

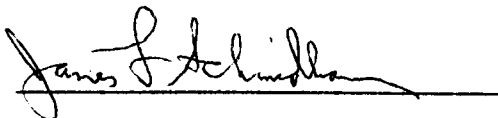
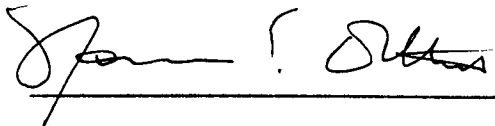
To the Graduate Council:

I am submitting herewith a dissertation written by Thomas Lynn Albright entitled "The Impact of Process Variation on Unit Manufacturing Cost." I have examined the final copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Business Administration.



James M. Reeve, Major Professor

We have read this dissertation  
and recommend its acceptance:



Accepted for the Council:



Vice Provost  
and Dean of The Graduate School

THE IMPACT OF PROCESS VARIATION ON UNIT MANUFACTURING COST

A Dissertation

Presented for the

Doctor of Philosophy

Degree

The University of Tennessee, Knoxville

Thomas Lynn Albright

August 1990

Copyright © by Thomas Lynn Albright 1990  
All Rights Reserved

DEDICATION

To my wife,  
Deborah Early Albright

## ACKNOWLEDGMENTS

I would like to express my appreciation to all faculty members of the Department of Accounting and Business Law at the University of Tennessee, Knoxville (UTK). I am especially indebted to my committee Chairman, Dr. James M. Reeve for his unselfish efforts that made this research project and so many other opportunities become reality. I would also like to gratefully recognize the members of my dissertation committee, Dr. Norman Dittrich, Dr. Harold Roth, and Dr. James Schmidhammer, who generously contributed their time and support. Additionally, I would like to express my gratitude to Dr. Jan Williams, for providing the departmental flexibility that made the research possible.

A very special note of thanks is extended to the corporate officers, employees, and mill financial personnel who must remain anonymous. Their insights and support added immeasurably to the success of the research.

I would like to thank Dr. James Scheiner, Mike Finch, and Julie Cassidy for sharing their computing skills when problems arose. To the doctoral students, Mark Higgins, Kurt Reding, Aline Girard, Rick Walter, Mark Steadman, Cindy Norwood, Gwen Richardson, Paul Cardwell, Beth Walter, Paul Bowen, Ben Foster, Tina Mills, Terry Ward, Mike Finch, Susan Coomer, and Gary Schneider, who have provided their support in countless ways, I would like to express my gratitude. Finally, I would like to thank my parents, Mr. and Mrs. C.L. Albright, and my wife, Deborah Albright, to whom this dissertation is dedicated, for believing that it was possible.

## ABSTRACT

The purpose of this study is to explore the impact of process variability on unit manufacturing cost. Hence, the engineering concept of variability is incorporated with the accounting literature relative to cost management in the new manufacturing environment. More specifically, the study seeks to determine whether selected activities that are thought to be cost drivers are relevant (statistically significant) in explaining variability in product quality within the context of a continuous-process manufacturing environment.

The research setting is a manufacturing plant that produces paperboard in large reels; each reel is measured on critical quality characteristics according to predetermined engineering standards. The unacceptable sections within a reel are separated and classified as subquality production. The sample used in this study consists of 1096 reels from the production period June 4, 1989 through July 19, 1989. The outcome variable is a measure of the acceptable quality pounds within each reel expressed as a percentage of the total pounds per reel.

An Analysis of Variance (ANOVA) model was used to test the differences among various crews, shifts, rest time between shifts, product grades, grade changes, shift changes, and machine downtimes. Additionally, a repeated measures ANOVA was employed to test the stability of the process across the span of an eight-hour shift. Finally, a methodology from the statistical quality control literature, the Shewhart Chart, was used to search for additional potentially relevant cost drivers, or sources of variability.

This study found the differences in quality to be a function of crew and various interactions, length of break between shifts, incidence of downtime during a production run, and a shift change (during shift 1). These variables are all process-level cost drivers whose effects may not be associated with the cost of a specific product. This research shows the necessity of continuous improvement and the extent of the potential cost savings from improved manufacturing processes.

This study calculates production costs by grade, a statistically significant product-level driver, and by grade change, a statistically significant batch-level driver. The financial consequences of grade diversity and grade change instabilities are evaluated in the context of an Activity-Based Cost system. Finally, the product costs suggested by this study are compared with the product costs from the manufacturer's cost system. The results suggest that when the effects of variability are considered in the product cost calculation, the cost of certain grades of product appear understated by the current accounting system. The understatement becomes apparent when the cost of lost contribution margin and the effects of cross-subsidizations resulting from variability in batch sizes are considered.

## TABLE OF CONTENTS

CHAPTER	PAGE
I.	INTRODUCTION TO THE RESEARCH PROBLEM . . . . . 1
	Introduction . . . . . 1
	Description of the Research Problem . . . . . 1
	Overview of the Research . . . . . 3
	Organization . . . . . 5
II.	REVIEW OF RELEVANT PRIOR RESEARCH . . . . . 7
	Introduction . . . . . 7
	Field-Based Research . . . . . 7
	Process Variability . . . . . 8
	Activity-Based Costing . . . . . 11
	Introduction . . . . . 11
	The Motivation for Improved Cost Accounting Systems . . . . . 11
	The Activity-Based Cost System Defined and Developed . . . . . 14
	Summary . . . . . 22
	The Cost of Quality . . . . . 23
	Summary . . . . . 26
III.	RESEARCH METHODOLOGY AND DESIGN . . . . . 27
	Introduction . . . . . 27
	The Manufacturing Process: An Overview . . . . . 27
	Measurement Variables and Hypotheses . . . . . 28
	Dependent Variable . . . . . 29
	ACCEPT . . . . . 29
	Independent Variables . . . . . 30
	CREW . . . . . 30
	SHIFT . . . . . 31
	GRADE . . . . . 31
	BREAK . . . . . 32
	GRADE CHANGE 1 (GRDCHG1) . . . . . 33
	GRADE CHANGE 2 (GRDCHG2) . . . . . 33
	DOWNTIME . . . . . 34
	Models Used in Hypothesis Testing . . . . . 35
	Model 1: The ANOVA Model . . . . . 35
	Model 2: The Repeated Measures ANOVA . . . . . 36
	Assessing the Financial Impact of Variability . . . . . 37
IV.	DATA ANALYSIS AND INTERPRETATION . . . . . 39
	Introduction . . . . . 39

The Data Set . . . . .	40
The Results of the Analysis: Model 1 . . . . .	41
The Results of the Analysis: Model 2 . . . . .	48
ANOVA Model Summary . . . . .	50
Special and Common Causes of Variability . . . . .	50
The Financial Impact of Selected Cost drivers . . . . .	53
Unit-level and Product-level Cost drivers . . . . .	54
Batch-level Cost driver . . . . .	56
Product Costs Based Upon ABC vs Product Costs Based Upon the Standard Cost System: A Comparison . . . . .	59
V.    CONTRIBUTIONS, LIMITATIONS, AND CONCLUSION . . . . .	62
Introduction . . . . .	62
Contributions . . . . .	62
Limitations . . . . .	63
Conclusion and Implications for Future Research . . . . .	64
 BIBLIOGRAPHY . . . . .	66
 APPENDICES . . . . .	71
APPENDIX A Tables . . . . .	72
APPENDIX B Figures . . . . .	87
 VITA . . . . .	110

## LIST OF TABLES

TABLE		PAGE
1.	Dependent and Independent Variables: Model 1 . . . . .	73
2.	Dependent and Independent Variables: Model 2 . . . . .	74
3.	Correlation Matrix of Main Effects . . . . .	75
4.	ANOVA Table . . . . .	76
5.	Significance of Scheffe' Contrasts: Variable = BREAK . . . . .	77
6.	Repeated Measures ANOVA . . . . .	78
7.	Significance of SHIFT x SHFTCHG Interaction . . . . .	79
8.	The Impact of Unit-level and Product-level Cost drivers on Unit Manufacturing Cost . . . . .	80
9.	Average ACCEPT Percent of the GRADE x GRDCHG1 Interaction	82
10.	The Impact of Grade Changes on Unit Manufacturing Cost . . . . .	83
11.	A Comparison of Existing Standard Costs per Ton Versus Costs per Ton as Determined by this Study . . . . .	85

## LIST OF FIGURES

FIGURE		PAGE
1.	The Conceptual Link of Process Variables to Manufacturing Cost drivers . . . . .	.88
2.	The Four Approaches to Product Costing . . . . .	.89
3.	The Conventional Loss Function versus the Taguchi Loss Function .	.90
4.	The Relationship of Quality Cost to Process Variability . . . . .	.91
5.	The Hypothesized Pattern of Variability in ACCEPT Within a Shift	.92
6.	ACCEPT by CREW . . . . .	.93
7.	ACCEPT by SHIFT . . . . .	.94
8.	ACCEPT by GRADE . . . . .	.95
9.	The CREW x SHIFT Interaction . . . . .	.96
10.	The CREW x GRADE Interaction . . . . .	.97
11.	The SHIFT x GRADE Interaction . . . . .	.98
12.	ACCEPT by BREAK . . . . .	.99
13.	ACCEPT by GRDCHG1 . . . . .	100
14.	ACCEPT by GRDCHG2 . . . . .	101
15.	The Effect of Grade Change on Operating Stability . . . . .	102
16.	ACCEPT by DOWNTIME . . . . .	103
17.	Repeated Measures TIME x CREW . . . . .	104
18.	Repeated Measures TIME x SHIFT . . . . .	105
19.	The Individuals Chart, An Excerpt . . . . .	106
20.	The Logic for Including GROSS in the ANOVA Model . . . . .	107
21.	ACCEPT by GROSS . . . . .	108
22.	The SHIFT x SHFTCHG Interaction . . . . .	109

# CHAPTER I

## INTRODUCTION TO THE RESEARCH PROBLEM

### I. INTRODUCTION

The purpose of this chapter is to consider the relationship of process variability to unit manufacturing cost. The two objectives of the study are formulated within the context of the new demands placed upon the accounting system of the world-class manufacturer. Additionally, the chapter develops the research problem and describes the research setting. Finally, the chapter provides information regarding the organization of the dissertation.

### II. DESCRIPTION OF THE RESEARCH PROBLEM

All activities performed within a manufacturing organization generate costs. An understanding of key manufacturing activities, termed cost drivers, and the resulting variation in product quality is important to the management accountant in many areas, including a) preparing product-cost analyses, b) assessing quality costs, and c) formulating relevant nonfinancial performance measures. Johnson [1988] has shown that an Activity-Based Cost (ABC) system may provide a structure encompassing nonfinancial performance measures, activity-based chargeout information, and activity-based product cost information. This research identifies some manufacturing cost drivers (both selected and discovered) in the context of an

ABC system and tests how they relate to variation in product quality. The objectives of the study are as follows:

- 1) To explore the impact of process variability on unit manufacturing cost;  
and
- 2) To determine which selected and discovered cost drivers are relevant (statistically significant) in explaining variability in product quality within the context of a continuous-process<sup>1</sup> manufacturing environment.

The ability of the traditional cost accounting system to provide accurate product cost data that is free of bias has been criticized by both academics and practitioners [Kaplan, 1988a; Howell and Soucy, 1988]. Researchers have also suggested that the traditional cost system does not provide performance measures consistent with the firm's strategic objectives. The competitive environment of world-class manufacturers has placed increased demands on management accountants and accounting systems to provide reports and analyses which may be considered nontraditional. Examples of the new demands include: a) accounting for the cost of quality [Roth and Morse, 1983; Morse et al., 1987] and b) measuring factory performance by utilizing nonfinancial performance measures [Albright, 1989; McNair and Mosconi, 1987].

---

<sup>1</sup> A paperboard manufacturing operation was the setting of the study. A continuous process is characterized by a relatively homogeneous supply of raw material that proceeds through the manufacturing process at a continuous speed. In contrast, the discrete-part manufacturing process is characterized by the assembly of many dissimilar parts into nonhomogeneous products. The two types of processes may produce different cost drivers.

Figure 1<sup>2</sup> illustrates three activities that are conceptually linked by process variables or cost drivers, the building blocks of an ABC system. These activities are: 1) preparing product cost analyses, 2) assessing the cost of quality, and 3) formulating nonfinancial performance measures. Cost drivers operate within an environment of variability that is hypothesized in this study to have a direct impact on the quality and cost of the finished product. Examples of cost drivers, which are further developed in Chapter III, include product diversity (grade diversity) and machine downtime. Field-based research methodology was employed to identify and statistically test manufacturing activities that may cause variability in unit quality and impact production costs. Some potentially relevant cost drivers were identified from research found in the literature, while others were discovered as a result of employing statistical process control methodology.

### III. OVERVIEW OF THE RESEARCH

The objectives, stated in Section II. were accomplished by observing and statistically analyzing the operations of a paperboard manufacturing process. Before undertaking the study, the literature on ABC systems was researched to provide a framework for selecting potentially relevant cost drivers. The statistical quality control literature provided the theoretical support for evaluating the cost of variability as well as statistical techniques for detecting variation in the manufacturing process.

---

<sup>2</sup> All tables may be found in Appendix A and all figures may be found in Appendix B.

The environment which was selected for study is somewhat unique to the ABC literature because it is a continuous, rather than a discrete-part manufacturing process. The production of paperboard begins by converting logs into wood chips that are approximately one inch square. The wood chips proceed to a digesting system where they are treated with chemicals, heat, and pressure to remove the natural glue-like substance that binds the wood fibers together. The fibers then advance through various processes, including a bleaching cycle before ultimately arriving in the form of pulp to be used by the paperboard machine.

This study focuses on the manufacturing events that occur after the wood fiber (pulp mixture) arrives at the paperboard machine. The manufacturing process is operated three shifts per day, seven days per week by four crews consisting of five individuals per crew. The crew members are permanently assigned to a crew; however, crews work all shifts as specified by a rotation schedule. Associated with the changing shift schedule is variability in rest time between shifts, i.e., workers are subjected to changes in shifts as well as changes in rest periods between shifts.

Paperboard is produced according to different engineering specifications for thickness, weight, and surface coating; the sample in this study includes 23 different grades of product. In addition to complexity resulting from grade diversity, the various grades have different demand profiles that create batch size diversity. The paperboard machine must be adjusted between production runs of different grades; grade changes occur "on the fly" without halting production. The analogy in a discrete part manufacturing environment is a machine setup. As a result of instabilities induced by a grade change, a certain amount of scrap is produced until a steady state is regained.

Machine maintenance is performed on a routine basis, usually during shift one (7:00 a.m. to 3:00 p.m.). However, unscheduled maintenance, which also results in machine downtime, may occur during any shift as repairs become necessary. For example, a shut-down may become necessary to correct mechanical problems that manifest themselves in poor quality production. Additionally, downtime is usually associated with the production of off-quality material because the machine requires time to stabilize following a shut-down for repairs.

The end product, which is a large spool of paperboard, is termed a reel. Sections within a reel often vary in quality; therefore, each reel is analyzed and the unacceptable sections are removed before further processing. Therefore, a key measure of manufacturing performance is the acceptable quality pounds within the reel expressed as a percentage of the total pounds within the reel.

Variability in the proportion of acceptable quality production relative to total production is explored by analyzing independent variables selected from the four levels of cost drivers identified by Cooper [1989]. These levels of cost drivers which are developed in greater detail in subsequent chapters are as follows: a) unit-level, b) product-level, c) batch-level, and d) process-level.

#### IV. ORGANIZATION

This dissertation is organized into five chapters. Chapter I introduces the research problem and the concept of key manufacturing activities, or cost drivers. Chapter II provides a review of relevant prior research appearing in both the accounting and the statistical quality control literatures. Chapter III presents the

research methodology used in conducting the study. Chapter IV describes the results of the statistical analyses. Chapter V presents the conclusions of the study and the implications for future research.

## CHAPTER II

### REVIEW OF RELEVANT PRIOR RESEARCH

#### I. INTRODUCTION

The purpose of Chapter II is to summarize the previous research from the accounting and statistical quality control literatures that is relevant to this study. First, the chapter provides support for the use of field-based research methodology within the context of managerial accounting. Next, the chapter presents a discussion of process variability and its relevance to the cost accountant, followed by a review of the literature of Activity-Based Costing. The chapter closes with a review of the relevant quality cost literature.

#### II. FIELD-BASED RESEARCH

Kaplan [1983] emphasizes the need for field-based research in the area of management accounting in order to understand the revolution in manufacturing technology that is occurring in many U.S. corporations. "Research will therefore require a greater emphasis on field studies of relatively few observation sites" [Kaplan, 1983, p. 703]. An important role of the modern cost accounting system is to assist management in reducing the "randomness caused by uncertain supply, poor quality, and erratic machine performance" [Kaplan, 1983, p. 688]. These issues are

central to the proposed research, i.e., to gain an understanding of the key elements within the manufacturing processes which drive product costs and create variability.

The purpose for selecting the field study method of research centers around the joint objectives of understanding a highly technical process and financially quantifying the impact of variation within the process. The objectives of the research are consistent with the framework of applications described by Bonoma [1985].

"When researchers' interests or phenomenon requirements dictate theory building rather than verification or extension, the tasks of description, classification, and comparison become relevant" [Bonoma, 1985, p. 201]. Additionally, Mintzberg [1979] describes the two essential steps in inductive research as detective work and the creative leap. The value of exploratory work "stems from detective work well done, followed by creative leaps in relevant directions" [Mintzberg, 1979, p. 584]. Thus, Kaplan [1983] suggests that exploratory, descriptive, and analytical research can meaningfully contribute to the existing body of literature, given the current stage of research development in the field of cost management.

### III. PROCESS VARIABILITY

Reeve [1989] cites two types of variation that are relevant to the accountant for the purpose of cost control: a) product variation and b) process variation. Product variation relates to the differences that occur across product lines as a result of complexity cost drivers, while process variation relates to manufacturing systems. Each form of variability is unique; however, both have the ability to affect manufacturing costs.

Process variation may be observed within both the strategic and operating systems of an enterprise [Reeve, 1989]. Strategic systems variation is the result of decisions or policies made at the macro level within the organization. For example, the decision to produce paperboard in various thicknesses, or grades, ranging from thin to thick, may induce variation into the manufacturing process. The decision to produce a diverse product mix implies that changeovers will be required of the machinery between runs of different grades of product. Both direct and indirect costs are hypothesized to occur because of operating instability induced by the grade changeover. For example, when a grade change occurs, crews must adjust the machinery to produce different grade specifications. Since the manufacturing system is a continuous process, a certain amount of off-grade product is produced until the machinery can stabilize following the adjustment. Variability in product quality and cost is the result of induced macro, or strategic, systems variation.

Operating systems variation occurs at the micro level of the organization and relates to the daily production tasks of the facility. For example, Goldratt and Cox [1986] illustrate how the effects of variability in processing times among workcenters will negatively impact the throughput of a manufacturing plant. If upstream workcenters are unreliable as a result of random downtime, the productive capability of downstream workcenters may be hampered as well. To mitigate the effects of process variability, management often constructs inventory buffers that enable downstream workcenters to continue producing in the event of an upstream production disruption. Variation in operating reliability increases costs by requiring larger amounts of inventory than would be otherwise sustained. Potential costs include carrying costs, obsolescence, and the risks of damage or theft. "Other

examples of operating system variation that translate into reduced system effectiveness are variations in batch sizes, repair times, time between repairs, raw material and finished goods shipments, schedule, and speed" [Reeve, 1989, p. 88].

An interaction may exist among strategic and operating variables. For example, if managers are evaluated exclusively by the Return on Investment (ROI) formula, an incentive exists to postpone routine maintenance in an effort to improve the ROI measure in the short run. As a result, strategic variables (performance evaluations based upon ROI) may impact operating reliability (increases in downtime resulting from unscheduled maintenance).

Researchers have suggested that the accounting profession use statistical process control (SPC) techniques to understand process variability [Reeve and Philpot, 1988; McNair et al., 1988]. Traditional control systems, such as variance analysis based upon standard costing, do not provide a time-ordered record of system performance but rely upon an aggregation of performance levels for a specific time period. In addition, traditional control systems stress the level of output while ignoring the issue of system variation. For example, a process that generates defectives of five percent and fifteen percent on two consecutive days would produce at an average rate (level) of ten percent defective. A process that generates defectives of ten percent on two consecutive days may be an entirely different process than the one previously described; however, traditional variance analysis is not sensitive to the differences. SPC methodology overcomes many objections of the traditional control system and provides insight into the sources of process variability. In fact, Howell and Soucy [1987] suggest that variance analysis may no longer be relevant because of advances in manufacturing technology and the use of SPC. They believe that

improved processes and better operational control will eliminate significant variances from standard.

