Optimizing Log Truck Payload Through Improved Weight Control

by

Paul David Overboe

Thesis submitted to the Faculty of the

Virginia Polytechnic Institute and State University

in partial fulfillment of the requirements for the degree of

Master of Science

in

Forestry

APPROVED:

Robert M. Shaffer, Chairman

William B. Stuart

Thomas A. Walbridge

Steven A. Sinclair

April 1987

Blacksburg, Virginia

Optimizing Log Truck Payload Through Improved Weight Control

by

Paul David Overboe

Robert M. Shaffer, Chairman

Forestry

(ABSTRACT)

Trucking of forest products is a very important segment of the harvesting process and it is monitored relatively closely by external sources. Load weight is the focal point of the attention received by log hauling. The optimization of load weights is therefore very important to a logging operation's success and this can be achieved only through adequate gross vehicle weight control.

Methods of load weight control are reviewed and possible applications discussed in this report. Studies were conducted to evaluate the adequacy of load weight control achieved utilizing two quite different methods. A reporting technique which provided loader operators with information about trends in the delivery weights of trucks which they loaded was used to heighten their awareness of problem areas in load weight distributions. This study was conducted at two southern papermills with substantially different truck weight regulation environments. Two separate case studies were conducted on Virginia loggers utilizing on-board electronic truck scales.

Results of the loading study indicated that the passive treatment had affected the behavior of some of the producers studied. The behavioral changes observed generally improved the economic optimization of load delivery weights. The on-board scale studies indicated that the scale systems did perform well in the applications observed. However, the economic benefits associated with use of the scales were negligible for the two producers studied due to a reduction in delivery weights after installation of the scales.

Acknowledgements

I would like to express my appreciation to the members of my Advisory Committee, Dr. Robert M. Shaffer, Dr. Steven A. Sinclair, Dr. William B. Stuart, and Dr. Thomas A. Walbridge, for their assistance on this project. Special thanks go to Dr. Shaffer and Dr. Stuart for their guidance throughout my Master's program. Their suggestions were invaluable in completing this project.

This project was made possible through the cooperation and support of the following organizations: Georgia Kraft Company, Hiwassee Land Company, Mead Paper Company, Union Camp Corporation, Tennessee Valley Authority, and Weyerhaeuser Company. I would like to thank for their support and assistance in this project. Special thanks go to all of the loggers who cooperated in data collection, without their efforts this project would not have been possible.

Sincere thanks go to my fellow graduate students who provided assistance, moral support, and friendship throughout my time at Virginia Tech.

Table of Contents

Introduction 1

Background 1

Importance of Weight Control 3

Methods of Weight Control 5

Objectives 5

Literature Review 7

Load Weight Estimation Techniques 8

Visual techniques 8

Suspension Deflection 9

Weight Calculations 9

Load Weighing Devices 11

On-board Truck Scales 11

Electronic Systems 12

Pneumatic and Hydraulic Systems 20

Loader Weighing Systems 23

Hydraulic Systems 24

Electronic Systems . . . 25
Portable Scales . . . 25
Wheel Scales . . . 26
Axle Scales . . . 27
Platform Scales . . . 27

Methods and Procedures . . . 30
Loading Improvement . . . 30
Study Format . . . 31
Data Analysis . . . 33
Economic Analysis . . . 33
On-board Electronic Scales . . . 34
Study Format . . . 34
Data Analysis . . . 35
Economic Analysis . . . 36

Economic Model . . . 38
General Model . . . 40
Model Adjustments . . . 43
Lost Volume Adjustment . . . 43
Reduced Quota Adjustment . . . 44
Overweight Fine Adjustment . . . 45

Results and Discussion . . . 46
Loading Study . . . 46
Study Description . . . 48
Mill #1 . . . 48
Mill #2 . . . 48

Data Interpretation 50
Mill #1 50
Mill #2 55
Statistical Analyses 58
Comparison of Variances 61
Comparison of Means 61
Kolmogorov-Smirnoff Test 66
Learning Curve 71
Statistical Summary 78
Economic Analysis 79
Assumptions 79
Mill #1 Results 82
Mill #2 Results 84
On-Board Scales Studies 86
Producer #1 86
Accuracy Determination 88
Comparison of Variance 91
Economic Analysis 93
Producer #2 95
Accuracy Determination 96
Comparison of Variance 97
Economic Analysis 100
Discussion 103

Summary and Conclusions 104

BIBLIOGRAPHY 107

Appendix A. Variable Mileage Cost Nomograph **110**

Appendix B. Description of Producers Included in the Loading Studies **112**

Mill #1 112

Mill #2 116

Appendix C. Frequency Distributions for Mill #1 Producers **120**

Appendix D. Graphic Plots of Cumulative Relative Frequency for Mill #1 . . . . **131**

Appendix E. Frequency Distributions for Mill #2 Producers **142**

Appendix F. Graphic Plots of Cumulative Relative Frequency for Mill #2 . . . . **151**

Vita **160**

List of Illustrations

Figure 1. Suspension Deflection Measurement 10

Figure 2. Strain Gauge Load Cell 14

Figure 3. Typical Locations of Load Cells 16

Figure 4. Alternative Locations of Load Cells 17

Figure 5. Pneumatic Lifting Chambers 22

Figure 6. Orientation of Axle Scales 28

Figure 7. Variable Hauling Cost per Ton for Individual Loads 42

Figure 8. Example Weekly Summary for Mill #1 49

Figure 9. Example Weekly Summary for Mill #2 51

Figure 10. Frequency Plot of Gross Weights for Treatment Producer Group (Mill #1) 73

Figure 11. Frequency Plot of Gross Weights for Control Producer Group (Mill #1) 74

Figure 12. Frequency Plot of Gross Weights for Treatment Producer Group, Excluding E (Mill #1) 75

Figure 13. Frequency Plot of Gross Weights for Treatment Producer Group (Mill #2) 76

Figure 14. Frequency Plot of Gross Weights for Control Producer Group (Mill #2) 77

Figure 15. Cumulative Relative Frequency (Producer #1) 92

Figure 16. Cumulative Relative Frequency (Producer #2) 101

Figure 17. Nomographical Prediction of Mileage Costs 111

Figure 18. Frequency Plot of Gross Weights for Treatment Producer A (Mill #1) 132

Figure 19. Frequency Plot of Gross Weights for Treatment Producer B (Mill #1) 133

Figure 20. Frequency Plot of Gross Weights for Treatment Producer C (Mill #1) 134

Figure 21. Frequency Plot of Gross Weights for Treatment Producer D (Mill #1) 135
Figure 22. Frequency Plot of Gross Weights for Treatment Producer E (Mill #1) 136
Figure 23. Frequency Plot of Gross Weights for Control Producer F (Mill #1) 137
Figure 24. Frequency Plot of Gross Weights for Control Producer G (Mill #1) 138
Figure 25. Frequency Plot of Gross Weights for Control Producer H (Mill #1) 139
Figure 26. Frequency Plot of Gross Weights for Control Producer I (Mill #1) 140
Figure 27. Frequency Plot of Gross Weights for Control Producer J (Mill #1) 141
Figure 28. Frequency Plot of Gross Weights for Treatment Producer A (Mill #2) 152
Figure 29. Frequency Plot of Gross Weights for Treatment Producer C (Mill #2) 153
Figure 30. Frequency Plot of Gross Weights for Treatment Producer D (Mill #2) 154
Figure 31. Frequency Plot of Gross Weights for Treatment Producer E (Mill #2) 155
Figure 32. Frequency Plot of Gross Weights for Control Producer F (Mill #2) 156
Figure 33. Frequency Plot of Gross Weights for Control Producer H (Mill #2) 157
Figure 34. Frequency Plot of Gross Weights for Control Producer I (Mill #2) 158
Figure 35. Frequency Plot of Gross Weights for Control Producer J (Mill #2) 159

List of Tables

Table 1. Mill #1, Selected Comparisons Between the History and Study Periods for Treatment and Control Producers 53

Table 2. Mill #2, Selected Comparisons Between the History and Study Periods for Treatment and Control Producers 56

Table 3. Descriptive Statistics for Mill #1 Producers 59

Table 4. Descriptive Statistics for Mill #2 Producers 60

Table 5. F-test Comparing Variance in Gross Weight for the History and Study Periods of Producers at Mill #1 62

Table 6. F-test Comparing Variance in Gross Weight for the History and Study Periods of Producers at Mill #2 63

Table 7. Scheffe's Test for Mean Gross Weights of Producers at Mill #1 64

Table 8. Scheffe's Test for Mean Gross Weights of Producers at Mill #2 65

Table 9. Comparison of Distributions for Mill #1 Producers using the Kolmogorov-Smirnoff Test 68

Table 10. Comparison of Distributions for Mill #2 Producers using the Kolmogorov-Smirnoff Test 69

Table 11. Comparison of Distributions for Treatment and Control Producer Groups using the Kolmogorov-Smirnoff Test 70

Table 12. Fines for Gross Weight Limit Violations 81

Table 13. Mill #1, Margin per Ton Economic Analysis for History and Study Periods of Treatment and Control Producers 83

Table 14. Mill #2, Margin per Ton Economic Analysis for History and Study Periods of Treatment and Control Producers 85

Table 15. Overall Accuracy of Producer #1 Scale System 89

Table 16. Accuracy in Comparison to GVW (Producer #1) 90

Table 17. Overall Accuracy of Producer #2 Scale System 98

Table 18. Accuracy in Comparison to GVW (Producer #2) 99

Table 19. Target Weights and Mean Number of Loads Delivered per Week for Mill #1 Producers 113

Table 20. Target Weights and Mean Number of Loads Delivered per Week for Mill #2 Producers 117

Table 21. Distribution of Gross Weights for Treatment Producer A (Mill #1) 121

Table 22. Distribution of Gross Weights for Treatment Producer B (Mill #1) 122

Table 23. Distribution of Gross Weights for Treatment Producer C (Mill #1) 123

Table 24. Distribution of Gross Weights for Treatment Producer D (Mill #1) 124

Table 25. Distribution of Gross Weights for Treatment Producer E (Mill #1) 125

Table 26. Distribution of Gross Weights for Control Producer F (Mill #1) 126

Table 27. Distribution of Gross Weights for Control Producer G (Mill #1) 127

Table 28. Distribution of Gross Weights for Control Producer H (Mill #1) 128

Table 29. Distribution of Gross Weights for Control Producer I (Mill #1) 129

Table 30. Distribution of Gross Weights for Control Producer J (Mill #1) 130

Table 31. Distribution of Gross Weights for Treatment Producer A (Mill #2) 143

Table 32. Distribution of Gross Weights for Treatment Producer C (Mill #2) 144

Table 33. Distribution of Gross Weights for Treatment Producer D (Mill #2) 145

Table 34. Distribution of Gross Weights for Treatment Producer E (Mill #2) 146

Table 35. Distribution of Gross Weights for Control Producer F (Mill #2) 147

Table 36. Distribution of Gross Weights for Control Producer H (Mill #2) 148

Table 37. Distribution of Gross Weights for Control Producer I (Mill #2) 149

Table 38. Distribution of Gross Weights for Control Producer J (Mill #2) 150

Introduction

Background

The transport of raw forest products, from the woods landing to the mill, is somewhat unique from the transport of many other commodities. Wood is a very heterogeneous product, whose weight per given volume is affected by the size of the stems making up the volume, species, density, and moisture content. In addition, wood is loaded onto trucks at remote woods landings, usually without the aid of weighing devices, making it difficult to determine payload. Most log trucks travel over public roads enroute to mills or other delivery points and are subject to state and federal weight regulations applying to those roads. Truck weight laws are complex and often stringently enforced with regard to log truck weights.

Transporting pulpwood or sawlogs from the woods to a primary processing point by truck is very common. In the south, 64 percent of the pulpwood received by mills was delivered by truck in 1983 (APA, 1984). The importance of trucking is not expected to decrease in the near future. Trucking is subject to relatively high regulation when compared to other phases of timber harvesting. Goals of this regulation include protection of the public and roads, and vehicle weight limits are a major type of regulation. Enforcement is carried out by law enforcement agencies and the wood products industry itself.

Law enforcement responsibilities fall primarily on state and federal governments. Federal policies are consistent from state to state but tend to be inconsistent in terms of their objectives. They are intended to provide uniformity for interstate commerce, protect highway and bridge conditions, and improve safety, while at the same time increase transportation productivity and stabilize railroad markets (Road Research Group, 1982). State regulations vary significantly from one state to the next as well as from federal regulations. Many states have special regulations which apply to log trucks of various configurations, hauling wood in specific forms. Beardsell (1986) provides a summary of weight restrictions applicable to vehicles hauling timber in the southeastern United States.

Many mills in the southeast have adopted policies which limit the gross weight of log trucks delivering to them. Examples of these policies are, no payment for the weight of wood over a specific gross vehicle weight and reduced quota for the delivery of excessively overweight loads. Mills have adopted restrictive policies for several reasons including attempts to improve the image of the forest products industry, as a result of pressure from law enforcement agencies, and to avoid potential law suits associated with overloaded vehicles delivering to them which are involved in accidents.

A fine resulting from an overweight load or being penalized by a mill can be expensive but failing to maximize the legal payload may be equally important under certain conditions. Since trucking is generally considered the single most expensive phase of logging, inefficiency in this activity can cause serious financial loss. With the exception of loads comprised almost exclusively of small or low density stems, most semi-trailers designed for log hauling have bunk areas capable of holding a volume of wood large enough to cause gross vehicle weight to exceed legal limits. A logger is therefore continually faced with the challenge of maximizing payload without exceeding legal weight limits.

Importance of Weight Control

Given the importance of trucking in the forest products industry, related legal constraints can substantially affect wood supply economics. As a result of the variability of the product, conditions under which it is loaded, and the diverse array of regulations confronted, individuals involved in the trucking of raw forest products have difficulty satisfying all of the weight-related regulations, while optimizing their financial returns. Although difficulties in regulation compliance are especially significant in the logging industry, they are not limited to it. Marlin, et. al. (1980) indicated that 22% of all loaded tractor-trailers exceeded state weight limits. The Road Research Group (1982) reported results of a study conducted by the University of Pennsylvania which found that one third of tractors with semi-trailers were illegally overweight on gross and axle weights.

Several significant factors are associated with overweight trucks, most but not all are negative. One 80,000 pound truck produces road damage equivalent to 9,600 passenger cars weighing 4000 pounds each (Marlin et. al. 1980). Damage to pavement, associated with heavy load weights, increases exponentially as axle weights increase. The American Association of State Highway Transportation Officials (1978) provided the following comparisons of road damage versus axle load. In terms of the damage caused by one pass, one 36,000 pound tandem axle load weight is equivalent to two 18,000 pound single axles, a direct correlation. However, the damage associated with a tandem axle weight of 42,000 pounds is equivalent to four 18,000 pound single axles and a 61,000 pound tandem to twenty 18,000 pound single axles. This supports the conclusion that road damage does increase exponentially as axle weight increases. Bridges are equally subject to damage caused by heavy loads due to their floor design.

Results of a study conducted by the U.S. Department of Transportation, presented by the Road Research Group (1982), provided a different viewpoint on road damage associated with heavy trucks. The purpose of the study was to estimate the benefits and costs to the nation as a result of theoretical changes to Federal weight limits from 1981 through 1985. In formulating the estimates, the assumption was made that roads and bridges could and would be repaired as needed, although funds for doing this were not identified. It was found that heavier and larger trucks increased transportation productivity, resulting in cost savings greater than the added costs of highway and bridge repairs. The transportation cost savings was expected to be reduced significantly in the absence of sufficient funds for the anticipated increased road maintenance requirements. A suggested source of funds would be the development of a highway use tax which varies proportionately with gross vehicle weights. The highest weights considered in this study were 22,400 pound single axles and 36,000 pound tandem axles. It was at these weights that the cost savings had the highest net present value.

The weights considered in the above study exceeded the legal limits in most states. Although excessively heavy weights can reduce the life of vehicles, especially for off-road travel, it reinforces the conclusion that it can be economically beneficial to maximize the legal load on vehicles. This can be accomplished only through the ability to control load weight. It should be noted that some operators feel vehicle life can be greatly extended by hauling lighter loads. They feel the returns associated with increased useful life exceed the opportunity cost of hauling light loads.

Safety is another factor closely tied to gross vehicle weight. Heavy weights affect the steering and reduce the maneuverability of trucks, require greater braking distances, and result in greater frequency of tire failure (Marlin et.al. 1980). Although a dollar value can be placed on highway damage, it is impractical to attempt it on human life. Therefore, an increase in maintenance and safety efforts should surely accompany any increase in load weight. This is particularly true in logging due to the rough roads on which vehicles are often operated.

Several load weight estimation techniques are available which are intended to help loggers attain optimum legal payloads. Each has strengths and weaknesses in relation to the regulatory environment in which they are used and the type of logging and trucking system to which they are applied.

Methods of Weight Control

Methods of weighing loads or estimating load weight, while in the woods, must satisfy several criteria which are based primarily on environmental conditions and the nature of logging. Weather conditions are often adverse and terrain variable. Any electrical, pneumatic, or hydraulic requirements must match the capabilities of typical harvesting and trucking equipment. All components must be durable, and those which are not permanently mounted on harvesting equipment must be easily transported and installed due to the frequency of moves.

The range of techniques available can be divided into two groups, those requiring specialized equipment and those not. Methods which do not utilize specialized equipment are based on visual measurement or observation and generally require increased operator training. They are relatively inexpensive but the accuracy and consistency of estimates are subject to human error and bias. Specialized weighing equipment can be more accurate and consistent but the capital investment can be high. The three primary categories of weighing devices are; (1) those mounted on the log truck, (2) those mounted on the loader, and (3) those which operate independently of the harvesting equipment. Several techniques of truck weight estimation or determination which can be utilized by logging crews while at the woods landing are reviewed and possible applications discussed.

Objectives

The objectives of this research are; (1) to identify the benefits of increased ability to control load weight, and (2) to determine the technological and economical suitability of visual weight estimation and weight determination using on-board electronic truck scales, for the purpose of optimizing payload. Results of this study should provide loggers or contract truckers with information to aid in selecting the weight control method best satisfying their needs. Mills will also receive information which is helpful in evaluating the effects of restriction policies and limiting quotas on loading and hauling strategies.

Literature Review

Transporting wood from the harvest site to the mill is usually considered the most costly phase in logging. It has been estimated that it comprises 50 to 60 percent of the total logging cost (Conway, 1982). Inefficiency in this phase of logging will greatly reduce an operation's economic success. For this reason, in addition to legal regulations and mill applied restrictions affecting log transport costs, it is very important to optimize payloads on log trucks without exceeding weight limits.

A study conducted by Beardsell (1986) at mills in South Carolina and Georgia examined the effects of underloading and overloading on ton-mile hauling efficiency. If all loads were delivered at the legal gross weight limit, 1.0 percent and 11.1 percent reductions in ton-mile costs would be achieved for the mills, respectively. The reduction is especially significant for the Georgia mill where law enforcement efforts tend to be rather vigorous, resulting in the tendency of loggers to underload their log trucks

To optimize load weight, a logger must improve his ability to control log truck load weight. Several methods of weight control are available, ranging from simple visual methods to complex mathematical formulae to sophisticated mechanical or electrical devices.

Load Weight Estimation Techniques

Visual techniques

Visual weight estimation techniques are simple and inexpensive but tend to be the least accurate weight control methods available to loggers. Most loggers use them to some degree every time they load their trucks, for example, the height of the load compared to the height of the trailer's standards. Additionally, the counting of stems on some loads may yield a comparative estimate of payload weight. Although these techniques may aid in weight control, there is often little consistency in the relationship of size and weight of a load. Stems of identical size can vary significantly in weight, due to growth characteristics of the tree, species, moisture content, time of year, and vigor (Lewis, 1985).

When combined with a sincere desire for improvement, visual weight estimates can be effective in improving the distribution of load delivery weights. A west coast logging company improved the percent utilization of legal payload on company log trucks through goal setting. Prior to initiation of the study conducted by Latham and Locke (1979) in the early 1970's, loaded trucks were arriving at the mill with only 58 to 63 percent utilization of the legal payload capacity. The truck drivers were allowed to set a goal for the percent utilization they felt could be achieved and they selected 94 percent. After three months the 90 percent level was exceeded and they remained at or above this level for seven years, until publication of the article. This improvement was attained with no monetary rewards or negative actions for failure to achieve the goal.

Suspension Deflection

Load weight estimation techniques which consider only the size or volume of the load tend to be significantly less accurate than those with a direct relationship to load weight. This is primarily due to the elimination of a personal judgment factor (Husch, et.al., 1972). A simple technique which some loggers report using is a measure of vehicle suspension deflection as the load weight is increased. The vertical distance between the vehicle frame and the leaf spring suspension is measured as shown in Figure 1. As the weight of logs is added, this distance is reduced. When the vertical distance equals a predetermined value, the approximate load weight is known. Calibration of this method is a rather tedious process which must be done and periodically checked for each truck or tractor-trailer combination. Although some loggers report that using such a method allows them to consistently estimate load weights to within 2000 pounds, other loggers report virtually no success with this method. Use of such a method would depend on the type of suspension in use, the terrain operated in, and the level of commitment to the method.

Weight Calculations

The next level of sophistication in log truck weight estimation is the combination of product measurements and weight equations. Prior to being loaded on a truck, diameter and length measurements must be taken for each stem. These figures are entered into a green weight prediction equation to determine the expected weight of each individual stem. Green weight prediction equations commonly appear as follows (Burkhart and Clutter, 1971):

$$G.W. = b_0 + b_1 DBH^2 H$$

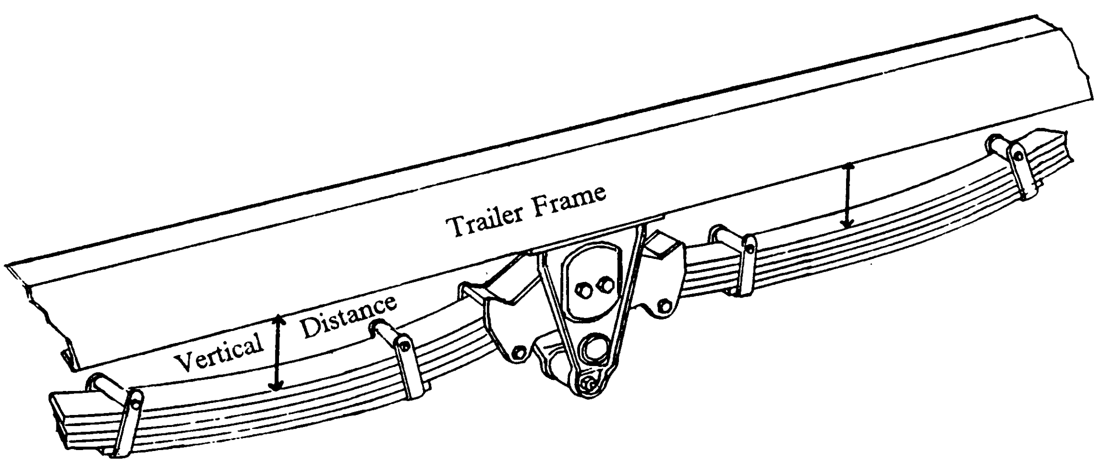


Figure 1. Suspension Deflection Measurement

The b_0 and b_1 coefficients have been estimated for different tree species grown under different conditions by several researchers and are readily available (Burkhart and Clutter, 1971; Burkhart, et.al., 1972 A; Burkhart, et.al., 1972 B).

This method of weight determination is quite time consuming and probably infeasible for use on actual logging operations. The time required to collect the necessary information in most instances would cause delays in the loading process which could reduce the overall production of the operation. In addition, use of such formulae may exceed the patience of loggers or loader operators under field conditions. If no steps are taken to adjust for the variation in growth and moisture characteristics of individual stems, the use of such formulae is susceptible to the same errors as simple visual estimates.

Load Weighing Devices

The most reliable methods of weight determination are those utilizing a weight scale of some type. Three basic categories of scales are appropriate for use at remote logging locations: (1) On-board log truck scales, (2) loader mounted scales, and (3) portable pad scales. Each type of scale will be described in the remainder of this literature review.

On-board Truck Scales

On-board scales are mounted on a truck and determine the weight of the load. Therefore, these scales do not weigh the truck itself but combine a predetermined truck tare weight with the determined payload weight. Depending on the location of the load sensing components, axle weights as well as gross and net weight can be provided by the system.

