1)

The role of the production manager is that of the decision maker in a production system. Production managers initially plan how the inputs should be allocated. (6) The function of the production manager is that of putting together inputs of men, capital, materials, information, and energy; and transforming them into products and services in the quantity, quality, time and location that will best meet the organization objectives. (7)

The theory component of production management is frequently referred to as methodology. This ranges from the use of schematic diagrams such as organizational charts and flow diagrams to the

employment of sophisticated and abstract mathematical models. All of these embody certain specific ideas about what factors are relevant and how they are related to each other. (5)

Production Systems

The word "system" has many uses, all stemming from the initial recognition that a system is a complex of functionally related components designed to achieve a predetermined objective. A simple conception of a system is one which very closely resembles the process outlined in Figure 3.

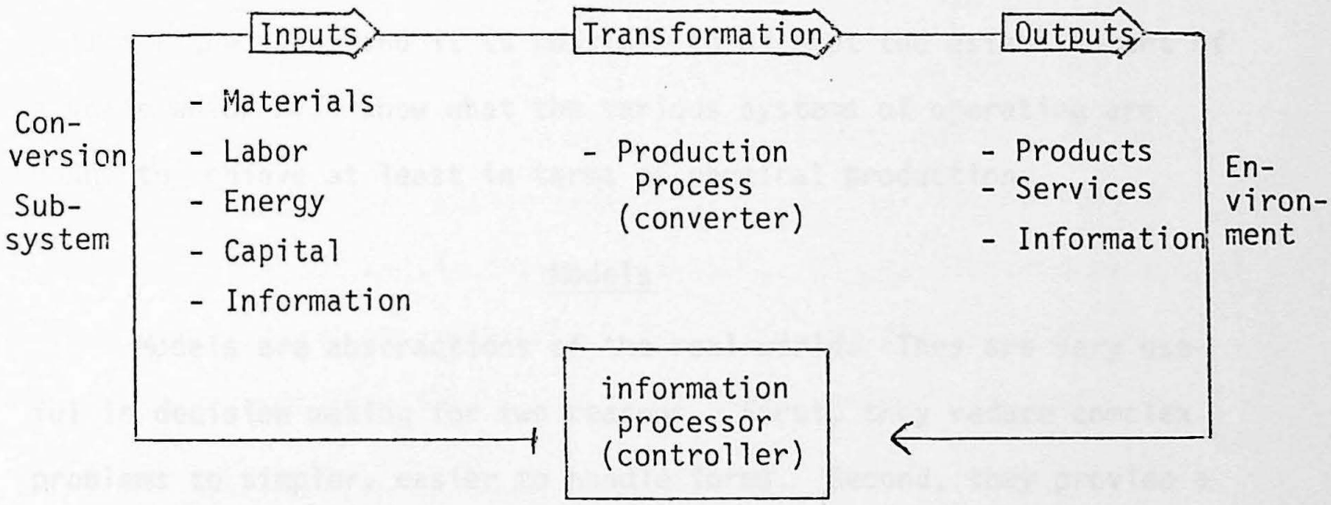

Figure 3: A Simple Description of an Operating System

It contains two subsystems (sets of components and interrelationships viewed as components of an aggregated larger system). The conversion process is one subsystem. The second is a control subsystem which is a component of any managed system. It involves the feedback of information from the output of the converter to an information processor.

This information processor may be all or partly human. (7)

Ehbrecht (1) described the importance of the operation of a system:

> It is certain that any primitive system can give only primitive results. Production does not just happen: it is only as good as its management. Production can be made more efficient by the use of various systems by those who will take proper actions to change these systems into reality. The kinds of operating systems that bring this about must gradually be developed from their primitive forms into higher, more refined, more elaborate systems of operating. The performance of all activities, the engineering, production, sales and financial work, must be improved uniformly if a higher system of operating is to result. (p. 219)

In all this evolution, production always has and probably always will set the pace, and it is possible to attempt the establishment of a scale which will show what the various systems of operating are bound to achieve at least in terms of physical production.

Models

Models are abstractions of the real world. They are very useful in decision making for two reasons. First, they reduce complex problems to simpler, easier to handle forms. Second, they provide a means of predicting what the outcome of a decision will be before it is made. (6)

Similar to Hopeman's explanation, but in more detail, Garrat and Silver (3) defined the use of a model:

> A model can be a useful decision aid because it presents a simplified description of the problem at hand and thus facilitates the isolation and analysis of the issues that will have the greatest influence on the decision to be made. In this fashion, models provide an operating perspective that tends to improve the quality of the solution formulated. (p. 62)

Beyond the basic level (words, numbers, symbols) there are three general categories of models that are useful in analyzing and understanding real-world situations.

1. Schematic models. These models include all forms of diagrams, drawings, graphs, and charts, most of which are designed to deal with specific types of problems. By presenting significant factors and interrelationships in pictorial form, schematic models are used to indicate problems in a manner that facilitates analysis. Some types of schematic models are: flow-process charts, Gnatt charts, organizational charts, and routing diagrams.

2. Mathematical models. Mathematical models use arrangements of symbols to depict the process or system being modeled. The symbols are arranged to form equations or mathematical expressions. These models represent the ultimate in abstractions of reality.

3. Physical models. These models are usually three dimensional representations of other objects. They are tangible objects made to look like and perform like some aspect of the system being modeled. (2)

Wood Lamination

Gamble Brothers of Louisville, Tennessee is considered an authority on specialty wood products. They are recommended as a great source of practical answers to clear the existing confusion between theoretical technology and problems that occur on the assembly line. While the company would be capable of generating encyclopedic volumes of wood technology, the practical solution to every problem is evaluated on how well it works in the plant.

The proper lamination of wood products is successfully completed

by them, by paying close attention to the variables. The company dries its materials down a bit lower than standard furniture practice and works in a range of 5-7 percent moisture content. A continuous film of sufficient thickness of glue and good wetting of both mating surfaces is a necessary element of good bonding. After gluing, products are equalized from 24 to 48 hours before machining. This relieves most of the stresses and leaves conditioned wood that machines flat and stays flat. Except for high temperature requirements of some adhesives, cold presses, clamps and carriers are used extensively throughout the plant. Selecting the adhesive designed to do the job was also a necessity. Gamble Brothers credit their lamination success to scientific and engineering talent as well as manufacturing facilities unmatched throughout most of the industry. (10)