#### IV. ACTIVITY-BASED COSTING

##### Introduction.

The body of literature that encompasses ABC systems is typically descriptive in nature. The researcher generally introduces the deficiencies of an existing traditional cost system and proposes solutions based upon an understanding of the activities within a manufacturing process. The benefits often include: 1) manufacturing performance measures that are more consistent with the strategic mission of the firm and 2) better estimates of product cost.

The research in the area of ABC does not always follow a progression with subsequent studies building upon the results of prior ones. Instead, as is appropriate in an exploratory phase, researchers converge on fundamental issues concerning ABC system design. This chapter dichotomizes the research of ABC systems into two logical, although not mutually exclusive streams. This section begins with a review of the research that provides motivation for improving the existing cost accounting model and closes with a summary of the research that defines and develops the ABC model.

##### The Motivation for Improved Cost Accounting Systems.

Many researchers have suggested that crucial variables which ultimately affect firm performance and profitability are not adequately captured in the traditional

accounting system [Miller and Vollmann, 1985; Howell and Soucy, 1988 and 1987; Grady, 1988; Schubert, 1988; McNair and Mosconi, 1987; Kaplan, 1988a, 1988b, and 1984; Shank and Govindarajan, 1988 and 1989; Hiromoto, 1988; Staubus, 1988]. These crucial variables relate to physical manufacturing activities that are often misunderstood by those who have designed the cost reporting system.

Miller and Vollmann [1985] and Shank and Govindarajan [1989] address the importance of understanding the nature of manufacturing overhead. They maintain that accounting models based upon engineered standards allocate overhead costs but do little to explain them; therefore, system designers should seek to understand the engineering phenomena that drive costs. Hence, activities or cost drivers should form the basis of an accounting system to more accurately allocate the costs of overhead to products.

Howell and Soucy [1987, 1988] speculate that operating measures based upon direct labor utilization rates may encourage managers to perform in a dysfunctional manner. The objective of a manufacturing unit is not to absorb overhead but to minimize it. They propose a number of operating measures that are related to the total cost of overhead as follows: a) product quality or defect rate, b) inventory levels, c) material scrap, d) equipment maintenance and unscheduled downtime, and e) throughput volume.

McNair and Mosconi [1987] have accused accountants of myopia in the past because they focus only on cost while ignoring critical nonfinancial performance measures such as those outlined by Howell and Soucy [1987,1988]. Ultimately, operating factors reflected in nonfinancial measures are hypothesized to affect unit production cost. According to McNair and Mosconi, the measurement system should

a) identify key elements in the manufacturing strategy, b) expose nonvalue-added costs (overhead), c) provide accurate information on cost drivers within the process, and d) provide reliable and accurate product cost information.

Cooper [1988a] states that traditional systems often allocate costs based upon volume-related cost drivers such as direct labor. Volume-based drivers ignore economies of scale and can create nonproportionalities in product cost as a result of cross-subsidization. Cooper [1988a] maintains that not all activities consume resources as a function of production volume. Cost systems that do not recognize the existence of volume-unrelated cost drivers may induce bias into product costs.

Other potential sources of bias in product costs include a) production volume diversity, b) complexity diversity, c) material diversity, d) size diversity, and e) batch diversity [Cooper, 1988a]. Cooper identifies several types of errors that may occur as a result of using inadequate product cost information as follows: a) poor product mix decisions, b) poor product-design decisions, c) poor capital investment decisions, and d) inaccurate budgeting decisions relative to the level of operating expenses. He suggests that an ABC system may provide increased reporting accuracy such that management may prevent or significantly reduce many common errors in judgement.

Kaplan [1988a, 1988b, and 1984] suggests that many problems resulting from the use of traditional cost accounting systems stem from requiring three different functions of the system as follows: a) inventory valuation, b) operational control, and c) product cost measurement. The ABC system is designed to eliminate product cost distortions and dysfunctional behavior which can result from information provided by a traditional cost system. Kaplan states that an ABC system is a tool of corporate strategy in addition to a formal accounting system.

Cooper [1987a] summarizes the flaws that may be associated with the traditional cost system as follows: a) overhead allocations are based upon direct labor hours, b) overhead allocations are based exclusively upon volume-related allocation bases, c) cost pools are too large and have machines with different cost structures, and d) marketing and distribution costs are ignored. Cooper describes the following symptoms that may be present if the existing cost system is inadequate: a) products that are difficult to produce are reported to have high margins; i.e., margins are not easily explained, b) high margins are reported on products that are not sold by competitors, c) the results of bids are not easily explained, d) competitors high-volume products are priced at seemingly low levels, e) vendors bids are lower than expected (impacts make versus buy decisions), and f) customers do not react to price increases.

Shank and Govindarajan [1988], in their field study of a manufacturing facility within Champion Paper Company, identify system flaws that ignore cross-subsidies when both high and low volume products are manufactured. Their findings conclude that handling and processing costs of low volume products are averaged across an entire product line, thereby overstating the cost of high volume products and understating the cost of low volume products. Additionally they show how the traditional cost system ignores the cost of carrying inventory, which is also a result of producing a product mix with varying demand profiles.

#### The Activity-Based Cost System Defined and Developed.

A definition of ABC accounting, as proposed by Computer Aided

Manufacturing-International, Inc. (CAM-I), is as follows:

[Activity-based accounting is] a collection of financial and operational performance information dealing with significant activities of the business. Activities represent repetitive tasks performed by each specialized group within a company as it executes its business objectives [Romano, 1989a, p. 65].

To develop an ABC system, the underlying processes which consume resources must be understood, because processes consume resources and products require processes [Turney, 1989]. Cooper [1988a, p. 45] further explains the fundamental elements of an ABC system as follows:

Activities are the focus of the costing process in activity-based cost systems. Costs are traced from activities to products based on the product's demand for these activities during the production process. The allocation bases used in activity-based costing are thus measures of the activities performed.

Romano [1989a] explains the concept of using the accounting system to report activities that may be associated with key manufacturing tasks, and hence, costs. The following definitions proposed by Romano [1989a, p. 65], although apparently simplistic, are fundamental to the development of an ABC system:

1. Activities are cost drivers. They are the cause of costs.
2. Resources are consumed by activities. The consumption is usually recorded in dollars.

Johnson [1988] proposes an accounting and information system that uses activities as the common denominator. He views activity accounting as a unit that encompasses three distinct but interrelated functions as follows: a) nonfinancial performance measures, b) activity-based charges for internal service centers, and c)

activity-based information relative to product cost. Hence, Johnson reveals the diversity and potential usefulness of an Activity-Based system.

Researchers have identified the benefits of ABC systems [Turney, 1989; Cooper, 1988a; Cooper, 1988b; Cooper, 1989a; Cooper, 1989b; Turney and Anderson, 1989; Cooper and Kaplan, 1988; Romano, 1989b; Cooper, 1990; Eiler and Campi, 1990; and Beaujon and Singhal, 1990]. The ABC system is essentially an evolution of the traditional two-stage cost system, where costs are traced to a cost center (stage 1) and ultimately to the final product (stage 2). However in an ABC system, multiple allocation bases, known as cost drivers, are employed to achieve increased accuracy and overcome many limitations of traditional cost systems which were discussed in the previous section.

Cooper [1988b] considers the tradeoffs that would make an ABC system economically justifiable. He suggests that the optimum accuracy of a reporting system should occur where the combined costs of measurement and errors are minimized. The cost of measuring relevant data has decreased significantly as a result of improved computing technologies.

Cooper [1989a] discusses the selection criteria, as well as the number of cost drivers required for accurate reporting. He suggests three factors to consider when selecting a cost driver: a) the ease of obtaining the data (cost of measurement), b) the degree of correlation between the implied consumption of an activity and the actual consumption, and c) the behavior that is induced by the cost driver.

In the fourth article of a four-part series, Cooper [1989b] describes what an ABC system may look like in an actual manufacturing setting. He explains how the two-stage allocation method is used to apply overhead first to activities and then to

products. Cooper illustrates how the ABC system may require more cost drivers as the system becomes more complex. The issue of balancing the complexity, accuracy, and cost of an ABC system is shown in Figure 2 as developed by Cooper [1987b, p. 50]. He identifies four approaches to selecting the number of cost drivers and cost pools as follows:

Approach 1 (Number of Cost Pools: One; Number of Cost Drivers: One) - The quantity of a manufacturing resource consumed is proportional the number of direct labor hours consumed in producing a product.

Approach 2 (Number of Cost Pools: One; Number of Cost Drivers: Many) - The cost per unit of any resource does not vary directly, depending upon where in the production process the resource is consumed. For example, this approach ignores the operating cost diversity among multiple cost pools such as sequentially placed machinery.

Approach 3 (Number of Cost Pools: Many; Number of Cost Drivers: Many) - This approach is prohibitively expensive because of the large numbers of cost pools and cost drivers employed, although increased accuracy in product costing may result.

Approach 4 (Number of Cost Pools: Many; Number of Cost Drivers: One) - This approach assumes that the ratio of the quantity of a resource consumed to the number of cost drivers does not depend upon the product that is produced.

Cooper maintains that Approach 4 frequently reports accurate product costs. If the number of cost drivers may be economically expanded to a small set, Approach 4 may be used in a variety of manufacturing settings. In this manner, Approach 4

becomes a collection of cost systems, with multiple cost drivers that trace costs to multiple pools for allocation to the final product.

In addition to improving product-costing, Turney [1989] maintains that the ABC system may be used to achieve manufacturing excellence in a number of ways. For example, the ABC system may create behavioral incentives for continuous process improvement by emphasizing waste elimination, reduced lead time, improved product quality, and reduced manufacturing cost. Behavioral incentives are possible because the designer of the ABC system can select cost drivers that measure performance based on variables that are consistent with the strategic goals of the firm.

A number of researchers have illustrated the strengths of ABC in an advanced manufacturing environment [Brimson, 1989; Campi, 1989; and Keegan, et al., 1988]. In general, this stream of research highlights the ability of the ABC system to accurately represent the dynamic nature of the modern production process and incorporate concepts such as target costing and product life cycle considerations.

The concept of target costing focuses attention on the early phases of product development, i.e., the product design phase [Campi, 1989]. The target cost is set by estimating the selling price of a product based upon market conditions and subtracting an acceptable profit margin. The ABC system may help identify potential areas for cost reduction that will enable a company to attain the target cost.

Life cycle considerations, according to Campi [1989] recognize the various stages of development in the life of a product as follows: startup, growth, maturity, and decline. He maintains that the life cycle concept has been ignored by accountants in the past. However, the umbrella of activities found in an ABC environment [Johnson, 1988] may enable the firm to incorporate the life cycle approach to costing.

A fundamental concept found in most ABC research involves understanding activities before assigning costs to products. Manufacturing activities may be classified according to a number of criteria depending upon the needs of the firm. Cooper [1989] suggests that activities can be classified into four levels as follows: 1) unit-level, 2) batch-level, 3) product-level, and 4) process-level.

Unit-level costs occur every time a unit is produced and include traditional variable costs such as direct labor, direct materials, and variable overhead. The effects of unit-level cost drivers may be more immediately obvious than those of other levels. Examples of unit level cost drivers include material dollars, number of units, and number of insertions [Cooper, 1989].

Batch-level costs occur every time a batch of product is initiated. For example, grade changes in a continuous manufacturing process induce variability and result in the production of off-grade material immediately following the change. These costs must be allocated to the batch that is associated with the grade change if proper cost estimates are to be obtained. If all grade change costs were pooled and allocated based upon direct labor hours, high volume products manufactured in long production runs would appear to have the same grade change costs as low volume products manufactured in short production runs. By manufacturing products with different run lengths, the firm creates batch diversity. An understanding of the financial impact of this diversity will help improve the accuracy of product costing in an ABC environment.

Product-level costs relate to attributes of each type of product [Cooper, 1989]. For example, some grades of paperboard require the application of an opaque coating which adds complexity to the process. Cooper maintains that the number of

components (materials) required to produce a grade will drive production costs. Another interesting product-level driver is the relationship of a product's technical characteristics to machine capability. For example, a product may have engineering specifications that are near the limit of the machine's production capability. Costs may vary across product lines as a result of unfavorable machine by product interactions. Each time a unit is produced, costs may be incurred as a function of this relationship; hence, a machine by product interaction may serve as a relevant cost driver in a paperboard process.

Process-level activities are required by all products and are necessary to maintain the general manufacturing process [Cooper, 1989]; examples include differences among crews and shifts. Additionally, rest time between shifts may serve as a potentially relevant process-level cost driver. While no direct association among these cost drivers and individual product costs is evident, they are hypothesized in this study to affect the overall quality of production. Examples of research involving process-level cost drivers include Jaikumar [1989], Deming [1982], McGurrin [1987], Buren and Stenzel [1984], and the Canadian Centre of Occupational Health and Safety [1988].

Jaikumar [1989] illustrates the relationship of an accounting system to issues involving process control in a manufacturing environment. He argues that the effectiveness of a process control system is evaluated based upon the extent to which variances are minimized. To control variation, one must gain an understanding of the sources and kinds of variability that can occur within a process. Furthermore, Jaikumar maintains that the system must distinguish between systematic and random events that disrupt the process and cause variability.

He argues that assigning a variance to a product when an event occurs is insufficient. Instead, the cost system must identify the cause of the event and assign the variance to the cause, not the product. Jaikumar explains that the production system should not be viewed as a black box consisting merely of inputs and outputs. Instead, the relationships and economic consequences of the events must be considered. Many auxiliary activities such as burr removal, machine qualifying, material handling, tool management, and fault diagnosis that have been traditionally performed manually are integrated into the automated factory. "In the small lot size automated facility, auxiliary activities must be treated as variable costs because they occur with almost the same frequency as transformational activities" [Jaikumar, 1989, p. 21].

Jaikumar summarizes the characteristics of a process costing system as event-based, statistical in nature, attention-focusing, and allows the building and refinement of production models. Additionally, these characteristics may allow the user to distinguish between systematic and random events and also detect new events that impact the production process. Hence, activities that affect the quality of output must be understood and captured by the control system.

In the Monte Carlo funnel experiments, Deming [1982] illustrates how outcomes that are based upon a previous event tend to follow a random walk pattern. For example, if a crew member (machine operator) trains his or her successor, personal biases regarding machine control are passed along to subsequent generations of operators. If each crew operates independently, a random walk pattern of quality is expected. Centralized training courses could, according to Deming, reduce the variability in output resulting from differences in crews.

McGurrin [1987] reports that error rates in manufacturing are materially larger during shift 3 than other production periods. Specifically, the error rate between the hours of 4:00 a.m. and 6:00 a.m. was found to be ten times greater than that of other periods. Therefore, variability in quality may result from differences in the process-level variable relative to the time of day, or shift.

Another process-level cost driver that may affect the general level of productivity is the amount of rest time between shifts. Buren and Stenzel [1984] and the Canadian Centre of Occupational Health and Safety [1988] have studied both the effects of shift changeovers and rest time between shifts. The results of their studies suggest that fatigue is a major factor in the productivity decline experienced by shift workers.

### Summary.

Researchers have suggested that an ABC system may overcome many limitations of the traditional cost system. However, most applications of ABC, as developed in the literature, focus on discrete-part manufacturing environments<sup>3</sup>. Additionally, as illustrated in this chapter, the research on ABC systems and cost drivers is descriptive. To further develop the body of knowledge relative to ABC, this research empirically examines cost drivers suggested in the literature and seeks to identify new drivers that may be unique to the continuous-process manufacturer.

---

<sup>3</sup> Examples are Harvard Cases (Case numbers appear in brackets) including John Deere Component Works (A)-(B), (9-187-107\108), Schrader Bellows (A)-(H), (9-186-273), and Tektronix (A)-(C), (9-188-142\143\144). An exception is Shank and Govindarajin [1988] who study the complexity and cross-subsidies within a production facility of Champion Paper Company. This research considers additional levels of cost drivers and their associated costs as well as an empirical evaluation.

## V. THE COST OF QUALITY

McNair et al. [1988] suggest the defect rate in manufacturing to be an important performance measurement. Much has been written about measuring the costs associated with product quality [Morse et al., 1987; Roth and Morse, 1983; Lenane, 1986; Daetz, 1987; Sullivan, 1986; Schneiderman, 1986]. The dependent variable in this study is a measure of the acceptable quality produced as a percentage of total production. The distinction between a unit of acceptable versus unacceptable quality is a dichotomous function (Acceptable or Not Acceptable). Alternatively, the concepts incorporated in the Taguchi Loss Function (TLF) discussed in this section are based upon a continuous measure of variability from a target specification. The TLF provides the underlying theory supporting a financial analysis to understand the costs of the engineering concept of process variability.

The industrial statistics literature emphasizes the importance of meeting engineering specifications. In fact, statistical process control techniques were developed to assess the ability of a process to meet them, i.e., capability analysis [Burr, 1976]. A product produced within the upper and lower specification limits was assumed to incur no financial loss. As an alternative, the TLF [Sullivan, 1987, p. 21; Gunter, 1987; Roslund, 1989; Kackar, 1986] expresses financial loss in increasing amounts as a product's actual measurement or characteristic deviate from a given target specification. The TLF is an attempt to define the impact of variability in terms of financial costs and is contrasted with the Conventional Loss Function (CLF) in Figure 3.

The CLF described in Panel A of Figure 3 is a dichotomous function. For example, if the paperboard caliper measurement is within the specification limits, no loss is thought to occur; however, if the measurement is outside the specification limits, the product is useless and total loss occurs<sup>4</sup>. The CLF does not consider variability around the target specification that is within the upper and lower specification limits to incur costs. In direct contrast, the TLF considers all variability to incur costs.

Assume a manufacturing process must produce a paperboard grade that has a target thickness (caliper) of .016 inches, as illustrated in Figure 3, Panel B. The design engineers have determined that the product will not perform its function if the caliper is less than .0155 inches or greater than .0165 inches. Therefore, the upper and lower specification limits are .0165 inches and .0155 inches, respectively.

The TLF as shown in Panel B of Figure 3 illustrates the concept of increasing loss as actual caliper measurements deviate from target specifications. Taguchi considers not only raw material, labor, and overhead costs in the loss function, but also societal losses resulting from inferior quality products which do not function as intended. The cost consequences of producing paperboard within the upper specification limit but in excess of the target value are important. Thick paperboard contains more pulp, runs at slower machine speeds, requires more energy to dry, and is more expensive to transport than thin paper board. In addition, the equipment used in downstream processing operations may be subjected to extra maintenance costs and downtime to mitigate the effects of highly variable paperboard input.

---

<sup>4</sup> In reality, the off-grade material may be recycled or sold as scrap; however, the loss is substantial relative to products that meet specifications.

Alternative models for the relationship of product cost and quality have been explored in both the engineering and accounting literature [Morse et al., 1987; Roth and Morse, 1983; Lenane, 1986; Daetz, 1987; Sullivan, 1986; Schneiderman, 1986]. Most analyses incorporate the Optimum Quality Cost model as proposed by Juran [1979] which is reproduced in Figure 4, Panel A. Juran hypothesizes that total quality costs are a quadratic function which can be minimized where the marginal costs of appraisal<sup>5</sup> and prevention<sup>6</sup> equal the marginal costs of internal and external failure<sup>7</sup>.

Juran's model illustrates the concept that processes which strive for zero defects incur appraisal and prevention costs that increase without bound as the quality level approaches 100 percent. The model suggests that the attainment of zero defects may be prohibitively expensive. The TLF supports the logic of Juran's model by emphasizing variation around a target specification rather than the defective rate.

Figure 4, Panel B illustrates two distributions. Process 1 is a rectangular distribution which produces zero defectives as a result of 100 percent inspection; therefore prevention and appraisal costs are high. In addition, the variability around the target specification is great. Process 2 is a normal distribution that is centered

---

<sup>5</sup> Appraisal costs generally comprise a firm's quality control activities and include tasks such as inspecting finished goods and checking incoming raw materials against established quality or grade standards.

<sup>6</sup> Prevention costs encompass expenses relating to design engineering and manufacturing engineering. In addition, activities which screen prospective suppliers to determine if materials meet or exceed quality standards are appropriately included as prevention costs.

<sup>7</sup> Failure costs may be classified as either internal or external, depending upon whether the defect was discovered prior or subsequent to final delivery to a customer. Failure costs are somewhat narrower in scope than losses as defined by Taguchi [Kackar, 1986].

around the target specification. Process 2 manufactures a small number of defectives as illustrated by the tails of the distribution which exceed the upper and lower specification limits. According to Juran's model, Process 1 has excessively high quality costs. Additionally, the TLF suggests that Process 1 is inferior to Process 2 even though Process 2 ships a small number of defectives to the customer.