Studies have shown that the use of truck mounted on-board scales can significantly improve load weight distributions. Conway (1982) reported on a case study where a 10 percent increase in payload was obtained through the use of on-board scales. Other studies have suggested that increases in payload average 15 percent (Anonymous, 1981). Increases may not occur in every case as they are a function of the loading strategies before and after scale installation, as well as the ability to estimate load weight without scales. The primary benefit of scale use is the ability to consistently control load weight, allowing a logger to load to whatever weight desired. Approximately 90 percent of all log trucks in the coastal Pacific northwest are presently equipped with some type of on-board scale system (Lodec, Inc., no date A).

There are three types of on-board scale systems, electronic, hydraulic, and pneumatic. Discussion of the components and recommended use of each type of system will follow.

Electronic Systems

Electronic on-board truck scales were introduced in 1970. They were originally designed for the logging industry but many types of trucks now use them. The primary load sensing component of electronic scales is a strain gauge or a pressure transducer. Each of these are small electronic devices which convert a mechanical force to an electrical equivalent. The metallic components of these devices are temporarily deformed as physical pressure is applied (Blomquist, 1970). The deformation causes a change in resistance which alters an electrical current. Change in the electrical current is measured and converted to a weight reading.

When strain gauges are used to sense the load weight, they are installed in high strength steel bars, and the combined unit is called a load cell (Figure 2). The load cell is positioned on the truck so as to actually support the weight of the load. If transducers are used, they are attached to the surface of suspension members such as walking beams, through trunnions, or steering axles and do not support any portion of the load weight. Instead, they sense the stress or deflection of suspension components which do support the load (Structural Instrumentation, Inc., 1984). Pottie and Sinclair (1985) suggested that transducers are subjected to less stresses because they do not support the load, leading to an increase in mechanical reliability

A summary of the method of operation will be helpful in understanding on-board electronic scale systems. When the system is in operation, a small electrical current continually passes through the cabling and load cells. The weight of logs added to the bunks causes the load cells to bend very slightly, altering the internal strain gauges' resistance to electrical current. Current passing through them is altered, the change is measured and converted to a weight reading by the indicator (Lodec, Inc., no date A). The indicator readout is provided in gross and net weight for the front or rear pairs of load cells, individually or combined. The reading is most commonly in 100 pound/kilogram increments but can be narrowed further by more expensive indicators. Thus, such a scale system provides the trailer's tandem axle weight, and the combined weight of the tractor's steering and drive tandem axles. Based on the location of the fifth wheel in relation to the tractor's tandem drive axle, the percentage of weight applied to the fifth wheel which is transferred to the steering axle can be determined. This can be determined using the theory of moments or if scales designed for weighing individual axles are available, by weighing each axle to determine the percent of gross weight applied to the steering axle.

The on-board electronic scales discussed here will be those utilizing load cells unless otherwise noted, as they are much more commonly used. An on-board electronic scale system has three primary components: Load cells, a digital indicator, and cabling connecting all components. Load cells are positioned at primary load bearing points of the tractor and trailer or straight truck. On conventional tractors and rigid frame trailers commonly used in southeastern logging, these points and the number of load cells are as follows: A load cell is located at each of the two fifth wheel mounting brackets and one between the trailer frame and the equalizer bracket on each side of the trailer rear tandem axle assembly (Figure 3). The total number of load cells is then four. Alternative locations include two load cells mounted on the king-pin plate of the trailer, or at the point

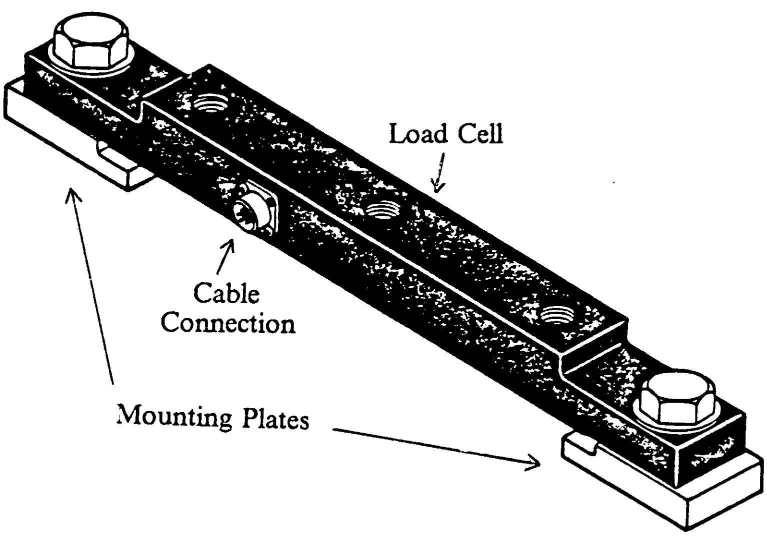


Figure 2. Strain Gauge Load Cell

where the log bunks are attached to the trailer frame (Figure 4). Such positioning allows the scale system to be independent of the tractor except for a power supply.

The steel load cells are environmentally sealed to prevent damage to the electrical strain gauges by water or other contaminants (Lodec, Inc., no date A). Load cells are mounted by weld and/or bolts, depending on the installation point on the truck and cell design. Structural Instrumentation, Inc. (no date) provides load cells already attached to fifth wheel mounting brackets and equalizer hangers. Manufacturers combine the strength and reliability of the load cells with special safety features to prevent damage to the truck in the event of cell breakage.

The digital indicator is generally located in the cab of the tractor or truck at a convenient, visible location on the dash or roof. If the scale system's load sensors are independent of the tractor, the indicator can be located in a weather resistant case on the trailer frame. The digital indicator, which generally powers the rest of the scale system, is powered by the 12 volt DC tractor electrical supply. Power is carried to load cells by a series of heavy duty, environmentally sealed cables. Lodec, Inc. (no date A) powers the load cells with an electrical current of 10 volts AC originating at the indicator. This conversion from DC to AC is intended to reduce the effects of temperature and noise, and additionally does not require any amplification to carry the signal to the rear load cells. Structural Instrumentation, Inc. (1984) does not convert the signal to AC, but instead reduces the DC voltage and utilizes an amplifier to aid in carrying the signal from the rear load cells to the indicator. The Vulcan Scale System from Lake Goodwin Scale Co., Inc. (no date) utilizes one "coder" unit on the tractor and one on the trailer to power the load cells. These coders are also used to convert the signal from analog to digital and increase the power before it is sent to the meter in the cab. This is intended to improve the accuracy by reducing interference and aid in the ability of the current to penetrate moisture and dirt.

On-board electronic scale systems utilizing transducers operate in the same manner as those equipped with strain gauge load cells, with the exception of the location and function of the load

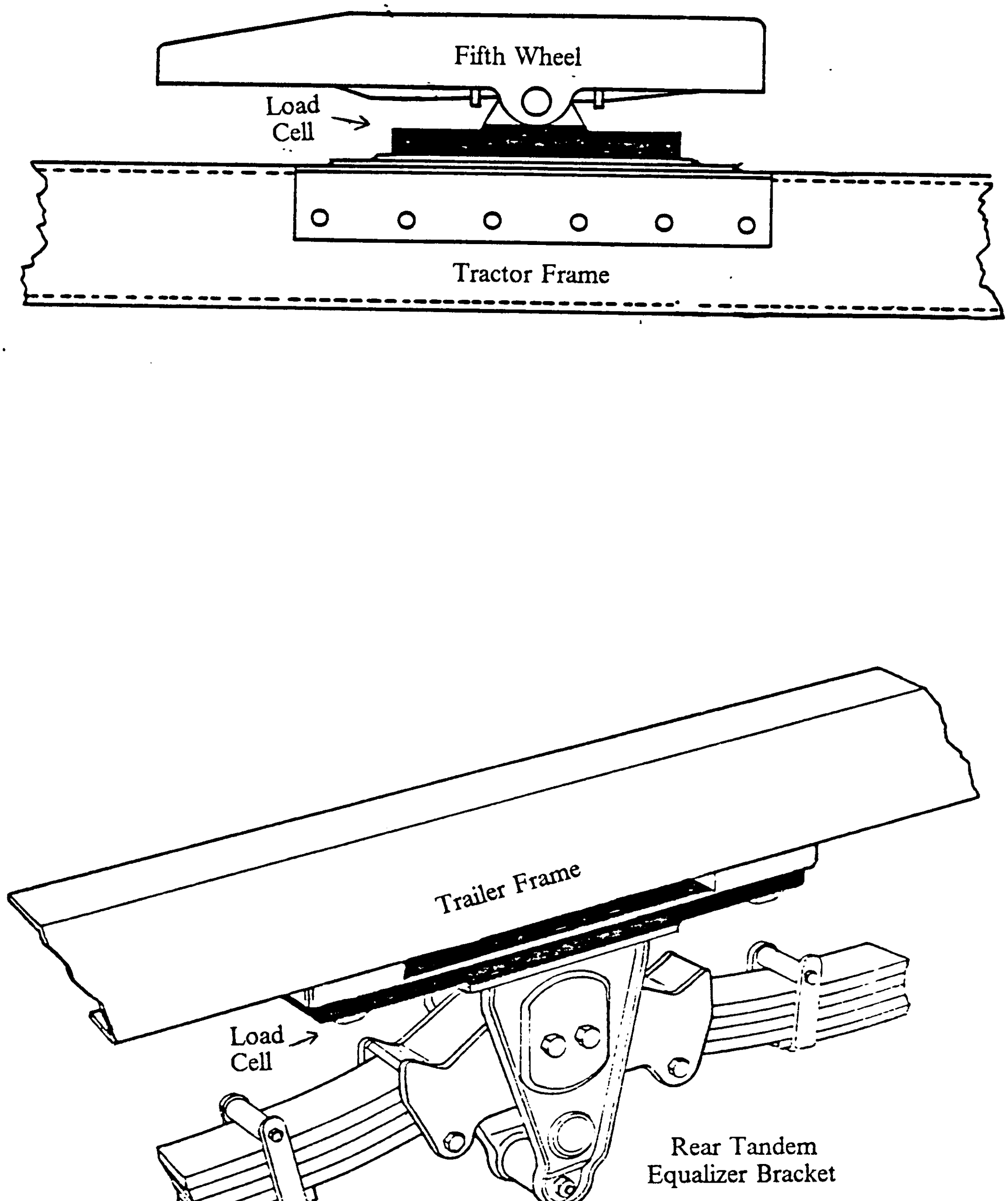


Figure 3. Typical Locations of Load Cells

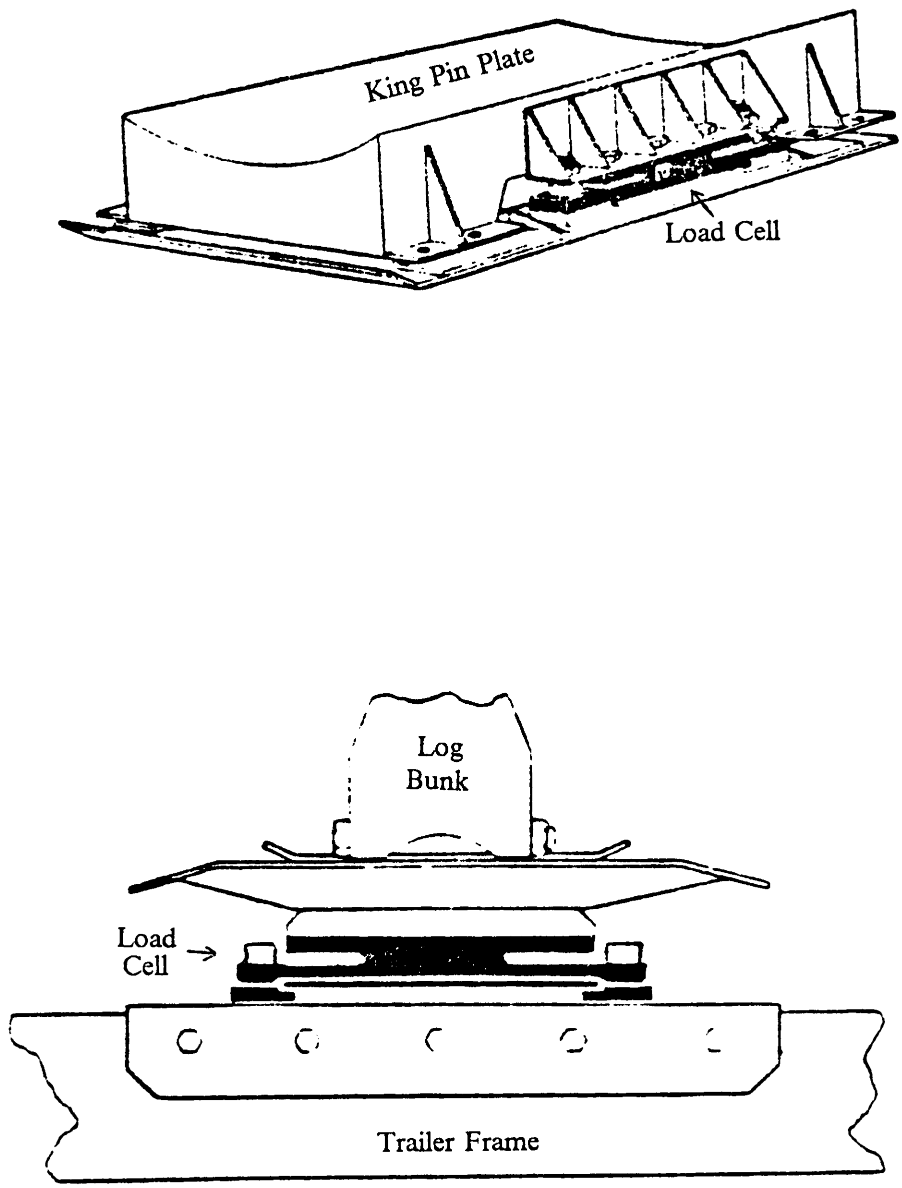


Figure 4. Alternative Locations of Load Cells

sensors mentioned earlier. The cabling and indicators are essentially the same. The use of transducers is more common on pole trailers, straight trucks, or chip vans (Anonymous, 1981).

Accuracy of on-board electronic scale systems, as reported by the manufacturers, is within ± 1.0 percent of the actual weight on fully loaded trucks located on level ground. Sloping ground affects the accuracy only slightly according to manufacturers. Lodec, Inc. (no date A) states that a 6 percent side slope will reduce accuracy to 1.5 percent and a 6 percent end to end slope will result in a 1.0 percent transfer of weight when compared to the indicator readings for the front and rear load cell pairs. To help ensure accuracy of the scales, load cells are factory calibrated to reduce calibration requirements at the time of installation. However, systems must be calibrated for the specific truck or tractor-trailer on which they are to be used, at the time of installation and periodically checked thereafter. This process requires a minimum amount of time and effort. The cost of standard electronic on-board scale systems is $4000 to $5000 installed. Systems can be installed in most machine shops where welders are present.

Maintenance requirements of electronic on-board scale systems are not large but like any equipment used in the logging industry, preventive maintenance is important. Load cells or transducers should be kept free of debris such as branches, ice, or excessive dirt build-up, as these may reduce their ability to function properly. Load cells and any welds or mounting bolts should be periodically inspected for cracks or improper torque. Pottie (1986) found that cracks in load cells significantly reduced the accuracy of scale systems although manufacturers did not expect it to. Indicators are typically located in the cab, protected from the elements, although intense sunlight may cause damage to any electrical component. Lodec, Inc. (no date B) reports in their owners manual that only about 20 percent of all system failures are attributable to indicators.

The cables connecting system components are the location of the majority of system failures and some accuracy problems. Cables are relatively easily broken by branches or contact with sharp objects on the truck. It is imperative that all cables are securely attached to the tractor or trailer frame and excess cable is stored in a safe place. Connections between the tractor and trailer and at load sensors are quite susceptible to damage. Care should be taken to keep these connections dry and free of debris. Under severe winter conditions, effects of moisture and temperature on the cables and connections can reduce scale system accuracy. Connections should be kept covered when not in use and periodically cleaned and sprayed with an electrical contact cleaner (Structural Instrumentation, Inc., 1984). Permanent or semi-permanent connections should be kept tight and sealed with a silicone caulk.

Structural Instrumentation, Inc. (no date) reports the development of a "Signal Communicator" which eliminates the cable in the tractor-trailer connection. The signal is transmitted from the load cells or transducers through existing wiring on the vehicle and is decoded at the meter. This is claimed to reduce the frequency of some system failures.

Pottie (1986) reported on the use of radio telemetry to eliminate the cables connecting load cells on the trailer to the indicator in the tractor cab. This system utilizes a signal transmitting unit on the trailer and a receiving/decoding unit in the tractor cab. After the signal from the trailer load cells is transmitted to the receiving decoding unit, it is converted back to the standard electrical signal used in electronic scale systems. This is sent by cable to a standard digital indicator for readout. Components of the experimental telemetry system were developed by RMS Industrial Controls Ltd. and are still under study. Preliminary results indicate the system is mechanically more reliable than standard systems utilizing reach cables between the trailer load cells and the tractor. Accuracy of the system appears to be comparable to standard systems and possibly improved under adverse weather conditions.

Application of telemetry to transmit the signal from the truck to the loader cab is also being studied. Preliminary successes indicate that this technique could be used to improve communication during the loading process.

Pneumatic and Hydraulic Systems

On-board truck scales utilizing hydraulic or pneumatic pressure offer a low cost alternative to electronic on-board scales. However, popularity of these scales has been reduced due to the greater accuracy and reliability of electronic scales.

The two main categories of pneumatic or air scales are those which work in combination with air bag suspensions and those which utilize lifting pads attached to the log bunks. Air scales which determine load weight by measuring pressure changes in the air bag suspension have two levels of sophistication. The first level utilizes a simple pressure gauge to directly read the change in air pressure associated with the load weight. Such a system typically requires two gauges, one tied into the tractor's air suspension and one tied into the trailer's suspension (Cascade Trailer and Equipment, 1973). The gauges are generally located on the tractor and trailer frames at a point near the two respective axle assemblies. Accuracy is reported to be within 3 to 4 percent of true under good operating conditions and systems cost approximately $300 per axle assembly.

The second level of sophistication in scales for air suspensions utilize a pressure transducer to convert changes in air pressure to an electrical equivalent. This electric current is sent to an indicator in the cab of the tractor, where it is converted to a digital weight reading (Lodec, Inc., no date A). Scale systems of this type are quite similar to the electronic on-board scales in weighing features, the primary difference lying in the method of sensing load weight. The cost and accuracy are comparable to standard electronic on-board scales.

The second category of air scales are those which utilize air powered lifting chambers (Figure 5). Two chambers are located under each log bunk of the truck or semi-trailer. Air is input to the chambers until the pressure is sufficient to temporarily lift the load from the trailer frame (Schneider, 1984). Bleeder valves are used to limit the pressure entering the lifting chambers to the exact amount necessary to lift the load (Dana Corporation, 1984). The air pressure required to lift the load is measured directly on gauges, or through the use of pressure transducers converted to an electrical impulse for read-out by a digital indicator. The entire scale system utilizing lifting chambers can be controlled and read from the cab of the truck, due to the presence of lift control valves located in the cab.

Pottie and Sinclair (1985) identified the following problems associated with the use of scales utilizing pneumatic lifting chambers. Air pressure in excess of the standard 125 psi available on most trucks is required on slopes and when lifting very heavy loads. The pressure limiting bleeder valves require careful cleaning and lubrication to avoid failure. If failure does occur, diaphragms in the lifting chambers can be damaged. Operators also reported difficulty connecting air hoses in cold weather.

The final alternative for on-board weighing is through the use of hydraulic pressure. Weighing systems in this category use lifting chambers, similar to those discussed for pneumatic weighing systems. These are generally located under the log bunks and are used to temporarily lift the entire load a short distance for weight measurement purposes. With hydraulic scales, the weight is generally determined by directly reading the pressure increase required to lift the load on a dial type gauge. One gauge is located near each bunk, requiring the driver to leave the cab to record the weight readings.

Problems associated with hydraulic scales are similar to those for pneumatic scales. The quick disconnect fittings on the hydraulic lines can allow dirt to enter the system making the scales inoperable. The height limiting valves also periodically fail causing damage to the lifting components (Pottie and Sinclair, 1985).

Under actual logging conditions pneumatic and hydraulic weighing systems can be used to determine the weight of loads with considerably more accuracy than can be obtained by visual estimation or weight calculations. With care and practice such scale systems are reported by the manufactures to obtain accuracies to within 3 percent of the actual weight for full loads. However,

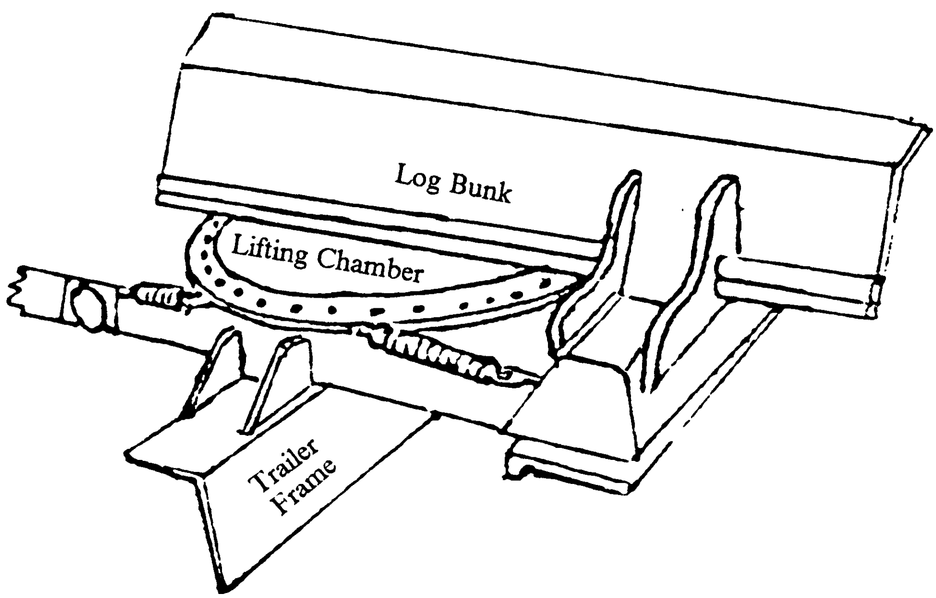


Figure 5. Pneumatic Lifting Chambers

the accuracy of pneumatic and hydraulic scales is more adversely affected by environmental factors than it is for electronic scales. Many of these systems require an individual at the side of the truck to read the scales, resulting in a potential safety hazard. In addition, most systems do not provide weight readings on a continuous basis as do electronic scales. Each of these factors can cause delays in the loading process and reduce the safety of the logging operation.

Loader Weighing Systems

Loader mounted weighing systems are an alternative to on-board truck scales and can be especially cost effective on operations with several trucks since only one loader is generally utilized. The majority of logging operations in the south utilize from two to several trucks or tractor-trailers for hauling logs from the woods landing, therefore, a relatively high expense would be incurred to equip each vehicle with on-board scales. There are additional problems with the interchangeability and accuracy of on-board systems when tractor and trailer pairings vary.

Wood is weighed prior to placement on the truck, therefore, loader weighing systems provide an estimate of net payload only. When regulations emphasize axle as well as gross weights, the disadvantage of loader weighing systems becomes obvious. Axle weights must be estimated based on the expected load distribution. When predicting load distribution on tractor-trailers, factors such as the location of the fifth wheel, the distance between axles and king-pin, and the center of gravity of the load must be considered (Beardsell, 1986). By identifying the approximate center of gravity of the load and measuring the dimensions of the vehicle, the theory of moments can be used to estimate the axle weights. However, the accuracy of these estimates has not been extensively tested under field conditions. Pottie and Sinclair (1985) suggested that loader weighing in combination with on-board scales on the tractor would provide accurate information for all axles on most tractor-trailers. This suggestion could be used to reduce cost when a large number of trailers are in use.

The majority of loader weighing systems available at present are designed for use on front-end loaders. Some models have been adapted for use on knuckle-boom loaders with varying levels of success. Further discussion will be limited to weighing systems utilized on knuckle-boom loaders due to the very limited number of front-end loaders on southern logging operations.

Two alternative methods of load sensing are available, those measuring changes in hydraulic pressure when logs are lifted and those using electronic load sensors to directly measure weight. Each provide a digital weight reading for the loader operator and most systems have the ability to provide the weight for individual grapple loads as well as a running total.