Gluing, abrasive planning and clamping are process features in turning waste material into valuable parts of Norwalk Furniture Corporation in Cookeville, Tenn. The company converts waste material through lamination, into useful thick block furniture parts. Due to the short length of the scrap materials the pieces are planed on a abrasive planer rather than a knife planer. A spokesman for the company explained there is nothing like abrasive planing for good glue joints, especially for laminating. Other variables, considered important in lamination, which are closely controlled at the plant are; adhesive formulation, straight ripsaw cuts, clamping alignment and pressure, amount of adhesive application, and clamping times. The company admits there is more labor put into the operation for facing, handling, and

gluing the parts together, but the operation does salvage material that otherwise would be thrown away. Salvaging is still less costly than previous methods. (9)

Summation

To summarize, most of the difficulty encountered in the design and installation of a manufacturing system is caused by inadequate understanding of what should be required in a bill of materials or planning system. Ignorance is still more common than knowledge and is actually so widespread that nearly all businesses that have installed limited systems are proud of their achievements; in reality however they have locked themselves into a method of operation that severely limits the potential of their system. (3)

CHAPTER III

METHOD OF THE STUDY

This chapter describes the methods used to solve the problem of the study. The problem was to develop an efficient model production system for producing laminated wood products. The study was accomplished through the following procedures: (1) the literature was reviewed, (2) a survey was conducted, (3) a model system was designed, and (4) the traditional production system was compared to the designed model production system.

The objectives for the study were:

1. To identify and investigate variables encountered in the production of selected wood products.
2. To design an efficient model system for the production of a laminated wood product.
3. To compare general efficiency of the output from the designed production model to a traditional hand produced laminated wood product.

Two major assumptions were tested in the study:

Assumption 1. Variables and procedures relating to laminated wood products could be identified and used to design a production system.

Assumption 2. A model which systemizes the processes would result in a more efficient production system when compared to traditional production techniques.

Obtaining the Data

To determine the variables encountered in the lamination of wood products several journal articles involving wood lamination were studied. The variables from each journal article were listed and finally compared to determine the variables common and viewed important in the production of laminated wood products. To further investigate and validate the variables found to be important, sixty one companies and individuals involved with wood lamination were surveyed. (See Appendix A) Addresses were selected from the Thomas Registry, wood industry periodicals, and marketed laminated wood product packages. The criteria for selection of survey recipients was that the organization claimed or advertised to specialize or have information pertaining to wood lamination.

The recipient of each survey was asked to give limitations of the listed variables, types of equipment used, and procedures employed in their lamination processes (Appendix B). The recipients of the surveys were; major furniture companies, wood production organizations, individuals, and small companies specializing in wood lamination. The responses were then compared to determine the limitations of variables and types of procedures deemed important throughout the industry.

The Model Design

The variables and procedures deemed important and essential by the returned surveys were used to design schematic, mathematical, and physical models of a lamination system. This system was first theoretically designed, using procedures acquired from the survey, for the lamination of the selected wood product. Once the procedures

had been organized to develop a system, the surveyed variables were implemented for the production of the product. Finally, an actual lamination production run was completed based on the models.

The designed model system involved the use of process charting, process layout, and break-even analysis. The theoretical model system was transformed into an actual production operation system involving the following inputs: machines, materials, manpower, and management.

Product Selection

The product to which the model was specifically designed for was a hardwood cutting board. The board was constructed of alternating strips of oak and walnut. (See Figure 4)

This product was chosen to be laminated for several reasons. First, the procedures used to produce it were similar to other surveyed products. Second, it was small and relatively inexpensive. Third, it was possible to set up and conduct an actual production run and produce twenty five products.

The Comparison

It was necessary to compare the traditional hand produced method to the designed model system to determine which method of lamination was more efficient. This was accomplished through a comparison of production times, process charts, process layout diagrams, and cost analysis.

CHAPTER IV

ANALYSIS

This chapter is an analysis of the three purposes for the study. First, the data solicited through the survey of laminated wood products' manufacturers, was analyzed. Second, this data was used in the design of the model system. Third, the model system and the traditional system were compared.

The first two models, the schematic and mathematical were theoretical and were used to formulate a model lamination production system. The formation of these two models was used to design the physical model. Information taken from the survey was used in the physical model for the actual lamination of the hardwood cutting boards.

Survey Responses

The survey was sent to 61 companies, individuals, and organizations who were prominent in the field of wood lamination. Of the 61 recipients of the survey, 21 responded for a rate of return of 34.5%. Table 1 shows a list of names of returned surveys and the laminated product(s) they manufacture.

TABLE 1

RETURNED SURVEYS AND THEIR PRODUCTS

Name	Product(s)
Martens Manufacturing Company	Cutting Boards
RHF Enterprises	Belt Buckles, Pencil Cups, Clocks, Salt & Pepper Shakers
James W. Rogers	Jewelry Boxes
Koppers Company, Inc.	Arches and Beams
Hickory Manufacturing Company	Chair Posts and Rails
Vermillion, Inc.	Wood Bowls
Drexel Heritage Furniture	Tables, Chairs, Dressers, Beds
Dan Warner	Rolling Pins
Baker Furniture	Plywood, Cabinets
Bruce Hardwood Floors	Hardwood Flooring
Dimensional Products	Parquet Table Tops
Wayne N. Raab	Cutting Boards
Gamble Brothers	Beams, Rails, Squares for turning, Cutting Boards
Brandenfels Blocks	Wood Cutting Blocks, Tables
Harrington House Ltd.	Parquet Flooring
Hartco	Parquet Flooring
Pulaski	Chairs, Casegoods
Armstrong Cork Company	Chairs
Chicago Cutlery	Knife Blocks
Emperor Clock Company	Parquet Tables
Shade of the Tree	Cutting Boards

For the tabulation of the data, a summation is given below to avoid duplication of products. The returns were representative of similar products produced by other companies. The following are (1) questions from the survey; and (2) representative responses received through the survey:

1. Question 1. Name of laminated wood product(s):

   The companies and/or individuals and the laminated products they produced were shown in Table 1.

2. Question 2. Specie(s) of wood used;

product	specie(s)
arches and beams	pine, oak, walnut, maple, poplar, cherry
chair posts and rails	oak, pine, birch
cutting boards	oak, walnut, beech, maple, cherry ash
furniture components	oak, walnut, pine, maple, birch, ash, mahogany, gray elm, pecan, hickory
hardwood flooring	oak, walnut
parquet table tops	oak, walnut
plywood	oak, pine, walnut, maple, birch, mahogany, teak, cherry, satinwood
rolling pins	walnut, maple, cherry, lemon, purple heart
wood bowls	walnut

3. Question 3. Moisture content of wood at time of construction:

product	moisture content
arches and beams	8-16%
chair posts and rails	6-7%
cutting boards	6-8%
furniture components	6-8%
hardwood flooring	8-12%
parquet table tops	7%
plywood	5-7%
rolling pins	5%
wood bowls	10%

4. Question 4. Is the clamping device commercial_____ or specialty made_____? Brand name/builder and address

product	commercial or specialty	brand name
arches and beams	specialty	
chair posts and rails	commercial	Rosen Avis
cutting boards	commercial	Taylor
furniture components	commercial	Columbia Cold Press
hardwood flooring	commercial	Superior PMI
parquet table tops	commercial	L & L Glue Machine
plywood	commercial	Ott, Fritg
rolling pins	commercial	Jorgensen
wood bowls	commercial	Taylor

5. Question 5. Brief description of clamping device; (a picture or diagram would be appreciated)

Five of the twenty one returned surveys listed the Taylor Clamp Carrier made by Taylor Manufacturing Company of Poughkeepsie, New York, as the clamp they used. The only pictures included were also of the Taylor Clamp (Appendix C).