Variability is the key issue. The TLF illustrates how costs increase in a quadratic manner as actual product specifications deviate from the target specification. Both Juran and Taguchi provide the theoretical foundation for assessing the cost impact of variability in a manufacturing process.

## VI. SUMMARY

This chapter reviews the relevant research from the accounting literature in terms of field-based research strategies, ABC systems, and the cost of quality. Additionally, this chapter explores the engineering concept of process variability and its association with the cost of quality. The concepts that were outlined in Chapter II are further utilized in Chapter III in developing the research methodology and design.

## CHAPTER III

### RESEARCH METHODOLOGY AND DESIGN

#### I. INTRODUCTION

The purpose of this chapter is to describe the manufacturing environment, define and theoretically support the research variables of interest, and propose the research hypotheses. Two ANOVA models are developed to test the relationship between various independent variables (unit-level, product-level, batch-level, and process-level cost drivers) and the dependent variable (quality of production). Finally, the methodology is described for determining the financial impact of process variability as defined in this study.

#### II. THE MANUFACTURING PROCESS: AN OVERVIEW

Inherent in the research objectives is the need to understand the special dynamics which may be present in a continuous manufacturing environment. The process to be studied is a paperboard manufacturing operation that may be subdivided into eight interrelated parts as follows: 1) Head Box, 2) Wire Section, 3) Press Section, 4) Drying Section, 5) Size Press, 6) Calendar Stack, 7) Coater Section, and 8) Reel Section.

The stock flow (pulp)<sup>8</sup> is mixed in the head box and applied to a porous wire mesh; formation of paperboard actually occurs within the wire section. In the press section, the pulp mixture is forced against the wire with pressure and suction to eliminate water within the mixture and form the desired paperboard thickness. The material then proceeds to the drying section where it travels across numerous cylindrical dryers which are heated with steam. After the drying process, the paperboard advances to the size press where various coatings are applied. The calendar stack section presses the material to reduce variation across the width and length of the sheet thereby improving the surface quality of the paperboard. The coater section applies a clay-based opaque material to the sheet if required by the engineering specifications. The reel section is the final process before shipping. Long sections of material in a continuous sheet, termed reels, are rolled up (rewound) and cut into parent rolls (termed jumbo rolls or sets) to await shipment. The subquality sections within the reel are separated from the acceptable quality sections during the rewinding process.

### III. MEASUREMENT VARIABLES AND HYPOTHESES

An Analysis of Variance (ANOVA) model was used to test the relationship between product quality, the dependent variable, and hypothesized cost drivers, the independent variables. The amount of acceptable quality pounds produced relative to total pounds produced, termed ACCEPT, expresses the yield percentage. Scrap,

---

<sup>8</sup> Pulp preparation constitutes a separate process and is not considered in the analysis.

yield, and rework are interrelated variables that serve as cost drivers regarding quality [McNair et al., 1988].

This section defines and develops the dependent variable, ACCEPT, and the independent variables as follows:

Product-level cost driver - GRADE

Batch-level cost drivers - GRADE CHANGE 1, GRADE CHANGE 2.

Process-level cost drivers - CREW, SHIFT, BREAK, and DOWNTIME

The unit-level cost drivers (or variable manufacturing costs) are later used in the computations to determine the product costs. Support from the literature is provided for each variable prior to presenting the research hypotheses. Additionally, insights that were gained from interviews and observations at the test site are provided where appropriate.

#### Dependent Variable.

ACCEPT. The dependent variable throughout the study is ACCEPT and is specified as follows:

$$\text{ACCEPT} = \text{ACCEPT WEIGHT} / (\text{ACCEPT WEIGHT} + \text{HOLD WEIGHT} + \text{REWIND WEIGHT})$$

Where:

ACCEPT WEIGHT - The production of reels is measured in pounds. The pounds which meet specifications are termed accept weight.

HOLD WEIGHT - The reel production in pounds which does not conform to specifications but may be sold as off-grade material is termed hold.

REWIND WEIGHT - The reel production in pounds which is rejected as scrap is termed rewind.

Independent Variables.

CREW. Crews are comprised of five individuals who are responsible for production within a given shift. Crews may induce variation into the process as a result of individual styles of operating the machinery. Although the operator has current information on key manufacturing parameters, much individual judgement is involved in adjusting the process to attain desired specifications.

For example, a computer monitoring system provides crew members with relevant data on key processing variables such as moisture content and variability in thickness across the sheet of paperboard. The operator may observe the moisture level and make decisions regarding the timing and amount of adjustment necessary to bring the moisture content closer to a target specification. As a result of differences in individual judgement among operators, variation in quality may be observed within and between the four levels of crew.

The theoretical support for including the variable, CREW, comes primarily from Deming's Monte Carlo funnel experiments [Deming, 1986]. Skill levels, and the quality of production, are hypothesized by Deming to follow a random walk pattern when each successive employee is trained by his or her predecessor. The resulting variation in skill level may produce differences in the quality of production

among the four crews.

$H_A1$ : Significant differences in ACCEPT exist among the four levels of CREW.

**SHIFT.** The process is operated for three eight-hour shifts daily. A rotation system is in effect which permits one of the four crews to be off duty during any given 24 hour period. Since all crews are required to work each shift as specified in the rotation schedule, workers may experience mental and physical incompatibilities with certain shifts that affect the quality of production. Additionally, two routine activities may also induce variation into the process during shift one: 1) the plant engineers typically perform product tests and adjust the machinery, and 2) crew members perform scheduled maintenance. McGurrin [1987] reports that error rates in manufacturing are materially larger during Shift 3. Specifically, the error rate between the hours of 4:00 a.m. and 6:00 a.m. was found to be ten times greater than that of other periods. The shifts used in this research are as follows: Shift 1: 7:00-15:00, Shift 2: 15:00-23:00, and Shift 3: 23:00-7:00.

$H_A2$ : Significant differences in ACCEPT exist among the three levels of SHIFT.

**GRADE.** Each of the 23 grades of paperboard is classified based upon thickness (caliper), coating, and weight per lineal foot (basis weight). The paperboard machine is hypothesized to produce certain grades more efficiently than

others. Operating characteristics of the machine impose limitations on the variety of grades that can be produced. Paperboard grades produced near the boundary of the machine's capabilities are hypothesized to result in lower percentages of acceptable pounds relative to total pounds produced (ACCEPT). The expected result is higher operating costs [Kaplan, 1983]. As such, GRADE is hypothesized to serve as a product-level cost driver. The implications involve higher production costs associated with certain grades because of machine to grade incompatibilities. GRADE also captures technical differences in the paperboard product. For example, some grades are coated with an opaque material while others are not coated.

H<sub>A</sub>3: Significant differences in ACCEPT exist among the 23 levels of GRADE.

BREAK. The production facility employs four crews and operates three shifts per day, seven days per week. Crews are not permanently assigned to a particular shift, but follow a rotation schedule which allows them to work on different shifts. BREAK refers to the number of hours that a crew has been off duty prior to the beginning of current shift. For example, a crew that completes its shift at 3:00 p.m. on Monday and returns to work at 7:00 a.m. on Tuesday has been off duty for 16 hours; therefore, BREAK = 16. The rotation schedule creates values of BREAK ranging from 16 to 128 hours.

The importance of BREAK relates to its effect upon the operators, i.e., fatigue. For example, breaks are associated with changes in a crew's shift schedule. The crew must not only recover from the previous work period but adjust to another

shift schedule. The only exception is BREAK = 16 because the crew does not change shifts after a 16 hour break. Much has been written regarding the negative effects of both shift changeovers and rest time between shifts [Buren and Stenzel, 1984; Canadian Centre of Occupational Health and Safety, 1988]. The rotation schedule which is followed by the facility provides for six levels of BREAK as follows: 16, 32, 56, 64, 80, and 128.

H<sub>A</sub>4: Significant differences in ACCEPT exist among the six levels of BREAK .

GRADE CHANGE 1 (GRDCHG1). Cooper [1988a] defines the number of machine setups and setup hours as volume-unrelated cost drivers. The analogy in a continuous-process manufacturing environment is a grade change, i.e., the machine settings must be changed to conform to a different GRADE specification. A certain amount of off-grade material is generally produced until the machine can stabilize following a grade change. To capture this effect, the reel produced immediately following a grade change was coded as an indicator variable (0,1) in the model to explain changes in ACCEPT resulting from grade changes. The first reel produced following a grade change was coded (1), all other reels were coded (0).

H<sub>A</sub>5: Significant differences in ACCEPT exist as a result of GRDCHG1.

GRADE CHANGE 2 (GRDCHG2). The second reel produced following a grade change was coded as an indicator variable (0,1) in the model to explain the

duration of changes in ACCEPT resulting from grade changes. The second reel produced following a grade change was coded (1), all other reels were coded (0). Taken together, GRDCHG1 and GRDCHG2 tests whether a reduction in quality occurred and the duration of the reduction following a grade change. As stated previously, grade changes generally require some time to reach equilibrium, although it is an empirical question as to how much time is required. This test attempts to understand the issue better, because the duration of instability can be used as the basis of a batch-level cost driver to assist in more accurately calculating product costs.

H<sub>A</sub>6: Significant differences in ACCEPT exist as a result of GRDCHG2.

DOWNTIME. The machinery typically operates constantly unless a mechanical breakdown occurs or routine maintenance is required. For purposes of analysis, downtime is coded as a dichotomous variable. If downtime occurs for scheduled or unscheduled maintenance, the reel which is in production when the downtime occurs is coded 1. If no downtime occurs during the production of a reel, the observation is coded 0. Grades, shifts, and crews may be positively or negatively associated with downtime. Variation in the acceptable percentage of production resulting from downtime is hypothesized to occur because of adverse physical characteristics involved in a machine shut-down. In a continuous process environment, time is required to regain operating stability when production is interrupted<sup>9</sup>. Kaplan [1983] highlights variation in machine downtime as a significant contributor to high levels of Work in Process (WIP) inventory. Downtime

---

<sup>9</sup> Production engineers revealed this operating characteristic during discussions prior to data collection.

may be an important cost driver from the perspective of reducing inventory and associated costs.

$H_A7$ : Significant differences in ACCEPT exist as a result of DOWNTIME.

#### IV. MODELS USED IN HYPOTHESIS TESTING

##### Model 1: The ANOVA Model.

The main effects of Model 1, shown in Table 1, test the relationship between hypothesized cost drivers and variability in product quality. The variables and model definitions are useful in explaining the significant costs of quality in this process. From this, the sources of improvement can be identified by evaluating the leverage opportunities for cost reduction, i.e., the significance of the F statistics. The final model excludes all nonsignificant two-way and greater interactions. Three-way and greater interactions were not considered in the analysis because of their limited practical significance even if statistically significant.

Model 1 addresses the issues of induced variation in ACCEPT resulting from a variety of independent variables and their interactive effects. However, Model 1 does not address the sources of variation occurring across an eight-hour shift; a repeated measures analysis was necessary to detect within-shift variation. Operator-specific methods of controlling the machinery may induce variation which would not

be detected in a model that compares the means of ACCEPT by crew. For example, when Crew 2 arrives to begin production, the operator may adjust the machine to conform to his or her preferred settings. As a result, an initial period of instability was hypothesized<sup>10</sup> to occur immediately following a shift change; stability is expected to resume over the course of the shift. Any adjustment to the process creates instability that may result in the production of second-quality paperboard until stability resumes. Figure 5 illustrates the hypothesized pattern of ACCEPT across an eight-hour shift. A repeated measures analysis of variance was employed to test whether the level of ACCEPT was consistent over the course of a shift. Significantly different levels of ACCEPT when measured across a shift would suggest the existence of operating instabilities which have a direct impact on output quality and operating cost.

#### Model 2: The Repeated Measures ANOVA.

Model 2 defines ACCEPT in two hour increments within each shift as  $T_1$ ,  $T_2$ ,  $T_3$ , and  $T_4$ . Model 2 is a repeated measures ANOVA which examines a TIME effect, a TIME x CREW interaction, and a TIME x SHIFT interaction. The multivariate statistic, Wilks' Lambda, was used to test all of the TIME effect hypotheses. The model specification is shown in Table 2.

---

<sup>10</sup> While conducting an initial investigation, both management and production engineers who are intimately familiar with the manufacturing process hypothesized the "within shift" phenomenon.

## V. ASSESSING THE FINANCIAL IMPACT OF VARIABILITY

The purpose for understanding cost drivers, in the context of this research, is to assess the financial impact of process variability upon the firm. The total cost of variability was measured as a function of the quantity of off-grade units produced and the imputed value of each unit. In order to empirically assess the cost of variability, product cost estimates that are free of outside influences should be used. Actual data are available for key manufacturing costs such as base materials, direct materials, energy, shipping and handling, labor, maintenance, direct salaries and benefits, and hourly benefits. However, these data may include events, such as price changes, that have the potential to add inconsistencies or bias to the analysis. Therefore, a normative rather than actual financial measure is preferred.

The normative measure used in this study to assess the financial impact of variability is the unit selling price. Since the firm is capacity-constrained, a better measure of the full financial impact of producing off-grade material would include not only manufacturing cost but lost contribution margin as well. For this reason, transfer pricing models generally recognize the market price as the appropriate transfer value in a capacity constrained environment. As Kaplan [1982, p. 487] states, "The unifying concept for obtaining an appropriate transfer price is to recognize the opportunity cost to the company as a whole for making the transfer." Likewise, the comprehensive cost of producing off-grade products must include the value of both net direct manufacturing costs and lost contribution margin.

The actual selling prices, standard net variable manufacturing costs, and ACCEPT percentages were obtained from the sales records, standard product cost

sheets, and production log books, respectively, for each paperboard grade manufactured during the period under investigation. A reasonable approximation of the cost of variability<sup>11</sup> may be assessed by considering the lost contribution margin and net variable manufacturing costs expressed in terms of the percentage of off-grade pounds produced. For example, if product grade were statistically significant in explaining variation in the dependent variable ACCEPT, GRADE would then serve as a product-level cost driver producing different cost structures across the various grades of paperboard. If these grade differences were not incorporated into the product cost calculation, cross-subsidizations may occur which would have important strategic implications for both product mix and product pricing decisions.

An important aspect of the study includes the synthesis of engineering variables and financial analysis. The ANOVA models and Shewhart chart are designed to provide an assessment of the sources of variability, or engineering variables, described in this section and their effects upon the dependent variable, ACCEPT. As a result, cost benefit trade-offs may be considered by understanding both the sources and financial impact of variability in product quality. Such analyses are not possible with information provided solely by an engineering study. For example, one may consider the value of standardizing crew member training or changing the shift strategy in order to reduce variability and costs within the process.

---

<sup>11</sup> Deming has stated that the true cost of variation is unknown and unknowable [Deming, 1982] because of effects such as customer badwill. The societal effects of variation have been hypothesized by Taguchi in his quadratic loss function. Understanding the extent of costs such as these, which are undoubtedly real and significant, is beyond the scope of this research.

## CHAPTER IV

### DATA ANALYSIS AND INTERPRETATION

#### I. INTRODUCTION

The purpose of this chapter is to empirically test the relationship of the various independent variables to the dependent variable, ACCEPT. The variables and model definitions are useful in explaining the significant cost drivers in the process. From these, the sources of improvement can be identified by evaluating the opportunities for cost reduction, i.e., by considering the statistical significance of the main and interactive effects.

Chapter IV is divided into seven sections; the first of which serves as an introduction. The second section describes the data set and the precautions taken to detect errors and multicollinearity. The third section presents the results of Model 1 in terms of both main and interactive effects. Next, the results and implications of Model 2, the repeated measures ANOVA, are discussed in section four. Section five summarizes the results of the ANOVA models and considers the potential for further analysis. In section six, a methodology from the industrial statistics literature is discussed which was employed to explore the data set for potentially relevant cost drivers. Finally, in section seven, the financial impact of selected process cost drivers is considered.

## II. THE DATA SET

The data were obtained by examining operator log sheets for the period June 4, 1989 through July 19, 1989. The company did not place any constraints upon the time period allowed for study. The research time period was chosen because it represents the most recent production data and is typical of the manufacturing process. The variables of interest were entered into a Lotus 1-2-3 spreadsheet from the operator log sheets and were later transformed into a SAS data set for analysis. To help ensure the integrity of the data set, a sensitivity analysis was conducted to detect and correct outliers that may represent errors. The sensitivity analysis consisted of calculating the mean, median, high value, and low value for each field in the data set. Points exceeding a reasonable cutoff, based upon judgement sampling, were examined and corrected if errors were present. Most errors involved either incorrect manufacturing minutes per reel or incorrect pounds per reel recorded by the machine operators.

To detect potential multicollinearity in the models, a correlation analysis was performed. The matrix of Pearson Product Moment Correlation Coefficients which is produced in Table 3 suggests that multicollinearity is not a problem because the correlation coefficients are small, therefore uninfluential. As a result, no main effect variables were omitted. The data set contains 1096 observations, including 48 grade changes, and is deemed representative of the process.

### III. THE RESULTS OF THE ANALYSIS: MODEL 1

The purpose of this section is to report and evaluate the results of the ANOVA model which was developed in the previous chapter. Table 4 presents the results of Model 1. All effects hypothesized in Chapter III are summarized and discussed in the following paragraphs.

The CREW effect, as hypothesized, is statistically significant in the model as evidenced by a p-value of .0002. Because crews appear to differ in skill level or have different paradigms relative to optimum machine settings, the variable CREW represents a statistically significant process-level cost driver in this environment. The nature of a process-level cost driver does not allow one to specifically identify its effects upon products, but it is a source of costs that may be reduced only by improving the system. Deming's Monte Carlo funnel experiments [Deming, 1982] suggest that when crews are relatively independent and each predecessor trains his or her successor, the output quality follows a random walk pattern. The resulting variation in skill level would, therefore, produce differences in the quality of production among the four crews. Figure 6 illustrates the marginal means of ACCEPT by CREW. Although the differences may appear small, the financial consequences of lost production may be very significant when the volume of output is considered. The financial consequences of variability are considered in Section VII of this chapter.

Although suggested in the literature, the shift main effect is not statistically significant in this study. However, previous research has shown that error rates increase significantly between the hours of 4:00 a.m. and 6:00 a.m. [McGurrin,

1987]. A test of differences in overall SHIFT means is not sensitive to changes in ACCEPT that may occur during the course of a shift (Figure 7 illustrates the marginal means of ACCEPT by SHIFT). To increase the sensitivity of the test, a repeated measures analysis was conducted to further understand the within-shift effect that may occur during Shift 3. This test is discussed in the following section, Repeated Measures Analysis.

The variable GRADE is statistically significant in the model thereby allowing one to ask some interesting questions regarding the impact of this product-level cost driver on output quality. Figure 8 represents the relationship of product grade to ACCEPT. The horizontal axis represents nominal GRADE specifications arrayed from thin to thick as defined by caliper specifications and basis weight. The plot suggests that as production moves from left to right, ACCEPT appears to increase and then to stabilize except for two points, Grades 13 and 17. The function appears to be quadratic, i.e., thin paperboard is more difficult to manufacture than thick paperboard. Therefore, as suggested by engineers prior to the study, product grades with specifications approaching the limit of the machine's capability appear to result in a reduced level of ACCEPT. As such, gaining an understanding of the function of ACCEPT across the various product grades may provide guidance for better product costing.

As previously discussed, Figure 8 suggests the presence of two points that are different, i.e., grades 13 and 17. Further analysis revealed that these points were two of the four uncoated grades contained in the sample. Uncoated grades are more difficult to produce because they do not have an opaque coating to mask flaws that are structurally sound but visually unappealing. The data shown in Figure 8 suggest

that uncoated grades may be a source of variability in product quality. The interaction plots which are discussed later in this section provide further evidence that uncoated grades induce variability into the process. This finding is consistent with the hypothesis [Cooper, 1988a] that product complexity may serve as a product-level cost driver.

Because significant interactions exist among crews and shifts, crews and grades, and shifts and grades, a Sheffe' contrast to test differences among the means of crews, shifts, or grades is not appropriate. However, the statistical significance of the CREW x SHIFT, CREW x GRADE, and SHIFT x GRADE interactions, suggests that these effects may serve as process-level cost drivers. The CREW x SHIFT, CREW x GRADE, and SHIFT x GRADE interactions are presented in Figures 9, 10, and 11, respectively. Figure 8 (ACCEPT proportions by GRADE) identifies each of the 23 grades contained in the sample, while Figure 10 and Figure 11 report a total of only eight and 14 grades, respectively. The differences are the result of missing cells in the data set, i.e., not all grades were produced by every crew and every shift. The F statistic for the interaction in Table 4 is based upon the grades that are common among the three shifts (SHIFT x GRADE interaction) or four crews (CREW x GRADE interaction).