Hydraulic Systems

Hydraulic loader weighing systems utilize a pressure transducer to monitor pressure changes in the stick-boom hydraulic cylinder. The pressure in a small diameter hydraulic hose, tapped into the stick-boom cylinder, increases as the load is lifted. A pressure transducer senses the pressure change and alters an electrical impulse which passes through it (Kilowate, Inc., no date). This altered impulse is converted to a digital weight reading by an indicator in the cab of the loader. Maximum accuracy is achieved when boom configuration is identical each time a weight reading is taken. The exact configuration is determined when the system is calibrated. When the proper boom configuration is reached the weight is measured and accumulated by a manual trigger or automatic micro switch (Hudson, 1986). Stopping the boom movement is not necessary, so long as it passes through the prescribed position.

Accuracy of the hydraulic weighing systems is reported to be within 2.5 percent of true weight (Lewis, 1986). Such accuracy is obtainable only with considerable practice and slightly reduced loader productivity (Deal, 1986). Accuracy is significantly reduced when logs are heeled or otherwise lifted at points differing from the center of gravity. Hydraulic fluid should be warmed and the engine operated at relatively low levels of rpms to achieve maximum accuracy (Ellis, 1986).

Systems of this type cost approximately $6000 and they may provide an alternative to on-board truck scales. However, the reliability and accuracy described by manufacturers have not been achieved by all individuals using these systems, and operator confidence and practice appear to be of critical importance in successful use of the system.

Electronic Systems

Knuckle-boom loaders can be equipped to weigh a grapple load of logs directly through the use of electronic strain gauges. Strain gauges would generally be located in the pin connecting the two portions of the knuckle at the end of the boom or the entire knuckle could contain strain gauges. Although the strain gauge concept has been successfully utilized on front-end grapple loaders, it is in an experimental stage on knuckle-boom loaders. Prototypes have been developed and will be in commercial production in the near future. To avoid some of the problems associated with heeling wood, discussed for hydraulic loader scales, a load cell equipped heel could be utilized (Archer, 1986). The accuracy, reliability, and effect on production of this technology remain to be determined.

Portable Scales

The final method of in-woods weighing to be discussed is portable pad scales which are placed on the ground and used to weigh a loaded log truck. Portable scales are frequently used by law enforcement officials for the purpose of establishing temporary weighing locations. A relatively hard and level surface is required for scale placement. Concrete is not necessary but a soft dirt surface is inadequate to achieve reasonable accuracy. Care is required to keep the scales free of mud, ice, and debris as these hamper their ability to operate correctly.

Portable scales appear to have limited applications in the timber harvesting industry. One possible application is for small logging operations, utilizing older equipment, for which the capital investment of equipment mounted weighing systems would be difficult to justify. Another possible application is on large tracts utilizing a common access road for multiple logging operations. Several trucks, from one or more logging companies, could utilize the same scales, at a common weighing location. In such a situation it would be advantageous to have a loader at the scale site to adjust loads. The configuration of portable scales varies rather significantly. The three primary designs are wheel scales, axle scales, and platform scales.

Wheel Scales

Wheel scales are used to support one wheel or a dual wheel at a time. To weigh an axle, a pair of scales must be utilized, one under each wheel assembly. A tandem axle can be weighed in two steps by one pair of scales, assuming the two axles are equalized and are at approximately the same level while one is on the scale. There would be time delays associated with movement of the scales or truck, as these scales must be accurately centered under the wheel to ensure accuracy. Wheel scales generally work on a mechanical or hydraulic principle. The use of electronic load cells is more commonly limited to scales of larger dimensions.

Wheel scales are light weight, weighing from 50 to 100 pounds, and are easily transported. Most have mechanical dial readouts but some manufactures offer electronic indicators which can provide weight readings for 2, 4, or 6 scales in combination (General Electrodynamics Corporation, no date). The accuracy expected with these scales is within ± 1.0 percent of the true weight, when properly used. The cost is approximately $1500 to $2500 each, depending on the level of sophistication desired.

Axle Scales

Axle scales, as they are defined here, are long pads the width of the "wheel to ground" surface area, designed to weigh one axle or two wheels at a time. A pair of such scales, oriented either parallel or perpendicular to the trucks direction of travel, are generally used to weigh a tandem axle assembly (Figure 6). Axle scales are better suited for weighing tandem axles than are wheel scales because of the positioning required. Although portable, this type of scale would generally be used in a more permanent location than wheel scales.

Depending on the size of the axle scales, 2 to 6 electronic load cells are utilized to sense the weight applied through the vehicle tires (Lodec, Inc., no date C). Digital weight readings are provided by an indicator positioned so that the truck driver can read the weight without leaving the cab. As with any scale containing electronic components, a power source must be present. The power source required is a 12 volt DC electrical system as is used in motor vehicles, or a 115 volt AC current (Lodec, Inc., no date C).

Axle scales weigh in excess of 1000 pounds and therefore require special handling in transport. Specially designed trailers are available to minimize the effort required. The cost of the scales ranges upward from $8000 depending on the size preferred. Lodec, Inc. (no date C) reports the accuracy expected for their scales is within ± 0.5 percent of applied load, under recommended operating conditions.

Platform Scales

Platform scales are very similar to axle scales, the primary difference lying in their dimensions. Platform scales have a surface area at least large enough to support an entire tandem axle assembly, approximately 7 by 9 feet. This type of scale generally has a somewhat higher profile, requiring a

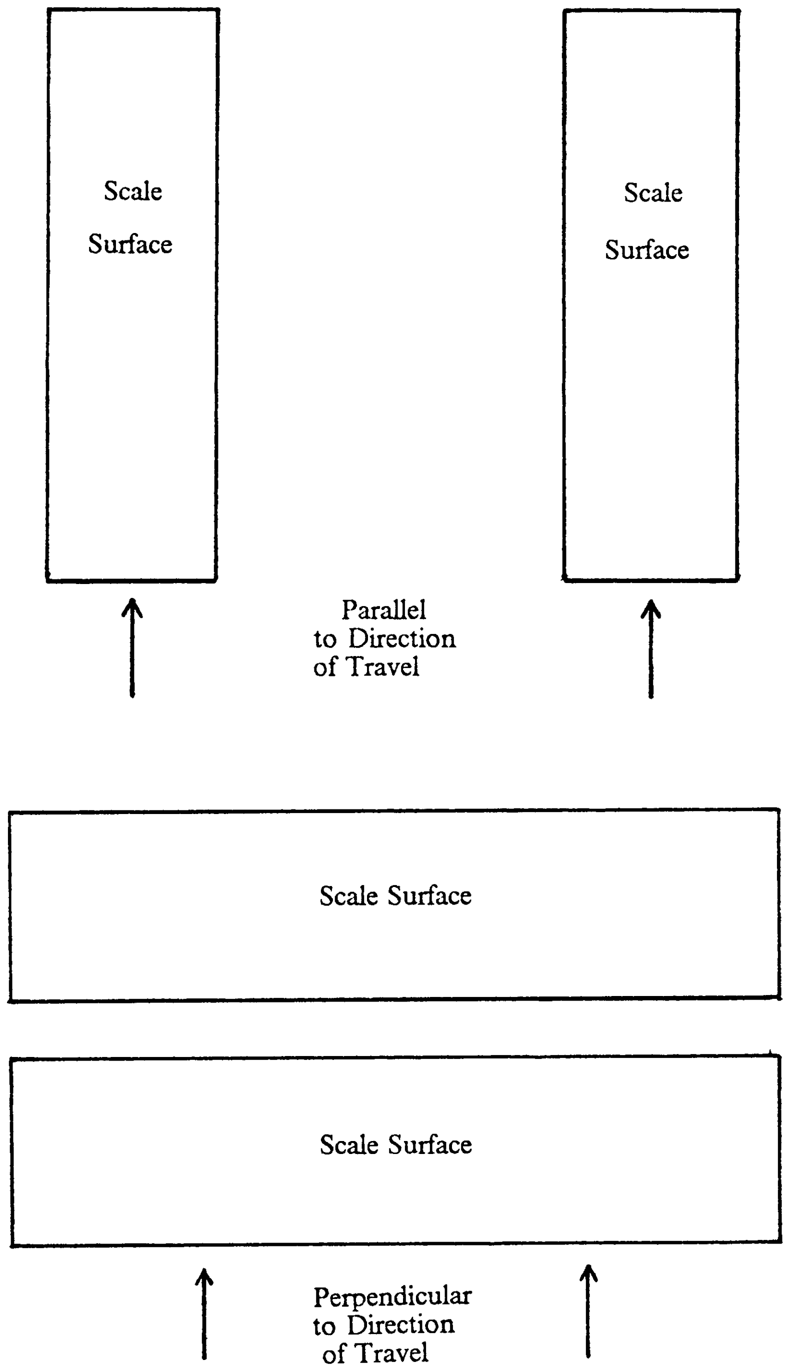


Figure 6. Orientation of Axle Scales

shallow depression for installation, as the vehicle should be sitting approximately level for accurate weighing.

Platform scales utilize electronic strain gauge load cells and a digital indicator. The weight of these scales generally exceeds 1500 pounds, so special steps must be taken to transport them from one site to the next. Butler Manufacturing (1985) reports that the expected accuracy is within ± 0.5 percent of true. The cost is approximately $4000 and up, depending on platform size.

McConnell (1987) found that accuracy of platform scales in actual operating conditions tended to be within 2.5 to 3.0 percent of true. The accuracy was slightly higher for light loads and in dry weather conditions. The most significant factor in achieving maximum accuracy was the stability of the base material supporting the scale. Although packed soil was used, gravel would have been better.

Methods and Procedures

While a variety of weighing or weight estimation methods which can be used to optimize payload are available to loggers, this research examines only two: (1) Visual weight control by the loader operator without the aid of any mechanical or electrical weighing devices but with an improved source of information and communication, and (2) weight control using electronic on-board truck scales. The two methods contrast operator training and equipment technology and are extreme opposites in capital investment requirements for a logger. Separate studies were conducted on the above techniques to evaluate the effects on load weight distribution and to determine the importance of accurate, precise weight control.

Loading Improvement

A loading improvement study was used to improve and quantify the ability of loader operators to optimize load weight under conditions of heightened awareness. The term "heightened awareness" is used here to describe a treatment with the following characteristics: Periodic reports were provided to loader operators indicating short- and long-term trends in load weights, improved communication between truck drivers and loader operators, and passive encouragement from the mill to which wood is delivered. Results of this study are intended to provide a better understanding of the benefits associated with the use of more advanced and expensive weighing devices. This study was replicated at two mills to account for effects of legal and environmental operating conditions on load weight trends.

Study Format

At each mill, two groups of five producers delivering tree-length pine pulpwood were randomly selected for the study. Loggers were selected from the population of loggers delivering to the mills who were considered representative, operate primarily in the state in which the mill is located, and do their own trucking. These restrictions were applied to limit the effects of variables which do not directly apply to this study and which may in fact confuse the results.

The two producer groups were defined as (1) the control group and (2) the treatment group. The control group continued to operate in an unmodified fashion, receiving no information regarding the study. The gross and net weights of loads delivered by members of this group were monitored for use in the statistical and economic analyses. The treatment group was treated in the manner discussed in the remainder of this study description, to heighten their awareness of trends in their load weights.

The weights of the 50 most recent loads delivered by each logger in both groups prior to initiation of the study were recorded and defined as the "history" period. Those for loggers in the control group were simply retained for comparative purposes. The load weights for each individual logger in the treatment group were divided into 1000 pound classes. The class containing the largest number of observations, the mode, was considered the temporary target weight for that logger.

Upon initiation of the study period, loggers in the treatment group received a summary table showing their distribution of gross weights about the temporary target weight. The method of deriving the temporary target weight was discussed with each logger at this time and the actual target weight he desired was determined. Producers in the treatment group were encouraged to increase the number of loads falling into their target weight class and reduce the frequency and range of loads falling outside the target weight class.

Mill personnel discussed the study, its objectives, and each individuals role, in an effort to motivate producers to reduce the range of their load weight distribution. Improvement was judged on the basis of the percent of loads falling in each weight class. Loggers were requested to utilize the information they received in the weekly load weight summaries and to improve communication between the truck driver and the loader operator regarding individual scale house tickets in an effort to increase the percentage of loads falling in the vicinity of their target gross weight class.

Each producer in the treatment group received a weekly report summarizing load weights during the study period. The report included information about that logger's load weights as well as those of the remaining four loggers in the group. Each producer received the distribution of loads he delivered in the week prior to issuance of the report, all previous weeks in the study period, and the 50 loads delivered in the history period. The summary was also to include the combined distribution of the loggers in the treatment group for the prior week. This was done in an attempt to foster competition for improvement among the loggers. Since producers had differing target weights, a 1000 pound class was defined as the grouped target and no numeric value was attached. Weight classes adjacent to the grouped target had values of plus 1000 pounds and minus 1000 pounds, adjacent to those were plus 2000 pounds and minus 2000 pounds, etc. The percent of the total loads delivered, by the other four loggers in the treatment group, in each weight class with respect to the target were then listed. The primary purpose of this information was for each logger to see how the distribution of his loads compared to the distributions for other loggers. No information was provided to the logger for comparing the actual weight of loads he delivered with those of other producers.

Data Analysis

The data gathered on the two groups prior to initiation of the study were compared to verify that no significant differences existed prior to treatment. This characteristic should exist if loggers with differing loading and trucking strategies are distributed proportionally between each of the groups. Data gathered on loggers in each group were compared after the study period to determine if the load weight distributions had been significantly affected. The results indicate whether the treatment received by loggers in the heightened awareness group actually appeared to improve the ability of the loader operator to control load weight.

Weight distributions before and after treatment were compared for each logger in order to observe the effects of the reporting technique on individuals with differing characteristics. Differences which occurred for the control producers indicate what would be expected of the treatment producers in the absence of this study. Comparison of the magnitude and direction of changes demonstrate the effect this treatment has had on loading strategies.

Economic Analysis

The economic analysis was based on changes in the logger's costs and returns associated with the treatment of this study. Mill costs and benefits were not considered for this analysis. Although the economic analysis incorporates all costs associated with producing and delivering wood, major emphasis is on transport costs. This approach was adopted due to the significant effect load size can have on transport costs without greatly altering other production costs. The development of an economic model to evaluate cash flows associated with hauling loads of various sizes is discussed in a later section of the report.

On-board Electronic Scales

Several methods of in-woods weighing are presently available to loggers. Although none of the more advanced electronic or mechanical methods are commonly used in the southeast, one system stands out as showing the greatest potential for application. On-board electronic scales, which have been used successfully in the Pacific Northwest for several years, are now receiving limited use in the Southeast.

Study Format

Case studies were developed with loggers using on-board electronic truck scales while transporting pulpwood in the Southeastern coastal states in an effort to evaluate the success with which the scales can be used to control load weight. Success was analyzed in terms of accuracy of weighing, the effects on load weight variance, and the cash flows associated with the two previous factors. Loggers who had recently equipped their truck with on-board scales were studied, due to the availability of data originating in the period immediately prior to installation of the scales. Two loggers, one handling random-length hardwood pulpwood and one handling primarily tree-length pine pulpwood were identified and found willing to cooperate in data collection.

The weights of loads delivered in the time prior to scale installation were acquired from the mills to which each of the loggers deliver. The length of the time period depended on the frequency of load deliveries, as an adequate number of load weight values are required to allow statistical analysis. In addition to load weights, descriptive information regarding trucking strategy, weight related law enforcement encounters, and weighing system selection were also gathered through discussion with each logger.

Following installation of scales, load weight data collection was done by the logger or his truck driver. The data collected was used to evaluate the functional adequacy of the system in an actual operating situation. Data collection sheets containing the following information categories were provided to each producer.

1. Gross and net load weights determined by the certified mill scales.

2. Gross and net load weights determined by the on-board scales.

3. Tractor and trailer axle load weights from the mill and on-board scales.

4. Tare weights from the mill scales.

In addition, general operating information was acquired to aid in case description and economic evaluation. Areas of primary interest were cash flows associated with installation, calibration, and maintenance of the scale system and also overweight fines. Other descriptive information, including but not limited to, trip distance and routes, landing conditions, and loading technique was gathered. Data were recorded over a 6 to 12 month period following installation of the scales.

Data Analysis

The data were analyzed in a manner which allowed two questions to be answered. (1) What level of accuracy in load weight prediction can be obtained through the use of on-board scales? (2) Does the use of on-board electronic scales provide the logger with a tool which can be used to limit load weight variation and aid in the maximization of trucking efficiency?

Accuracy of the on-board electronic scale systems was determined using the weight readings from the mills' certified scales as the actual or true weight. Gross weights were used to test accuracy rather than net weights because of their importance in the legal environment. The accuracy of the scale system over the entire range of gross weights as well as in relation to 2000 pound gross weight classes was examined.

System accuracy was checked using the signed differences between mill scale weights and corresponding on-board scale weights. Those for which the on-board scale readings were less than the mill scale readings being negative differences and those for which the on-board scale readings were higher being positive. The mean positive and negative differences were determined and taken as a percentage of the "true" mean gross weight found using the mill's weight readings. Confidence limits were formed for these mean differences, providing a level of certainty with which gross weight can be predicted. The resulting figures indicate the positive and negative percent accuracy the logger could expect to achieve in estimating the weight of his loaded log truck.

The effects of load weight on the accuracy of the on-board scales is checked in the following manner. Gross weights determined at the mill were separated into 2000 pound weight classes and the accuracy determined for each weight class.

The ability to control variability in gross weight through the use of on-board scales is a function of the scale system accuracy and the manner in which an individual uses this accuracy. The significance of changes in the variation of gross vehicle weights before and after installation of on-board scales was determined.

Economic Analysis

The economic analyses emphasize changes in cash flows associated with hauling, following acquisition of the on-board scales. This approach is similar to that used in the loading improvement study. The economic model discussed in the next section of this report was used to quantify the associated cash flows.

The use of on-board scales and the associated level of accuracy in controlling weight can provide benefits to the user which may not directly lead to changes in cash flows. Some of these non-monetary benefits are also discussed.

Economic Model

Economic analyses of trucking are commonly based on one of two types of models: (1) Those which use mileage based depreciation and (2) those which utilize time based depreciation. Each of these model types has strengths and weaknesses, depending on the trucking operation under consideration. The trucking operations of logging contractors often have peculiar characteristics, making it difficult to utilize either of these model types effectively.

Mileage based models are most appropriately used for commercial, long distance hauling situations. Truck depreciation and other fixed costs are distributed over the number of miles traveled in a year. Generally, it is assumed that the same number of miles will be traveled each year. Variable costs are typically given a fixed value per mile. This approach is most appropriate when road quality is not highly variably, therefore engine time reflects a specific number of miles. It would also be desirable for load size to be relatively consistent. The effect of load size on hauling cost would be an inversely proportional relationship, costs increasing directly with decreases in load size.

Time based models are best suited for use with equipment which operates almost entirely off of the road. Costs are considered to be based on engine hours rather than mileage. This approach is similar to the machine rate for other forestry equipment. It assumes that equipment value is consumed by the hours of operation rather than the distance traveled. Equipment obsolescence is not a significant factor in such an analysis. Variable costs may be adjusted to reflect the application in terms of load size and the type of terrain. An approach such as this is most appropriate for trucking on short hauls, where a substantial portion of the travel is over woods roads. Load size is incorporated into hauling cost on the basis of the effects on travel speed.

Neither of the above models truly represents the situation which often exists for a small producer's hauling operation. In this situation, vehicles are often purchased used and obsolescence depreciation is minimal. Use of the vehicle is limited to that required to move the volume of wood produced, there are not a scheduled number of hours or miles per year. Drivers are commonly paid on a load basis and because obsolescence depreciation is minimal, stand-by costs are minimal. Therefore, the majority of trucking costs can be determined in relation to load size.

Based on the above discussion, it was desirable to develop a method of quantifying the economic impact of hauling various load weights. This information could then be used to identify the optimum load weight or load weight range for a given situation. With the knowledge of this optimum range and the financial benefits of hauling within it, the appropriate level of investment in weight control can be determined.

There are three principle types of costs associated with hauling; (1) capital investment, (2) labor costs, and (3) mileage costs. For incremental changes in load size, capital investment, labor costs, as well as in-woods production costs will remain essentially fixed. As changes in load size become increasingly greater, these costs will also vary. However, mileage costs fluctuate freely with relatively small changes in load size and are therefore the key factor in evaluating the effects of hauling various load sizes.

Beardsell (1986) reported that representatives of the transportation industry felt that mileage costs fluctuated in the following manner. Beginning at a base gross vehicle weight (GVW) of 80,000 pounds, total mileage costs would increase or decrease by 1.0 percent for a 1000 pound increase or decrease in GVW. For the next 1000 pound change, mileage cost would change by 1.0 percent from what it was at the previous weight. This is an exponential rather than a straight line relationship because of truck engineering and power constraints. Total mileage costs at the base level of 80,000 pounds are assumed to be $0.45 per mile (Beardsell, 1986).

General Model

The above assumptions were incorporated into a model to estimate the effects of load weight on transportation mileage costs, and ultimately on the profit margin per ton. The assumed values previously mentioned were considered appropriate for comparisons made in this study but the variables could be assigned any value desired by other users. The first portion of the model determines the adjusted variable hauling cost per mile:

$$I = \frac{A - B}{1000\,Lbs}$$

$$V = C(1 + P)^{I}$$

Where,

A = Actual GVW of a Load in Pounds

B = Base GVW

I = Number of Incremental Changes

C = Mileage Cost at Base GVW

P = Percent Change (expressed as a decimal) in Mileage Cost per Increment

V = Adjusted Mileage Cost.

Figure 7 depicts the variable hauling cost per ton for 25, 50, 75, and 100 mile haul distances for GVW's ranging from 40,000 pounds to 100,000 pounds, using an assumed tare weight of 28,000 pounds. As the haul distance increases, the penalty of hauling lighter loads increases. Thus maximizing payload becomes more important for longer haul distances. The relationship between GVW and variable hauling cost is not a straight line relationship. This graph shows how the effects of additional weight on hauling cost are compounding. This characteristic is not incorporated in many hauling cost models. The relatively flat areas of the curves represent the range of gross weights over which variable mileage cost per ton are relatively constant for a given one-way haul distance. The narrower this range, the greater the importance of accurate load weight control in terms of the effect on hauling costs.

A relatively large number of values are assumed when determining the variable mileage costs in the manner presented here. The nomograph presented in Appendix A allows a user to estimate the cost using different assumed values. The nomograph can be useful for conducting sensitivity analyses on each level of assumption. The mileage cost obtained using the nomograph will be the same as would be achieved using the previous formulae.