6. Question 6. Amount of pressure used in the clamping operation;

_____psi.

product	pressure in psi
arches and beams	150
chair posts and rails	150
cutting boards	75
furniture components	150
hardwood flooring	150-200
parquet table tops	25-35
plywood	150
rolling pins	N/A
wood bowls	N/A

7. Question 7. Method of pressure application;

product	application
arches and beams	air wrench
chair posts and rails	hydraulic rams
cutting boards	manual, air wrench
furniture components	hydraulic rams
hardwood flooring	hydraulic platens
parquet table tops	air wrench
plywood	hydraulic platens
rolling pins	manual
wood bowls	air wrench

8. Question 8. What kind of adhesive is used;

product	adhesive
arches and beams	Koppers Penacolite G-5514A
chair posts and rails	P.V.A.
cutting boards	Gulf VL77 with catalyst, Jitebond
furniture components	Urea Formaldehyde
hardwood flooring	Polyvinyl, Urea, Resorcenol
parquet table tops	Franklin Chemical Mixture
plywood	Urea Resin
rolling pins	Titebond
wood bowls	Caesin

9. Question 9. What are the environmental conditions under which the product is laminated, i.e., temperature, relative humidity, etc.:

product	conditions
arches and beams	temp. 65-100°F (seasonal variations) R.H. 50-100% (seasonal variations)
chair posts and rails	temp. 65-75°F R.H. 35%
cutting boards	temp. (ideally) 70-80°F R.H. 45%
furniture components	normal ambient conditions
hardwood flooring	temp. 45°-95°F, normal 75°F R.H. N/A
parquet table tops	temp. 70°F R.H. N/A
plywood	normal ambient conditions
rolling pins	temp. 55-80°F R.H. 20-50%
wood bowls	temp. minimum 70°F R.H. minimum 40%

10. Question 10. Open assembly time;

product	time(minutes)
arches and beams	75
chair posts and rails	12
cutting boards	1-15
furniture components	10-60
hardwood flooring	60
parquet table tops	15
plywood	1
rolling pins	5
wood bowls	10

11. Question 11. Closed assembly time;

product	time(minutes)
arches and beams	75
chair posts and rails	60
cutting boards	1-5 hours
furniture components	1-5
hardwood flooring	5
parquet table tops	3
plywood	2
rolling pins	8 hours
wood bowls	2.5 hours

12. Question 12. Method used for application of adhesive;

product	method
arches and beams	extruder
chair posts and rails	Black Brothers glue spreader
cutting boards	motor driven glue spreader with conveyor
furniture components	Black Brothers glue spreader
hardwood flooring	Globe roll spreader
parquet table tops	conveyorized glue spreader
plywood	Black Brothers glue spreader
rolling pins	tooth brush or paint brush
wood bowls	N/A

13. Question 13. Precautions used to prevent warping and deformation of product;

product	precaution
arches and beams	none, large structural pieces do not easily warp
chair posts and rails	proper moisture content consistent in all pieces, wood was properly dried and conditioned
cutting boards	proper kiln drying with equalization and stress conditioning at end of kiln cycle, well maintained straight line saws
furniture components	conditioning all components to same moisture content, balanced construction and use of x-bands
hardwood flooring	prepress 12-15 minutes, rapid load and unload, pray alot
parquet table tops	pieces to be glued should not be wider than 4", moisture content should be held at 6 to 10%, panels should be kept at room temperature 48 to 72 hours before finish machined
plywood	either weight on the dead piled stock or spaces between the rows of stock to allow air to get to both sides of stock
rolling pins	none, objects are turned on lathe so minor distortions are of no consideration
wood bowls	N/A

14. Question 14. Procedure used in the finishing process;

product	procedure
arches and beams	planed, holes drilled, stained or sealed, wrapped
chair posts and rails	sprayed, sanded-filled, wiped, glazed, lacquered
cutting boards	dipped in an oil, wax solution which is heated to approximately 135°F
furniture components	same as solid parts
hardwood flooring	cut to size, machine edges, stain and wax
parquet table tops	pieces, after being finished sanded are: 1. sprayed, stained and wiped for color 2. spray sealed 3. sealer is sanded to make finish coat stick 4. two coats of lacquer - first coat light for holding strength, then baked - second coat for "fill in" and added lustre 5. polished, rubbed, and inspected
plywood	a normal finish included; water stain, lacquer sealer, alcohol, hand padded colors, lacquer sealer and two coats of top coat lacquer
rolling pins	40 grit steel wool and oil
wood bowls	N/A

15. Question 15. Materials used in the finishing process;

product	materials
arches and beams	stain, varnish, sealer
chair posts and rails	stains, filler, glaze, wash coat, sealer, pad stains, lacquers
cutting boards	mineral oil
furniture components	nitrocellulose finish
hardwood flooring	penetrating oil - type sealer stain, hot melt wax
parquet table tops	finish coat
plywood	water based stains, solvent based stains, lacquer sealers, alcohol colors and lacquers
rolling pins	oil
wood bowls	N/A

Application of Variables

The survey provided useful information on the limitation of variables, equipment, procedures, and materials used in wood lamination throughout the industry. The wide range of companies surveyed along with their variety of products provided a basic understanding of the lamination process. Although the variety of products was wide, the variables deemed important were similar from company to company. The variables cited as important were: moisture content, exact machining, clamping pressure, adhesive selection, and adhesive application.

The survey identified several variables and procedures encountered in the production of the laminated cutting board. Many of these variables and procedures were used in the formation of the schematic and

physical models. Although some variables such as moisture content and relative humidity were deemed important, it was quite impractical to attempt to control or alter them.

The information from the survey proved useful in both system and product design. The model laminated cutting board was constructed of alternating strips of oak and walnut lumber. (See Figure 4) The product was manually clamped in a specially made clamping device. Elmers Titlebond was the selected adhesive and applied at room temperature or 72^{o}F. The open assembly gluing time was five minutes. The closed assembly gluing time was 50 minutes. The adhesive was manually applied. After the closed assembly time, the board was removed from the clamp and stored for 24 hours before further maching to help prevent warping or deformation of the board. Mineral oil was used as the finishing agent and was manually applied.