The CREW x SHIFT interaction suggests that all crews except CREW 1 produce better quality paperboard during SHIFT 2 than SHIFT 1. Additionally, each CREW except CREW 3 produces a lower quality product during SHIFT 3 when compared to SHIFT 2. The CREW x SHIFT interaction appears to be a source of variability in product quality; however, one must ask if the relationships are unique to these data or if the interaction will remain over time. This is an issue involving the

stability of the data set that is beyond the scope of this research. Additionally, further studies may reveal if special cause or systematic common cause variability is present.

The two interaction graphs involving GRADE reveal interesting commonalities with the GRADE main effect plot (Figure 8). The spikes in each plot provide additional support for the argument that uncoated grades are a source of variability in product quality. The uncoated products contained in the sample are grades 3, 12, 13, and 17. The major spikes shown in Figures 10 and 11 involve uncoated grades; in their absence, little interaction appears to exist.

The ANOVA table presented in Table 4 suggests the presence of another significant interaction involving GRADE, i.e., GRADE x GRDCHG1. This interaction implies that certain grades are more adversely affected by a grade change than others. Prior evidence suggests that uncoated grades may be difficult to produce; therefore, a grade change may affect uncoated grades more negatively than coated grades. To statistically test if grade changes impact uncoated grades to a greater extent than coated grades, a one degree of freedom contrast was conducted. For example, the average ACCEPT of the first reel following a grade change was compared to the average ACCEPT of all other reels in the batch to obtain the effect of a grade change on each grade. Next, the grades were dichotomized into two levels, coated and uncoated. The contrast tests whether the change in the average ACCEPT rate is different for coated versus uncoated grades. The contrast is specified as follows:

$$[\text{ACCEPT}_{c,gc,n} - \text{ACCEPT}_{c,ngc,n}] - [\text{ACCEPT}_{u,gc,n} - \text{ACCEPT}_{u,ngc,n}] = 0$$

Where

c = coated grade

u = uncoated grade

gc = grade change

ngc = no grade change

n = number of observations

The result of the contrast suggests that a grade change does not affect coated and uncoated grades differently ( $p = .364$ ). Therefore, the significance of the GRADE x GRDCHG1 interaction must be based upon other product or process characteristics.

Differences in the variable BREAK, as shown in Figure 12, are statistically significant in explaining variability in ACCEPT. The management literature suggests that rotating shifts with varying rest periods between shifts produce an increased level of errors [Buren and Stenzel, 1984]. Each BREAK period involves a change in SHIFT except BREAK = 16. For example BREAK = 32 implies that a worker has changed from working on SHIFT 1 to working on SHIFT 3, and has been off duty for 32 hours. BREAK = 32 is different from all other levels of BREAK because it involves both a shift change and allows only one day for workers to adjust to a new shift schedule. The average ACCEPT of BREAK = 32 was contrasted with the average accept of all other rest periods to determine if statistically significant differences exist.

Since the data were observed prior to the contrast, the appropriate F statistic is based on the Scheffe' familywise comparison method. Neter et al., [1985, p. 582]

state that "the Scheffe' method can be used for a wide variety of data snooping since the family of statements contains all possible contrasts". Additionally, because of properties inherent to the Scheffe' method, "confidence coefficients of 90 percent and 95 percent are frequently mentioned [Neter et al., 1985, p. 582]". The F critical value, based upon the Scheffe' method for a 90 percent confidence coefficient is 9.26. Therefore, the contrast shown in Table 5 is significant at an alpha level of at least .10 because the F statistic for the contrast exceeds the Scheffe' F critical value. The data suggest that crew members produce at a lower ACCEPT rate when allowed only one day to recover between shift changes.

The purpose of including GRDCHG1 in the model is to empirically test references in the literature suggesting the relationship of batch-level cost drivers to unit manufacturing cost [Cooper, 1989; McNair et.al., 1988]. A grade change in a continuous-process manufacturing environment is analogous to a machine setup in a discrete-part manufacturing environment. In an ABC system, the cost of a grade change is a batch-level cost that should be allocated to the units of production that are associated with the grade change. Interestingly, GRDCHG1 is statistically significant in the ANOVA model. As shown in Figure 13, the average ACCEPT of the reel immediately following a grade change is lower than the averages of all other reels in the data set. This finding suggests that a batch-level cost driver exists as a result of production instabilities following a grade change. However, the duration of the production instability resulting from grade changes is also a key driver that impacts costs in a variety of ways throughout the manufacturing facility.

When production setups (grade changes) are slow, large batch sizes are typically produced to gain economies of scale. As a result, the cost of a grade change

is spread over a large batch, thereby reducing the per unit cost of the change. Unfortunately, producing in large batch sizes may result in an increased level of inventory. Just in time (JIT) principles require production in small batches to meet product demand. Short setup times (grade changes) are necessary to allow the manufacturer to produce in smaller quantities; consequently, inventory levels and the associated costs of work-in-process (WIP) and finished goods may decline [Albright, 1989]. Additionally, factory throughput time (lead time) is compressed which results in a more responsive manufacturing facility. For these reasons, both the significance and duration of a machine setup (grade change) are important elements to the cost accountant in seeking to improve system performance and accurately reflect unit manufacturing costs.

GRDCHG2 tests the duration of the instability following a grade change by comparing the average ACCEPT of the second reel following a grade change to the averages of all other reels. As indicated by its absence in Table 4, GRDCHG2 is not statistically significant ( $p = .64$ ) in Model 1. Figure 14 presents the marginal means of GRDCHG2. Taken together, GRDCHG1 and GRDCHG2 suggest that a period of instability follows a grade change and negatively impacts product quality in the first reel following the change. However, the duration appears to affect only one reel, as evidenced by the insignificance of GRDCHG2. These statistics are based upon grade changes averaged across all grades, shifts, and crews. A combined marginal means plot of GRDGHG1 = 1 and GRDCHG2 = 1 is illustrated in Figure 15. Clearly, a grade change induces instabilities that impact output quality; the duration of the instability is apparently one reel.

A GRADE x GRDCHG1 interaction exists as shown in Table 4. The marginal means of the interaction that are shown in Table 9 are used in subsequent calculations (section VII) to determine the financial impact of a grade change. An ABC system would reveal that the costs per unit of a grade change for small, special-order grades are higher than those of grades with larger volumes. The implications are important for product mix, scheduling, and pricing decisions. This point is developed further in Section VII.

The variable, DOWNTIME, is significant in the ANOVA model and, as such, suggests that production interruptions negatively affect the quality of output until operating stability resumes. Sources of downtime include both scheduled and unscheduled maintenance. A marginal means plot of DOWNTIME appears in Figure 16. The plot suggests that reels produced in the presence of downtime have an average ACCEPT of 84 percent compared to 91 percent for those reels produced in the absence of downtime. In an ABC environment, DOWNTIME serves as a process-level cost driver with important implications. Like grade changes, downtime in a capacity-constrained environment has financial implications not only in opportunity costs while the machine is idle, but in the production of off-grade material that precedes or follows the machine shut-down. The financial consequences of production interruptions are further considered in Section VII.

#### IV. THE RESULTS OF THE ANALYSIS: MODEL 2

In order to assess the operating stability of the process across time, a repeated measures ANOVA was conducted. Table 6 reports the results of Model 2, the

repeated measures ANOVA, that tests the hypothesis of no TIME effect across the four two-hour increments within a shift. Test A indicates that ACCEPT varies when collapsed over all levels of both Crew and Shift effects. The results of the test suggest that significantly different levels of ACCEPT are produced across TIME ( $p = .089$ ). There is little evidence to support the hypothesis of operating stability across an eight-hour shift.

Test B, which tests the TIME x CREW interaction, suggests that crews differ in ACCEPT rates across the span of a shift, ( $p = .009$ ). Figure 17 illustrates the various production patterns across time, by CREW. For example, Crew 4 typically improves the level of ACCEPT throughout the course of a shift, while Crew 2 tends to regress. The results support the significance of the CREW main effect from the ANOVA analysis. Not only are the crews different on average, they appear to respond differently to the fluctuations and variations in the process across time.

The TIME x SHIFT interaction as shown in Test C, indicates that production patterns vary across the three levels of SHIFT. This effect is illustrated in Figure 18. As discussed previously, McGurrin [1987] found an increased error rate over the course of the third shift. While the paired comparison of ACCEPT at the beginning and end of shift three is not statistically significant at traditional alpha levels, (T1 versus T4;  $p = .20$ ), Figure 18 suggests that the quality of production steadily declines during shift three.

## V. ANOVA MODEL SUMMARY

Both the ANOVA and Repeated Measures ANOVA models provide insight into significant factors which drive unit manufacturing costs. However, a third type of analysis was conducted in an attempt to increase the explanatory power of the ANOVA model and discover additional cost drivers. A methodology from the statistical quality control literature was employed, i.e., the Shewhart Chart. The following section describes the analysis that was conducted in order to better specify the model and understand the sources of variability and costs.

## VI. SPECIAL AND COMMON CAUSES OF VARIABILITY

The data, in terms of ACCEPT, were plotted on a Shewhart chart [Burr, 1976; Deming, 1982] with upper and lower control limits placed at three standard deviations from the process mean. Figure 19 provides an excerpt from the Shewhart chart which contains 1096 reel observations. The horizontal axis represents individual reel observations ranging from reel number 3425 to reel number 3450, while the vertical axis represents an ACCEPT value corresponding to each reel. Experimentation within the Bell System since 1924 has substantiated that three standard deviations from the process mean provides an acceptable balance in minimizing the risks of Type 1 and Type 2 errors [Burr, 1976]. A Type 1 error involves taking action to prevent the reoccurrence of a point outside three standard deviations, when no special causes exist. A Type 2 error involves attributing the errant point to chance and failing to take action when special causes, in fact, exist.

An Individuals Chart<sup>12</sup> was constructed with ACCEPT as the dependent variable. Observations exceeding the bounds of the control limits (three standard deviations) were examined to determine if common or special causes are present.

Although few concrete rules exist to determine if variation is a result of common or special causes, the following characteristics generally apply. Common cause variation is characterized by a very large number of chance causes; the effect of each is slight. Special cause variation is characterized by few observations with a significant impact on output and cost [Burr, 1976].

Special cause variation may provide clues in searching for relevant cost drivers; therefore, a new dichotomous indicator variable, GROSS, was constructed. Observations varying more than three standard deviations from the process mean were coded (1), while observations within three standard deviations of the process mean were coded (0). The new variable, GROSS, was added to Model 1. The coefficient of determination ( $R^2$ ) of the ANOVA model containing GROSS was compared to that of the model without GROSS to assess the amount of variability explained by points in excess of three standard deviations that are not explained in Model 1. The analysis suggests that approximately 47 percent ( $R^2$  of the model containing GROSS = 81 -  $R^2$  of the model without GROSS = 34) of the total variability in ACCEPT may be from special causes that remain unexplained, i.e., points in excess of three standard deviations.

The purpose of including GROSS in the model is to stratify the variability into two types, common cause and special cause. The flowchart in Figure 20

---

<sup>12</sup> The individuals chart does not employ subgrouping schemes. Individual points are plotted on the chart around the process mean. Upper and lower control limits are set at the short term three standard deviation limits from the process average.

summarizes the logic behind stratifying process variability to aid in the search for relevant cost drivers. The importance of discovering the sources of the potential special cause variation is underscored by examining the marginal means plot of GROSS which is illustrated in Figure 21. Reels produced within three standard deviations have an average ACCEPT of 95.5 percent; however, those produced outside three standard deviations have an average ACCEPT of 27.2 percent. The financial aspects of producing reels with low ACCEPT percentages are evaluated in the following section.

Each GROSS observation was examined to identify potentially relevant special causes of variation. After examination, the observation was further classified, by specific cause of variation, to help discover potentially relevant sources of variability or cost drivers. The analysis was conducted and revealed that approximately 40 percent of the points exceeding three standard deviations represent reels immediately following a shift change.

A new dichotomous indicator variable, SHFTCHG (shift change), was created and added to the ANOVA model to statistically test the association of a shift change with ACCEPT. As shown in Table 7, the main effect of SHFTCHG proved to be statistically nonsignificant, which means that the first reel produced following a shift change is not different from all other reels in the data set in terms of ACCEPT. This finding contradicts the assumption that machine operators immediately adjust the machinery to conform to their preferences upon beginning a shift. If the "shift change" phenomenon occurs, the effect is not immediately recognizable from examining changes in the first reel of production. However, as shown in Table 7, the interaction of SHIFT and SHFTCHG is statistically significant.

The SHIFT x SHFTCHG interaction, illustrated in Figure 22, reveals an important characteristic that may be serving as a process-level cost driver. Notice that for both Shift 2 and Shift 3, the ACCEPT proportion is lower for the first reel following the shift change than the average of all other reels produced within the shift. However for Shift 1, the trend is reversed. Discussions with plant personnel revealed a potential explanation. Production engineers and technical support personnel conduct tests and adjust the process during Shift 1 but are absent from the mill during shifts two and three. Additionally, routine machine maintenance is performed during Shift 1. It appears that variability is induced into the system by organizational operating procedures. The analysis has revealed a potential process-level cost driver that has a direct impact upon the quality of production.

## VII. THE FINANCIAL IMPACT OF SELECTED COST DRIVERS

The discussion presented thus far in Chapter IV has focussed on the statistical significance of various parameters in explaining variability in ACCEPT. Various process-level cost drivers such as CREW, BREAK, and DOWNTIME were found to represent significant effects. Additionally, the main and certain interaction effects of the batch-level driver, GRDCHG1, and the product-level driver, GRADE, were found to have a significant association with the dependent variable ACCEPT.

Process-level cost drivers represent system effects that are associated with all grades. As such, the financial impact of a process-level cost driver is not specifically identifiable to individual products, but represents potential cost savings that may be obtained by improving the operating system. From the accountant's point of view,

opportunities exist to improve the representational faithfulness of product cost reports by accurately capturing the effects of significant batch-level and product-level drivers. The following analyses incorporate the effects of both batch-level and product-level drivers in order to improve the product cost estimates within an ABC framework.

In Chapter III, the theory of constraints is discussed in terms of more accurately defining the true costs of production. For example, each unit of scrap produced in a capacity-constrained process results not only in the cost of lost materials, labor, and overhead, but also in lost contribution margin. Therefore, to accurately assess the true impact of variability in a constrained process, the sum of lost net variable costs and lost contribution is used in the following analyses.

#### Unit-level and Product-level Cost drivers.

As discussed in Chapter II, unit-level costs occur every time a unit is produced and include traditional variable costs such as direct materials, chemicals, and variable labor and overhead. Table 8<sup>13</sup> reports the product grade (Column A), selling price per ton (Column B), variable manufacturing costs (Column C), and contribution margin (Column D) for the period under study. In order to assess the lost contribution margin as shown in Column F, two steps were conducted. First, the ACCEPT proportion, shown in Column E, was subtracted from 100 percent to obtain the percentage of lost production. Second, the percentage of lost production was multiplied by the contribution margin to obtain an estimate of the lost contribution

---

<sup>13</sup> The selling price per ton was obtained from sales records maintained by the firm. The variable costs were obtained from the standard product cost sheets prepared by the accounting department.

margin per ton resulting from producing off-grade material in a capacity-constrained environment.

The second part of the analysis involves estimating the amount of lost variable manufacturing costs that result from producing off-grade units. When output of unacceptable quality is produced, much of the fiber may be recovered and recycled, thereby reducing the cost of materials used in future production. Therefore, a better estimate of the cost of lost materials, labor, and overhead may be obtained by subtracting the materials recovery per ton from the variable manufacturing cost per ton. Column G reports the dollar value of materials that may be recovered per ton of off-grade production. After subtracting the value of recovered material per ton from the variable costs per ton, the difference is then multiplied by  $1 - \text{ACCEPT}$ . The results are shown in Column H. The result yields an estimate of the net variable manufacturing costs when unacceptable quality tons are produced. Column I totals the results of Column F and Column H, the costs of lost contribution margin and lost variable manufacturing costs, respectively. The dependent variable throughout the study is the acceptable quality of production per reel of product. Therefore, Column J adjusts the cost per ton shown in Column I to a cost per reel by multiplying by the average tons per reel. The equations upon which the analysis is based are presented

as follows:

$$SP - VC = CM$$

$$CM \times (1 - \text{ACCEPT}) = \text{LOST CONTRIBUTION MARGIN}$$

$$VC - MR = \text{LVC per ton}$$

$$\text{LVC per ton} \times (1 - \text{ACCEPT}) = \text{LOST VARIABLE COSTS}$$

$$\text{TOTAL COST} = \text{LOST CONTRIBUTION MARGIN} + \text{LOST VARIABLE COSTS}$$

Where

SP = Selling price per ton

VC = Variable costs per ton

CM = Contribution margin per ton

MR = Materials recovery per ton

LVC = Lost variable costs per ton

#### Batch-Level Cost driver.

Contained within the cost totals by grade, is a statistically significant batch-level cost driver, i.e., GRDCHG1. Additionally, a significant GRADE x GRDCHG1 interaction exists, which implies that some grades are more adversely affected by a grade change than others. Hence, the batch-level effect of a grade change is significant for some grades but insignificant for others. Table 9 summarizes the average ACCEPT rates of the GRADE x GRDCHG1 interaction which are used in subsequent calculations. Column A, GRDCHG1 = 0, represents the average

ACCEPT rate of all reels in the batch except the first reel following a grade change. Column B, GRDCHG = 1, represents the average ACCEPT rate of the first reel following a grade change. Column C illustrates the differences in ACCEPT rates between columns A and B. If the ACCEPT proportion shown in Column B exceeds that of Column A, the negative impact of a grade change is considered to be zero.

To understand the financial effects of a grade change, an analysis was performed similar to that conducted in Table 8. For example, the cost of a grade change may be evaluated in terms of both lost contribution margin and lost variable manufacturing costs. To determine the effects of a grade change, the loss must reflect the differences in ACCEPT which result from the change. Column C in Table 9 reports these differences. For example, the average ACCEPT rate when a grade change has not occurred is 81 percent for Grade 1. However, the ACCEPT rate of the first reel following the grade change drops to 13 percent. The change in ACCEPT, 68 percent (81-13), reflects the impact of a grade change for Grade 1. This difference is used to determine the financial impact in later calculations.

Table 10 illustrates the analysis that was performed to calculate the financial impact of a grade change. Columns A, B, C, and D represent the grade, selling price per ton, variable manufacturing costs per ton, and contribution margin per ton, respectively. Column E represents the percent loss resulting from the GRADE x GRDCHG1 interaction (Table 9, Column C). The lost margin per ton shown in Column F is obtained by multiplying the loss proportion, Column E, by the contribution margin per ton, Column D. This value represents the lost contribution margin per ton resulting from the production of off-grade material immediately following a grade change in a capacity-constrained environment.

To estimate the lost variable manufacturing costs per ton resulting from a grade change, the value of recovered materials as shown in Column G, was subtracted from the variable manufacturing costs per ton. The result was then multiplied by the loss proportion to obtain the result as shown in Column H. This value reflects the net marginal loss in variable manufacturing costs per ton which result from the production of off-grade material following a grade change.

Column I sums the values of lost variable manufacturing costs and lost contribution margin per ton, while column J converts the costs from a basis of tons to reels. The conversion in Column J is necessary because only the first reel following the change was adversely affected. To summarize, Column J reports the total cost of a grade change based upon the data in this study. However, in order to accurately reflect the nature of a batch-level cost driver, the batch size must be considered.

Column K reports the average number of reels produced per batch; some grades are produced in small quantities while others are produced in large quantities. To adequately capture the cost of producing a given grade, i.e., to minimize cross subsidizations, the costs of a grade change must be allocated among the units produced in the batch following the change. Column L reports the loss per reel as a result of a grade change when batch size is taken into account. To obtain the values as shown in Column L, the total loss shown in Column J was divided by the average batch size (Column K). Two factors affect the cost per reel of a grade change:

1. Product-level driver: Product grades have specific operating characteristics, i.e., some grades are more sensitive to grade change instabilities than others.

2. Batch-level driver: The size of the batch, or denominator level of activity, affects the cost per unit within a production run.

Product Costs Based Upon ABC vs Product Costs Based Upon the Standard Cost System: A Comparison.