The effects of GVW and travel distance on mileage cost, and the cash flows associated with net payload in tons for each load are combined in the next formula. The fixed expenses include all costs of production and hauling except those related to mileage, whether actually fixed or variable. The above statement assumes that the variable production costs remain fixed over the changes in production of interest here. This formula determines the profit margin per ton of wood delivered on an individual load basis, in the absence of mill restrictions and overweight fines.

$$M = \frac{R(Tons/Load) - E(Tons/Load) - V(Miles)}{(Tons/Load)}$$

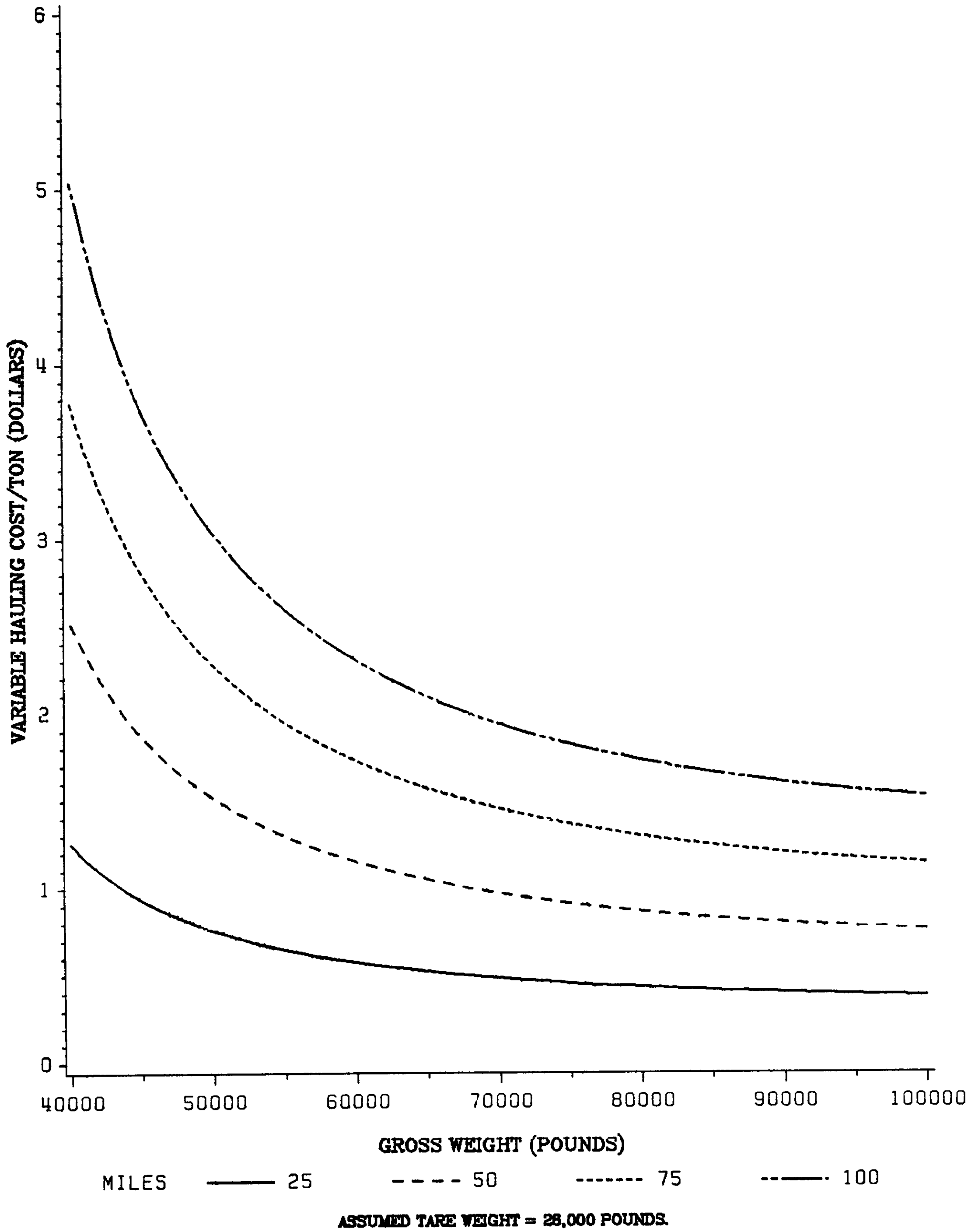


Figure 7. Variable Hauling Cost per Ton for Individual Loads

Where,

R = Revenue per Ton

E = Fixed Expenses per Ton

V = Adjusted Mileage Costs

M = Margin per Ton.

Model Adjustments

Many mills regulate the GVW of arriving loads. The regulation takes many forms and adaptations can be made to this model to adjust for most of them. However, only the two methods applied by the mills cooperating in the loading improvement study are discussed here.

Lost Volume Adjustment

If a mill does not pay for any wood delivered over a specific GVW, an adjustment is made when calculating the margin per ton for a load exceeding this value. This is accomplished by adjusting the tons/load used in calculating revenue but not for calculating expenses. The following formula is used to calculate the volume of wood for which production expenses are incurred but no revenue is received. The value generated is subtracted from tons/load before multiplying by the revenue per ton but not from the tons/load used in calculating "fixed" expenses in the previous equation.

$$L = \frac{A - W}{2000\ Lbs/Ton}$$

Where,

A = Actual GVW of Load in Pounds

W = Upper Weight Limit Established by the Mill

L = Lost Volume.

If L is ≤ 0.0, then L is set equal to zero with no lost volume.

If L ≥ 0.0, (Tons/Load - L) is used to calculate revenue per load.

Reduced Quota Adjustment

A mill may reduce the number of loads allotted in a subsequent week by one for each load delivered with a GVW exceeding a specific limit. This penalty does not directly affect the actual margin per ton, so no adjustment is made when calculating that parameter. When operating on a quota, the value associated with this penalty is actually an opportunity cost of lost potential profit. Since this is a cost which will affect the optimum load range, any opportunity cost can be distributed over each ton delivered in a given period. This value can be used to adjust the margin per ton for illustrative purposes only, as the opportunity cost would actually be a reduction in the operation's total profit potential during a period rather than a reduction in an actual profit margin. The following formula is used to calculate the opportunity cost per ton delivered.

$$O = M\left(\frac{Z}{N}\right)$$

Where,

Z = Number of Loads Delivered With GVW Exceeding the Upper Limit

N = Actual Number of Loads Delivered in a Period

M = Margin per Ton

O = Opportunity Cost per Ton Delivered.

The function, $\frac{Z}{N}$ simply determines the proportion of the volume which is forfeited when the opportunity costs associated with such a penalty are treated as an adjustment to the actual volume delivered. In this case, the proportion is multiplied by the unadjusted margin per ton.

Overweight Fine Adjustment

A formula predicting overweight fines received from law enforcement agencies can also be incorporated into the model. This is accomplished utilizing an assumed frequency of weighings, the potential fine associated with each overload, and the frequency of overloadings. The result of the following formula is the predicted value of fines and is used to adjust the margin per ton in a given period.

$$F = \frac{(P_w)(P_o)(D)}{T}$$

Where,

P_w = Probability per Trip of Being Weighed

P_o = Proportion of Loads Exceeding Legal Limits

D = Mean Potential Fine per Overload

T = Mean Number of Tons per Load

F = Predicted Dollar Value of Fines per Ton Delivered in a Period.

Results and Discussion

The results and discussion of the research are presented in two separate sections. The first section pertains to the loading improvement study and the second to the on-board truck scales study. No direct comparisons are drawn between the two studies due to the large difference in the manner in which they were conducted.

Loading Study

The loading improvement study was conducted at two mills, one is located in Tennessee and will be referred to as mill #1, the second is located in Georgia and will be referred to as mill #2. Both mills receive tree-length pine pulpwood and the physical operating environments are quite similar. However, in the legal environments for trucking, substantial differences exist between Tennessee and Georgia. The two mills' internal methods of discouraging overweight loads also differ.

In Tennessee, neither the Inner or Outer Federal Bridge Formula is vigorously enforced. Maximum legal limits are 20,000 pounds for single axles, 34,000 pounds for tandem axles, and 80,000 pounds for gross vehicle weight (GVW). Log trucks are subject to Highway Department weight checks infrequently in the region where the mill is located. As a method of discouraging excessively overweight loads, mill #1 attempts to restrict the delivery weight of log trucks to 85,000 pounds GVW. For loads which arrive at the mill weighing greater than 85,000 pounds, the net weight is calculated by subtracting vehicle tare weight from 85,000 pounds. In essence, the mill does not pay for the portion of wood on a load in excess of 85,000 pounds. The economic implications of this penalty will be discussed later.

In Georgia, the Outer Bridge Formula is strictly enforced, but the Inner Bridge Formula is not. Maximum weight limits are 20,340 pounds for a single axle, 37,340 pounds for a tandem axle, and 80,000 pounds for gross vehicle, assuming Bridge Formula requirements are satisfied. The intensity of truck weight law enforcement efforts is generally high, with temporary weighing stations established in the vicinity of the mill on a regular basis. Mill #2 limited gross vehicle delivery weights to 81,000 pounds as an internal method of discouraging overweight loads. This restrictive policy was utilized for nine of the eleven weeks in the study period and the entire history period. Recall that the history period represents the 50 loads prior to initiation of the study. Each time a load was delivered weighing more than 81,000 pounds the number of deliveries allotted to the producer in a subsequent week was reduced by one (all producers were operating on a limiting quota during the observation periods). The weight of wood delivered over 81,000 pounds on overweight loads was paid for on a normal basis. Producers were often penalized twice for each overload, due to the strict law enforcement efforts and the mill's regulation. The mill therefore indefinitely waved their policy on overloads in the ninth week of the treatment period. The high level of law enforcement activity continued, and no abrupt shifts in load weights were apparent in conjunction with the change in mill restriction. The economic implications of the mill's policy will be discussed later.

Study Description

Mill #1

The treatment portion of the study was conducted at mill #1 for eight weeks. In that time, the majority of loggers included in the study delivered 70 or more loads. All stems delivered by producers for this mill are used for pulping purposes. Therefore, 100 percent of the loads hauled were included in this study. Weekly reports summarizing previous load weights were provided to treatment loggers (Figure 8). Information showing the performance of other treatment loggers was not included in the report until week six. The weight distributions were set-up on 2000 pound classes to facilitate the reporting style desired by mill personnel. These reports were distributed to treatment producers on Monday of each week in the study period. Treatment loggers were visited at the beginning of the study and again at week five to discuss the study. Descriptive characteristics of the treatment producers at mill #1 and general information about control producers are included in Appendix B.

Mill #2

The treatment portion of the study was conducted at mill #2 for eleven weeks or the number of weeks required for a producer to deliver at least 100 loads, whichever came first. Two producers, one treatment and one control, ceased production during the course of the study. Observations on these two producers were omitted, resulting in four treatment loggers and four control loggers comprising the study groups. Descriptive characteristics of each treatment producer and general information on control producers for mill #2 are also included in Appendix B. Material produced for this mill was sorted in the woods and different products delivered to separate locations. Only pulpwood loads were monitored for this study. The weekly weight information summary provided

Weight Distribution by Class - in Percent

	< 75,500	75,500-77,500	77,501-79,500	Target 79,501-80,500	> 80,500
History:	10%	6%	8%	2%	74%
Week 1:	0%	13%	13%	0%	73%
Week 2:	7%	7%	21%	14%	50%
Week 3:	5%	5%	23%	14%	55%
Week 4:	13%	13%	0%	13%	63%
Week 5:	8%	0%	15%	8%	69%
Week 6:	11%	11%	22%	22%	33%
Week 7:	9%	45%	18%	0%	27%
Week 8:	0%	0%	80%	20%	0%

	< -4500	-4500 to -2501	-2500 to -501	Target ± 500	> + 500
Current Week Comparison With Other Producers:	7%	13%	11%	4%	65%

Figure 8. Example Weekly Summary for Mill #1

to each treatment producer was similar to that in Figure 9. Information on other treatment loggers' performance was not included at the discretion of mill personnel. Reports of this nature were provided to treatment producers on Mondays of each week of the study. Treatment producers were contacted upon initiation of the study and in week four regarding the study and its objectives. With these exceptions, the study was conducted without any influence exerted on producers other than providing the weekly reports.

Data Interpretation

The primary objective the loading study was to determine if the ability of loader operators to control the weight of loaded log trucks with visual estimation techniques could be improved, given feedback information from previous load weights to heighten their awareness. Frequency distributions based on 1000 pound weight classes were developed to summarize load weights for each producer during the history and study periods. These distributions are presented in Appendices C for mill #1 and E for mill #2. Graphic plots of the cumulative relative frequencies are provided in Appendices D for mill #1 and F for mill #2. After examining these tables and graphs, several trends were identified which may be attributed to the treatment of this study.

Mill #1

Several performance categories were developed for comparison of producers delivering to mill #1. These were based on the nature of the legal environment and mill restrictions which exist. Loads weighing less than 75,000 pounds were arbitrarily considered to be severely underloaded and those over 85,000 pounds severely overloaded. The combination of the frequency and severity of severe overloads was defined as the area of lost volume. The economic implications of both severe underloads and overloads will be discussed later. Loads falling between the legal maximum of

Percentage of Tickets per Weight Category

	68,999 and Below	69,000 to 69,999	70,000 to 70,999	71,000 to 71,999	72,000 to 72,999	73,000 to 73,999	74,000 to 74,999	Target Class 75,000 to 75,999	76,000 to 76,999	77,000 to 77,999	78,000 to 78,999	79,000 to 79,999	80,000 to 80,999	81,000 and Above
History	6%	6%	12%	4%	10%	10%	12%	8%	6%	4%	4%	2%	6%	10%
First Week	16%	17%	16%	--	17%	--	17%	--	17%	--	--	--	--	--
Second Week	29%	--	14%	--	--	14%	--	--	--	14%	14%	--	15%	--
Third Week	20%	--	--	20%	--	--	20%	20%	--	--	--	--	--	20%
Fourth Week	--	10%	--	--	30%	10%	10%	20%	10%	--	10%	--	--	--
Fifth Week	13%	--	--	--	--	13%	--	25%	13%	13%	--	--	--	25%
Sixth Week	--	13%	--	--	13%	25%	--	13%	25%	--	--	--	13%	--
Seventh Week	--	--	20%	20%	20%	20%	--	--	--	--	--	--	20%	--
Eight Week	--	--	--	--	--	17%	--	17%	25%	--	--	--	17%	17%
Ninth Week	50%	--	--	--	--	--	--	--	50%	--	--	--	--	--
Tenth Week	66%	--	--	--	--	--	--	--	--	33%	--	--	--	--
Eleventh Week	9%	--	--	--	--	27%	--	--	9%	9%	9%	9%	18%	9%

Figure 9. Example Weekly Summary for Mill #2

80,000 pounds and the mill limit of 85,000 pounds are not desirable from a legal stand-point. However, due to the low level of law enforcement efforts and the fact that the treatment loggers' target weights ranged from 79,000 to 82,000 pounds, loads considered acceptable ranged from 75,000 to 85,000 pounds. Comparisons of performance by each producer are provided in Table 1 and are summarized below.

Treatment producers B and C showed substantial improvements in load weight distributions in the study period based on the selected comparisons. Producer B increased the proportion of acceptable loads by 18.0 percent while decreasing the frequency of severe overloads by 12.4 percent. Loads falling within ±2000 pounds of producer B's target weight increased by 23.8 percent and the proportion of severe underloads decreased by 5.6 percent. Producer C increased the frequency of acceptable loads by 14.1 percent and decreased the occurrence of severe overloads by 16.1 percent. Loads delivered within ±2000 pounds of the target weight increased by 9.1 percent. A very slight increase in the percentage of severe underloads also occurred.

Treatment producer A showed a slight tendency to deliver more light loads during the study period and a greater percentage of loads were also delivered in excess of 85,000 pounds. This resulted in a 6.8 percent decrease in the proportion of loads falling in the acceptable range of 75,000 to 85,000 pounds. Treatment producer E displayed a substantial increase in the frequency of severe overloads, increasing the percentage of loads weighing in excess of 85,000 pounds by 18.0 percent. A decrease of 18.0 percent in acceptable loads accompanied the increased level of overloading. This reaction to the study may be attributable to several factors, but no definite cause can be identified at this point.

Treatment producer D,s performance was relatively constant from the history to the study period. Severe underloading was eliminated and the proportion of loads delivered in the acceptable range increased slightly, by 1.1 percent. Severe overloads also changed slightly, increasing by 2.9 percent.

Table 1. Mill #1, Selected Comparisons Between the History and Study Periods for Treatment and Control Producers

Treatment Producer

Load Weight	A		B		C		D		E	
Pounds	History	Study	History	Study	History	Study	History	Study	History	Study
< 75,000	4.0%	6.3%	10.0%	4.4%	0.0%	2.0%	4.0%	0.0%	4.0%	4.0%
> 85,000	8.0	12.5	28.0	15.6	22.0	5.9	16.0	18.9	8.0	26.0
75,000-85,000	88.0	81.2	62.0	80.0	78.0	92.1	80.0	81.1	88.0	70.0
Target ± 2000	40.0	32.5	24.0	47.8	34.0	43.1	50.0	39.2	42.0	36.0

Control Producer

Load Weight	F		G		H		I		J	
Pounds	History	Study	History	Study	History	Study	History	Study	History	Study
< 75,000	4.0%	21.3%	30.0%	5.9%	4.0%	0.0%	0.0%	1.4%	0.0%	8.9%
> 85,000	12.0	17.0	6.0	23.5	10.0	27.5	24.0	19.2	34.0	22.2
75,000-85,000	84.0	61.7	64.0	70.6	86.0	72.5	76.0	79.4	66.0	68.9

It was expected that control producers' performance would remain relatively constant between the history and study periods. This uniformity did not occur, although changes in weight distributions were generally less substantial than those of the treatment producers. Control producers I and J each showed slight increases in the proportion of loads falling in the acceptable range of 75,000 to 85,000 pounds while decreasing the frequency of severe overloads. Producer I increased acceptable loads by 3.4 percent and decreased severe overloading by 4.8 percent. The percent of acceptable loads delivered by producer J increased by only 2.9 percent but the proportion of severe overloads decreased by 11.8 percent. This was accompanied by an 8.9 percent increase in severe underloading.

Control producer G displayed an increase in acceptable loads during the study period of 6.6 percent. However, this was accompanied by strong shifts in severe underloading and overloading. The proportion of severe overloads increased in the study period by 17.5 percent while underloading decreased by 24.1 percent. This was due inpart to a relatively large percentage of loads under 75,000 pounds in the history period.

Producers F and H both showed rather substantial decreases in the proportion of acceptable loads delivered. Producer F decreased the frequency of loads delivered in the acceptable range of 75,000 to 85,000 pounds by 22.3 percent. However, severe underloading and severe overloading increased in the study period by 17.3 and 5.0 percent respectively. Such large shifts at both ends of the distributions were uncommon. Producer H displayed a decrease in acceptable loads of 13.5 percent and a rather substantial increase of 17.5 percent in severe overloading. This was accompanied by the elimination of severe underloading.

In general, the trends displayed by treatment producers were more consistent than those of the control producers. It appears that two of the treatment producers, B and C, made rather substantial improvements in controlling load weights, in terms of increasing the percentage of acceptable loads along with decreasing severe overloading. Treatment producers A and D showed only subtle alterations in load weight distributions, A's tending slightly toward less desirable load weights.

Treatment producer E changed the distribution of load weights in a manner not responsive to the objectives of the study.

None of the control producers demonstrated substantial improvement in the proportion of acceptable loads along with reductions in the frequency of severe overloads. It can be concluded that two of the five treatment producers receiving modified reports did show improvement in control of their load weights.

Mill #2

Performance analysis criteria for mill #2 differ from those selected for mill #1. This is a result of the difference in law enforcement efforts, mill restrictions, and the target weights selected by treatment producers. Severe underloads for mill #2 producers were considered to be those loads for which the gross delivery weight was less than 70,000 pounds. Gross delivery weights exceeding 81,000 pounds were considered to be severe overloads. Acceptable loads are based on producers' target weight classes which all fell between 73,000 and 77,999 pounds. Therefore, loads in the range from 70,000 to 79,999 pounds were considered to be acceptable loads. Comparisons of the performance of producers in the history and study periods are provided in Table 2.

Changes in loading behavior for producers at mill #2 were generally less pronounced than those of producers at mill #1. However, the nature of the shifts was more uniform among producers in each group and more consistently different between the treatment and control groups.

All of the treatment producers decreased the percentage of loads delivered in excess of 81,000 pounds (severe overloads) while increasing the percentage of severe underloads, those weighing less than 70,000 pounds. Although the percentage reductions in severe overloads were not large, they were rather substantial when compared to the actual percentage of overloads occurring. Three of the four treatment producers demonstrated slight reductions in the proportion of loads falling in the

Table 2. Mill #2, Selected Comparisons Between the History and Study Periods for Treatment and Control Producers

Treatment Producer

Load Weight	A		C		D		E	
Pounds	History	Study	History	Study	History	Study	History	Study
< 70,000	12.0%	16.9%	2.0%	13.1%	8.0%	13.3%	4.0%	9.1%
> 81,000	10.0	7.0	6.0	1.9	4.0	1.9	2.0	1.3
70,000-80,000	72.0	69.0	90.0	84.1	80.0	82.9	90.0	81.8
Target ± 1000	26.0	26.8	34.0	38.3	10.0	26.6	30.0	37.7

Control Producer

Load Weight	F		H		I		J	
Pounds	History	Study	History	Study	History	Study	History	Study
< 70,000	2.0%	3.7%	4.0%	4.9%	22.0%	18.1%	4.0%	4.9%
> 81,000	12.0	15.9	8.0	11.8	0.0	0.0	14.0	24.6
70,000-80,000	76.0	74.8	82.0	75.5	78.0	81.9	78.0	62.7

acceptable range. Producer D increased the frequency of acceptable delivery weights by 2.9 percent while producers A, C, and E all displayed 3.0, 5.9, and 8.2 percent decreases, respectively.

Three of the four control producers increased the percentage of severe overloads, while producer I delivering no loads in excess of 81,000 pounds in the history or study periods. Producers F and H increased the percentage of overloads by 3.9 and 3.8 percent respectively, while producer J increased the proportion by 10.6 percent. As with the treatment producers, three of the four control producers delivered proportionally fewer loads in the acceptable range during the study period. However, these three producers displayed relatively small increases in the percentage of severe underloads. Control producer I did deliver 3.9 percent more acceptable loads in the study period than in the history period. Again, producers B and G were dropped from the study when they ceased production during the study period.

In general, producers in both groups at mill #2 delivered proportionally fewer loads in the acceptable range but apparently for different reasons. Treatment producers tended to induce the reduction by increasing the percentage of severe underloads delivered. The control producers reduction in acceptable loads can be attributed primarily to increases in the percentage of severe overloads.

It can be concluded that in conjunction with the heightened awareness provided to treatment producers, efforts were made to reduce severe overloading by loading light. This may be attributable to their increased sensitivity to mill imposed restrictions and overweight fines. Or alternatively, a greater aversion to overweight loads as a result of the knowledge that, as part of the study, their delivery weights were being more closely monitored by the mill. The consistency of this reaction over time will be analyzed in a later section of this report.

Statistical Analyses

The statistical analyses for the loading study are intended to identify and determine the significance of changes in the distribution of load weights. Individual producer's performance was compared for the history and study periods, as well as group comparisons of the treatment and control producers. Descriptive statistics for mill #1 producers are presented in Table 3 and those for mill #2 producers in Table 4.

It was desirable to check for differences or changes in both location and dispersion in the distribution of gross load weights. Three tests were selected for use. The F-test or ratio of variances was used to check for differences in load weight variance between the history and study periods. Scheffe's test was used to test for differences in the mean GVW in the history and study periods for individual producers. Analyses were conducted using the SAS General Linear Model (GLM) procedure to adjust for unequal sample sizes.

The nonparametric Kolmogorov-Smirnoff (K-S) test was utilized to test for overall differences in the distributions of load weights. Because parametric tests are more sensitive to differences in location, they may not detect other differences in distributions (Conover, 1971). The K-S two sample test was carried out on the frequency distributions with 1000 pound class ranges provided in Appendices C and E.

In order to test for the presence of a learning curve or period of adjustment, the data sets were modified in the following manner for this analysis only. Data were pooled by treatment and control group for each mill and the study period subdivided into two time blocks. This was done to facilitate the observation of producers' performance over time.

Table 3. Descriptive Statistics for Mill #1 Producers

Treatment Producers

Producer/ Period	N	Mean GVW (Pounds)	Standard Deviation (Pounds)	Minimum Value (Pounds)	Maximum Value (Pounds)
A/History	50	80,906	3093.0	74,540	88,521
A/Study	80	80,519	3761.1	70,400	87,100
B/History	50	81,908	4758.6	65,560	89,800
B/Study	90	80,767	3627.8	71,160	89,140
C/History	50	82,502	4020.4	76,000	92,800
C/Study	51	79,922	3164.7	74,860	87,380
D/History	50	81,957	3574.5	74,180	92,800
D/Study	74	81,764	2898.2	75,840	87,920
E/History	50	80,790	3576.4	69,700	88,120
E/Study	169	82,444	4251.0	68,740	94,280

Control Producers

Producer/ Period	N	Mean GVW (Pounds)	Standard Deviation (Pounds)	Minimum Value (Pounds)	Maximum Value (Pounds)
F/History	50	80,473	3787.3	71,560	86,880
F/Study	94	79,322	5669.4	55,960	91,100
G/History	50	77,050	7118.1	41,080	87,980
G/Study	68	82,106	3714.7	70,520	88,600
H/History	50	80,709	3309.8	70,780	87,800
H/Study	120	83,132	3196.0	75,020	89,700
I/History	50	83,421	2604.8	78,660	89,520
I/Study	73	81,750	4180.7	59,820	91,060
J/History	50	83,858	2966.1	76,780	89,500
J/Study	90	81,339	4936.1	63,000	90,880

Table 4. Descriptive Statistics for Mill #2 Producers

Treatment Producers

Producer/ Period	N	Mean GVW (Pounds)	Standard Deviation (Pounds)	Minimum Value (Pounds)	Maximum Value (Pounds)
A/History	50	74,522	4308.4	65,420	84,180
A/Study	71	74,594	4427.7	63,880	85,280
C/History	50	75,177	3306.2	69,900	83,140
C/Study	107	73,118	3246.1	64,080	81,760
D/History	50	74,631	3581.9	67,700	81,400
D/Study	105	74,190	3852.8	62,940	85,680
E/History	50	75,564	2932.4	67,600	82,060
E/Study	77	75,753	3442.6	66,560	84,920

Control Producers

Producer/ Period	N	Mean GVW (Pounds)	Standard Deviation (Pounds)	Minimum Value (Pounds)	Maximum Value (Pounds)
F/History	50	76,738	3900.8	68,040	85,260
F/Study	107	77,075	3678.6	68,120	83,980
H/History	50	75,999	3524.1	69,560	85,920
H/Study	102	76,254	4221.8	62,920	84,680
I/History	50	72,242	2801.3	67,000	79,620
I/Study	94	72,803	2823.1	66,160	78,520
J/History	50	76,132	4138.0	68,720	87,480
J/Study	102	77,651	4676.0	67,320	88,280

Comparison of Variances

The F-ratio compares the two samples' variances, testing for significant differences in the history and study periods. A one-sided test was used to permit the determination of which period's variance is greater for an individual producer. The null hypothesis is no difference exists between sample variances. The results of the F-test at $\alpha = 0.05$ are provided in Table 5 for mill #1 and Table 6 for mill #2.