Modeling

Modeling was used to present an abstract representation of an actual lamination. The objective was not to identify all aspects of the subject but rather to identify significant factors and interrelationships. The models were used as decision aids because they presented a simplified description of the problem and thus facilitated the isolation and analysis of the issues that had the greatest influence on the decisions made. (4)

The design and formation of the three basic types of models (schematic, mathematical, and physical) were used as decision and

analysis aids. The schematic model included a process chart and process layout. The mathematical model included a break-even chart and break-even equation. The physical model was formed from the schematic and mathematical models. It was the purpose of these models to use information obtained from the survey to develop a lamination system. This system was then tested by the physical model or an actual lamination procedure. It incorporated data received from the survey by employing this data in the lamination of the hardwood cutting boards.

Schematic Models

The schematic model had two parts: (1) process chart, (2) process layout. The process chart was a graphic method of describing the sequence or flow of activities involved with the lamination of the selected wood product (cutting board). Table 2 depicts the symbols used in the process chart.

TABLE 2

PROCESS CHART SYMBOLS

	indicated an operation
	indicated a storage
	indicated a transportation
	indicated an inspection
	indicated a delay

The activities in the process chart were initially determined by the surveyed data and information obtained through the review of literature. The actual lamination caused a few changes to be made to provide for the most efficient process. The distances were obtained from the designed process layout. The distances were taken from the

designed layout as it would have been financially impossible to set up the layout as designed. In the actual lamination using the process chart, machines in several buildings were used to accomplish the lamination. The timed data was based on an average of the actual lamination of 25 cutting boards. The model process chart for the lamination is depicted in Table 3.

Process Layout

Once the process chart had been formed and the activities determined it was necessary to design the process layout. The process layout was concerned with moving materials for a particular job from one work station to another. When work was completed at one station, the lot was moved to the next where succeeding work was to be performed. (6) Process layout had the advantage of showing the flow of materials in the lamination process in a floor diagram. The process layout was designed specifically for the lamination of the cutting boards. The objectives of the design were: (1) minimize the amount of material movement, (2) provide a smooth flow of materials from one work station to the next. Figure 5 depicts the designed model layout for the lamination of the cutting boards.

Mathematical Model - Break-Even Analysis

Break-even analysis was the mathematical model used to provide an understanding of sales income, costs, profits, and how they were related at different volumes of production and sales. The break-even analysis for the cutting boards was shown into two methods; (A) break-even chart, and (B) break-even equation.

A. Break-Even Chart

The break-even chart graphically presented the relationship

TABLE 3

SCHEMATIC MODEL CUTTING BOARD LAMINATION PROCESS CHART

Symbol	Distance* (ft.)	Time** (min.)	Activity
○		3.00	Cut pieces to width on universal saw
⇨	12	0.25	Move pieces to cut-off saw
○		3.00	Cut pieces to length on cut-off saw
⇨	10	0.25	Move pieces to jointer
○		4.00	Joint edges on pieces
⇨	10	0.25	Move pieces to clamping device
▣		5.00	Glue, inspect, and clamp pieces in clamping device
D		50.00	Glue, curing time (no labor involved
○		2.00	Remove laminated board from clamp
⇨	12	0.25	Move to storage area #1
D		24(hours)	Store before further machining. (no labor involved)
⇨	12	3.25	Move to scraping table
○		4.00	Scrape and inspect glue joints
⇨	14	0.25	Move board to cut-off saw
○		1.00	Trim to length

TABLE 3 - Continued

Symbol	Distance* (ft.)	Time** (min.)	Activity
⇨	17	0.25	Move to abrasive planing sander
○		1.50	Sand boards
⇨	5	0.25	Move boards to work table
○		0.75	Mark curved cuts to be made (use template)
⇨	4	0.25	Move boards to band saw
○		1.25	Cut Curves
⇨	9	0.25	Move boards to disc sander
○		0.50	Disc sand corners
⇨	10	0.25	Move to router
○		1.50	Router board edges
⇨	7	0.25	Move to finish sanding table
○		2.00	Finish sanding
⇨	20	0.25	Move to finish area
○		2.00	Apply sealer
□		0.50	Final inspection
⇨	10	0.25	Move to storage area
○		5.00	Package
D		N/A	Store for shipment

* Distances taken from designed process layout (Fig. 4)
** Timed data was based on an average of actual lamination of 25 cutting boards