The previous sections evaluated the effects of product-level and batch-level cost drivers on unit manufacturing cost. The purpose of this section is to compare the unit standard costs from the firm's current accounting system with the unit costs determined by this research. The product costs by grade were found to be different when allocations were based upon the cost drivers suggested by this study.

The manufacturer currently allocates fixed costs to products as a function of ACCEPT; i.e., grades with high ACCEPT percentages are assigned more fixed costs than those with low ACCEPT percentages. Fixed costs are currently allocated to either a specific grade (Fixed cost x ACCEPT), or a common pool for second quality production (Fixed cost x 1-ACCEPT). The current accounting system distorts product costs by subsidizing grades that are difficult to produce at the expense of those that have a greater percentage of first-quality production per ton. The analysis in Table 11 adjusts the fixed cost allocation by removing cross-subsidies. For example, the adjusted fixed cost per ton for Grade 1 is \$230. Since the ACCEPT rate for Grade 1 is .76, 1.32 tons (1/.76) must be produced, on average, to yield one ton of acceptable quality paperboard. Therefore, the adjusted fixed cost shown in Column D was obtained by dividing the standard fixed cost per ton by the accept rate to more accurately reflect the fixed costs of production.

Table 11 reports the costs per unit that were suggested by this study in contrast to the existing cost per unit from the manufacturer's cost system. Columns A through C report the grade, selling price, and standard variable manufacturing cost. The adjusted fixed cost (with cross-subsidies removed) is shown in Column D. Column E sums the variable and fixed manufacturing costs to obtain a subtotal that does not consider the impact of variability as discussed in the previous section. Column F contains the estimates of the lost contribution margin and lost variable costs resulting from variability in product quality (as shown in Table 8, Column I). Column G reports the total of Column E and Column F and presents the cost by grade suggested by the cost drivers in this study. The total includes variable costs, fixed costs, lost contribution margin, and lost variable manufacturing costs.

The manufacturing costs from the existing cost system are shown in Column H. The full impact of the difference in costs is shown by examining the profit margin per ton as calculated in Column I (Selling Price - Total cost per Column G) and Column J (Selling Price - Total cost per Column H). Column K summarizes the percentage change in manufacturing margins that result from calculating product costs based upon this research. For example, the manufacturing margin for Grade 1 is \$227 and \$69 based upon the existing cost system and this study, respectively. The change, 70 percent, is calculated as follows:  $[(\text{Column J} - \text{Column I}) / \text{Column J}]$ . As shown in Column K, the uncoated grades are numbered 3, 12, 13, and 17. The mean change in manufacturing margins of the uncoated grades is 135 percent versus 19 percent for coated grades. The analysis suggests that the existing cost system systematically understates the cost of uncoated products.

In summary, product-level cost drivers that were shown to be statistically related to product quality greatly impacted the calculation of unit manufacturing costs. Additionally, by eliminating cross-subsidies, more accurate allocations of fixed costs were achieved by penalizing the grades with the lowest quality percentages and removing the allocation of fixed cost from second-quality production. Unit manufacturing costs shown in this study may impact strategic decisions regarding product mix, product pricing, and resource allocation because the costs differ radically in many instances from those reported by the current standard cost system. The results of this study suggest that the levels of cost drivers found in the literature do, in fact, have the ability to greatly impact the estimates of unit manufacturing costs.

## CHAPTER V

### CONTRIBUTIONS, LIMITATIONS, AND CONCLUSION

#### I. INTRODUCTION

The purpose of this chapter is to consider the potential contributions and limitations of the study and to recap the results and implications of the research. Both design and methodological issues are evaluated. Finally, suggestions regarding extensions and further developments are discussed.

#### II. CONTRIBUTIONS

Statistical process control techniques have long been the domain of engineers and production personnel. However, this research has shown that a knowledge of significant process cost drivers may enable accountants to provide more useful information for decision-making. This study has incorporated the engineering concept of variation and the accounting concept of product cost determination in order to understand the economic impact of variation within a continuous-process manufacturing environment. Specifically, this study has:

1. Empirically tested the association of various batch-level, product-level, and process-level cost drivers to variability in product quality.
2. Employed methodology from the statistical quality control literature to search for and discover significant sources of variability in product quality.

3. Further developed the ABC methodology to determine the financial impact of grade changes, a batch-level cost driver, and grade diversity, a product-level cost driver. The analysis revealed cross-subsidization of unit manufacturing costs. As a result, the representational faithfulness of product costs was shown to improve. Finally, the research has further extended the concepts of ABC systems outside the framework of the discrete-part manufacturer.

### III. LIMITATIONS

As with all field-based research, the generalizability of the results is limited. However, the purpose of the research is to provide knowledge about a process and the related variability in order to subsequently develop theories relative to product costing and cost drivers. The research methodology enabled the testing of hypotheses based upon existing theory, while permitting exploration for new types of cost drivers.

Another potential limitation includes the quality of the data set. The data were collected from the daily log sheets which are completed by crew members. The data were evaluated for reasonableness; however, the accuracy of the data set cannot be stated with absolute certainty.

The manufacturer has more than one machine that is capable of producing products similar to those used in this study. The machine chosen for study is believed to represent the process; however, machine-specific characteristics that are unknown may influence the results.

#### IV. CONCLUSION AND IMPLICATIONS FOR FUTURE RESEARCH

This research has evaluated the significance of unit level, batch-level, product-level, and process-level cost drivers within a continuous-process manufacturing environment. Methodology from the statistical quality control literature was successfully employed to search for significant sources of variability in the process. In doing so, cost drivers that have not been previously identified in the literature were found to have significant association with the quality of production, and hence cost.

Specifically, this research has identified the quality of output to be a function of the crew, a crew x shift interaction, a crew x grade interaction, grade, grade changes, a grade change x grade interaction, length of break between shifts, incidence of downtime during the run, and shift changes for shift one. This research underscores the importance of continuous improvement and the extent of the potential cost savings from better operating policies. This study has identified production costs by grade and grade change, i.e., certain grades run poorer or better, depending upon the paper machine operating characteristics. Additionally, the study has shown that grade changes induce waste. This information can be used for product-costing purposes, for improvement projects, and for paperboard machine scheduling decisions.

The implications for further research include expanding the sample to include more types of continuous-process manufacturers to determine if the significant operating variables suggested in this research remain significant when analyzed cross-sectionally. A larger sample size from diverse continuous-manufacturers would

increase the generalizability of the study. Additionally, future research may reveal other relevant cost drivers that will improve the accuracy and usefulness of information provided by the accounting community.

## BIBLIOGRAPHY

## BIBLIOGRAPHY

- Albright, T.L., "Can Changes in Cost Accounting Contribute To Making U.S. Companies More Competitive In World Markets?," Beta Alpha Psi Prize Papers National Manuscript Contest (1989), pp. 28-35.
- Beaujon, G.J., and V.R. Singhal, "Understanding the Activity Costs in a Activity-Based System," Journal of Cost Management (Spring 1990), pp. 51-72.
- Bonoma, T.V., "Case Research in Marketing: Opportunities, Problems, and a Process," Journal of Marketing Research (May 1985), pp. 199-208.
- Brimson, J.A., "Technology Accounting," Management Accounting (March 1989), pp. 47-53.
- Buren, M., and W. Stenzel, "The Impact of Police Work Scheduling on Patrol Productivity," Public Productivity Review (Fall 1984), pp. 236-251.
- Burr, I.W., Statistical Quality Control Methods (Marcel Dekker, Inc., 1976).
- Campi, J.P., "Total Cost Management at Parker Hannifin," Management Accounting (January, 1989), pp. 51-53.
- Canadian Centre of Occupational Health and Safety, "Rotational Shiftwork," Worklife Report (Canada) (Vol:5 Issue: 6 1988), pp. 9-10.
- Cooper, R., "Implementing an Activity-Based Cost System," Journal of Cost Management (Spring 1990), pp. 33-42
- , "Unit-Based Versus Activity-Based Manufacturing Cost Systems," Working Paper (April 1989).
- , "The Rise of Activity-Based Costing - Part One: What Is an Activity-Based Cost System?," Journal of Cost Management (Summer 1988a), pp. 45-54.
- , "The Rise of Activity-Based Costing - Part Two: When Do I Need an Activity-Based Cost System?," Journal of Cost Management (Fall 1988b), pp. 41-48.
- , "The Rise of Activity-Based Costing - Part Three How Many Cost Drivers Do You Need, and How Do You Select Them?," Journal of Cost Management (Winter 1989a), pp. 34-46.
- , "The Rise of Activity-Based Costing - Part Four: What Do Activity-Based Cost Systems Look Like?," Journal of Cost Management (Spring 1989b), pp. 45-54.

- , "Does Your Company Need a New Cost System?," Journal of Cost Management (Spring 1987a), pp. 45-49.
- , "The Two-Stage Procedure in Cost Accounting: Part One," Journal of Cost Management (Summer 1987b), pp. 43-51.
- Cooper, R., and R.S. Kaplan, "Measure Costs Right: Make the Right Decisions," Harvard Business Review (September-October 1988), pp. 96-103.
- Daetz, D., "The Effect of Product Design on Product Quality and Product Cost," Quality Progress (June 1987), pp. 63-67.
- Deming, W.E., Out of the Crisis (Massachusetts Institute of Technology, Center for Advanced Engineering Study, 1982).
- Eiler, R.G., and J. Campi, "Implementing Activity-Based Costing at a Process Company," Journal of Cost Management (Spring 1990), pp. 43-50.
- Goldratt, E.M., and J. Cox, The Goal (North River Press, 1986).
- Grady, M., "Is Your Cost Management System Meeting Your Needs?," Journal of Cost Management (Summer 1988), pp. 11-15.
- Gunter, B., "A Perspective on the Taguchi Methods," Quality Progress (June 1987), pp. 44-52.
- Hinomoto, T., "Another Hidden Edge- Japanese Management Accounting," Harvard Business Review (July-August 1988), pp. 22-26.
- Howell, R.A., and S.R. Soucy, "Management Reporting In the New Manufacturing Environment," Management Accounting (February 1988), pp. 22-29.
- , "Operating Controls in the Manufacturing Environment," Management Accounting (October 1987), pp. 25-31.
- Jaikumar, R., "An Architecture for a Process Costing System," Working Paper (January 1989).
- Johnson, H.T., "Activity-Based Information: A Blueprint for World-Class Management Accounting," Management Accounting (June 1988), pp. 23-30.
- Juran, J.M., Quality Control Handbook, Third Edition, (McGraw-Hill, 1979).
- Kackar, R., "Taguchi's Quality Philosophy: Analysis and Commentary," Quality Progress (December 1986), pp. 21-29.
- Kaplan, R.S., "Measure Costs Right: Make the Right Decisions," Harvard Business Review (September-October 1988a), pp. 61-66.

- , "One Cost System Isn't Enough," Harvard Business Review (January-February 1988b), pp. 61-66.
- , "Measuring Manufacturing Performance: A New Challenge for Managerial Accounting Research," Accounting Review (October 1983), pp. 686-705.
- , "Yesterday's Accounting Undermines Production," Harvard Business Review (July-August 1984), pp. 95-101.
- Kaplan, R., Advanced Management Accounting (Prentice-Hall, 1982).
- Keegan, D.P., R.G. Eiler, and J.V. Anania, "An Advanced Cost Management System for the Factory of the Future," Management Accounting (December 1988), pp. 31-37.
- Lenane, D., "Accounting for the Real Cost of Quality," Quality Progress (January 1986), pp. 22-34.
- McGurrin, L., "Scientists Adjust the Hands of Time to Ease Shift Change Stress on Workers," New England Business (February 2, 1987) p. 39.
- McNair, C.J., W. Mosconi, and T. Norris, Meeting the Technology Challenge: Cost Accounting in a JIT Environment (National Association of Accountants, 1988).
- McNair, C.J., and W. Mosconi, "Measuring Performance in an Advanced Manufacturing Environment," Management Accounting (July 1987), pp. 28-31.
- Miller, J.G., and T.E. Vollmann, "The Hidden Factory," Harvard Business Review (September-October 1985), pp. 142-150.
- Mintzberg, H., "An Emerging Strategy of "Direct" Research," Administrative Science Quarterly (December 1979, Volume 24), pp. 582-589.
- Morse, W.J., H.P. Roth, and K.M. Poston, Measuring, Planning, and Controlling Quality Costs (National Association of Accountants, 1987).
- Neter, J., W. Wasserman, and M. Kutner, Applied Linear Statistical Models, Second Edition (Irwin, 1985).
- Reeve, J.M., and J.W. Philpot, "Applications of Statistical Process Control for Financial Management," Journal of Cost Management (Fall 1988), pp. 33-40.
- Reeve, J.M., "The Impact of Variation on Operating System Performance," Performance Excellence in Manufacturing and Service Organizations AAA NAA (March, 1989), pp. 75-89.

- Romano, P.L., "Activity Accounting - An Update - Part 1," Management Accounting (May 1989a), pp. 65-66.
- , "Activity Accounting - An Update - Part 2," Management Accounting (June 1989b), pp. 63-64.
- Roslund, J.L. "Evaluating Management Objectives with the Quality Loss Function," Quality Progress (August 1989), pp. 45-49.
- Roth, H.P., and W.J. Morse, "Let's Help Measure and Report Quality Costs," Management Accounting (August 1983), pp. 50-53.
- Schneiderman A., "Optimum Quality Costs and Zero Defects: Are they Contradictory Concepts?," Quality Progress (November 1986), pp. 28-31
- Schubert, J.K., "The Pitfalls of Product Costing," Journal of Cost Management (Summer 1988), pp. 16-26.
- Shank, J.K., and Vijay Govindarajan, "Transaction Based Costing for the Complex Product Line: A Field Study," Journal of Cost Management (Summer 1988), pp. 31-38.
- , "Strategic Cost Analysis: The Crown Cork and Seal Case," Journal of Cost Management (Winter 1989), pp. 5-16.
- Staubus, G.J., Activity Costing for Decisions (Garland Publishing, Inc. 1988).
- Sullivan, E., "OPTIM: Linking Cost, Time, and Quality," Quality Progress (April 1986), pp. 52-61.
- Sullivan, L.P., "The Power of Taguchi Methods to Impact Change in U.S. Companies," Target (Volume 3, Number 2, Summer, 1987), pp. 18-22.
- Turney, P.B.B., "Using Activity-Based Costing to Achieve Manufacturing Excellence," Journal of Cost Management (Summer 1989), pp. 23-31.
- Turney, P.B.B., and B. Anderson, "Accounting for Continuous Improvement," Sloan Management Review (Winter 1989), pp. 37-47.

## APPENDICES

## APPENDIX A. Tables

Table 1.

## Dependent and Independent Variables: Model 1

<u>DEPENDENT VARIABLE</u>	<u>INDEPENDENT VARIABLE</u>	<u>EXPLANATION</u>
ACCEPT		Accept Weight per reel/ Total Weight per reel
	CREW	Crew 1, Crew 2, Crew 3, or Crew 4
	SHIFT	Shift 1, Shift 2, or Shift 3
	GRADE	Product classification
	BREAK	Rest time between shifts
	GRDCHG1	The first reel of product manufactured after a grade change
	GRDCHG2	The second reel of product manufactured after a grade change
DOWNTIME	A dichotomous variable that indicates the presence or absence of machine downtime associated with the production of each reel	

Table 2.

## Dependent and Independent Variables: Model 2

<u>DEPENDENT VARIABLE</u>	<u>INDEPENDENT VARIABLE</u>	<u>EXPLANATION</u>
ACCEPT		Accept Weight per reel/ Total Weight per reel
	CREW	Crew 1, Crew 2, Crew 3, or Crew 4
	SHIFT	Shift 1, Shift 2, or Shift 3
	TIME	<p><math>T_1</math> = The average ACCEPT for the first two-hour production period within a shift</p> <p><math>T_2</math> = The average ACCEPT for the second two-hour production period within a shift</p> <p><math>T_3</math> = The average ACCEPT for the third two-hour production period within a shift</p> <p><math>T_4</math> = The average ACCEPT for the fourth two-hour production period within a shift</p>

Table 3.  
Correlation Matrix of Main Effects

EFFECT							
Correlation Coefficient (P-value)							
	CREW	SHIFT	GRADE	BREAK	GRDCHG1	GRDCHG2	DOWNTIME
CREW	1.0 (.000)	-.053 (.079)	.005 (.876)	.035 (.249)	-.032 (.283)	-.053 (.081)	-.008 (.790)
SHIFT		1.0 (.000)	.044 (.141)	.180 (.000)	.008 (.789)	.019 (.526)	-.063 (.038)
GRADE			1.0 (.000)	.112 (.000)	-.028 (.358)	-.018 (.543)	.034 (.260)
BREAK				1.0 (.000)	-.048 (.106)	-.007 (.813)	-.038 (.210)
GRDCHG1					1.0 (.000)	-.044 (.147)	-.027 (.494)
GRDCHG2						1.0 (.000)	.015 (.611)
DOWNTIME							1.0 (.000)

Table 4.  
ANOVA Table

Effect	Sum of Squares	Degrees of Freedom	Mean Square	F-Statistic	P - Value
CREW (A)	.72	3	.240	6.80	.0002
SHIFT (B)	.13	2	.065	1.87	.1548
GRADE (C)	2.79	22	.127	3.57	.0001
BREAK (D)	.54	5	.108	3.03	.0101
GRDCHG1 (E)	.22	1	.220	6.14	.0134
DOWNTIME	.33	1	.330	9.37	.0023
A x B	.83	6	.138	3.89	.0008
A x C	4.05	22	.184	5.19	.0001
B x C	2.52	13	.194	5.46	.0001
C x E	1.40	22	.064	1.80	.0135
Error	34.65	977	.0355		

Table 5.

Significance of Scheffe' Contrasts: Variable = BREAK.

(BREAK = 32 versus BREAK = 16, 56, 64, 80, 128)

---

Variable BREAK	Degrees of Freedom	Sum of Squares	F- Statistic
32 versus 16 56 64 80 128	1	.408	11.56

---

Table 6.

Repeated Measures ANOVA.

(A = No TIME Effect;

B = No TIME x CREW Effect;

C = No TIME x SHIFT Effect)

Test	Wilks' Lambda	F-Statistic	Numerator Degrees of Freedom	Denominator Degrees of Freedom	P-Value
A	.979	2.19	3	308	.089
B	.931	2.46	9	750	.009
C	.950	2.66	6	616	.015

Table 7.  
Significance of SHIFT x SHFTCHG Interaction

Effect	Sum of Squares	Degrees of Freedom	Mean Square	F-Statistic	P - Value
CREW (A)	.74	3	.246	7.00	.0001
SHIFT (B)	.20	2	.100	2.82	.0602
GRADE (C)	2.66	22	.121	3.43	.0001
BREAK (D)	.55	5	.110	3.09	.0089
GRDCHG1 (E)	.20	1	.200	5.77	.0165
DOWNTIME	.33	1	.330	9.21	.0025
SHFTCHG	.00	1	.000	.07	.7883
A x B	.83	6	.138	3.93	.0007
A x C	4.08	22	.185	5.26	.0001
B x C	2.48	13	.191	5.42	.0001
C x E	1.35	22	.061	1.74	.0186
B x SHFTCHG	.26	2	.130	3.69	.0253
Error	34.39	974	.0353		

Table 8.

## The Impact of Unit-level and Product-level Cost drivers on Unit Manufacturing Cost.

(All Amounts Are Expressed in Dollars Except Columns A &amp; E)

(A) GRD <sup>a</sup>	(B) SP <sup>b</sup> PER TON	(C) VC <sup>c</sup> PER TON	(D) CM <sup>d</sup> PER TON	(E) ACC <sup>e</sup>	(F) LOST <sup>f</sup> CM PER TON	(G) MTL <sup>g</sup> REC PER TON	(H) LOST <sup>h</sup> VC PER TON	(I) LOST <sup>i</sup> CM PLUS VC	(J) TOTAL PER REEL
1	700	271	429	.76	103	160	27	130	2802
2	663	262	401	.83	68	162	17	85	1778
3	631	259	372	.83	63	182	13	76	1728
4	663	254	409	.87	53	168	11	64	1290
5	670	256	414	.94	25	168	5	30	700
6	670	255	415	.94	25	170	5	30	650
7	670	256	414	.91	37	168	8	45	1063
8	663	258	405	.93	28	164	7	35	694
9	663	262	401	.99	4	162	1	5	119
10	663	257	406	.91	37	164	8	45	890
11	663	256	407	.92	33	166	7	40	771
12	646	252	394	.89	43	170	9	52	1135
13	646	256	390	.65	137	170	30	167	3561
14	663	255	408	.93	29	166	6	35	693
15	670	250	420	.99	4	170	1	5	107
16	670	259	411	.86	58	172	12	70	1428
17	631	236	395	.32	269	176	41	310	8192
18	663	256	407	.92	33	166	7	40	785
19	663	253	410	.88	49	168	10	59	1067
20	670	249	421	.95	21	172	4	25	519
21	648	257	391	.92	31	170	7	38	713
22	663	256	407	.99	4	170	1	5	94
23	672	258	414	.85	62	172	13	75	1302

<sup>a</sup>GRD = Grade of paperboard determined by engineering specifications<sup>b</sup>SP PER TON = Selling price per ton of paperboard<sup>c</sup>VC PER TON = Variable manufacturing cost per ton

Table 8 Continued

<sup>d</sup>CM PER TON = Contribution margin per ton (Selling price - Variable manufacturing costs)

<sup>e</sup>ACC = ACCEPT.