All of the producers in both groups at mill #1, with the exception of control producer H, had significant differences in variance between the history and study periods. Trends were not apparent for the treatment and control producers with regard to which observation period had the larger variance. However, control producers generally had more highly significant differences than the treatment producers.

At mill #2, only control producer H had a significant difference in the variance for the history and study periods. The remaining producers did have differences in the variance for the two periods but these were not significant at $\alpha = 0.05$. The first variance listed under the conclusion for each producer was the larger of the two.

Comparison of Means

Scheffe's test was selected for comparing the means of each producer because the assumption of homogeneity of variance required for many tests was violated. This was demonstrated when comparing the variances. Scheffe's test adjusts for the difference in variances and is therefore better suited for this analysis than some other techniques. When conducting Scheffe's, the null hypothesis (H_0) is no difference exists in the two sample means. If H_0 is rejected, the conclusion would be that significant differences do exist between the means. The results provided in Table 7 and Table 8 indicate that at $\alpha = 0.05$ significant changes did occur for some producers at each mill.

Table 5. F-test Comparing Variance in Gross Weight for the History and Study Periods of Producers at Mill #1

Treatment Producers

Producer	F-value	P-value	Conclusion at $\alpha = 0.05$
A	1.48	$.05 > P > .01$	$S_2^2 > S_1^2$
B	1.72	$.001 > P$	$S_1^2 > S_2^2$
C	1.61	$.01 > P > .001$	$S_1^2 > S_2^2$
D	1.52	$.01 > P > .001$	$S_1^2 > S_2^2$
E	1.41	$.05 > P > .01$	$S_2^2 > S_1^2$

Control Producers

Producer	F-value	P-value	Conclusion at $\alpha = 0.05$
F	2.24	$.001 > P$	$S_2^2 > S_1^2$
G	3.67	$.001 > P$	$S_1^2 > S_2^2$
H	1.07	$P > .25$	$S_1^2 = S_2^2$
I	2.58	$.001 > P$	$S_2^2 > S_1^2$
J	2.77	$.001 > P$	$S_2^2 > S_1^2$

S_1^2 = Variance in GVW for history period
S_2^2 = Variance in GVW for study period

Table 6. F-test Comparing Variance in Gross Weight for the History and Study Periods of Producers at Mill #2

Treatment Producers

Producer	F-value	P-value	Conclusion at $\alpha = 0.05$
A	1.06	$P > .25$	$S_2^2 = S_1^2$
C	1.04	$P > .25$	$S_1^2 = S_2^2$
D	1.16	$.25 > P > .10$	$S_2^2 = S_1^2$
E	1.38	$.10 > P > .05$	$S_2^2 = S_1^2$

Control Producers

Producer	F-value	P-value	Conclusion at $\alpha = 0.05$
F	1.12	$.25 > P > .10$	$S_1^2 = S_2^2$
H	1.44	$.05 > P > .01$	$S_2^2 > S_1^2$
I	1.02	$P > .25$	$S_2^2 = S_1^2$
J	1.28	$.25 > P > .10$	$S_2^2 = S_1^2$

S_1^2 = Variance in GVW for history period
S_2^2 = Variance in GVW for study period

Table 7. Scheffe's Test for Mean Gross Weights of Producers at Mill #1

Treatment Producers

Producer	Mean GVW History Period (Pounds)	Mean GVW Study Period (Pounds)	Conclusion at $\alpha = 0.05$
A	80,906	80,519	Accept H_0
B	81,908	80,767	Accept H_0
C	82,502	79,922	Reject H_0
D	81,957	81,764	Accept H_0
E	80,790	82,444	Reject H_0

Control Producers

Producer	Mean GVW History Period (Pounds)	Mean GVW Study Period (Pounds)	Conclusion at $\alpha = 0.05$
F	80,473	79,322	Accept H_0
G	77,050	82,106	Reject H_0
H	80,709	83,132	Reject H_0
I	83,421	81,750	Reject H_0
J	83,858	81,339	Reject H_0

Table 8. **Scheffe's Test for Mean Gross Weights of Producers at Mill #2**

Treatment Producers

Producer	Mean GVW History Period (Pounds)	Mean GVW Study Period (Pounds)	Conclusion at $\alpha = 0.05$
A	74,522	74,594	Accept H_0
C	75,177	73,118	Reject H_0
D	74,631	74,191	Accept H_0
E	75,564	75,753	Accept H_0

Control Producers

Producer	Mean GVW History Period (Pounds)	Mean GVW Study Period (Pounds)	Conclusion at $\alpha = 0.05$
F	76,738	77,075	Accept H_0
H	75,999	76,254	Accept H_0
I	72,242	72,803	Accept H_0
J	76,132	77,651	Accept H_0

Two of the five treatment producers for mill #1, C and E, showed significant changes in the location of their mean GVW. Treatment producer C reduced the value of his mean in the study period and treatment producer E increased his mean GVW. Four of the five control producers at mill #1 had significant changes in mean load weights. Two control producers, G and H, increased their mean GVW in the study period and producers I and J reduced their mean weights.

At mill #2 only one individual, treatment producer C, displayed a significant change in mean gross weight. This change was a decrease in the mean during the study period. The remainder of the treatment and control producers did show some changes in mean GVW but these were not found to be significant at $\alpha = 0.05$.

Using an alpha level of 0.10 for comparing the mean GVW's of individual producers at each mill would have resulted in the same conclusions with one exception. Control producer J at mill #2 would also have had a significant difference in his mean GVW for the history and study periods.

Kolmogorov-Smirnoff Test

The K-S test evaluates the similarity in the distributions for the two sample periods based on the largest difference in the cumulative relative frequency distributions. This difference is compared to a critical value representing the largest difference which would be expected to result from chance alone. The one-sided K-S test was used in this analysis to evaluate the direction and degree of difference in observations made on each individual producer in the history and study period. The two-sided K-S test was used to test for differences in the distributions of the treatment and control producer groups in the history and study periods.

The null hypothesis of the one-sided K-S test is that the observation values in one distribution tend to be smaller than the values in the other. The null hypothesis for the two-sided K-S test is one of no difference in the sample distributions. A significance of $\alpha = 0.10$ was selected for the one-sided

K-S test to allow the conclusions to be more sensitive to subtle changes in the distributions. An α level of 0.05 was selected for the two-sided test on grouped comparisons to avoid making an incorrect general statement regarding the results of the study. Results of the one-sided K-S test are provided for mill #1 and mill #2 in Table 9 and Table 10, respectively.

At mill #1, treatment producers B and C significantly reduced the values in their frequency distributions in the study period. This could also be stated as a shift towards the lighter loads. Treatment producer E significantly increased the distribution values of his load weights and producers A and D showed no significant difference in the two periods.

Control producers G and H significantly increased the distribution values of their load weights and producers I and J reduced theirs. The distribution of loads for control producer F did not change significantly.

Results of the one-sided K-S test for mill #2 producers indicated that only one of the treatment producers showed a significant change in the distribution of load weights. Treatment producer C significantly reduced the weight values in his distribution. Three of the four control producers, H, I, and J, significantly increased the weights in their distributions. Control producer F showed no significant change in the distribution of load weights.

A contrast of the reactions of producers in each group at mill #2 indicates that the treatment producers maintained or lightened their load weights during the study period. The control producers, operating independently of the study, generally hauled heavier loads in the study period. This trend would have been expected of the treatment producers in the absence of this study.

The treatment and control producers were grouped for each mill and their respective cumulative distributions compared using a two-sided K-S test. These group comparisons were done for both the history and study periods. Results of the group tests are provided in Table 11 for both mills. The results of this test point out differences in the response to the study by producers at each mill.

Table 9. Comparison of Distributions for Mill #1 Producers using the Kolmogorov-Smirnoff Test

Treatment Producers

Producer	Largest Positive Difference	Largest Negative Difference	Test Statistic D_α at $\alpha = 0.10$	Conclusion (Distribution Values)
A	0.045	0.180	0.193	No Difference
B	0.056	0.260	0.189	Study < History
C	0.000	0.284	0.213	Study < History
D	0.059	0.098	0.196	No Difference
E	0.225	0.021	0.176	Study > History

Control Producers

Producer	Largest Positive Difference	Largest Negative Difference	Test Statistic D_α at $\alpha = 0.10$	Conclusion (Distribution Values)
F	0.085	0.173	0.187	No Difference
G	0.439	0.000	0.199	Study > History
H	0.308	0.000	0.180	Study > History
I	0.014	0.247	0.196	Study < History
J	0.011	0.258	0.189	Study < History

Table 10. Comparison of Distributions for Mill #2 Producers using the Kolmogorov-Smirnoff Test

Treatment Producers

Producer	Largest Positive Difference	Largest Negative Difference	Test Statistic D_α at $\alpha = 0.10$	Conclusion (Distribution Values)
A	0.093	0.067	0.198	No Difference
C	0.000	0.237	0.183	Study < History
D	0.116	0.103	0.184	No Difference
E	0.063	0.051	0.194	No Difference

Control Producers

Producer	Largest Positive Difference	Largest Negative Difference	Test Statistic D_α at $\alpha = 0.10$	Conclusion (Distribution Values)
F	0.125	0.040	0.183	No Difference
H	0.188	0.085	0.185	Study > History
I	0.294	0.029	0.187	Study > History
J	0.188	0.010	0.185	Study > History

Table 11. Comparison of Distributions for Treatment and Control Producer Groups using the Kolmogorov-Smirnoff Test

Mill #1

Period	Largest Unsigned Difference	Test Statistic D_α at $\alpha = 0.05$	Conclusion
History	0.056	0.121	Accept H_0
Study	0.073	0.090	Accept H_0

Mill #2

Period	Largest Unsigned Difference	Test Statistic D_α at $\alpha = 0.05$	Conclusion
History	0.060	0.136	Accept H_0
Study	0.171	0.098	Reject H_0

The proportion of individual producers at mill #1 who displayed significantly different distributions for the periods was higher than that for mill #2. The differences or changes exhibited by individual producers at mill #1 tended to be more significant but in random directions, resulting in a cancelling effect when grouped. Thus, the conclusion at mill #1 that group distributions were not significantly different in the history and study periods. At mill #2, changes tended to be less substantial but in the same general direction, resulting in an additive effect when grouped. As a result, the grouped distributions for the study period were significantly different. No significant difference existed between the two groups in the history period as would be expected based on the random selection of the producers.

Learning Curve

In order to get an understanding of how the producers reacted to the study over time, observations on the producers were pooled by treatment and control groups for each mill and cumulative relative frequency distributions developed. Two assumptions were made in developing these distributions. First, all loads arriving at the mills with a GVW less than 70,000 pounds were eliminated from the data set, for this analysis only. This was done because it seemed quite apparent that such severe underloads were not due to gross overestimates of the load weight. Instead, it was felt that they were intentionally loaded light for operational purposes. These values were also eliminated because of the effect their outlying nature has on the frequency distributions. Secondly, the study period was divided into two time blocks because it was felt there was possibly a period of adjustment to the treatment provided. The dividing point selected was between weeks four and five as this was halfway through the study period for all producers at mill #1 and also for producers with the shortest study periods at mill #2. Recall that the study period at mill #2 extended for eleven weeks or until a producer delivered at least 100 loads, whichever came first.

The plots for mill #1 (Figure 10 for treatment producers and Figure 11 for control producers) indicate that both producer groups did exhibit changes in load weight distributions for different time blocks within the study period. A one sided K-S test at $\alpha = 0.10$ was utilized to determine if the producer groups' distributions were increasing or decreasing significantly over time. Comparisons were made on the history period, weeks one to four of the study period, and weeks five and up.

At mill #1, the treatment producer's distribution of load weights for the first four weeks of the study period was significantly lighter than for the history period. This suggests a reaction to initiation of the study. In weeks five through eight of the study period the deliveries became significantly heavier than they were during weeks one through four but not significantly different from the loads delivered in the history period. The control producers delivered loads in weeks five through eight which were significantly heavier than the distribution of loads for the first four weeks of the study period or the history period. No significant differences existed between the treatment and control producer groups in the distribution of loads for the time blocks discussed here.

When observations for treatment producer E are removed from the data set, interesting changes occur in the weight distributions (Figure 12) leading to different conclusions for the K-S test. As has been discussed previously, producer E reacted to the study in a much different manner than the remaining treatment producers. The distribution of loads for weeks five and up of the study period are no longer significantly different from the loads delivered in the first four weeks. In this case, the treatment producers' distributions are significantly lighter than the control producers' in the two time blocks of the study period. This indicates that the inclusion of producer E obscures the reactions to the study of the other four treatment producers.

Cumulative relative frequency plots for producer groups at mill #2 (Figure 13 for treatment producers and Figure 14 for control producers) clearly show that the treatment has affected producer behavior and that change occurred over time.

The distribution of weights for treatment producers at mill #2 was significantly lighter in the first four weeks of the study period than in the history period. A greater percentage of light loads and fewer exceeding the mill limit were delivered. Weeks five and up of the study period had a load

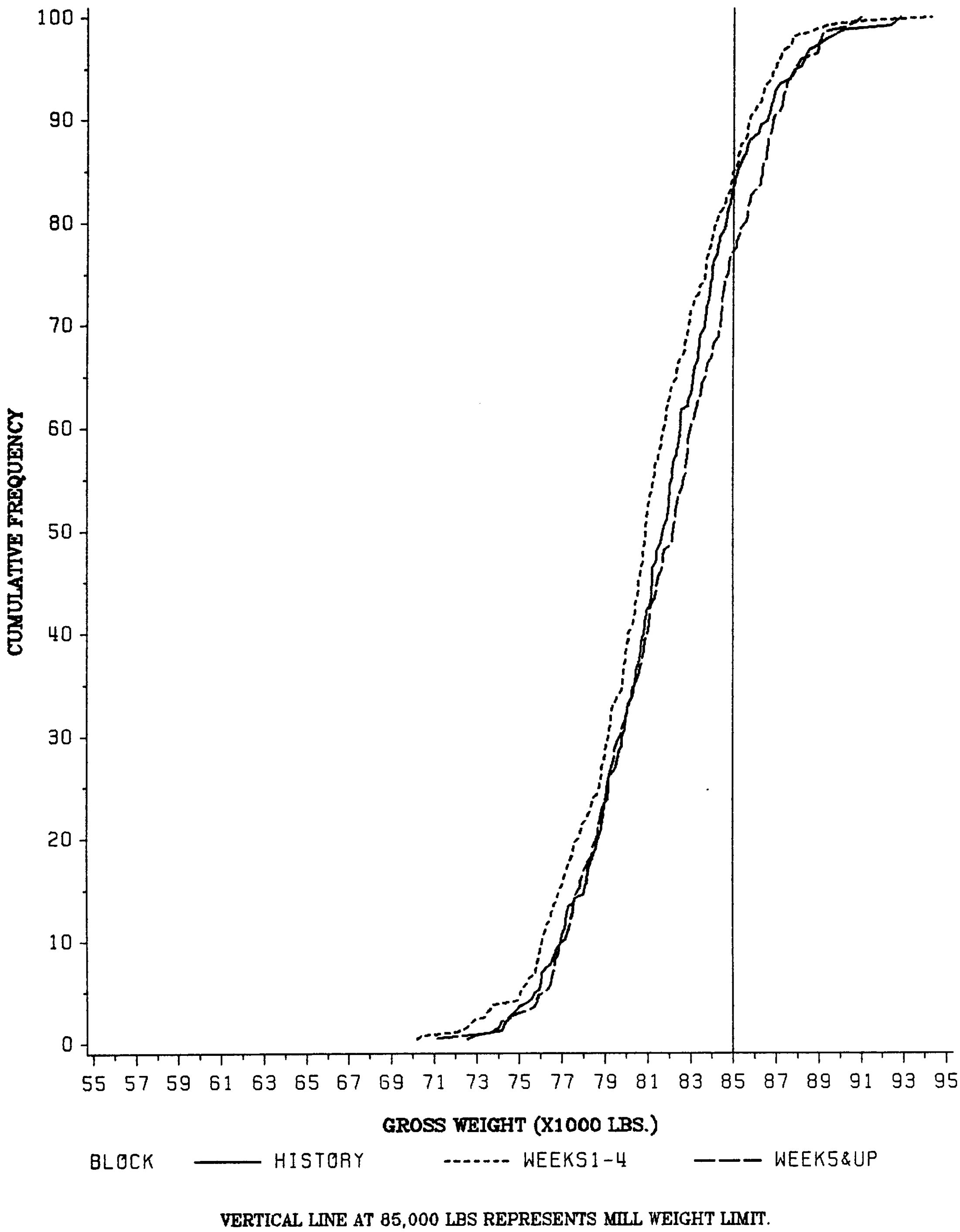


Figure 10. Frequency Plot of Gross Weights for Treatment Producer Group (Mill #1)

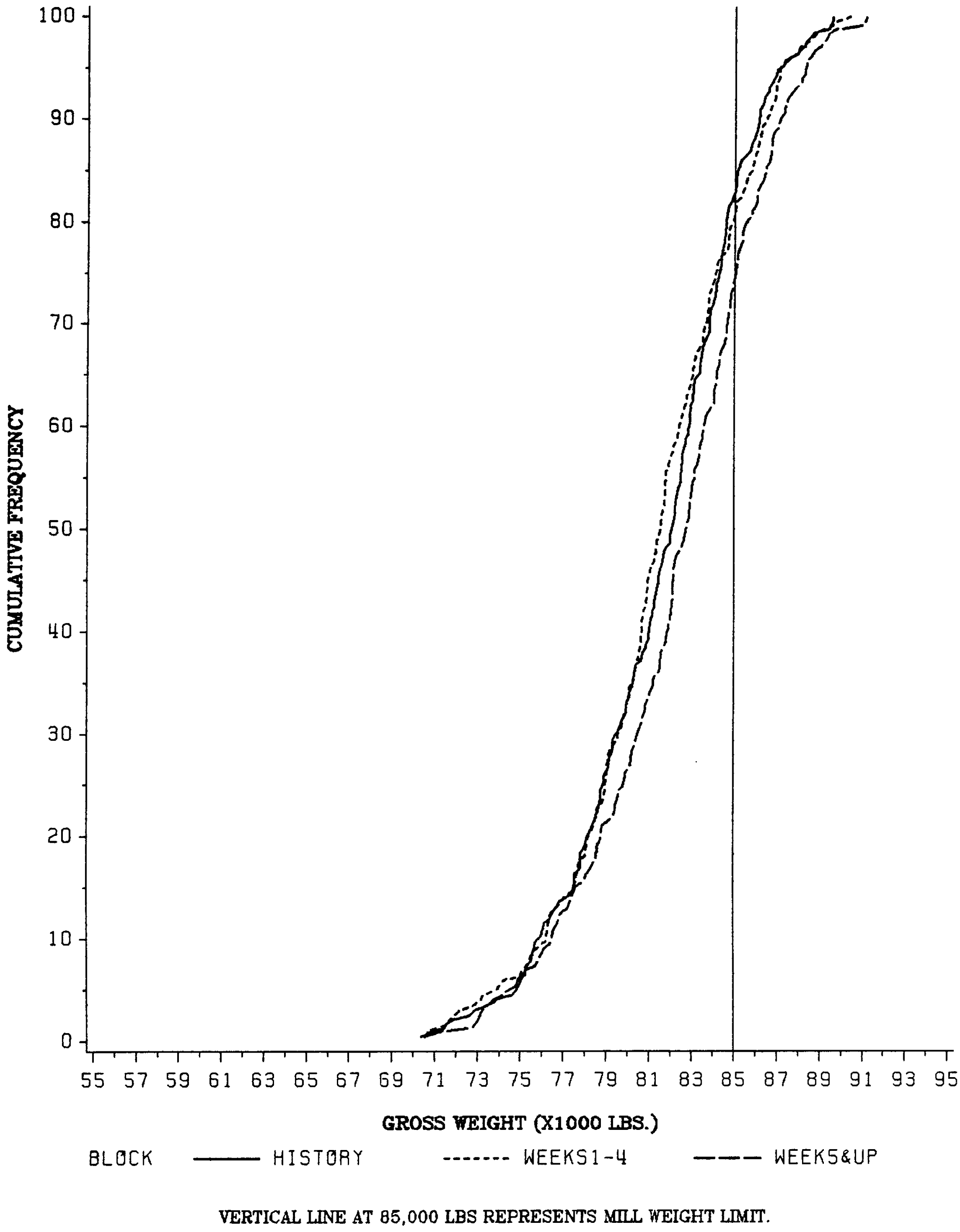


Figure 11. Frequency Plot of Gross Weights for Control Producer Group (Mill #1)

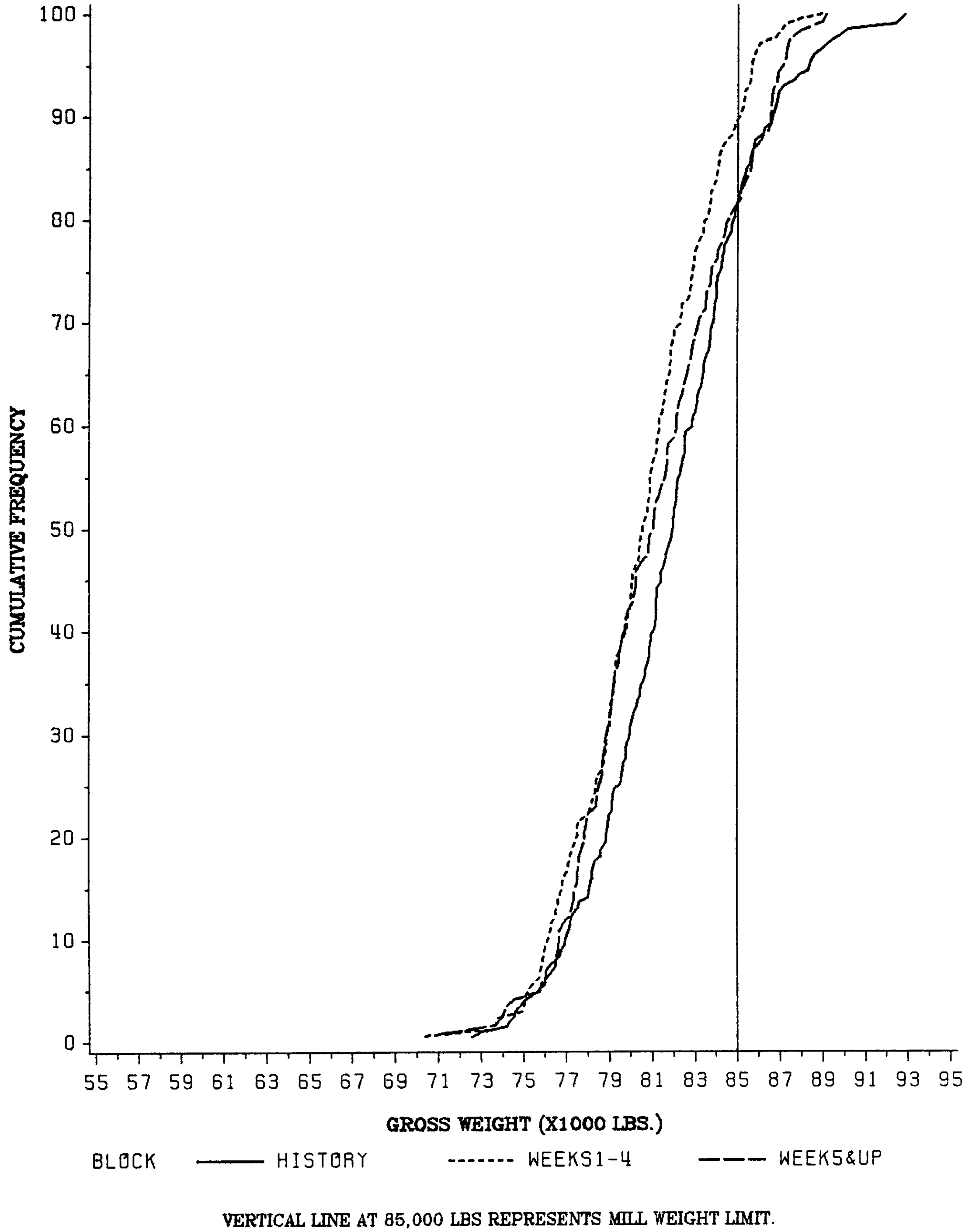


Figure 12. Frequency Plot of Gross Weights for Treatment Producer Group, Excluding E (Mill #1)