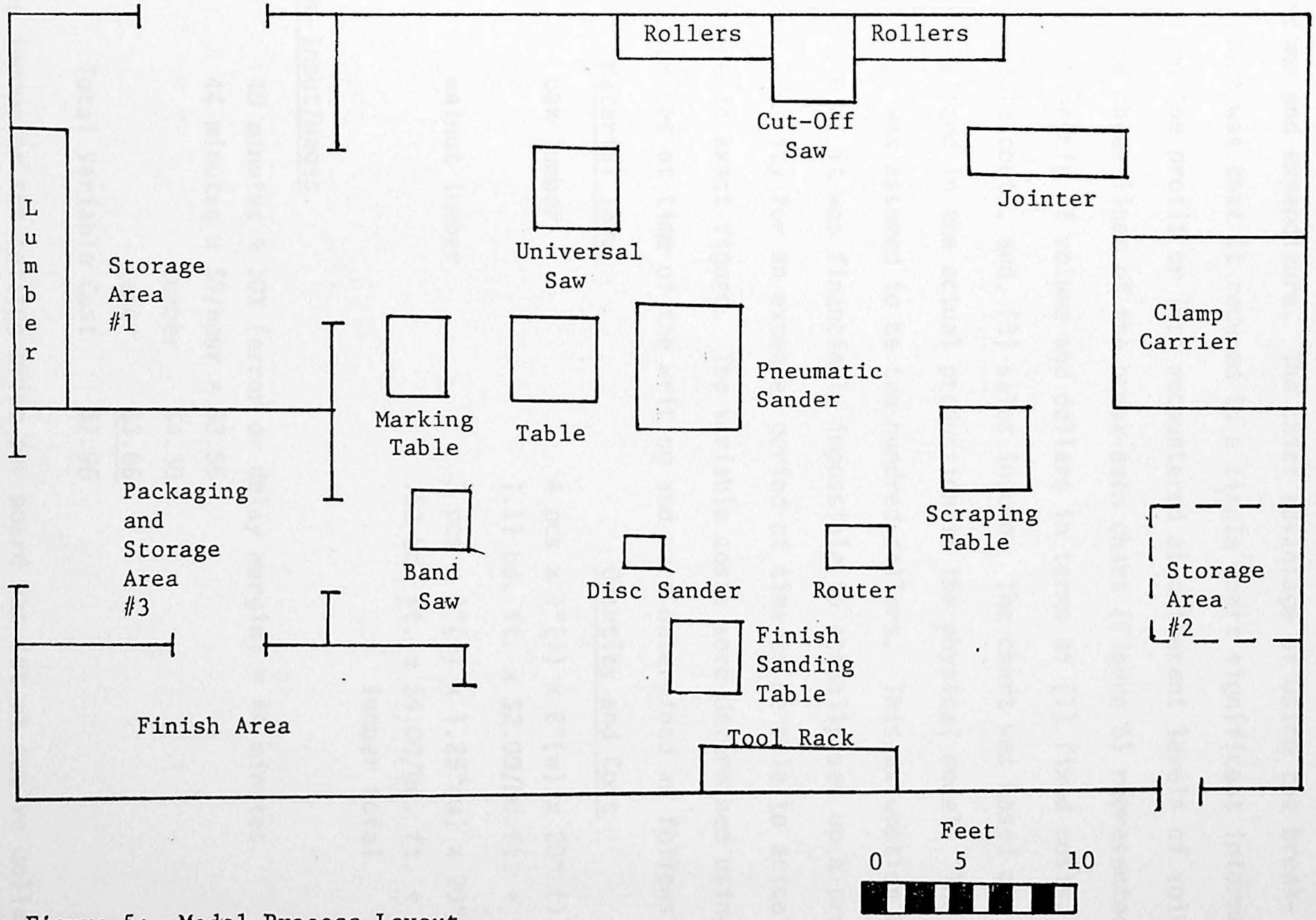

Figure 5: Model Process Layout

between the volume of cutting board production and sales and the amount of income and expenditure. The chief advantage of using the break-even chart was that it reduced to a single chart significant information regarding the profit or loss encountered at different levels of volume.

The three lines of the break-even chart (Figure 6) represented the relationship of volume and dollars in terms of (1) fixed costs, (2) variable costs, and, (3) sales income. The chart was based on costs realized in the actual production in the physical model. The fixed cost was assumed to be two hundred dollars. This assumption had to be made as it was financially impossible to actually set up a production facility for an extended period of time to be able to actually calculate an exact figure. The variable costs were determined using market prices at time of the writing and were determined as follows:

Material Input	Quantity and Cost
oak lumber	4 pcs x 1"(+) x 2"(w) x 20" (1)
	1.11 bd. ft. x $2.00/bd.ft. = $2.22
walnut lumber	3 pcs x 1"(+) x 1.25"(w) x 20" (1)
	.52 bd. ft. x $4.00/bd. ft. + $2.08
	lumber total $4.30

Labor-Input/Wages

40 minutes + 10% (error or delay margin) = 44 minutes.
44 minutes x $5/hour = $3.66

Lumber	$4.30
Labor	$3.66
Total Variable Cost	$7.96

Sales income or the selling price per board was set at twelve dollars.

Figure 6 represents the break-even chart for the designed model lamination system.

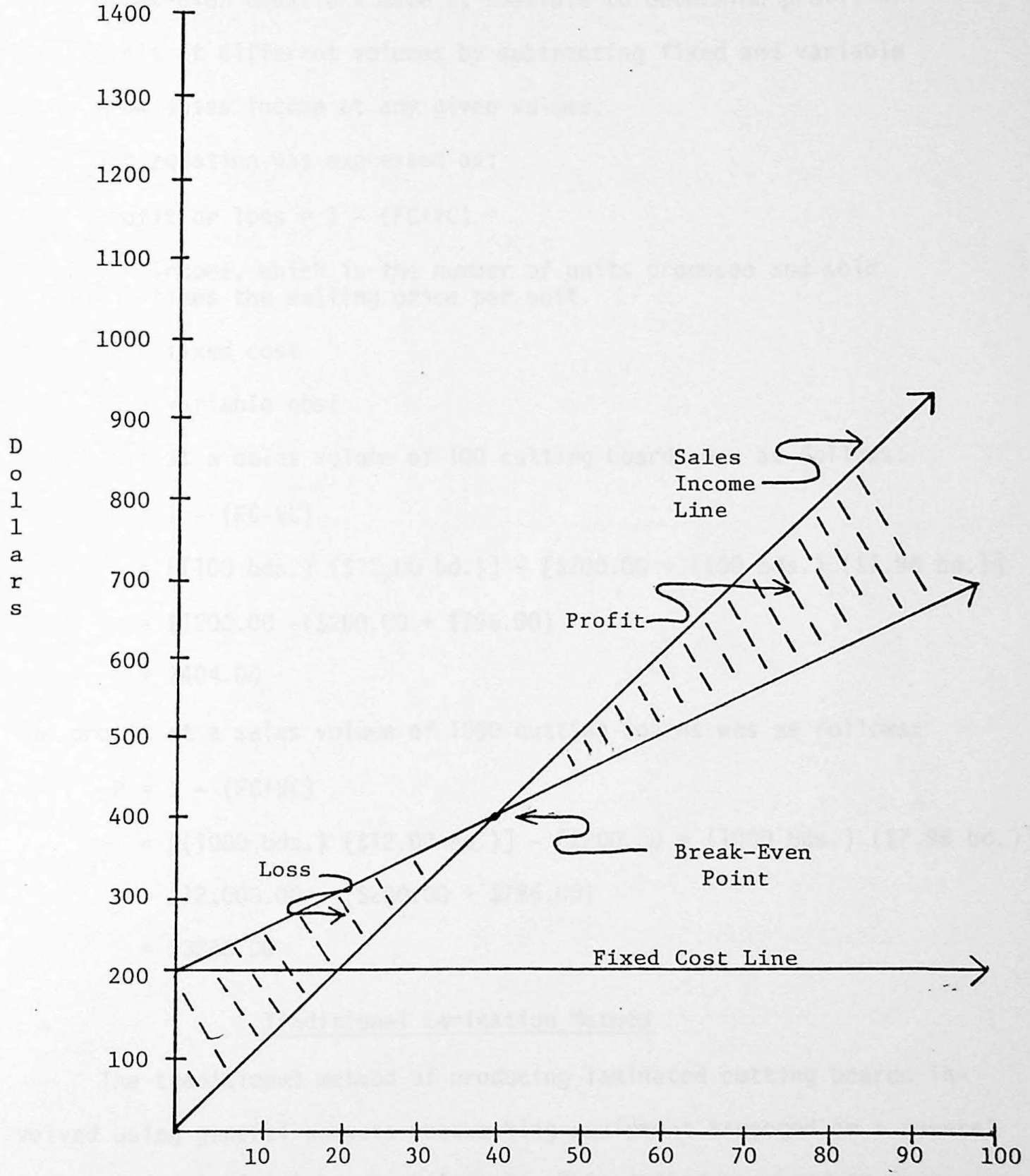

Figure 6: Model Break-Even Chart

B. Break-Even Equation

Break-even equations made it possible to determine profit or loss levels at different volumes by subtracting fixed and variable costs from sales income at any given volume.