<sup>f</sup>LOST CM PER TON = Lost contribution margin per ton. These values are calculated by multiplying the loss proportion by the contribution margin per ton.

<sup>g</sup>MTL REC PER TON = Material recovery per ton. The dollar value of recoverable materials resulting from defective production is shown in column G.

<sup>h</sup>LOST VC PER TON = Lost variable costs per ton. The dollar value of recoverable materials is subtracted from the variable manufacturing costs per ton to obtain an estimate of the value of lost variable costs per ton of scrap. Next, the lost variable cost is multiplied by the loss proportion to obtain the values shown in Column H. The formula is as follows: [(Column C - Column G) x (1 - Column E)].

<sup>i</sup>LOST CM PLUS VC = Lost contribution margin plus lost variable costs. (Column F + Column H)

<sup>j</sup>TOTAL PER REEL = Total losses per reel resulting from variability in ACCEPT. The total is calculated by multiplying the amount of total loss per ton in Column I by the average tons per reel.

Table 9.

Average ACCEPT Percent of the GRADE x GRDCHG1 Interaction

GRADE	(A) GRDCHG1 = 0 <sup>a</sup>	(B) GRDCHG1 = 1 <sup>b</sup>	(C) DIFFERENCE <sup>c</sup>
1	.81	.13	.68
2	.83	.79	.04
3	.99	.82	.17
4	.91	.71	.20
5	.94	.91	.03
6	.94	.88	.06
7	.92	.80	.12
8	.92	.96	.00
9	.98	.99	.00
10	.90	.96	.00
11	.96	.55	.41
12	.90	.49	.41
13	.68	.37	.31
14	.93	.99	.00
15	.99	.93	.06
16	.90	.68	.22
17	.25	.43	.00
18	.94	.75	.19
19	.87	.99	.00
20	.94	.99	.00
21	.92	.90	.02
22	.99	.99	.00
23	.83	.93	.00

<sup>a</sup>GRDCHG1 = 0 = All reels except those produced immediately following a grade change.

<sup>b</sup>GRDCHG1 = 1 = The first reel produced following a grade change.

<sup>c</sup>DIFFERENCE = If ACCEPT is larger for a grade when a grade change occurs, the negative impact of a grade change is considered to be zero. See grades 8,9,10,14,17,19,20,22,23.

Table 10.

## The Impact of Grade Changes on Unit Manufacturing Cost.

(All Amounts Are Expressed in Dollars Except Columns A &amp; E)

(A) GRD <sup>a</sup>	(B) SP <sup>b</sup> PER TON	(C) VC <sup>c</sup> PER TON	(D) CM <sup>d</sup> PER TON	(E) LOSS <sup>e</sup> PROP	(F) LOST <sup>f</sup> CM PER TON	(G) MTL <sup>g</sup> REC PER TON	(H) LOST <sup>h</sup> VC PER TON	(I) LOST <sup>i</sup> CM PLUS VC	(J) LOST <sup>j</sup> MGN PER CHNG	(K) AVG <sup>k</sup> BAT SIZE	(L) LOSS <sup>l</sup> PER REEL
1	700	271	429	.68	292	160	75	367	7909	22	360
2	663	262	401	.04	16	162	4	20	418	35	12
3	631	259	372	.17	63	182	13	76	1728	18	96
4	663	254	409	.20	82	168	17	99	1995	5	399
5	670	256	414	.03	12	168	3	15	350	7	50
6	670	255	415	.06	25	170	5	30	650	22	30
7	670	256	414	.12	50	168	11	61	1441	6	240
8	663	258	405	.00	00	164	00	00	00	32	00
9	663	262	401	.00	00	162	00	00	00	2	00
10	663	257	406	.00	00	164	00	00	00	36	00
11	663	256	407	.41	167	166	37	204	3931	9	437
12	646	252	394	.41	162	170	34	195	4277	37	116
13	646	256	390	.31	121	170	27	148	3156	11	287
14	663	255	408	.00	00	166	0	00	00	26	00
15	670	250	420	.06	25	170	5	30	644	5	129
16	670	259	411	.22	90	172	19	109	2224	21	106
17	631	236	395	.00	00	176	00	00	00	3	00
18	663	256	407	.19	77	166	17	94	1844	18	102
19	663	253	410	.00	00	168	0	00	00	27	00
20	670	249	421	.00	00	172	0	00	00	32	00
21	648	257	391	.02	8	170	2	10	188	79	2
22	663	256	407	.00	00	170	0	00	00	3	00
23	672	258	414	.00	00	172	0	00	00	24	00

<sup>a</sup>GRD = Grade of paperboard determined by engineering specifications<sup>b</sup>SP PER TON = Selling price per ton of paperboard<sup>c</sup>VC PER TON = Variable manufacturing cost per ton<sup>d</sup>CM PER TON = Contribution margin per ton (Selling price - Variable manufacturing costs)<sup>e</sup>LOSS PROP = The loss proportion that results from the GRADE x GRDCHG1 interaction as shown in Table 9, Column C.

Table 10 Continued

<sup>f</sup>LOST CM PER TON = Lost contribution margin per ton. These values are calculated by multiplying the loss proportion by the contribution margin per ton.

<sup>g</sup>MTL REC PER TON = Material recovery per ton. The dollar value of recoverable materials resulting from defective production is shown in column G.

<sup>h</sup>LOST VC PER TON = Lost variable costs per ton. The dollar value of recoverable materials is subtracted from the variable manufacturing costs per ton to obtain an estimate of the value of lost variable costs per ton of scrap. Next, the lost variable cost is multiplied by the loss proportion to obtain the values shown in Column H. The formula is as follows: [(Column C - Column G) x (Column E)].

<sup>i</sup>LOST CM PLUS VC = Lost contribution margin plus lost variable costs. (Column F + Column H)

<sup>j</sup>LOST MGN PER CHNG = Lost margin per grade change. The total cost in column I is multiplied by the average tons per reel to obtain an estimate of the lost materials and contribution margin resulting from a grade change.

<sup>k</sup>AVG BAT SIZE = Average batch size. The average number of reels produced in a production run is presented in Column K.

<sup>l</sup>LOSS PER REEL = The loss per reel resulting from a grade change. (Column J / Column K)

Table 11.

A Comparison of Existing Standard Costs per Ton Versus Costs per Ton as  
Determined by this Study

(All Amounts Are Expressed in Dollars Except Column A)

(A) GRD <sup>a</sup>	(B) SP <sup>b</sup> PER TON	(C) VC <sup>c</sup> PER TON	(D) FC <sup>d</sup> PER TON	(E) (C+D) <sup>e</sup> SUB- TOTL	(F) LST <sup>f</sup> CM PLUS LOST MTLS	(G) (E+F) <sup>g</sup> TOTL PER THIS STDY	(H) TOTL <sup>h</sup> PER STD COST CARD	(I) (B-G) SP <sup>i</sup> LESS COST	(J) (B-H) SP <sup>j</sup> LESS COST	(K) PCT <sup>k</sup> CHG
1	700	271	230	501	130	631	473	69	227	70
2	663	262	195	457	85	542	450	121	213	43
3	631	259	213	472	76	548	463	83	168	51*
4	663	254	188	442	64	506	443	157	220	29
5	670	256	176	432	30	462	447	208	223	7
6	670	255	177	432	30	462	447	208	223	7
7	670	256	182	438	45	483	447	187	223	16
8	663	258	170	428	35	463	442	200	221	10
9	663	262	166	428	5	433	453	230	210	-10
10	663	257	170	427	45	472	437	191	226	15
11	663	256	172	428	40	468	439	195	224	13
12	646	252	215	467	52	519	471	127	175	27*
13	646	256	308	564	167	731	484	-85	162	152*
14	663	255	169	424	35	459	437	204	226	10
15	670	250	165	415	5	420	439	250	231	-8
16	670	259	191	450	70	520	450	150	220	32
17	631	236	514	750	310	1060	425	-429	206	308*
18	663	256	169	425	40	465	436	198	227	13
19	663	253	175	428	59	487	432	176	231	24
20	670	249	173	422	25	447	439	223	231	3
21	648	257	178	435	38	473	446	175	202	13
22	663	256	165	421	5	426	445	237	218	-9
23	672	258	200	458	75	533	454	139	218	36

<sup>a</sup>GRD = Grade of paperboard determined by engineering specifications

<sup>b</sup>SP PER TON = Selling price

<sup>c</sup>VC PER TON = Variable manufacturing costs

<sup>d</sup>FC PER TON = Fixed Costs (adjusted)

Table 11 Continued

<sup>e</sup>(C+D) SUB-TOTL = The total variable manufacturing costs and fixed costs per ton.

<sup>f</sup>LST CM PLUS LOST MTLs = Lost contribution margin plus lost materials that result from variability in the acceptable proportion of production. These values are summarized in Table 8, Column I.

<sup>g</sup>(E+F) TOTL PER THIS STDY = Column E plus Column F summarizes the total costs by grade based upon the cost-drivers determined by this study.

<sup>h</sup>TOTL PER STD COST CARD = Total cost per the standard cost card. These values represent the standard costs determined by the company's existing accounting system. Column C + Column D does not equal Column H because of adjustments made to the fixed cost amounts during the course of the study. See the discussion regarding Table 11 in the text.

<sup>i</sup>SP LESS COST (B-G) = Selling price less cost, Column B - Column G. The manufacturing margin by grade is shown in Column I, based upon costs determined by this study.

<sup>j</sup>SP LESS COST (B-H) = Selling price less cost, Column B - Column H. The manufacturing margin by grade is shown in Column J, based upon costs determined by the existing accounting system.

<sup>k</sup>PCT CHG = The percent change in margin that results from calculating product costs based upon cost drivers that were identified as significant in this study. The percent change is calculated as follows: (Column J - Column I) / Column J.

\* This is an uncoated grade of paperboard.

## APPENDIX B. Figures

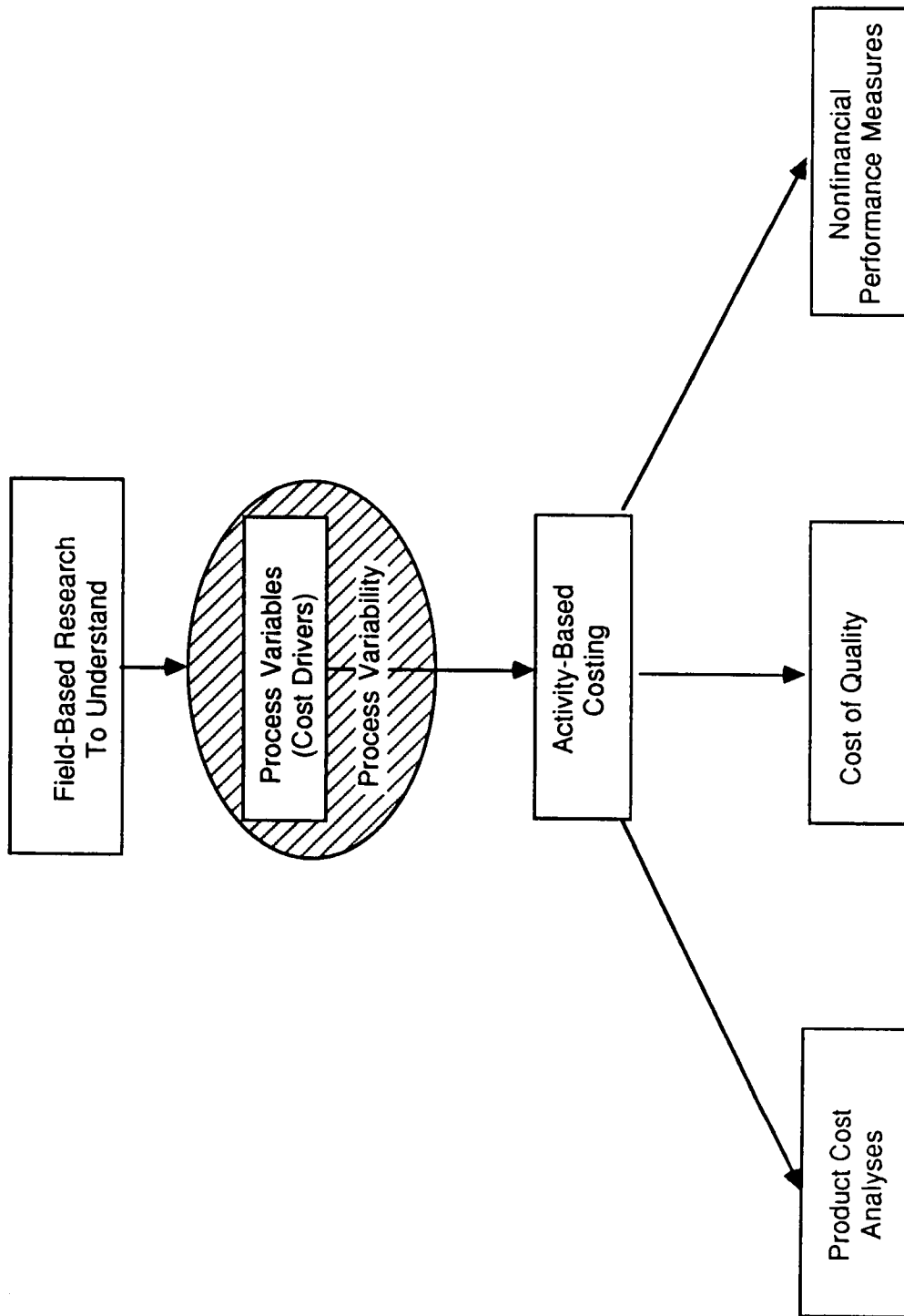


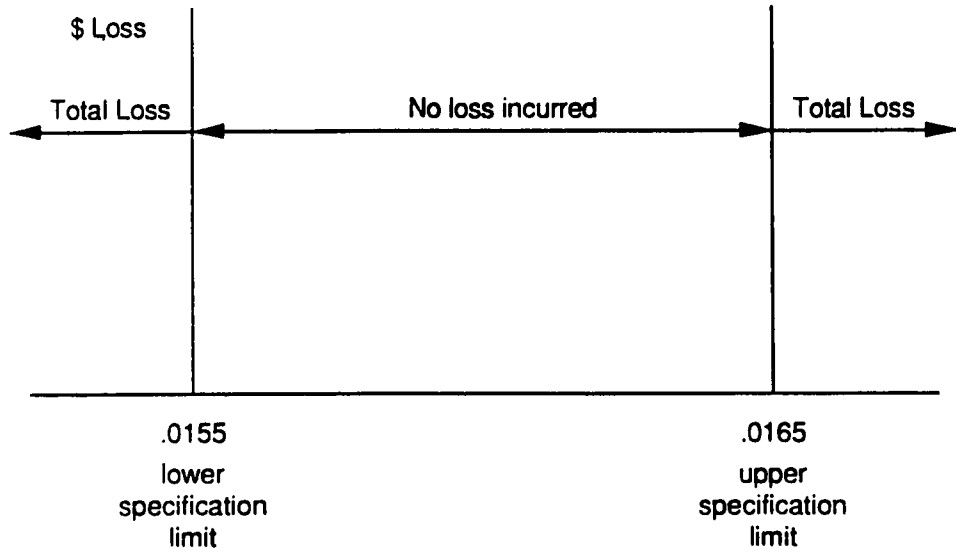
Figure 1. The Conceptual Link of Process Variables to Manufacturing Cost Drivers

		Number of Cost Drivers	
		One	Many
Number of Cost Pools	One	APPROACH 1	APPROACH 2
	Many	APPROACH 4	APPROACH 3

(From: Cooper, R. "The Two-Stage Procedure in Cost Accounting: Part One," Journal of Cost Management (Summer 1987), p. 50).

Figure 2. The Four Approaches to Product Costing

PANEL A: Conventional Loss Function



---

PANEL B: Taguchi Loss Function

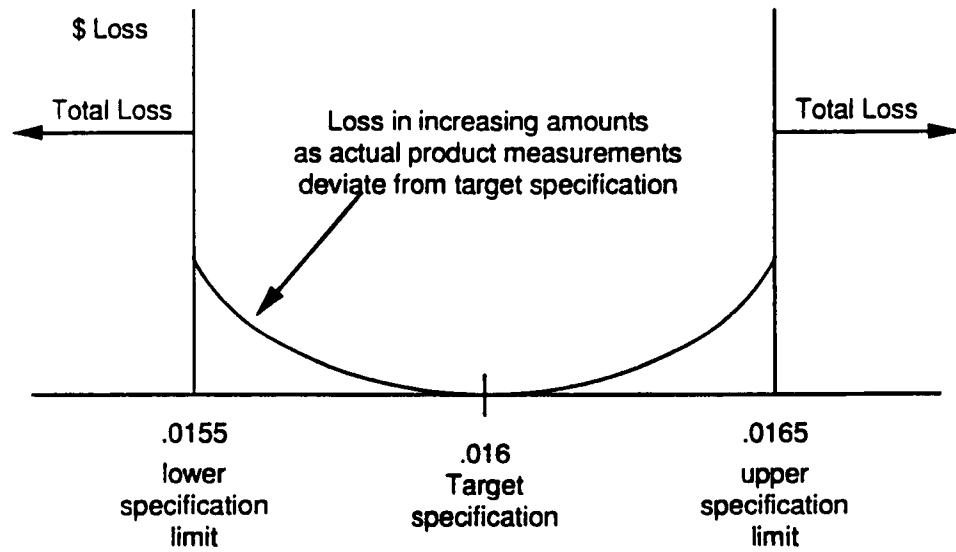
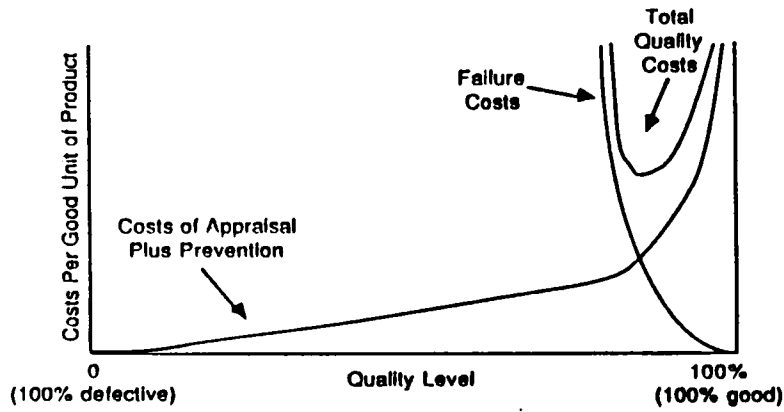