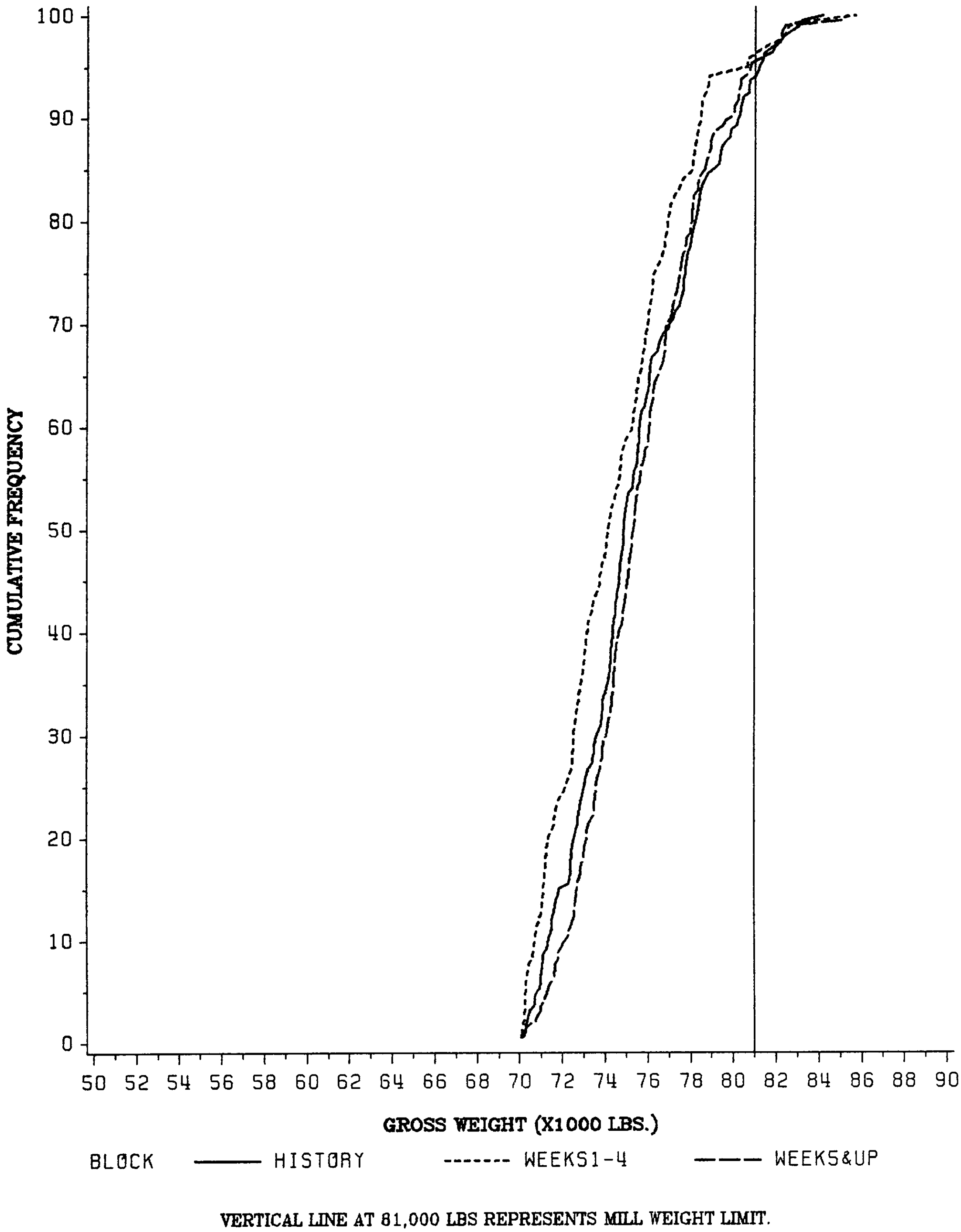


Figure 13. Frequency Plot of Gross Weights for Treatment Producer Group (Mill #2)

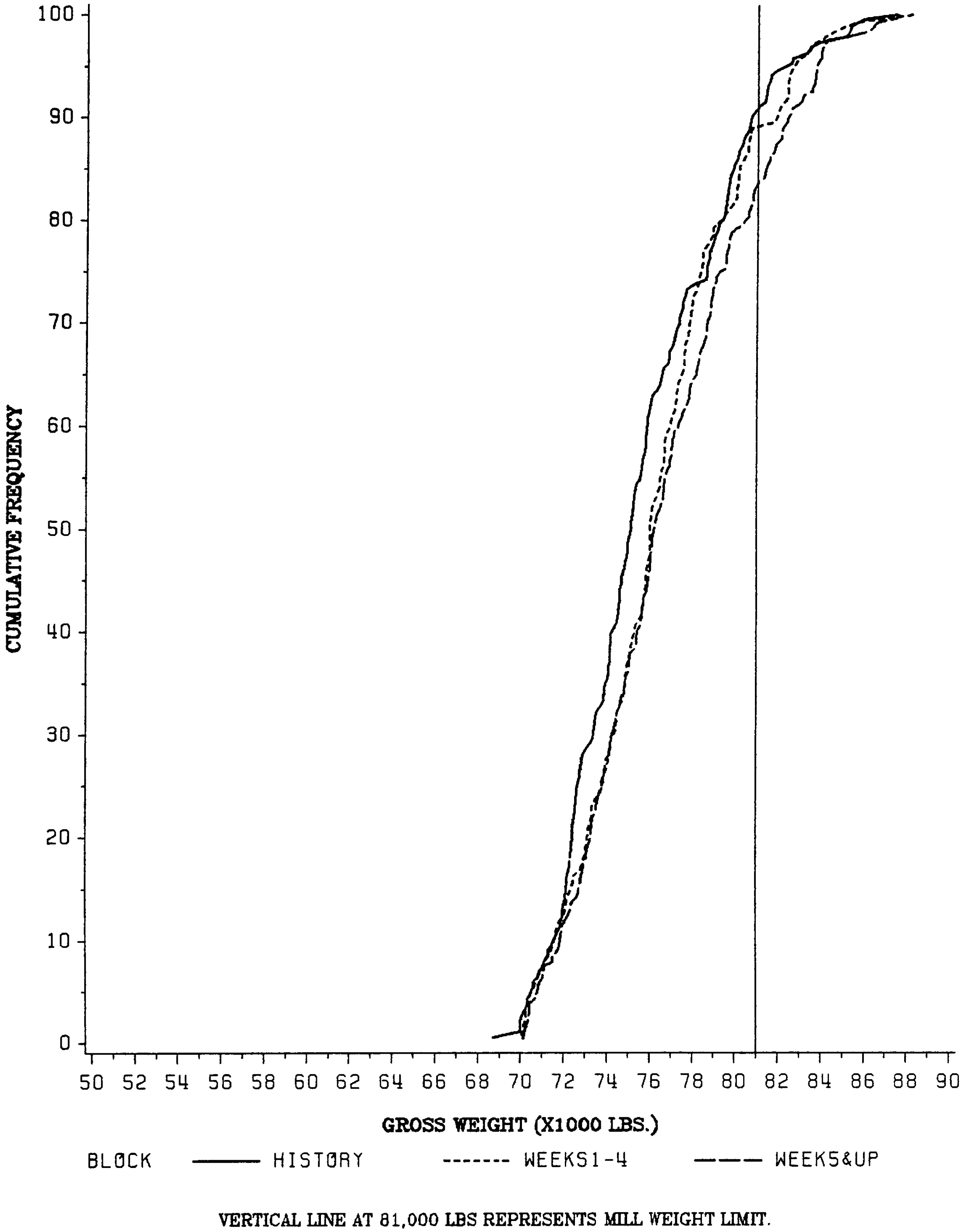


Figure 14. Frequency Plot of Gross Weights for Control Producer Group (Mill #2)

weight distribution that was significantly heavier than weeks one to four but not significantly different from the history period. The distribution showed what is considered definite improvement, with a greater proportion of the loads concentrated in the middle of the GVW range. This resulted in fewer loads which were excessively light or heavy. The control producers' weight distributions for the two time blocks in the study period were not significantly different from each other but both were significantly heavier than the distribution for the history period. The distributions of treatment producers were significantly lighter than those of the control producers for both time blocks within the study period.

The analyses on time blocks within the study period for both mill #1 and #2 indicate that the initial reaction of the producers to the treatment was different from their behavior after adjusting to the information provided them. The treatment producers at each mill reacted similarly, first reducing the typical load weights and later bringing them back toward their initial location but with a distribution slightly improved from that of the history period. The control producers tended to increase load weights as time passed, this change occurred independently from the study.

Statistical Summary

In summary, the statistical analyses conducted would not lead to the conclusion that the treatment provided in this study led to significant increases in the ability of all loggers to control the weight of loaded log trucks. However, indications are present that certain producers at mill #1 (two of five) reacted to the study in such a manner as to be able to improve the distribution of load weights while receiving the treatment. Intuitively, this may be the result expected with a passive treatment. At mill #2 it appears that the study caused a reaction on the part of most of the treatment producers which resulted in weight distributions which were significantly lighter than those of producers operating in an unmodified manner. A learning curve was associated with this treatment as was demonstrated by the comparisons of study period data subdivided into two time blocks.

Economic Analysis

The scope of this analysis is to quantify the economic effects of hauling various load weights and to evaluate the results of the loading study independently of in-woods production costs. Therefore, certain assumptions were made regarding logging production costs in order to limit the analysis to the effects that load size has on variable trucking costs. Assumptions were also made to eliminate the variability in equipment used by individual producers as well as differing legal constraints.

Assumptions

Loggers often have more than one log truck, and each may have a different maximum legal gross weight depending on the number and spacing of axles. The maximum legal GVW of each individual truck would serve as the optimum bench mark from which to conduct an economic analysis. However, no distinction was made in the vehicle delivering a load so this was not feasible. Therefore, the federal maximum legal GVW of 80,000 was selected for use as a universal bench mark. Calculated hauling costs were combined with assumed production costs and per unit revenues, applicable mill restrictions, and predicted overweight fines in conducting this economic analysis.

The following assumptions regarding costs and revenues were made. The combination of all in-woods production costs, truck ownership costs, and time related trucking costs were considered to be fixed at $10.00 per ton produced for the levels of production demonstrated in this study. Fuel, lubrication, maintenance, and repair costs and the miles traveled enroute to the mill were combined and defined as mileage costs. These mileage costs were allowed to vary in relation to GVW and distance to the mill and were estimated using the model previously presented. Revenue received by producers was assumed to be fixed at $12.00 per ton, regardless of haul distance. This results in a fixed production margin of $2.00 per ton. Average one-way haul distances for treatment producers were based on estimates by loggers and mill personnel. The mean one-way haul distance of all treatment producers at a mill was used as an estimate of the distance for that mill's control producers. These values are presented in Table 13 on page 84 and Table 14 on page 85 for mill #1 and #2, respectively. Potential fines were calculated using the economic model's Fine Adjustment and the values in Table 12. Potential fines must be calculated on an individual load basis, then averaged, since Georgia's, as well as several other state's, fine schedule varies proportionally to the degree of overload. Following discussion with mill personnel and the producers, the probability of a truck being weighed enroute to mill #1 was assumed to be 0.02 and 0.40 enroute to mill #2. The large difference in frequency of weighings reflects the respective levels of weight-related law enforcement in the regions in which the mills are located.

Adjustments in the margin per ton for mill regulation were determined using the methods discussed in the Model Adjustments section of this report. Adjustments for mill #1 used the Lost Volume Adjustment, with an upper weight limit (W) of 85,000 pounds. Adjustments for mill #2 were determined using the Reduced Quota Adjustment with an upper weight limit of 81,000 pounds.

The actual values resulting from the use of the economic model previously presented are not necessarily true indications of individual producers' actual economic performance. This is due to the fact that fixed revenues and expenses were used to simplify the analyses. In actual conditions, each producer may have revenues and expenses per ton that vary from those of other producers. However, shifts in the margin per ton and the associated adjustments do provide an accurate indication of the economic effects of changes in load size.

The unadjusted margin per ton varies in direct relationship to the manner in which individual load sizes have affected variable mileage costs. An increase in the margin indicates that a producer has generally loaded to a more optimum gross vehicle weight during the period. The adjusted margin per ton indicates the cumulative effect mill penalties and predicted fines have had on a producer's economic performance. The amount of change from the unadjusted margin is an indication of a producer's ability to limit load weight or the deliberate decision to underload or overload as a result of operating circumstances. The combined effect of the adjustments could be reduced or eliminated

Table 12. Fines for Gross Weight Limit Violations

Fines for Specified Interval (cents/pound)

Pounds Exceeding Gross Limit	Georgia	Tennessee
1-1,000	.08	5.0
1,001-3,000	1.5	5.0
3,001-5,000	3.0	5.0
5,001-8,000	4.0	5.0
over 8,001	5.0	5.0

Adapted from Beardsell (1986).

if (1) an individual had the ability to accurately control load weight or allowed a sufficient margin of error in load weights through underloading, and (2) deliberate overloading was eliminated.

Complete elimination of the adjustments would be difficult if not impossible. At times it is more economical to face the consequences of deliberate overloading than to be required to haul an additional excessively light load. Regardless of the method of determining load weight, a margin would need to be incorporated into the upper load weight limit. The range of this margin for error would depend on the precision with which GVW could be predicted.

These analyses do not incorporate the effects of a producer's average payload on cash flows. When operating under a load restricting quota, as were the producers at each of these mills during the study, the effects of reduced payload on hauling and associated costs may be more than offset by increased cash flows from delivering larger loads. In such a situation, the benefits of improved load weight control become increasingly important.

Mill #1 Results

Results of the economic analysis for producers at mill #1 are presented in Table 13. Comparisons of the unadjusted margin per ton for each producer in the history and study periods did not show any trends between the treatment and control groups. Approximately equal proportions of producers in each group displayed increases and decreases in the margin. The magnitude of changes in the unadjusted margin were also similar between the two groups.

However, when the effects of the mill's policy of no payment for wood delivered in excess of 85,000 pounds GVW and predicted overweight fines are incorporated into the margin per ton, trends become apparent between producers in the two groups. Four of the five treatment producers showed increases in the adjusted margins per ton during the study period. Producer E, who as mentioned previously increased load GVW significantly during the study period, was the only treatment pro-

Table 13. Mill #1, Margin per Ton Economic Analysis for History and Study Periods of Treatment and Control Producers

Treatment Producers

Producer/ Period	Average Miles	Average Gross Weight	Average Tons/Load	Unadjusted Margin/Ton (Dollars)	Penalty Adjustment per Ton (Dollars)	Fine[1] Adjustment per Ton (Dollars)	Adjusted Margin/Ton (Dollars)
A/History	106	80,906	25.72060	0.12	-0.03	-0.07	0.02
A/Study	106	80,519	25.87025	0.14	-0.04	-0.07	0.03
B/History	30	81,908	27.15680	1.49	-0.10	-0.11	1.28
B/Study	30	80,767	27.00667	1.49	-0.05	-0.07	1.37
C/History	20	82,502	27.41940	1.66	-0.14	-0.11	1.41
C/Study	20	79,922	25.93588	1.65	-0.02	-0.05	1.58
D/History	55	81,957	27.18280	1.07	-0.07	-0.09	0.91
D/Study	55	81,764	26.91865	1.06	-0.04	-0.08	0.94
E/History	140	80,790	26.03700	-0.45	-0.04	-0.07	-0.56
E/Study	140	82,444	26.88846	-0.41	-0.13	-0.12	-0.66

Control Producers

Producer/ Period	Average Miles	Average Gross Weight	Average Tons/Load	Unadjusted Margin/Ton (Dollars)	Penalty Adjustment per Ton (Dollars)	Fine[1] Adjustment per Ton (Dollars)	Adjusted Margin/Ton (Dollars)
F/History	70	80,473	25.11400	0.74	-0.02	-0.08	0.64
F/Study	70	79,322	24.57718	0.71	-0.08	-0.08	0.55
G/History	70	77,050	24.49980	0.71	-0.02	-0.04	0.65
G/Study	70	82,106	27.19735	0.81	-0.06	-0.10	0.65
H/History	70	80,709	25.81120	0.77	-0.02	-0.07	0.68
H/Study	70	83,132	26.94292	0.79	-0.12	-0.13	0.54
I/History	70	83,421	28.34900	0.85	-0.10	-0.11	0.68
I/Study	70	81,750	27.46438	0.83	-0.08	-0.09	0.66
J/History	70	83,858	27.63060	0.81	-0.12	-0.15	0.54
J/Study	70	81,339	26.35367	0.78	-0.08	-0.10	0.60

[1]Estimated using a 2% probability of being weighed.

ducer who experienced a decrease in his adjusted margin per ton. Conversely, three of the five control producers experienced decreases in their adjusted margin per ton during the study period. Producer G's adjusted margin remained constant and producer J increased his margin during the study period.

The economic analysis of the producers at mill #1 indicate that a greater proportion of the treatment producers (those receiving weekly summaries of their load distributions) were able to increase their adjusted margin per ton than were control producers. This increase was primarily attributable to reductions in the effects of mill penalties and exposure to overweight fines through increased weight control, rather than reductions in variable hauling costs per ton.

Mill #2 Results

Results of the economic analysis for mill #2 producers are presented in Table 14. Changes in the unadjusted margin per ton were small. Two of the four treatment producers held their margin per ton constant in the study period and two treatment producers reduced their margin by $0.01. One of the control producers increased the unadjusted margin per ton by $0.02 and another by $0.01 while the remaining two held theirs constant. Increases in the two control producers' margins were primarily the result of hauling more loads close to the base GVW of 80,000 pounds.

However, as with the producers at mill #1, effects of the treatment became evident when adjustments for overweight fines and the mill's deterrent policy were incorporated. Two of the four treatment producers displayed increases in their adjusted margins per ton in the study period, one remained constant and one reduced the adjusted margin rather substantially. One of the four control producers held his adjusted margin constant while the other three experienced reductions.

The economic results for mill #2 producers lead to a conclusion that increasing the treatment producers' awareness of their load weights, possibly coupled with the knowledge that their load weights

Table 14. Mill #2, Margin per Ton Economic Analysis for History and Study Periods of Treatment and Control Producers

Treatment Producers

Producer/ Period	Average Miles	Average Gross Weight	Average Tons/Load	Unadjusted Margin/Ton (Dollars)	Opportunity Cost Adjustment per Ton (Dollars)	Fine[1] Adjustment per Ton (Dollars)	Adjusted Margin/Ton (Dollars)
A/History	27	74,522	23.27140	1.50	-0.15	-0.04	1.31
A/Study	27	74,594	23.15732	1.50	-0.11	-0.04	1.35
C/History	22	75,177	23.97100	1.61	-0.10	-0.03	1.48
C/Study	22	73,118	23.11121	1.60	-0.03	-0.00	1.57
D/History	54	74,631	24.02360	1.04	-0.04	-0.00	1.00
D/Study	54	74,190	24.17124	1.04	-0.02	-0.02	1.00
E/History	25	75,564	24.89460	1.57	-0.03	-0.01	1.53
E/Study	25	75,753	24.75610	1.56	-0.10	-0.03	1.43

Control Producers

Producer/ Period	Average Miles	Average Gross Weight	Average Tons/Load	Unadjusted Margin/Ton (Dollars)	Opportunity Cost Adjustment per Ton (Dollars)	Fine[1] Adjustment per Ton (Dollars)	Adjusted Margin/Ton (Dollars)
F/History	32	76,738	24.20420	1.42	-0.17	-0.10	1.15
F/Study	32	77,675	24.36701	1.42	-0.23	-0.08	1.11
H/History	32	75,999	23.73640	1.41	-0.11	-0.06	1.24
H/Study	32	76,254	23.91422	1.42	-0.17	-0.07	1.18
I/History	32	72,242	22.39960	1.40	0.00	0.00	1.40
I/Study	32	72,803	22.54723	1.40	0.00	0.00	1.40
J/History	32	76,132	23.32000	1.40	-0.20	-0.13	1.07
J/Study	32	77,651	24.23157	1.42	-0.35	-0.28	0.79

[1]Estimated using a 40% probability of being weighed.

were being monitored more closely by the mill, caused them to reduce the costs of overweight fines and mill penalizations. This led to an increase in the adjusted margin per ton for two of the four treatment producers.

On-Board Scales Studies

Case studies were conducted for two producers utilizing on-board electronic truck scales. The scale systems utilized by each logger were manufactured by Lodec, Inc. and were mounted on tractors and rigid-frame, double-bunk trailers under the supervision of the same manufacturer's representative. Load cells were located at the equalizer brackets on the trailer tandem axle and at the fifth-wheel mounting brackets on the tractor chassis. Although the scale systems were similar, the logging applications in which they were used differed substantially.

Producer #1

This producer operates in the mountain region of southwestern Virginia and hauls exclusively hardwood material. Although some loads consisting of sawlogs are hauled, the majority of loads are comprised of random-length hardwood pulpwood and are hauled exclusively to one mill. Only the pulpwood loads were monitored in this study since sawlogs were not sold on a weight basis and no information was available on the actual weight of these loads. Data were collected for a twelve month period prior to installation of the scales and for a twelve month period following installation.

Producer #1 hauled an average of five to six loads per week during the study, over an average one-way haul distance of 85 miles. The majority of this distance is travelled on interstate highway and no permanent weigh stations are passed enroute to the mill. Temporary weighing points were occasionally encountered. Overweight fines were infrequent, with one fine of $437.00 received in the 12 months prior to installation and none following it.

This producer utilizes one tractor and one or two trailers to haul wood. Originally only one trailer was equipped with scale components but the second was equipped during the course of the study. The second trailer equipped for on-board weighing was used infrequently and due to a limited number of observations, data for this trailer were not used in the study. Justification for this is based on the fact that the scale system was calibrated for the trailer originally equipped with weighing components and the use of other trailers with the system may not result in an equal level of accuracy, therefore, the readings should not be pooled. The comparable level of accuracy for each of the trailers could not be tested because of an insufficient number of observations for the second trailer equipped with scale components.

This is a small family type operation which is often on a restrictive quota from the mill. At times the stumpage harvested is owned by the mill, at others the producer purchases his own. The owner of the operation does the loading and truck driving, his son performs skidding activities and at times fells the timber. Felling is done with a chainsaw and a cable skidder is used. A third individual is hired to fell timber when conditions warrant. The owner and his son share road and landing construction responsibilities.

Producer #1 modified his loading and hauling strategy at the time of scale installation. Previously, trailers were intentionally overloaded and hauled to the mill at times when the probability of being weighed by law enforcement officials was expected to be light, generally in the evening or very early morning. Few loads were hauled from the woods during the daylight hours. After installing the scales, flexibility was increased due to greater knowledge of load weights and loads were hauled on a convenience basis. This resulted in a reduction in the number of hours the owner spent on the job and concentrated them in the daylight hours.