The equation was expressed as:

Profit or loss = I - (FC+VC)

where I = income, which is the number of units produced and sold times the selling price per unit.

FC = fixed cost

VC = variable cost

The profit at a sales volume of 100 cutting boards was as follows:

P = I - (FC-VC)

= [(100 bds.) ($12.00 bd.)] - [$200.00 + (100 bds.) ($7.96 bd.)]

= $1200.00 -($200.00 + $796.00)

+ $404.00

The profit at a sales volume of 1000 cutting boards was as follows:

P = I - (FC+VC)

= [(1000 bds.) ($12.00 bd.)] - [$200.00 + (1000 bds.) ($7.96 bd.)]

= $12,000.00 - ($200.00 + $796.00)

= $3840.00

Traditional Lamination Method

The traditional method of producing laminated cutting boards involved using general purpose woodworking equipment arranged in a general purpose woodworking laboratory layout. This method was used to represent the procedures used by the average woodworker to produce a laminated cutting board in a general purpose woodworking laboratory. Machines were not pre-set and had to be adjusted, and hand tools had

to be moved from their storage area to the work area for this production method. Also, no special template and jigs were used. The boards were produced one at a time with general woodworking equipment and procedures.

Process Chart

Table 4 depicts the process chart for the traditional method of cutting board lamination.

TABLE 4

TRADITIONAL CUTTING BOARD
LAMINATION PROCESS CHART

Symbol	Distance* (ft.)	Time** (min.)	Activity
○		4.00	Cut pieces to width on table saw
⇨	12	1.00	Move pieces to radial arm saw
○		1.00	Measure and mark pieces to be cut
○		2.00	Cut pieces to length on radial arm saw
⇨	8	1.00	Move pieces jointer
○		0.25	Adjust cutting depth on jointer
○		3.00	Joint edges on pieces
⇨	3	1.00	Move pieces to work bench
⇨	50	1.00	Move clamps to work bench
○		6.00	Glue, inspect, and clamp pieces
D		50.00	Glue curing time (no labor involved

TABLE 4 - Continued

Symbol	Distance* (ft.)	Time** (min.)	Activity
○		0.50	Remove laminated board from clamps
○		4.50	Scrape and inspect glue joints
⇨	13	1.00	Move board to radial arm saw
○		1.00	Measure and mark board
○		1.00	Trim to length
⇨	13	1.00	Move board to work bench
⇨	40	1.00	Move belt sander to work bench
○		12.00	Belt sand board
○		3.00	Measure and mark curved cuts to be made
⇨	16	1.00	Move board to band saw
○		0.50	Adjust band saw
○		1.25	Cut curves on band saw
⇨	3	1.00	Move board to disc sander
○		0.50	Disc sand board corners
⇨	20	1.00	Move to workbench

TABLE 4 - Continued

Symbol	Distance* (ft.)	Time** (min.)	Activity
⇨	40	1.00	Move router to workbench
○		1.50	Set up router and bit
○		1.50	Router board edges
⇨	40	1.00	Move hand sanders to workbench
○		1.00	Set up sanders
○	20	2.00	Finish Sanding
⇨		1.00	Move to finish area
○		2.00	Apply sealer
□		0.50	Final inspection
⇨	20	1.00	Move to workbench
○		5.00	Package
D		N/A	Store for shipment

*Distances taken from a general shop process layout (Figure 6)
**Timed data was based on lamination of one board at a time.

Process Layout

The process layout for the traditional method was shown in Figure 7. The layout was for a general purpose woodworking shop.