Figure 3. The Conventional Loss Function versus the Taguchi Loss Function

PANEL A: Juran's Model of Optimum Quality Costs



PANEL B: Normal vs. Rectangular Distribution

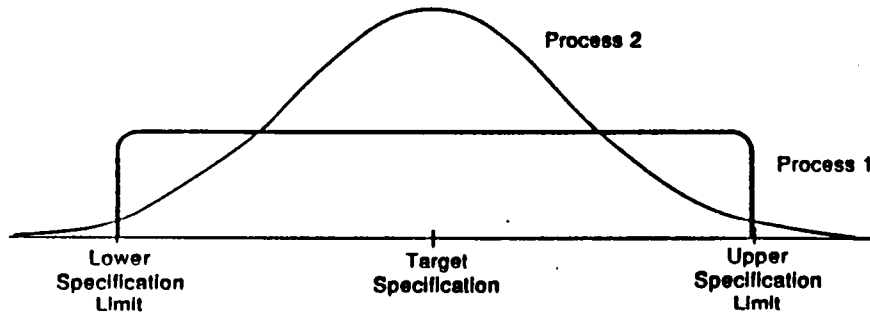


Figure 4. The Relationship of Quality Cost to Process Variability

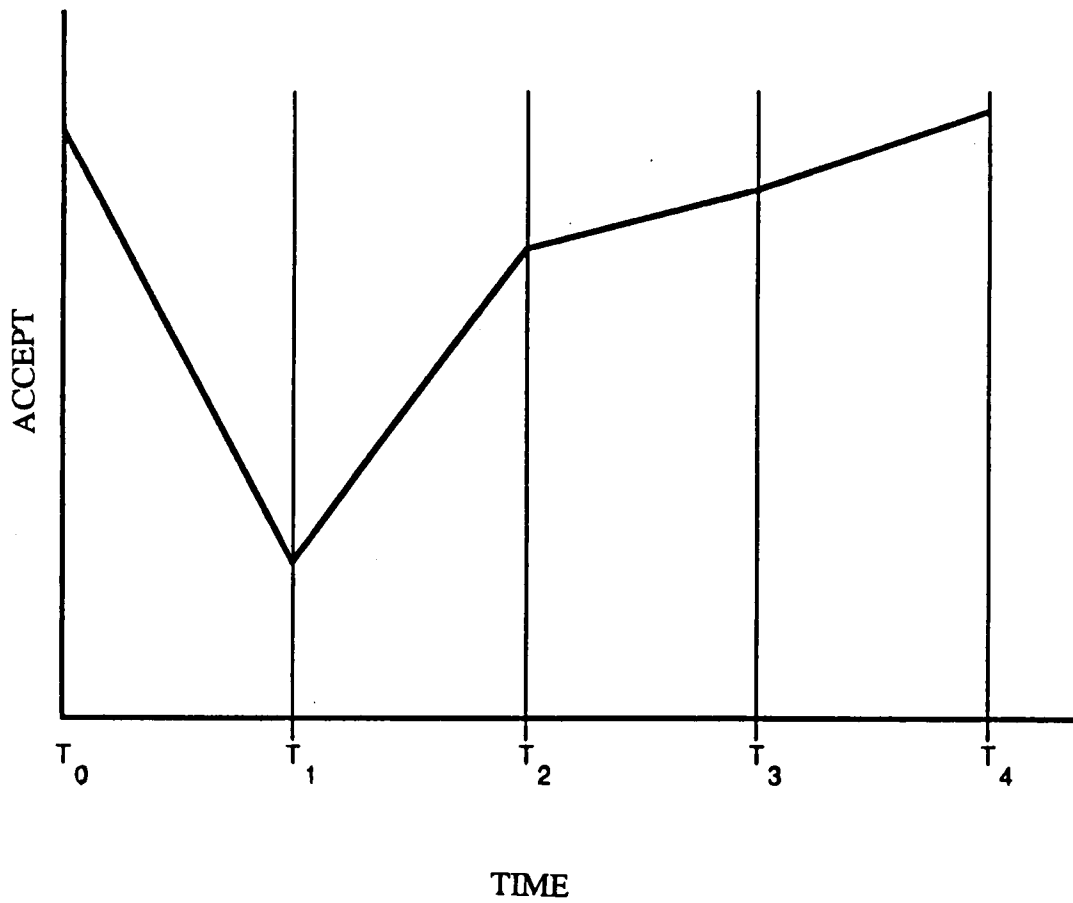


Figure 5. The Hypothesized Pattern of Variability in ACCEPT Within a Shift

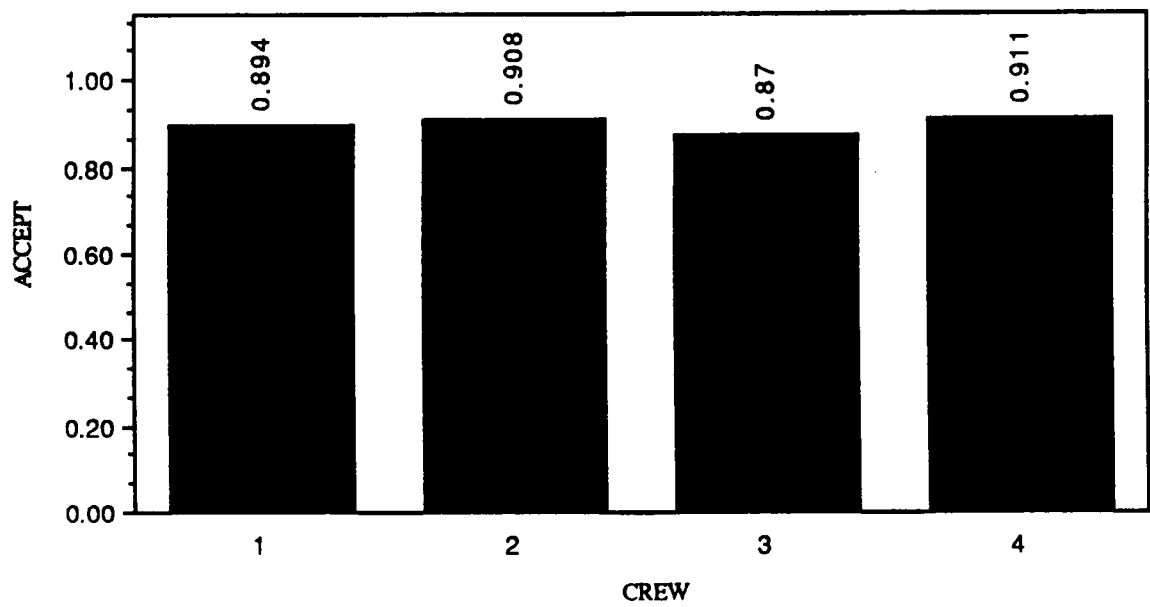


Figure 6. ACCEPT by CREW

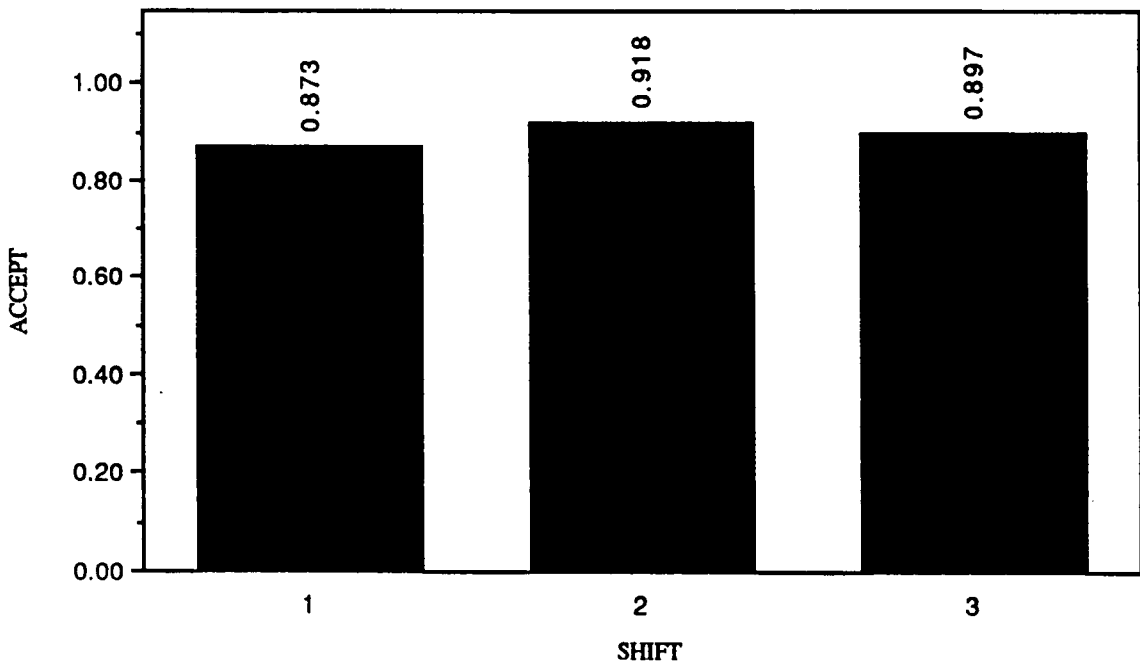


Figure 7. ACCEPT by SHIFT

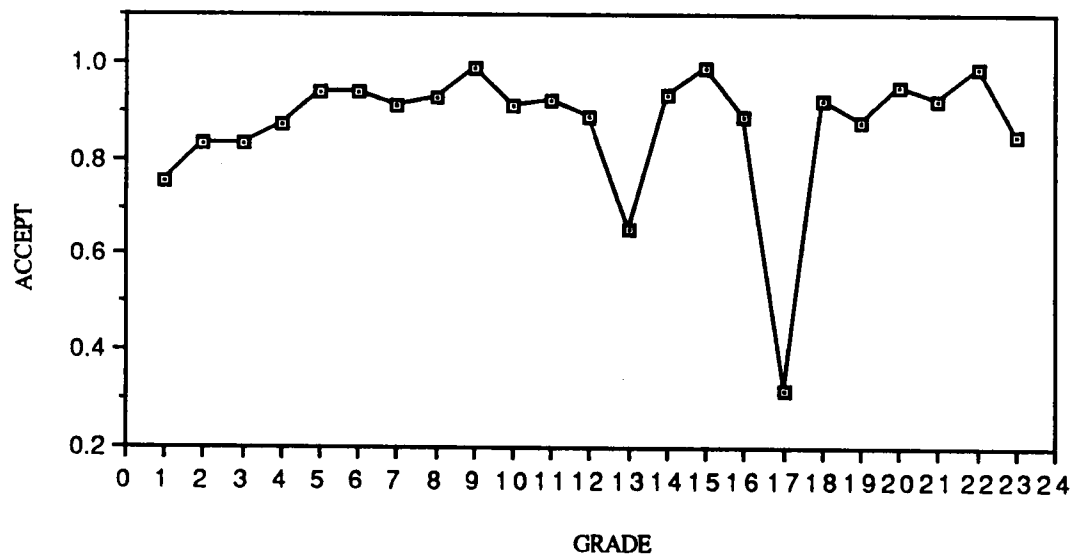


Figure 8. ACCEPT by GRADE

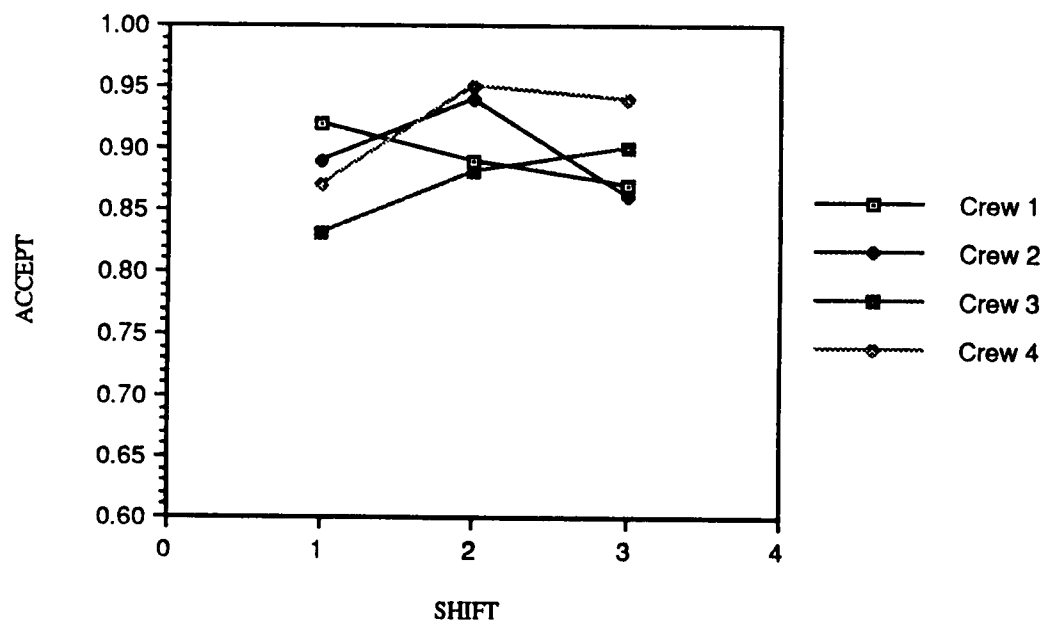


Figure 9. The CREW x SHIFT Interaction

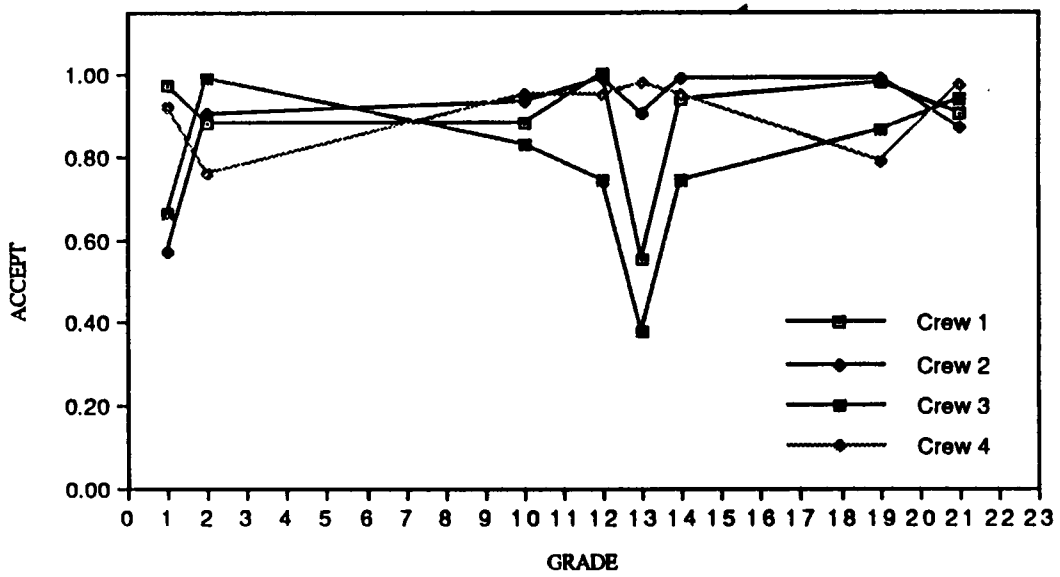


Figure 10. The CREW x GRADE Interaction

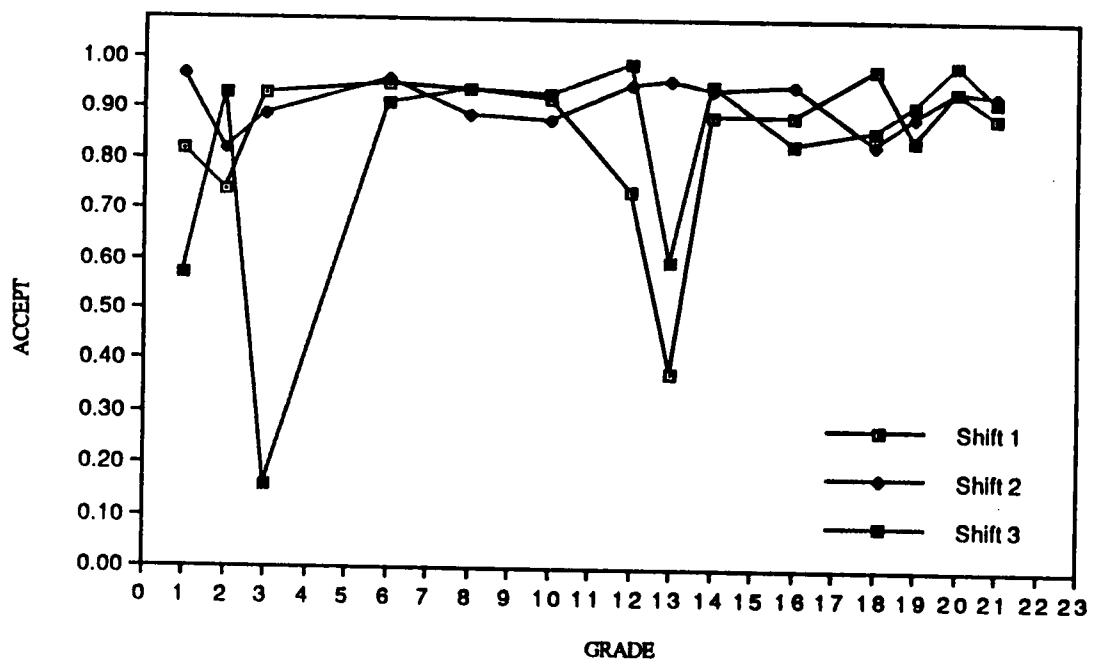


Figure 11. The SHIFT x GRADE Interaction

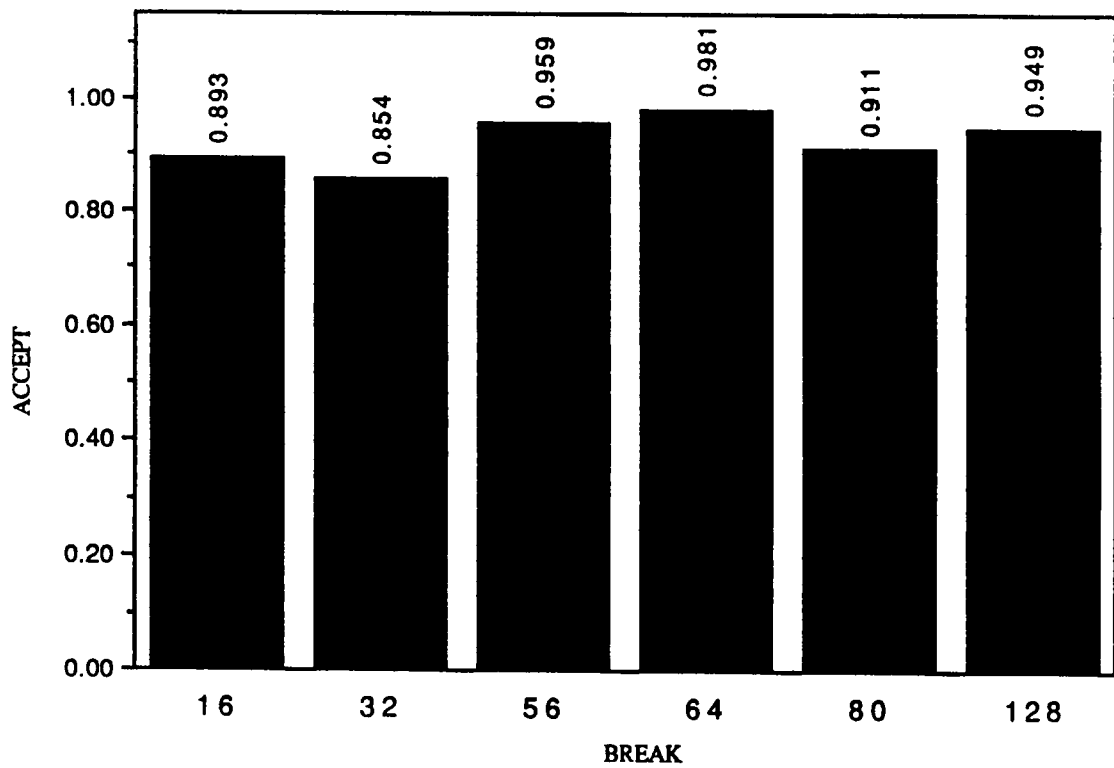


Figure 12. ACCEPT by BREAK

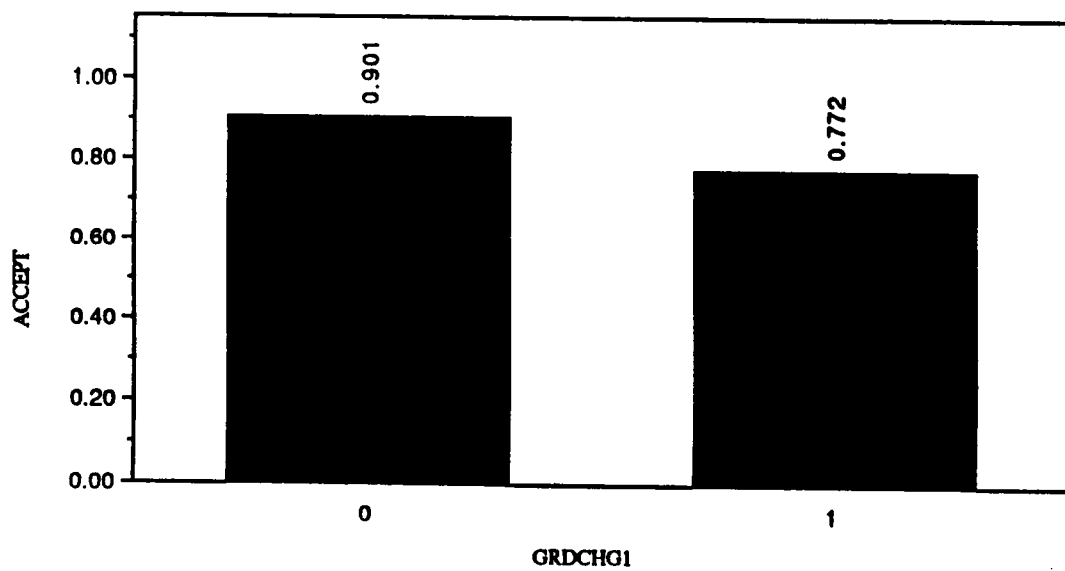


Figure 13. ACCEPT by GRDCHG1

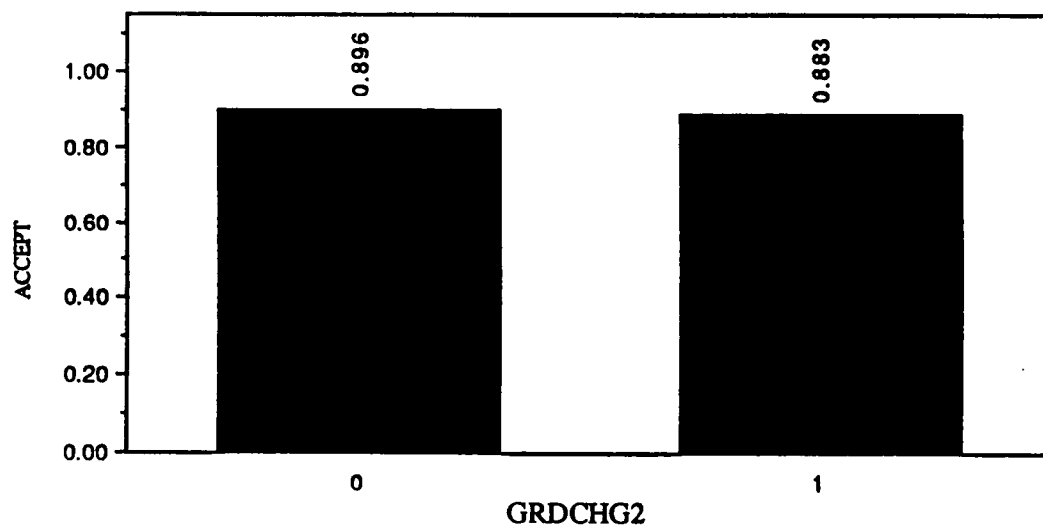


Figure 14. ACCEPT by GRDCHG2

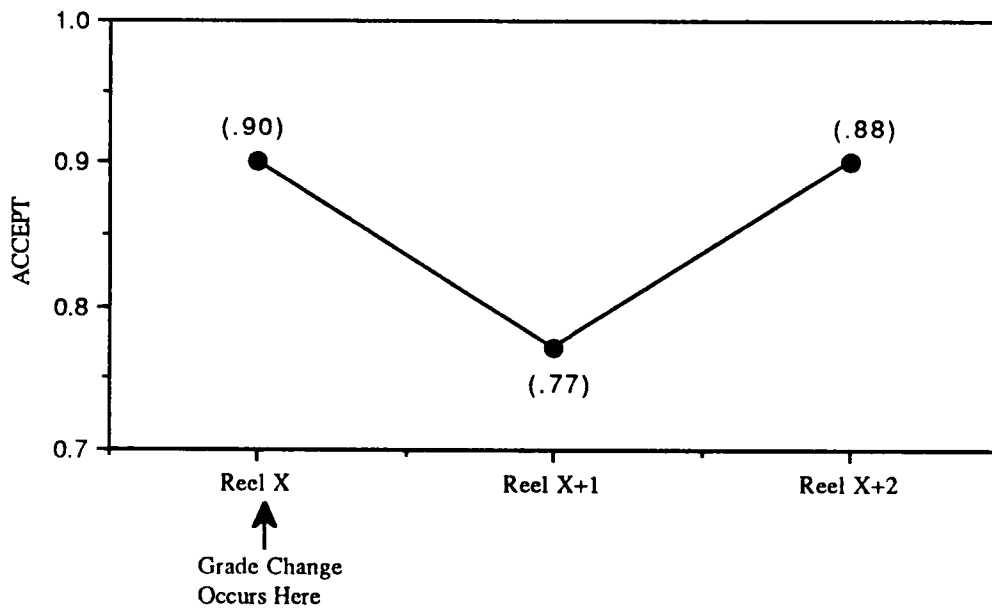


Figure 15. The Effect of Grade Change on Operating Stability

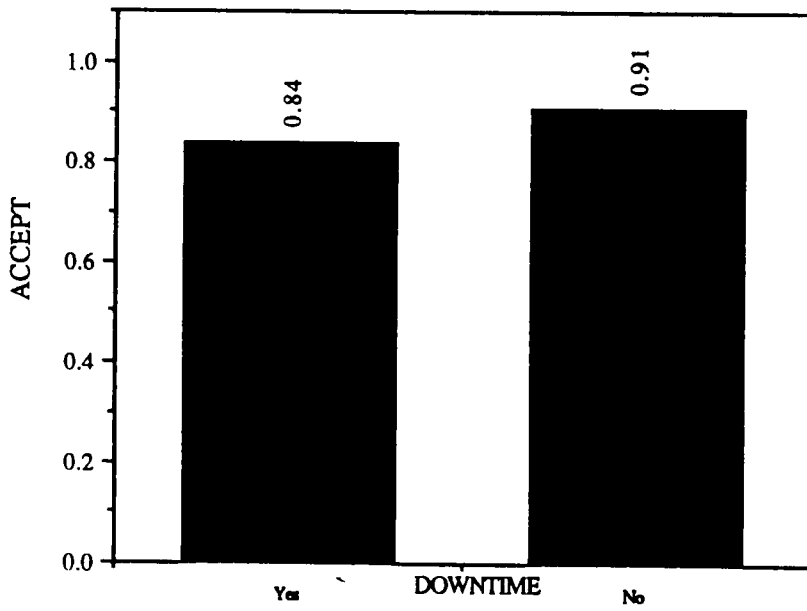


Figure 16. ACCEPT by DOWNTIME

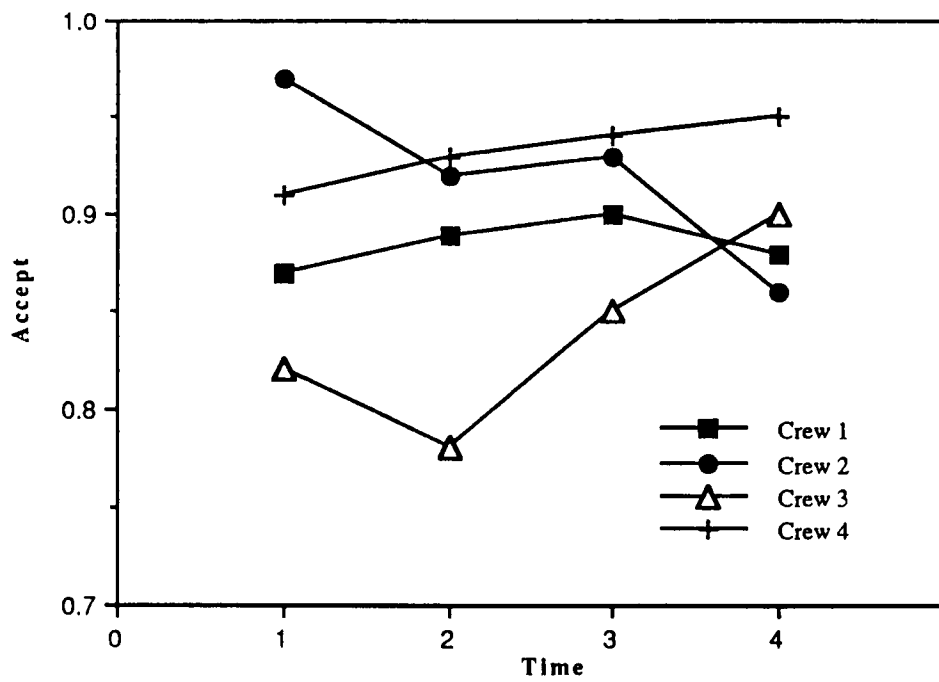


Figure 17. Repeated Measures TIME x CREW

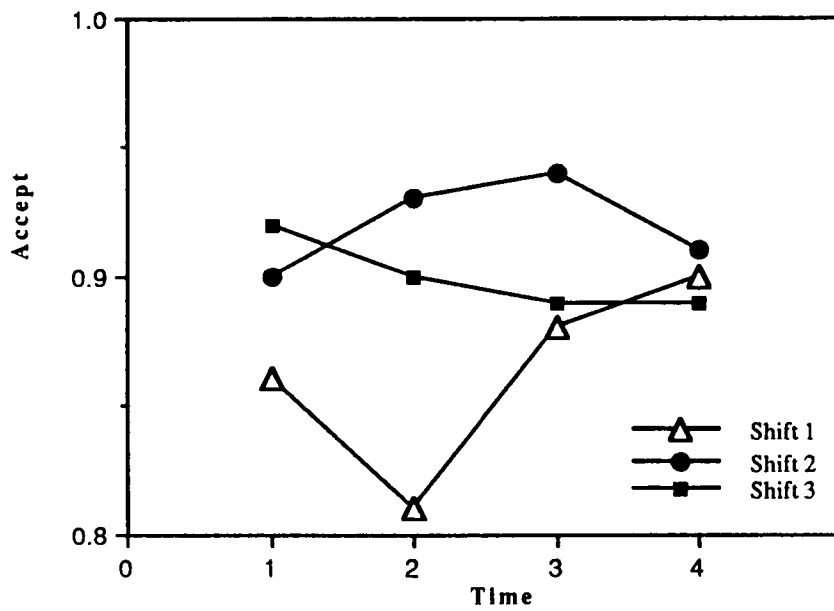


Figure 18. Repeated Measures TIME x SHIFT

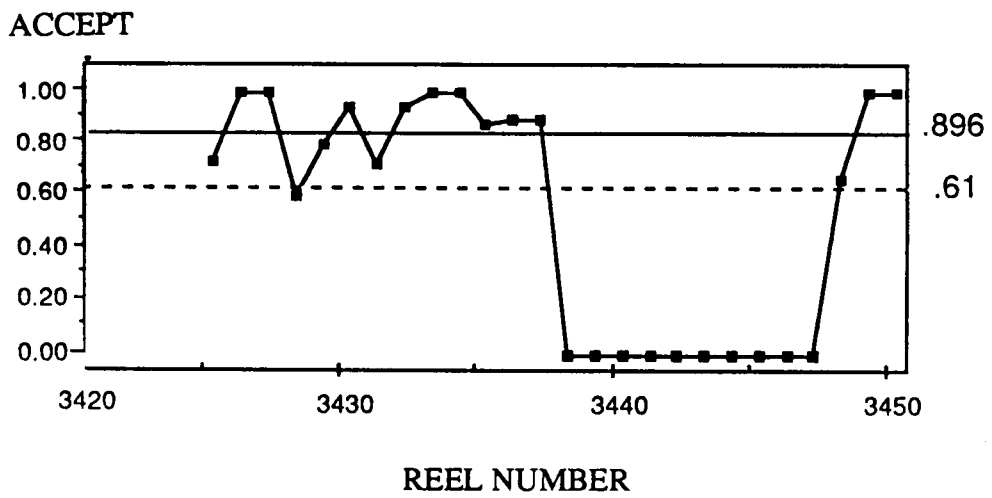


Figure 19. The Individuals Chart, An Excerpt