Some production delays occur during loading in conjunction with the use of scales. The loader operator or another individual is required to read the indicator in the tractor cab to identify necessary load adjustments. Delays are minimized by the skidder operator or feller making the readings and communicating with the loader operator via hand signals. However, this technique did require an individual to temporarily leave his other duties near completion of the loading process and this would reduce his production.

Accuracy Determination

Accuracy of the on-board scale system was checked separately for positive and negative error. A positive error, or difference, occurs when the on-board scale's weight reading is greater than the actual weight determined by the mill's certified scales. Negative differences occur when the on-board scale weight reading is less than the actual weight. Although it is desirable to minimize the frequency and severity of each type of difference, the consequences of underestimating the weight can be more detrimental than overestimates. This is due to the unexpected exposure to overweight fines which exists with underestimates. Therefore, the negative errors are considered to be more critical.

The mean and standard deviation of the positive and negative errors were determined for producer #1 and are presented in Table 15. In addition, confidence limits were established using a one-sided t-distribution at $\alpha = 0.05$. The confidence limits indicate that there is a 95 percent certainty that the on-board scale's estimate of the actual GVW would be no more than 513 pounds low or 965 pounds high. Stated as a percentage of the mean gross weight, accuracy of the scale system is within -0.6 to + 1.22 percent of true.

Accuracy of the on-board scale system was also determined in relation to various GVW ranges. Groups were formed on 2000 pound ranges, centered at 80,000 pounds. The group classifications an corresponding positive and negative means and standard deviations are provided in Table 16.

Table 15. Overall Accuracy of Producer #1 Scale System

Difference	Mean (Pounds)	Standard Deviation (Pounds)	Confidence Limit at $\alpha = 0.05$
Positive	778	1074.3	965
Negative	-423	398.3	-513

Table 16. Accuracy in Comparison to GVW (Producer #1)

GVW Range (Pounds)	Difference	N	Mean (Pounds)	Standard Deviation (Pounds)
< 75,000	Positive	0	--	--
	Negative	0	--	--
75,000-76,999	Positive	5	2950	2394.3
	Negative	0	--	--
77,000-78,999	Positive	62	683	722.3
	Negative	23	-315	256.4
79,000-80,999	Positive	21	388	306.1
	Negative	27	-430	317.1
81,000-82,999	Positive	1	170	--
	Negative	4	-1038	947.7
> 83,000	Positive	2	2690	3493.1
	Negative	1	-245	--

Scheffe's test was used to determine whether mean positive and negative differences between weight groups were significantly different at $\alpha = 0.05$. Selection of Scheffe's was based on the suspicion that the variances were not equal for the different GVW ranges. The mean positive differences for the GVW ranges of 75,000-76,999 pounds and 83,000 pounds and greater were significantly different from the mean positive difference for the 79,000 to 80,999 pound range. The mean positive difference for the 75,000-76,999 pound GVW range was also significantly different from the 77,000-78,999 pound range. The GVW range of 81,000-82,999 pounds had a mean negative difference which was significantly different from those for other ranges in which observations were made. The similarity of the positive and negative differences for GVW's near the center of the overall weight range and the dissimilarity at the ends of the range indicates that, in this application, the accuracy of the on-board scale system decreases as load weights become increasingly lighter or heavier. This characteristic is suspected to be due to the manner in which strain gauge load cells sense the weight. They are calibrated so that a specific level of electrical resistance in the strain gauges, resulting from the pressure applied to load cells, represents a given weight. This relationship deteriorates as the load weight diverges from the weight at which the scales were calibrated.

Comparison of Variance

Based on the accuracy levels determined, it appears that information provided by the on-board scales is useful in reducing load weight variance. A cumulative frequency plot contrasting before and after gross weight distributions is provided in Figure 15. The variance in gross weights before and after scale installation were compared using an F-test for the ratio of variances.

Certain inconsistencies which existed in the data were corrected before comparing gross weight variances. Only net weights were available for loads delivered prior to installation of the scales, therefore, the mean tare weight of 28,920 pounds was used to estimate gross weights for these loads. These gross weights were used for comparison to the gross weights recorded following installation of the scale system. The net weights collected prior to installation of the scales included loads de-

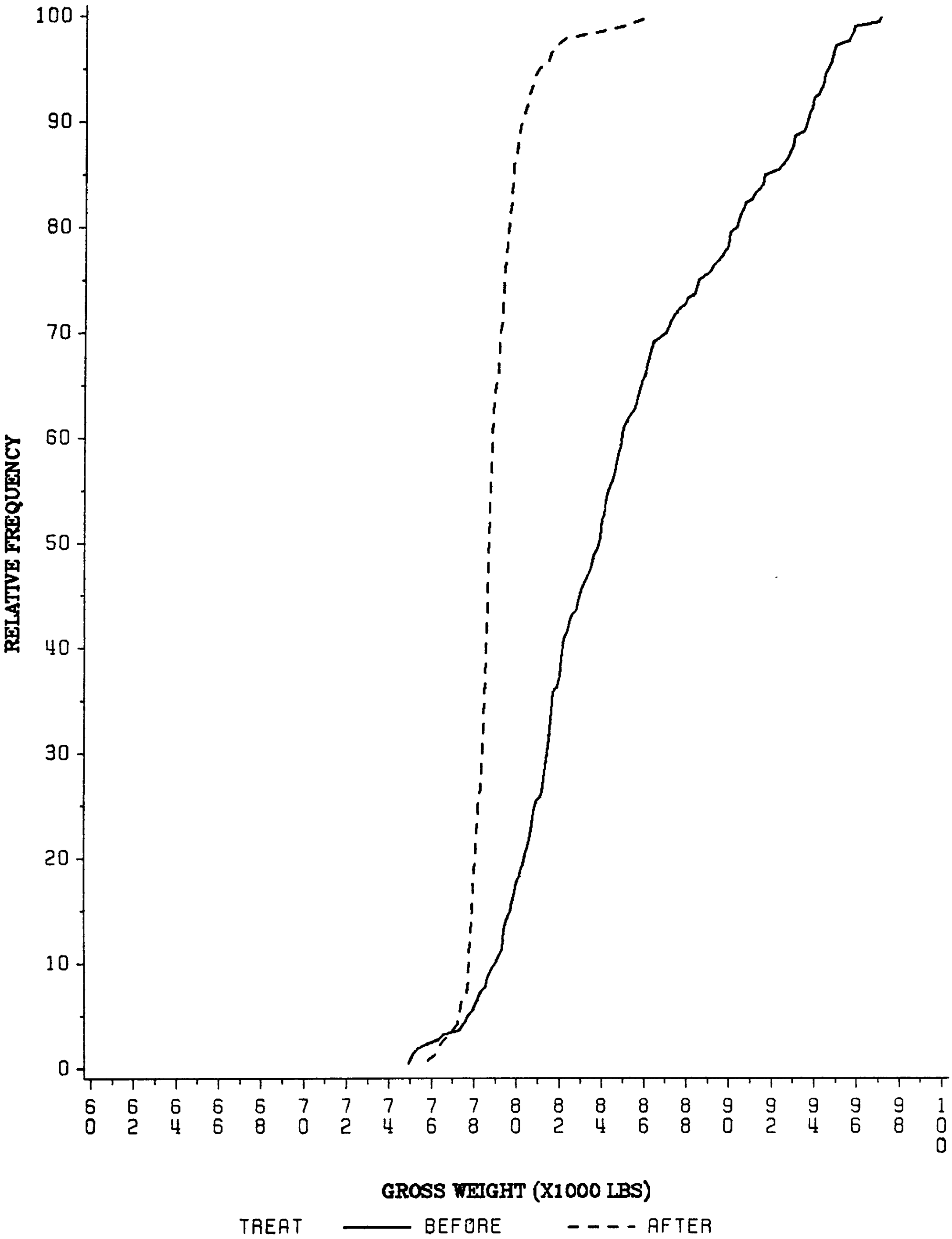


Figure 15. Cumulative Relative Frequency (Producer #1)

livered using two different trailers. However, both trailers were built by the same manufacturer with identical dimensions and differed in weight by only 500 pounds. This difference was not expected to significantly affect the variability in net load weights and no adjustment was made to the data.

The mean gross weight and standard deviation prior to installing the scale system were 84,915 and 5302.1 pounds, respectively. Following installation, the mean was reduced to 79,003 pounds and the standard deviation to 1362.6 pounds. The F-test for the ratio of variances had a P-value less than .001, indicating that a highly significant difference existed between the two variances. Scheffe's test at $\alpha = 0.05$ led to a conclusion that the mean gross weight was significantly reduced following scale installation. The reduction in the mean gross vehicle weight is attributable to modifications in the producer's hauling strategy. As previously mentioned, a conscious decision was made to attempt to load closer to the legal limits. The reduction in variance is largely due to the increased ability of the producer to control load weight through the use of the accuracy provided by on-board electronic truck scales.

Economic Analysis

The average variable mileage cost of hauling was determined separately for loads delivered prior to and following installation of the scales. Gross weights were estimated for loads delivered prior to installation of the scales using actual net weights and the mean tare weight. Mileage costs were calculated using the model previously discussed, with the average one-way distance of 85 miles, and are $1.44 per ton and $1.51 per ton for the periods prior to and following scale installation, respectively. As was done in the loading study, a margin of $2.00 was assumed for all costs excluding hauling mileage costs. Mileage costs include fuel, lubrication, maintenance and repair of the truck but do not include labor or capital investment costs for hauling. The resulting margin on hauling costs were $0.56 per ton before and $0.49 per ton after scale installation.

Producer #1 reduced his average payload from 27.998 tons to 25.041 tons following installation of the scale system. Associated with this 2.957 ton reduction in payload was the cost of hauling additional loads to attain the same delivered volume over a period of time. The number of additional loads required for every load delivered to maintain a fixed total volume is determined as follows:

$$Additional\,Loads = \left(\frac{Change\ in\ Mean\ Net\ Weight}{Mean\ Net\ Weight\ Following\ Installation} \right)$$

In this case the additional loads required for each load delivered is 0.118 or approximately 12 additional loads for every 100 delivered. The total cash flow associated with the additional loads is the product of the change in margin per ton and the total number of tons desired, provided the assumption of all costs except mileage costs remaining fixed is not violated by the desired production level. With the inclusion of the additional loads the total volume delivered and the revenue received would remain constant, with or without acquisition of on-board scales, therefore, the assumption of other costs remaining fixed is reasonable.

Driver labor hours were estimated by the contractor to be reduced substantially as a result of the perceived increase in flexibility associated with use of on-board scales. Deliveries were no longer delayed to avoid peak times in terms of the probability of being weighed. The labor hours were primarily reduced by shifting them to hours when the owner, who drives the truck, was normally on the job site. The production of the operation was not greater when the owner was working more hours in the time before the scales were installed than following installation. Therefore, it appears that the increased flexibility has actually resulted in more efficient use of the owners time rather than a time savings. This makes it difficult to place a dollar value on the reduced time requirements of the owner.

The cash flows associated with the use of on-board scales which can be accurately identified and quantified from the data acquired in this case are primarily negative. As a result, the acquisition of the system would have a negative internal rate of return. However, if the perceived value of the benefits the producer receives from increased confidence, flexibility, and reduced labor hours exceeded the negative cash flows, the internal rate of return might become positive. Producer #1 is confident that the value of these benefits does exceed the negative cash flows, and believes that he is receiving a positive return on his investment.

Producer #2

This producer operates along the border of the coastal plain and piedmont regions of southeastern Virginia and produces exclusively for one firm. The majority of material produced and hauled is tree-length pine which is sorted into sawlogs and pulpwood. Deliveries are made to one of three mills, all of which are owned by the same firm, depending on material type and the directions of company personnel. Loads comprised of both sawlogs and pulpwood were monitored in this study. Data was collected for four months prior to installation of on-board truck scales and for six months following installation.

Producer #2 delivers approximately eight loads per week with the scale equipped vehicle and has an average one-way haul distance of 50 miles. Portions of the distance could be travelled on interstate highway if desired, however due to the manner in which haul vehicles are licensed, travel when loaded is limited to state roads. This strategy allows the producer's trucks to have higher axle weights than are allowed on interstates but at a slightly lower legal gross weight limit of 79,800 pounds. No permanent weigh stations are encountered enroute to delivery points but temporary weigh points are frequently encountered. No overweight fines were received in the period prior to scale installation and one $50.00 dollar fine was received in the period following installation.

Two tractors and three trailers are utilized to deliver wood but only one tractor and one trailer are scale equipped. The second tractor and third trailer were acquired at approximately the same time as the original tractor and a trailer were equipped with scales. The scale equipped tractor and trailer are utilized full-time during regular working hours and remaining hauling equipment is used as needed to achieve the targeted number of daily deliveries. Trailers loaded without the use of on-board scales are generally hauled by the owner after the regular operating hours of the crew. Only those loads delivered with the scale equipped tractor-trailer were monitored in this study.

This operation is mechanized, with five individuals working at the harvest site, another driving a truck full-time, and the owner who fills in where needed. The owner does all of the "after hours" truck driving with the tractor not equipped with scales. Much of his remaining time is spent supervising the crew or acquiring repair parts. All of the material harvested by this producer is from stumpage owned by the mill.

Prior to installing on-board scales on one tractor-trailer and acquiring the second tractor and third trailer, this producer generally attempted to load legally. This was due to the relatively high frequency of weight checks by law enforcement officials. Following these acquisitions, the scale equipped vehicle is loaded as close to the legal maximum as possible. The gross weight of the vehicle not equipped with scales is not as closely limited and much of the time it is utilized after normal operating hours. To aid in the loading process and to avoid time delays which could result from the use of on-board scales, a CB radio was installed in the loader cab. This allows the truck driver, reading the indicator, to communicate directly with the loader operator during the loading process. In this manner instructions are given for optimum placement of stems on the trailer. This technique works well for this operation because the truck driver has no other duties during the loading process.

Accuracy Determination

Accuracy of the on-board scale system used by producer #2 was determined in the same manner as for producer #1. Mean positive and negative differences between the scale system and certified mill scales and the corresponding standard deviations are presented in Table 17. Confidence limits using the t-distribution at $\alpha = 0.05$ are also included in the table. It is indicated by the confidence limits that at a 95 percent level of confidence, the estimated gross weight will be within -689 to +762 pounds of the actual gross weight. The expected accuracy of the system is therefore within -0.9 to 1.0 percent of the true gross vehicle weight.

The on-board scale system used by producer #2 was checked for differences in accuracy in relation to the actual GVW. Weight ranges of 2000 pounds, centered on 80,000 pounds were established and the positive and negative errors determined for each class. The differences for each class are provided in Table 18.

The significance of differences in the mean positive and negative errors for GVW groups was tested using Scheffe's test at $\alpha = 0.05$. No significant differences were found in the mean positive or negative errors for individual GVW ranges. Very few observations were made in the extremes of the GVW ranges, therefore, it is difficult to make a statement about the effects of GVW on accuracy. However, the similarity of differences near the center of the GVW ranges would indicate that the accuracy in this application is not greatly affected by the GVW.

The accuracy of the on-board scale weight readings was also compared for each of the mills to which loads are delivered. No significant differences were observed in the differences for each mill using Scheffe's at $\alpha = 0.05$. This characteristic should be expected assuming the mill's scales, which are certified, do not differ significantly in their accuracy.

Comparison of Variance

The accuracy with which the scale system utilized by producer #2 determined gross vehicle weight indicates that the variance in delivery weights could be reduced. The cumulative frequency distributions provided in Figure 16 indicate the effects on-board scales have had on the variation in

Table 17. Overall Accuracy of Producer #2 Scale System

Difference	Mean (Pounds)	Standard Deviation (Pounds)	Confidence Limit at $\alpha = 0.05$
Positive	654	480.5	762
Negative	-568	552.5	-689

Table 18. Accuracy in Comparison to GVW (Producer #2)

GVW Range (Pounds)	Difference	N	Mean (Pounds)	Standard Deviation (Pounds)
< 75,000	Positive	1	1160	--
	Negative	1	-40	--
75,000-76,999	Positive	7	946	521.6
	Negative	5	-190	201.9
77,000-78,999	Positive	32	689	491.5
	Negative	19	-428	363.4
79,000-80,999	Positive	16	426	351.2
	Negative	32	-676	623.6
81,000-82,999	Positive	0	--	--
	Negative	2	-1395	77.8
> 83,000	Positive	0	--	--
	Negative	0	--	--

gross weight. As with producer #1, the ability to control load weight is analyzed using an F-test to compare the ratio of variances and Scheffe's to compare means for loads monitored before and after scale installation. As previously mentioned, this producer made an effort to keep loads delivered with the scale equipped truck within the legal limits. Another truck, not equipped with scales was used to haul loads expected to exceed the legal limits, when it was desirable for scheduling purposes. Therefore, the variance in gross weights associated with loads delivered using the scale equipped vehicle is possibly understated from what would occur if only one haul vehicle was in use.

As was the case for producer #1, only net weights were available for the period prior to installation of on-board scales by producer #2. Therefore, the gross weight of these loads was estimated using the mean tare weight of 30,160 pounds. These gross weights were compared to the actual gross weight recorded following installation of the scales. Net weight observations prior to installation of the on-board scales represented loads delivered using only the tractor-trailer later equipped with scales. This is due to the fact that the second haul vehicle was acquired at essentially the same time as the scale system.

Comparison of the gross weights for the two observation periods indicates a reduction in the variance of gross weights following installation of the scale system. The mean gross weight was reduced by 2121 pounds, from 80,737 to 78,616 pounds, when using the on-board scale system. The standard deviation of gross weights was 3717.1 before and 1332.8 following installation. The F-test indicated that the reduction of variance in gross weights following scale installation was highly significant, with a P-value less than .001. The change in mean gross weight was found to be significant using Scheffe's at $\alpha = 0.05$.

Economic Analysis

As a result of changes in producer #2's load weight distribution following installation of on-board scales, his variable hauling cost per ton on a mean one-way haul distance of 50 miles increased by

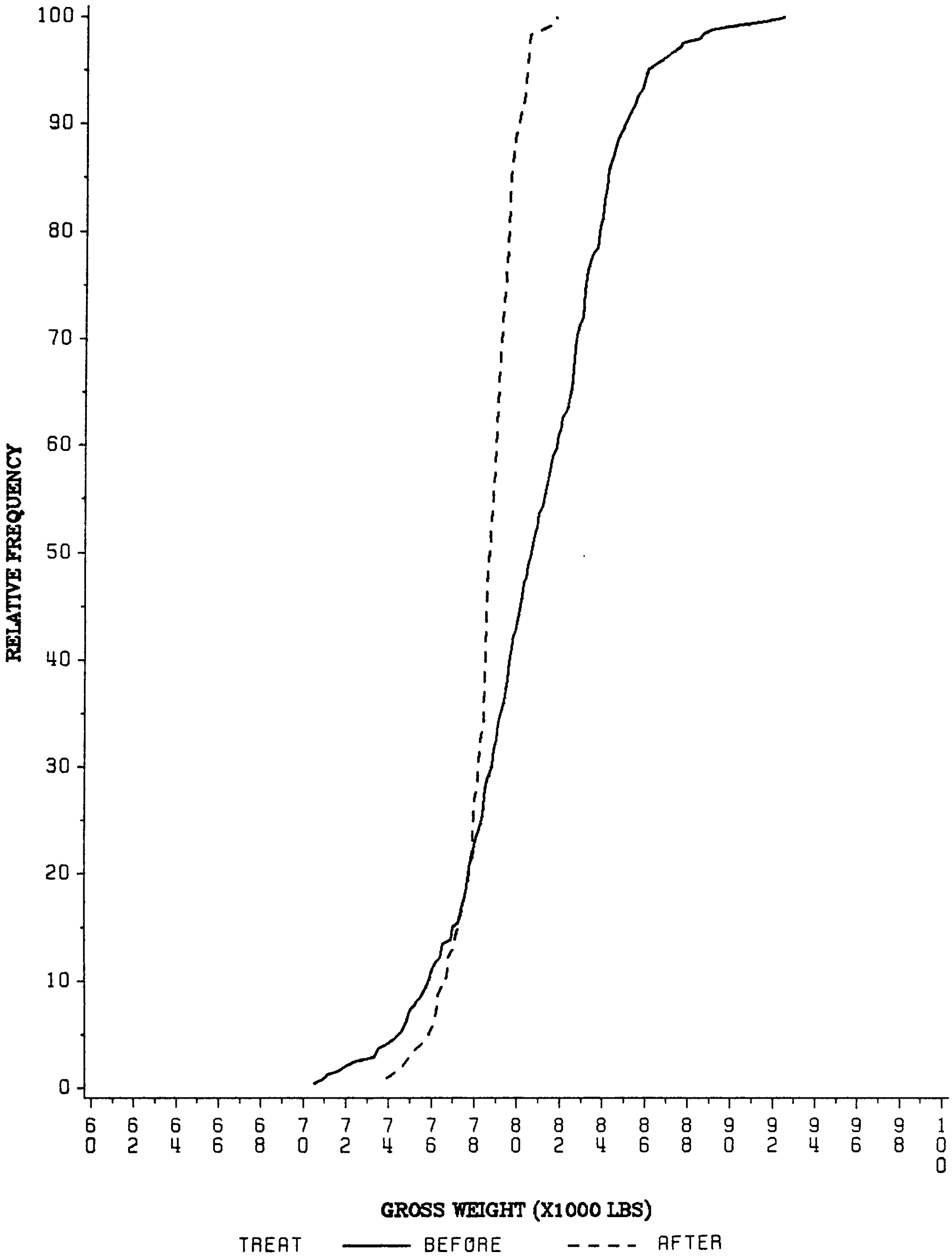


Figure 16. Cumulative Relative Frequency (Producer #2)

$0.02, from $0.90 to $0.92 per ton. This is primarily due to the reduced mean net weight. Using an assumed fixed production margin of $2.00 per ton as discussed previously, the margin for variable mileage cost decreased from $1.10 to 1.08 per ton.

The mean net weight of loads delivered with the scale equipped truck was 24.229 tons, as opposed to a mean net weight of 25.289 tons prior to installing scales. To compensate for the lost volume per load of 1.06 tons, additional deliveries would be required to maintain a constant level of production. This was calculated in the same manner as for producer #1 and is 0.044 additional loads for every load delivered or approximately four additional loads for every 100 loads delivered. Since the total volume produced would remain constant, the only change in cash flows associated with the additional loads would be the change in margin per ton times the total number of tons desired.

The contractor estimates he has reduced the time required for loading as a result of the use of on-board scales. Delays which previously occurred in estimating load weights and the supervision time required by the owner were considered significant. Through the use of the scale system, information was readily available for keeping GVW within the legal limits and as a result less supervision of the loading process was required of the owner. This allowed him greater freedom to conduct other activities as needed. Adequate documentation of the time savings is not available from the data collected, precluding determination of the actual cash flows associated with the time savings. Therefore, based on the cash flows associated with system purchase and installation, and reduced payload an internal rate of return calculation would not be positive. If the value of such qualitative factors as the confidence and flexibility obtained as a result of scale use, and the actual value of time savings are large enough, investment in on-board scales for this producer would become financially sound. This producer feels that he has gained sufficient time savings to rationalize the investment.

Discussion

Producer #1 and Producer #2 displayed similar reactions to the use of on-board electronic scales. Although producer #1 overloaded more frequently, both producers continued to load beyond the legal limit occasionally following installation of the scale system. Apparently this was done for operational purposes, at times when the benefits of overloading were believed to exceed the risks. It was observed that producer #1 typically hauled overweight loads with the second trailer equipped with scale components, although this observation was not proven in this research. Producer #2 hauled almost entirely legal loads with the scale equipped tractor-trailer. The other hauling equipment was used when it was desirable to load heavy.

In the cases examined for this study, mill penalties did not exist and law enforcement pressure was relatively low. However, on-board scales do provide a tool which can be helpful in reducing the frequency and severity of fines, in situations where the level of weight related law enforcement activity is high. McNeel and O'Rourke (1986) reported on a case in which the frequency of overweight fines received by a logging operation using on-board scales was reduced from 26.7 to 16.5 per truck, per year. The mean cost per overweight fine received was reduced by $35.05. The purchase of on-board scales had a high internal rate of return in this case.

The use of on-board scales does not ensure that more loads will be hauled legally. The scales give users the capability to haul at approximately whatever weight desired. The payload weight chosen depends on the operator's philosophy, the operational situation, and the expectation of being weighed by law enforcement officials. The weight of loads can be best optimized when using on-board scales in conjunction with improved planning and scheduling of the hauling phase of production.