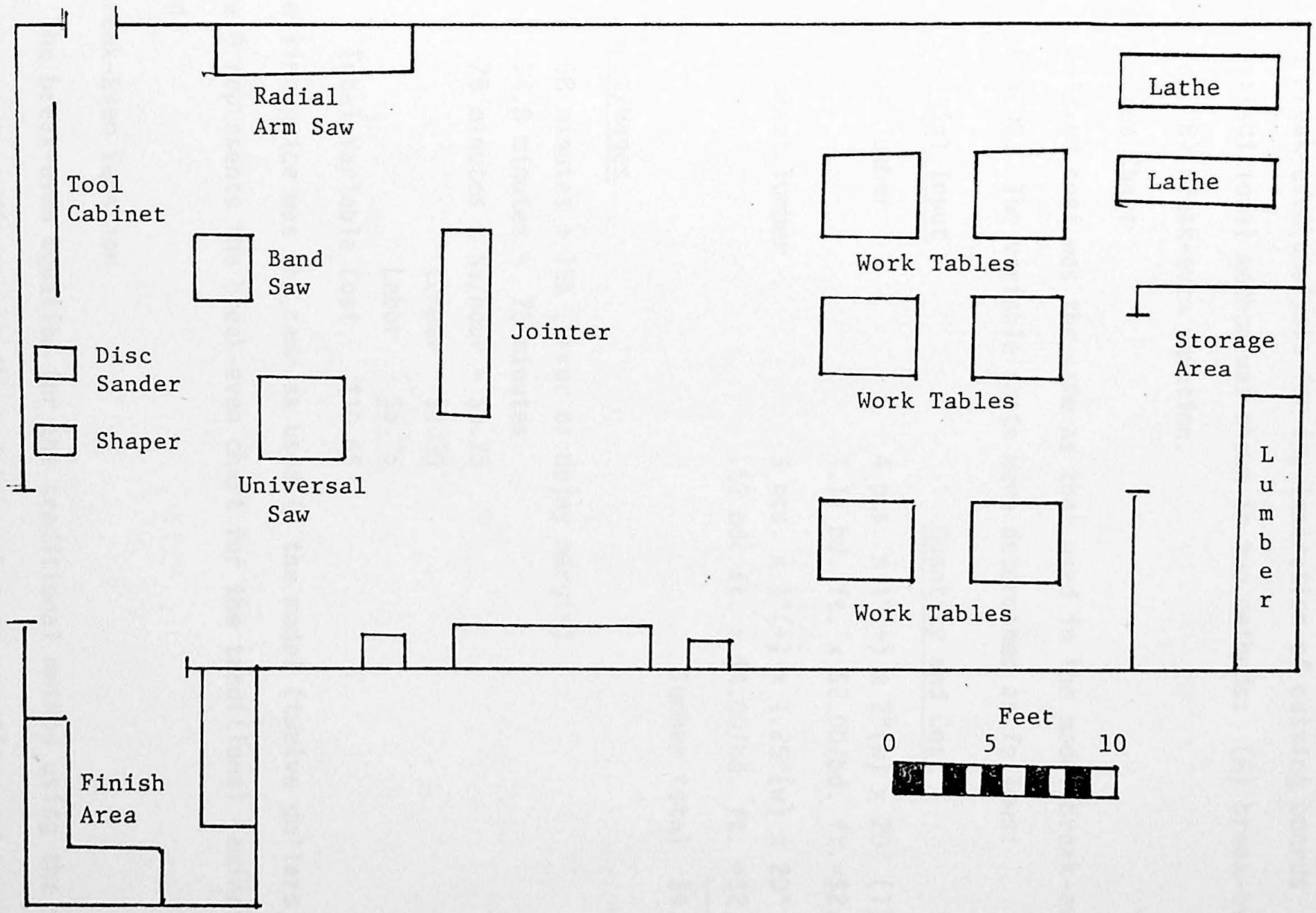

Figure 7: Traditional Method Process Layout

Break-Even Analysis

The break-even analysis for the lamination of cutting boards using the traditional method was shown in two methods: (A) break-even chart, and, (B) break-even equation.

A. Break-Even Chart

The fixed cost was the same as that used in the model break-even chart, $200.00. The variable costs were determined as follows:

Material Input	Quantity and Cost
oak lumber	4 pcs. x 1"(+) x 2"(w) x 20" (l)
	1.11 bd. ft. x $2.00/bd. ft.=$2.22
walnut lumber	3 pcs. x 1"(+) x 1.25"(w) x 20" (l)
	.52 bd. ft. x $4.00/bd. ft. =$2.08
	lumber total $4.30

Labor-Input/Wages

68 minutes + 15% (error or delay margin)
74.8 minutes ≈ 75 minutes
75 minutes x $5/hour = $6.25

Lumber	$4.30
Labor	$6.25
Total Variable Cost	$10.55

The selling price was the same as used in the model (twelve dollars). Figure 8 represents the break-even chart for the traditional lamination method.

B. Break-Even Equation

The break-even equation for the traditional method using the same production output figures as the model break-even equation was expressed as follows:

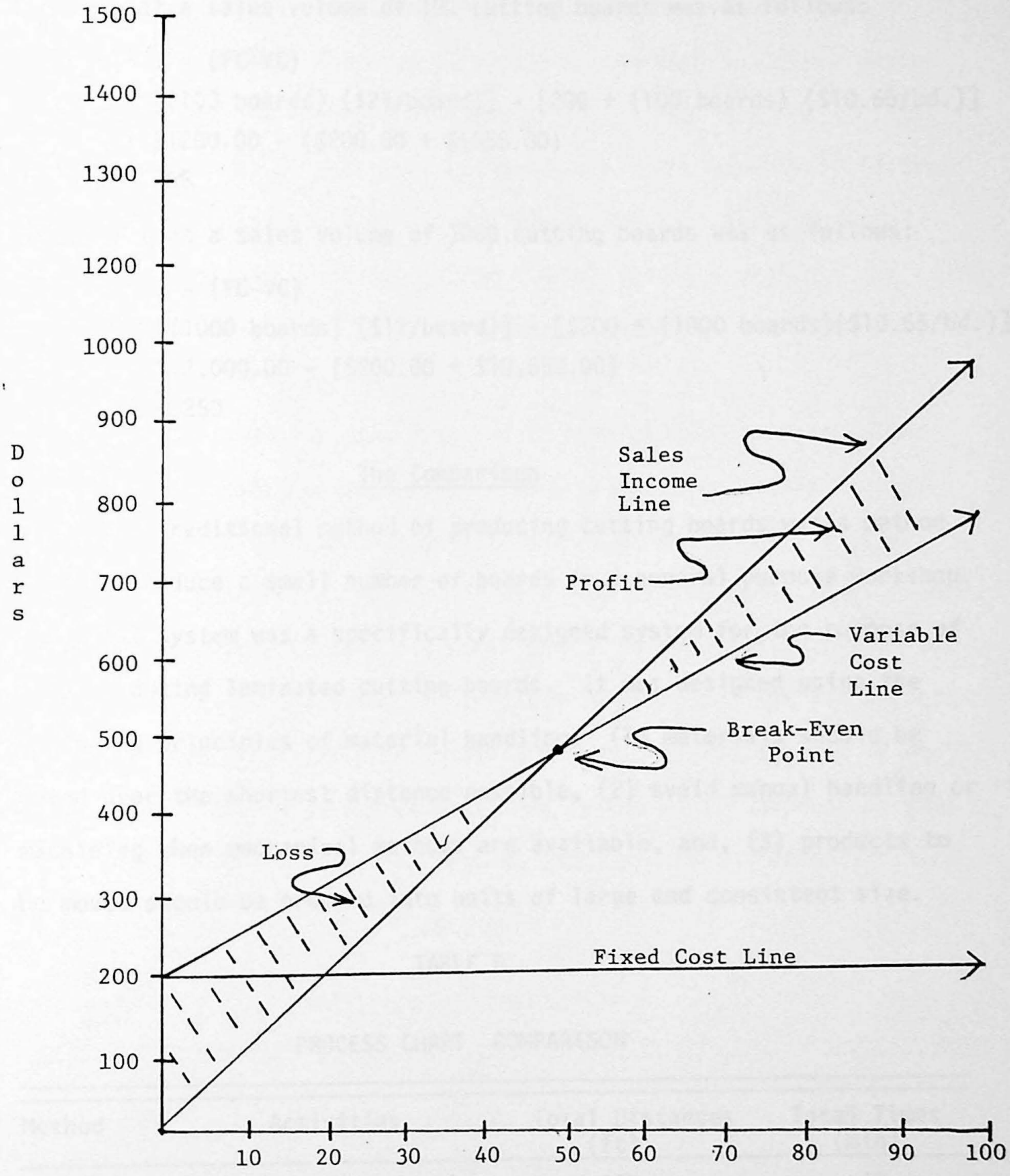

Figure 8: Traditional Method Break-Even Chart

Profit or loss = I - (FC+VC)

The loss at a sales volume of 100 cutting boards was as follows:

P = I - (FC-VC)
= [(100 boards) ($21/board)] - [200 + (100 boards) ($10.55/bd.)]
= $1200.00 - ($200.00 + $1055.00)
= -55

The profit at a sales volume of 1000 cutting boards was as follows:

P = I - (FC-VC)
= [(1000 boards) ($12/board)] - [$200 + (1000 boards)($10.55/bd.)]
= $12,000.00 - ($200.00 + $10,550.00)
= 1,250

The Comparison

The traditional method of producing cutting boards was a method used to produce a small number of boards in a general purpose workshop. The model system was a specifically designed system for the purpose of mass producing laminated cutting boards. It was designed using the following principles of material handling: (1) materials should be moved over the shortest distance possible, (2) avoid manual handling or machining when mechanical methods are available, and, (3) products to be moved should be grouped into units of large and consistent size.