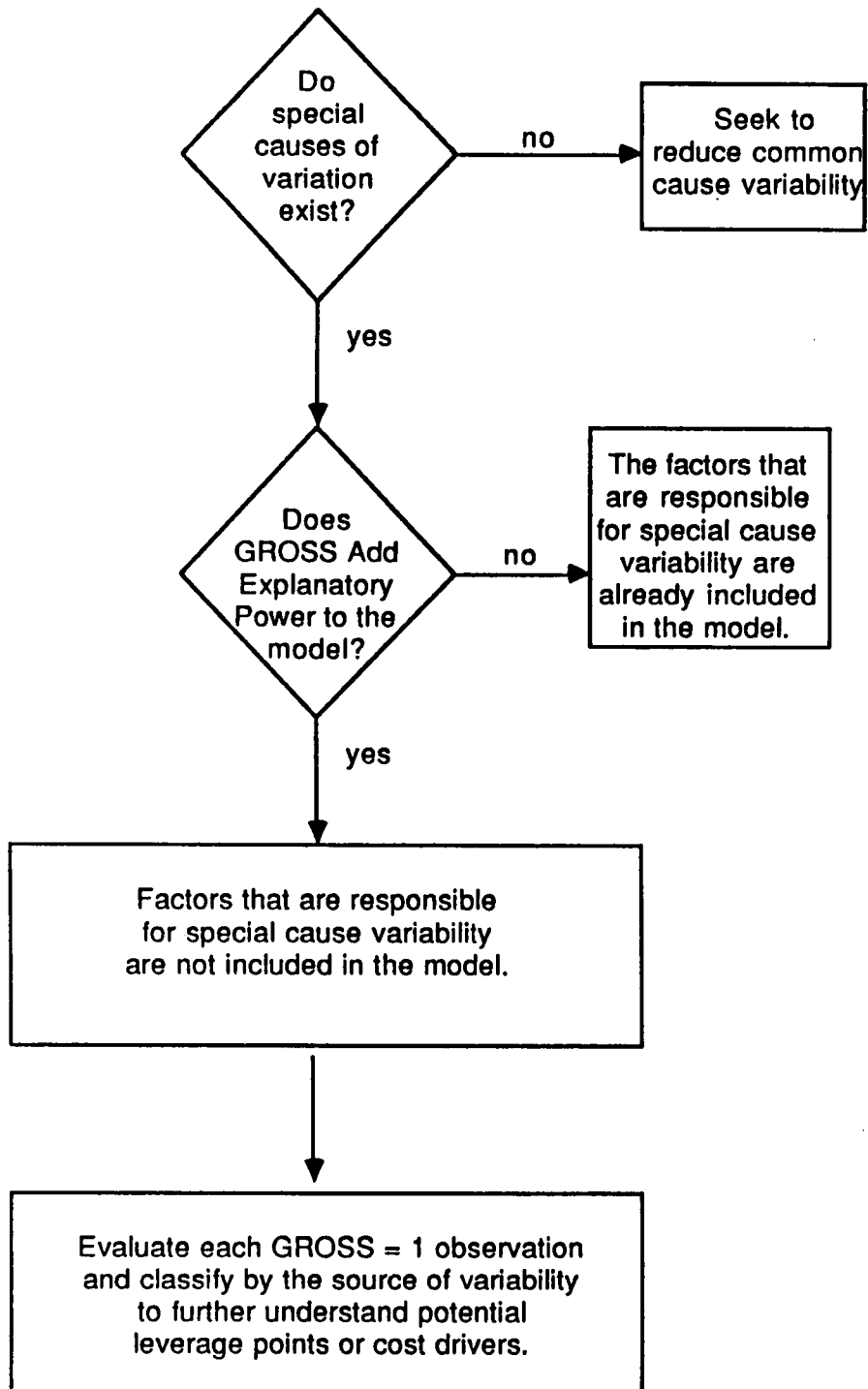


Figure 20. The Logic for Including GROSS in the ANOVA Model

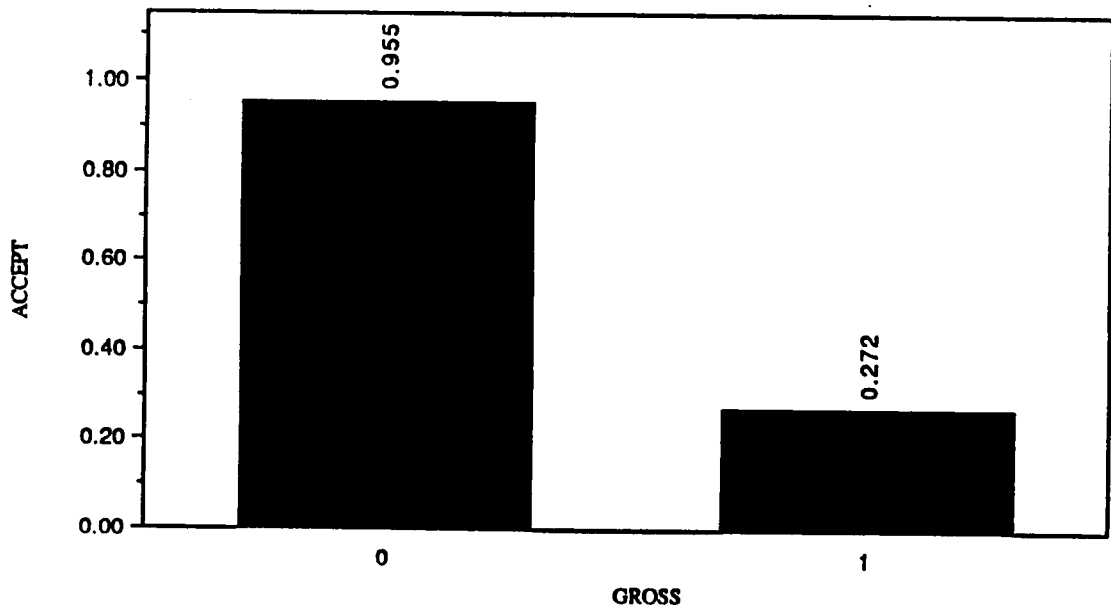


Figure 21. ACCEPT by GROSS

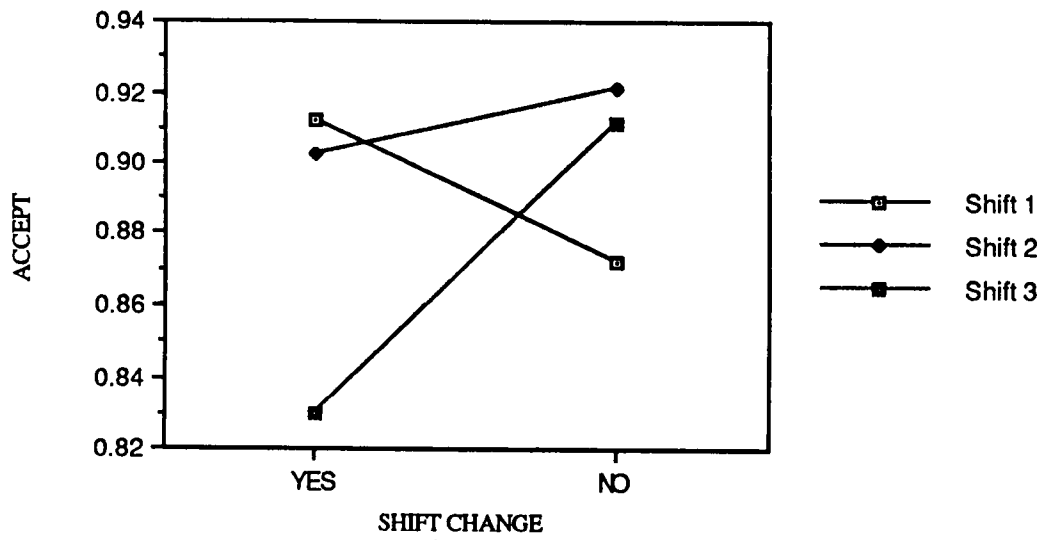


Figure 22. The SHIFT x SHFTCHG Interaction

## VITA

Thomas Lynn Albright, son of C.L. and Frances Albright, was born on January 14, 1955 in Burlington, North Carolina. He attended public schools in Alamance County, North Carolina and was graduated from Southern Alamance High School in May 1973. In August 1973 he enrolled at the University of North Carolina at Greensboro, North Carolina and completed the requirements for a Bachelor of Fine Arts degree in May 1977.

He received the Master of Business Administration degree from California State University in August 1982. He then accepted a position as a staff accountant with Turner and Chamberlain, Certified Public Accountants, in Modesto, California. In September 1985 he joined the faculty of California State University as a visiting lecturer where he taught accounting until September 1987.

He enrolled in the Graduate School at The University of Tennessee, Knoxville in September 1987 and received the Doctor of Philosophy degree in August, 1990. He is a member of the American Accounting Association, the American Institute of Certified Public Accountants, the National Association of Accountants, and Beta Alpha Psi.

He is married to the former Deborah Joan Early of Greensboro, North Carolina.