TABLE 5

PROCESS CHART COMPARISON

Method	Activities	Total Distances (ft)	Total Times (min)
Model	33	152	40
Traditional	38	298	68

The traditional method involved five more steps or activities than the model. (Table 5) The extra steps were due to having to go to different parts of the shop to retrieve necessary equipment while in the model system the equipment was placed at the necessary points.

The movement of materials and manpower in the model was 146 feet less than the traditional. This was due to the fact that the model layout was designed specifically for minimal moving distance. The general shop layout used in the traditional method was designed for general purpose construction.

The traditional method required 28 more minutes to produce the cutting board than the model. This was attributed to several causes. First, it was quicker to move several boards at one time as in the model method compared to moving one at a time in the traditional method. Second, in the general shop equipment had to be adjusted or set up for the cutting boards while the model system involved pre-set and adjusted equipment specifically for the cutting boards. Third, the use of equipment, such as the large pneumatic sander in the model compared to the belt sander in the traditional method, greatly reduced production time.

TABLE 6

PROCESS LAYOUT COMPARISON

	Size	Sq. Ft.
Model	67' x 43'	2881
Traditional	60 x 30	1800
	13 x 10	130
		1930

The model system shop required 951 more square feet than the traditional shop. (Table 6) This was due to the larger storage areas, 3 areas in the model to 1 in the traditional, and larger finishing area in the designed model. Although the model shop was larger it took 146 feet more movement in the traditional shop to produce the same product (cutting board) as in the model shop.

TABLE 7

BREAK-EVEN ANALYSIS COMPARISON

	Break-Even Point
Traditional Method	138 boards
Model System	50 boards

The break-even point using the model system was reached after construction and sales of 50 boards. The break-even point using the traditional method occurred at 138 boards or 88 more than that of the model system. At a production and sale of 100 boards using each method, the traditional method showed a loss of $55.00 compared to a profit of $404.00 using the designed model. At a rate of 1000 boards the traditional showed a profit of $1,250 compared to $3,840 using the designed model system. The total variable cost of the traditional board was $10.55 compared to $7.96 for the designed system board.

Finished Product

The quality of the finished products was quite similar using both methods. The surface of the traditional produced board was not as level as the designed system board. This was due to the use of a hand

held belt sander in the traditional method to the use of a pneumatic sanding machine in the designed model system for the surface sanding of the boards.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The purpose of Chapter 5 is: First, the summary explained how the two major assumptions were tested. Second, the data derived from the comparison of the two methods was reviewed. Third, recommendations for further study in this field were presented.

Summary

The study attempted to test the following two major assumptions:

1. Variables and procedures relating to wood lamination could be identified.
2. A systematically developed model and process would result in a more efficient production system.

Variables and procedures relating to wood lamination were identified in two ways; (1) review of the literature, and (2) mailed survey. The review of literature identified several important variables and procedures for specific laminated products. It was the purpose of the survey to gain more detailed information on a variety of products. The survey was sent to sixty-one companies and individuals involved with wood lamination. The returned surveys provided a broader view of lamination methods while attaining specific information on limitations of variables and types of equipment, materials, and procedures.

Modeling

The information obtained through the review of literature and

returned surveys was used in the design of schematic, mathematical, and physical models. Modeling was used to present abstract representations of a lamination process for the selected wood product. The schematic model consisted of a process chart and layout. The process chart was a graphic method of describing the sequence or flow of activities involved with the lamination of the selected wood product. The process layout was concerned with showing the equipment layout and flow of materials on a floor diagram. The mathematical model employed use of a break-even chart, and break-even equation. The break-even chart was used to represent the relationships of volume and dollars in terms of (1) fixed costs, (2) variable costs, and (3) sales income. From this chart the loss, break-even point, and profit of the product produced was determined at different units of volume. The break-even equation made it possible to determine profit or loss levels at different volumes by the use of mathematical equations.

The physical model was the actual implementation of the schematic and mathematical models. The physical model was an actual production of laminated cutting boards. The physical model was performed to compare the effectiveness and efficiency of the designed system to the traditional lamination system.

The traditional lamination system involved using general purpose woodworking equipment arranged in a general purpose woodworking laboratory layout. In the traditional system cutting boards were produced one at a time compared to multiple production in the designed model.

Conclusions

The traditional method of producing cutting boards was a method

used to produce five cutting boards in a general purpose woodworking facility. The model system was a specifically designed system for the purpose of mass producing laminated cutting boards. In the comparison of the two lamination methods, designed system vs. traditional method, the designed model lamination system proved superior in the analysis.

The designed model system required five fewer activities to produce the same board as the traditional method. The movement of materials was 146 feet or 48% less using the designed system. The total production time was 28 minutes or 41% less using the designed system. Economically, the total variable cost of producing the cutting board was $10.55 using the traditional method compared to $7.96 using the designed system. That was a difference of $2.58 or 24% less in favor again of the designed system. The break-even point was reached after marketing 138 cutting boards using the traditional method compared to a break-even point reached after marketing 50 boards using the designed system.

The only advantage the traditional method had was the square footage needed for the production facility. The traditional method facility required 1930 square feet as compared to 2881 square feet for the designed layout. The traditional layout required 951 square feet or 33% less room.

The quality of the designed system cutting board was also better than that of the traditionally constructed board. The board from the designed system had a smoother and more level surface than the traditionally produced board. This is due in part to the larger more easily

operated machines in the designed system as compared to similar hand operated machines in the traditional method.

The use of the time, motion, layout, and cost analysis has proven that a product can be produced without sacrificing quality in larger numbers. A properly designed and developed system can save time, minimize motion, and cut costs. The use of the designed models to formulate processes, layouts, and costs resulted in a more efficient production system.

Recommendations

The scope of this study included the design of a lamination system, completing a production run using the designed system, and comparing the results to a similar traditional method of lamination. This research provides evidence that the designed system approach to producing laminated products is superior to the traditional method. It is therefore recommended that: (1) a designed layout be used in lamination production runs, (2) a designed process should be incorporated in lamination production runs, (3) break-even analysis should be used to compare the economics of two production methods, and (4) models should be used to compare two or more competing systems.

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