Summary and Conclusions

The objectives of this research were to evaluate the benefits associated with the ability to control load weight and to determine the suitability of weight control methods in relation to log hauling. The optimization of log truck payloads was a prime concern and the basic issue was then; given varying degrees of accuracy, what investment is required to attain an adequate level of accuracy for a specific hauling situation? Two approaches were used to answer this question, (1) how well can load weight be controlled with operator training, and (2) are mechanized weighing devices an improvement over operator training.

An economic model was developed to evaluate benefits associated with load weight control. This model is particularly sensitive to the effect load weight has on the mileage costs of hauling. Other production and hauling costs were considered to be reasonably stable with respect to payload. Adjustments were incorporated into the model to reflect the influence legal constraints and mill regulation have on determining the optimum load weight. This model was then used to analyze the results of studies conducted.

A study designed to improve the ability of loader operators to control load weight was replicated at two mills. A modified reporting technique was used to improve the capabilities of loader operators by heightening their awareness of trends in delivery weights. No positive or negative reinforcement for producer performance was provided by the mills. Perhaps because of the passive manner in which this study was conducted, results were not overly conclusive but did indicate some changes which occurred. Based on the minimal cost to mills of implementing a reporting system similar to the one used here, the economic benefits to both the loggers and the mills are expected to be positive.

The use of on-board scales to control load weight was evaluated using case studies on two logging operations. This approach to weight control replaces operator training and skill with electronic technology. The scales proved to be reliable and accurate in the applications studied and had a high level of user satisfaction. Both of the loggers studied reduced their load weights following installation of the scales, due to the accuracy and modifications in hauling strategy. As a result of bringing load weights nearer the legal limits, the chance of fines was reduced but hauling costs were increased. Therefore, the economic returns associated with scale use were not positive. However, both producers felt that the non-economic benefits of scale use justified the expenditure.

Several significant factors were identified in the studies.

- The importance of maximizing load weight in log trucking may be overstated in many instances. The financial penalties of hauling light loads may not be as great as is often believed and in some instances there are positive returns associated with load weight reduction.

- On short haul distances, deliberate underloading as a substitute for accurate weight control, is an effective and economical means of avoiding penalties associated with overweight loads. On longer hauls, accurate weight control to minimize underloading becomes more important on the basis of hauling costs.

- Optimal load weight is a function of the sensitivity of hauling costs, the level of law enforcement activity, and the manner in which mills regulate logger production and load delivery weights. Therefore, the investment in weight control must reflect the nature of these factors.

- Heightening the awareness of loader operators, with regard to trends in the GVW of deliveries, did result in observed changes in loading behavior for some loggers studied, leading to improved optimization of load weights. The benefits of this treatment could possibly be increased in two ways: (1) Greater attention given to setting and achieving goals for improvement in the distribution of load weights, and (2) recording estimates of load weight for comparison to scalehouse weight tickets on a load by load basis.

- On-board electronic truck scales can perform well in southern logging applications. However, an individual producer must determine whether the increased ability to control load weight offsets the investment in scales.

- Many of the benefits associated with the use of on-board scales may not result in direct and measurable cash flows. The financial benefits are primarily a function of load weights before installation, mill restrictions, and legal constraints.

- Production restrictions (quotas) which are based on a certain number of loads rather than the total volume delivered penalize individuals for hauling within the legal limits. In the absence of these load restrictions, an individual may be able to operate more efficiently at lower payload weights.

Bibliography

American Association of State Highway Transportation Officials Study. 1978. U.S. Government Data, Washington, D.C.

American Pulpwood Association. 1984. 1984 Wood fiber forecast for the south. American Pulpwood Association Report 84-A-9, Washington, D.C. 10p.

Anonymous. 1981. On-board electronic scales: One way to beat ole′ smokey! Timber Harvesting, Vol.29, No.11:25-26.

Archer, H. 1986. International Paper Company. Personal communication.

Beardsell, M.G. 1986. Decreasing the cost of hauling timber through increased payload. Dissertation submitted in partial fulfillment of Ph.D. requirements at VPI&SU, Blacksburg, VA. 133p.

Blomquist, A.J.A. 1970. Weight sensors. *In* Instrumentation and Control Group Committees, Electronic weighing. IERE Conference. Proceedings. IERE, London, England. p211-234.

Burkhart, H.E. and J.E. Clutter. 1971. Green and dry weight yields for old-field loblolly pine in the Georgia Piedmont. Georgia Forest Research Council Report #22, Series 4. 11p.

Burkhart, H.E., R.C. Parker, and R.G. Oderwald. 1972 A. Yields for natural stands of loblolly pine. Publication FWS-2-72, Div. of For. and Wildlife Res., VPI&SU, Blacksburg, VA. 63p.

Burkhart, H.E., R.C. Parker, M.R. Strub, and R.G. Oderwald. 1972 B. Yields for old-field loblolly pine plantations. Publication FWS-3-72, Div. of For. and Wildlife Res., VPI&SU, Blacksburg, VA. 51p.

Butler Manufacturing Company. 1985. Weighmaster platform scale. Scale Group, Butler Manufacturing Company, Fort Atkinson, WI. 2p.

Cascade Trailer and Equipment. 1973. Parts catalog: Air scale kit. Cascade Trailer and Equipment, Portland, OR. 2p.

Conover, W.J. 1971. Practical nonparametric statistics. John Wiley and Sons, Inc., New York, NY. p309.

Conway, S. 1982. Logging practices: Principles of timber harvesting. Miller Freeman Publications, Inc., San Francisco, CA. p348-356.

Dana Corporation. 1984. Williams air controls: WM482 series. Dana Corporation, Portland, OR. 1p.

Deal, E. 1986. North Carolina State University. Personal communication.

Ellis, J.C. 1986 draft. The loadrite microprocessor-after three years of operation. Forest Research Institute, Rotorua, New Zealand. 8p.

General Electrodynamics Corporation. no date. GEC heavy duty portable scales: MD-500 series. General Electrodynamics Corporation, Garland, TX. 2p.

Hudson, S. 1986. Georgia Forest Products. Personal communication.

Husch, B., C.I. Miller, and T.W. Beers. 1972. Forest mensuration. John Wiley and Sons, New York, NY. p82.

Kilowate, Inc. no date. Legaloader III: Quickest weigh in the world! Kilowate, Inc., Georgetown, TX. 2p.

Lake Goodwin Scale Co., Inc. no date. Vulcan on-board scale system. Lake Goodwin Scale Co., Inc., Stanwood, WA. 1p.

Latham, G.P. and E.A. Locke. 1979. Goal-setting--A motivational technique that works. Organizational Dynamics, Vol.8 No.2:68-80.

Lewis, R. 1985. Turn signals. Forest Products Trucking Council, Washington, D.C. p6.

Lewis, W. 1986. Watford Logging Company. Personal Communication.

Lodec, Inc. no date A. On-board electronic scales. Lodec, Inc., Lynnwood, WA. 4p.

Lodec, Inc. no date B. L1042 Digital weight indicator: Operators manual. Lodec, Inc., Lynnwood, WA. 17p.

Lodec, Inc. no date C. Eldec electronic axle scales. Lodec, Inc., Lynnwood, WA. 4p.

Marlin, J.C., S.K. Dragula, and D.W. Marlin. 1980. Increased truck size and weight: The impact on highways, safety, and energy. Central States Resource Center, Urbana, IL. 38p.

McConnell, J. 1987. McConnell Logging Company. Personal Communication.

McNeel, J.F. and O'Rourke. 1986. Unpublished manuscript. Georgia Cooperative Extension Service and Buckeye Cellulose Corporation.

Pottie, M.A. 1986. Radio telemetry of logging truck load weights. Forest Engineering Research Institute of Canada, Vancouver, B.C. 20p.

Pottie, M.A. and A.W.J. Sinclair. 1985. Interim report on loader and truck scales project. Forest Engineering Research Institute of Canada, Vancouver, B.C. 17p.

Road Research Group. 1982. Impacts of heavy freight vehicles. Organization for Economic Co-operation and Development, Paris, France. 169p.

Schneider, R. 1984. Pneumatic scale monitors logging truck weight. Hydraulics and Pneumatics: The Magazine of Fluid Power and Control Systems, 8:12-13.

Structural Instrumentation, Inc. 1984. SI-100 on-board electronic scales: Owners manual. Structural Instrumentation, Inc., Tukwila, WA. 19p.

Structural Instrumentation, Inc. no date. The most important number on your truck. Structural Instrumentation, Inc., Tukwila, WA. 2p.

Stuart, W.B. no date. Constructing and using nomographs. School of For. and Wildlife Res., VPI&SU, Blacksburg, VA. 12p.

Appendix A. Variable Mileage Cost Nomograph

The nomograph presented in Figure 17 is based on the mileage cost model presented in the body of this report. It can be used to estimate variable mileage hauling costs for loads of specific gross vehicle weights. Mileage costs of hauling include cash flows associated with fuel, lubrication, maintenance, and repairs of haul vehicles. Hourly operating costs and capital investment costs are not included and must be added to the mileage cost to determine the total hauling cost.

The nomograph can be used to conduct a sensitivity analysis, allowing variable values to change independently or in combination (Stuart, no date). The final value obtained indicates the impacts which assumptions have had on the variable mileage costs.

To use the nomograph, progress through the charts in numerical sequence, as indicated by the example. Select the assumption line considered most appropriate for each variable and move at right angles from points of intersection. It may be necessary to interpolate between assumption lines in order to accurately represent the desired scenario. This was done in Chart 5 for the example which was assumed to have a net weight of 22.5 tons.

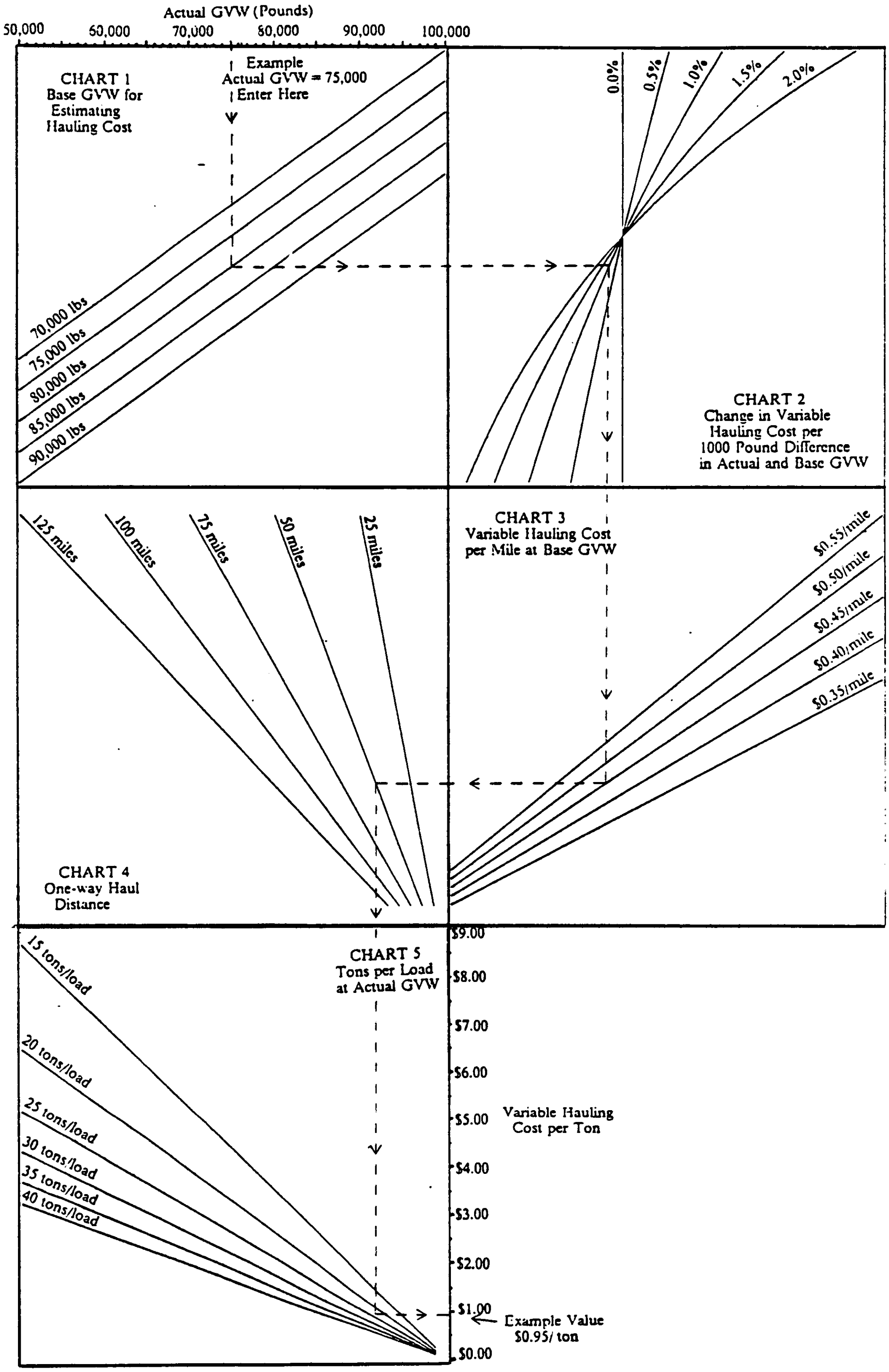


Figure 17. Nomographical Prediction of Mileage Costs

Appendix B. Description of Producers Included in the Loading Studies

Mill #1

The mean number of loads delivered per week by each producer during the study period and the target weights identified by the treatment producers are provided in Table 19. General descriptions of the treatment producers' operations are intended to provide background when observing individual reactions to this study.

Producer A: This operation produced and hauled an average of 13.3 loads per week during the study period using two tractor and double-bunk trailer combinations. The typical one-way haul distance is 106 miles. Each truck is loaded by its driver with essentially no supervision from the operation owner. One truck driver/loader operator just recently began driving a truck but has worked in the logging business for quite some time. The other truck driver/loader operator owns his own truck and as such could be classified as a contract hauler. However, since he hauls exclu-

Table 19. Target Weights and Mean Number of Loads Delivered per Week for Mill #1 Producers

Treatment Producers

Producer	Mean Loads/Week	Target (Pounds)
A	13.3	79,000
B	11.3	80,000
C	8.5	80,000
D	9.3	82,000
E	21.1	81,000

Control Producers

Producer	Mean Loads/Week
F	11.6
G	8.5
H	15.0
I	9.1
J	11.3

sively for producer A and has done so for a long time, loads he delivered were included in this study. Producer A relied entirely on contract haulers until three and a half years ago.

The target weight of 79,000 pounds was selected by the producer primarily for legal reasons. By adopting this target, overweight fines are infrequent, resulting in no need for intentional efforts to avoid law enforcement weight scales. Producer A is aware of some methods of in-woods weighing but has never been particularly interested in them due to the high initial cost.

Producer B: This operation produced and hauled an average of 11.3 loads per week in the study period. Wood is hauled using two tractors and up to three trailers. However, generally only one tractor is used on a full-time basis. The typical one-way haul distance is 30 miles. The tractor-trailer combination in full time use is driven and loaded by the same individual, with little supervision from the owner. This individual has approximately one year of experience in log hauling. When in use, the second tractor-trailer is loaded and driven by the owner of the logging company, who has been in the logging business for eight years. The owner is present at the logging site approximately 50 percent of the time.

The target weight of 80,000 pounds was selected primarily to avoid excessive wear and tear to the trucks. Confrontations with law enforcement officials regarding weight regulations are infrequent. Therefore, this producer is not greatly concerned with in-woods weighing devices.

Producer C: This is a small operation producing and hauling an average of 8.5 loads per week in the study period. Wood is hauled using one tractor-trailer, over a typical one-way haul distance of 20 miles. One individual loads and drives the tractor-trailer and has been doing so for five years. This is a family organization and the owner is not present much of the time. As a result, loading is done with little supervision.

The target weight of 80,000 pounds was selected primarily to avoid adverse effects of heavy loads. A relatively strong commitment exists for avoiding unnecessary abuse of the equipment. This operation is not highly production oriented, so incremental gains in efficiency which may be achieved with weighing devices do not tend to be of great importance.

Producer D: This is a relatively new operation, being in the logging business for only three years. An average of 9.3 loads per week were produced and hauled during the study period. One tractor and two trailers are utilized and the typical one-way haul distance is 55 miles. One individual does the majority of the loading and is entirely responsible for driving the truck. He has been loading and driving for this operation for nearly two years, prior to that time he operated a loader for a large company crew for two and a half years. Some supervision is provided to the loading process. At times when the mill is not open for wood delivery, this operation commonly loads and delivers a trailer to a point near the mill for storage. This process is called "dollying-up".

The target weight of 82,000 pounds was selected primarily for cash flow purposes. The owner considered an average of ten cords per load to be optimal. In selecting the target weight some concern was also placed on vehicle wear-and-tear but little concern existed for legal compliance. This producer has some knowledge of in-woods weighing systems and feels they would be beneficial in controlling load weight. However, he feels the benefits are not great enough to justify the initial cost.

Producer E: This producer has a relatively large operation producing and hauling an average of 21.1 loads per week in the study period. Three tractors and at least five trailers are required to accomplish this, due to the typical one-way haul distance of 140 miles. One of the three tractors is used only in the woods for setting-out trailers. Two individuals are employed full-time for highway truck driving and another as a loader operator. Trailers are loaded using a set-out system and are also dollied-up near the mill. As a result there is little communication between the truck drivers and loader operators regarding load weights. Little supervision is provided to the loading process.

The target weight of 81,000 pounds selected by the operation's owner is not a strong consideration at the time of loading. The weight was selected for its proximity to the legal maximum as approximately 12 overweight fines are received per year. This producer is somewhat interested in purchasing on-board electronic scales for the set-out tractor but they are not of interest for trailers, due to the large number utilized.

Producers F-J: These producers were used for control purposes as required by the design of this study. To avoid inducing any modification in their loading and hauling strategy, their operations were not contacted or studied. Therefore, little information was acquired on the equipment and personal used to produce and haul wood. The equipment and personnel were considered by mill personnel to be similar for all loggers in both the control and treatment group, this was a prerequisite for inclusion in the study.

Mill #2

The mean number of tree-length pulpwood loads delivered by each producer during the study period and the target weight classes of treatment producers are presented in Table 20. The general descriptions of the operations for treatment producers provided here will be helpful in understanding reactions of each individual producer to the study.

Producer A: This is a father/son operation which produced and hauled an average of 6.5 loads per week in the study period. They utilize one tractor and two trailers to haul wood a typical one-way haul distance of 27 miles. This operation has only been doing its own hauling for one year, prior to that time contract haulers were utilized. The owner's son loads the trailers and has been doing so for three years. Another individual drives the truck and has been doing so for one year. Communication between the driver and the loader operator is good, with the previous load's scale ticket being reviewed prior to binding the subsequent load. The loader operator is solely responsible for load weight control, receiving no supervision.

Table 20. Target Weights and Mean Number of Loads Delivered per Week for Mill #2 Producers

Treatment Producers

Producer	Mean Loads/Week	Target Class (Pounds)
A	6.5	75,000-75,999
C	13.4	73,000-73,999
D	9.5	77,000-77,999
E	7.7	76,000-76,999

Control Producers

Producer	Mean Loads/Week
F	10.7
H	10.2
I	9.4
J	12.8

The target weight class of 75,000 to 75,999 pounds was selected for legal reasons and is aimed for consistently. However, the frequency and severity of overweight fines is high and commonly costing up to $450 per week. This producer is aware of in-woods weighing devices and is interested in acquiring a system but feels he does not know enough to select the system best suited to his operation.

Producer C: This operation produced and hauled an average of 13.4 loads per week in the study period and has a typical one-way haul distance of 22 miles. One tractor and pole trailer is utilized on a full-time basis, another combination being used as needed. The owner of the operation does the majority of the loading and drives the second truck when in use. The driver of the truck used full-time is only responsible for driving. Frequently the loader operator will take a loaded truck towards the mill until he meets the returning empty truck. At this point vehicles are traded and the owner returns to load the empty truck. This strategy allows the owner to spend more time at the harvest site. Due to the nature of this strategy, relatively good information on previous weights is available when trucks are loaded.

The target weight class of 73,000 to 73,999 pounds was selected to avoid overweight violations. Producer C watches trends in load weights relatively closely and fines are low value and seldom received. He is aware of the benefits of some in-woods weighing devices but feels that their reliability is inadequate. Maintenance and calibration were believed to be the major problems.

Producer D: This producer cut and hauled an average of 9.5 loads per week in the study period and has a typical one-way haul distance of 54 miles. One tractor and two trailers are used for highway transport and a second tractor is used for setting-out trailers. One individual operates the loader and has been doing so for four years. Another individual drives the tractor-trailers on the highway. There is little communication between the loader operator and the truck driver due to the use of a set-out system.

The target weight class of 77,000 to 77,999 pounds was selected primarily for legal purposes but some concern did exist regarding the mill's restriction. This producer is aware of in-woods weighing devices but is not interested in acquiring a system. He has talked with individuals using weighing systems with little success and feels the initial cost is too high.

Producer E: This operation cut and hauled an average of 7.7 loads per week during the course of this study and has an average one-way haul distance of 25 miles. Two tractor-trailer combinations are utilized, each being hot loaded. One individual drives both trucks. The owner does the majority of the loading and does not bind a load until the driver returns with the weight of the previous load. As a result communication regarding load weights is relatively good. Both the truck driver and the loader operator assist in estimating the load weight and have been doing so for over 20 years. Still they feel it is difficult to accurately and consistently control load weights.

The target weight class of 76,000 to 76,999 pounds was selected primarily for legal reasons. The frequency of overweight fines is variable, sometimes being nonexistent and at others very frequent. This producer is aware of in-woods weighing devices but has little desire to own a system. Individuals he has talked to who do own weighing systems feel they need to be recalibrated too frequently. He also feels the initial cost is too high.

Producers F-J (excluding G): These producers were used as a control and were not informed of their inclusion in the study. To avoid altering loading and hauling strategies, they were not visited or studied in relation to this project. Therefore, little descriptive information is available regarding their operations. They were considered by mill personnel to be similar to producers in the treatment group upon initiation of the study.

Appendix C. Frequency Distributions for Mill #1 Producers

Table 21: Distribution of Gross Weights for Treatment Producer A

Table 22: Distribution of Gross Weights for Treatment Producer B

Table 23: Distribution of Gross Weights for Treatment Producer C

Table 24: Distribution of Gross Weights for Treatment Producer D

Table 25: Distribution of Gross Weights for Treatment Producer E

Table 26: Distribution of Gross Weights for Control Producer F

Table 27: Distribution of Gross Weights for Control Producer G

Table 28: Distribution of Gross Weights for Control Producer H

Table 29: Distribution of Gross Weights for Control Producer I

Table 30: Distribution of Gross Weights for Control Producer J

Table 21. Distribution of Gross Weights for Treatment Producer A (Mill #1)

History Period

Weight Class[1]	Frequency	Percent	Cumulative Frequency	Cumulative Percent
74,000	2	4.0	2	4.0
75,000	1	2.0	3	6.0
76,000	3	6.0	6	12.0
78,000	7	14.0	13	26.0
79,000	9	18.0	22	44.0
80,000	4	8.0	26	52.0
81,000	6	12.0	32	64.0
82,000	5	10.0	37	74.0
83,000	3	6.0	40	80.0
84,000	6	12.0	46	92.0
85,000	1	2.0	47	94.0
86,000	1	2.0	48	96.0
87,000	1	2.0	49	98.0
88,000	1	2.0	50	100.0

Study Period

Weight Class[1]	Frequency	Percent	Cumulative Frequency	Cumulative Percent
70,000	1	1.3	1	0.0
73,000	3	3.8	4	5.0
74,000	1	1.3	5	6.3
75,000	4	5.0	9	11.3
76,000	7	8.8	16	20.0
77,000	8	10.0	24	30.0
78,000	5	6.3	29	36.3
79,000	6	7.5	35	43.8
80,000	7	8.8	42	52.5
81,000	7	8.8	49	61.3
82,000	10	12.5	59	73.8
83,000	5	6.3	64	80.0
84,000	6	7.5	70	87.5
85,000	3	3.8	73	91.3
86,000	6	7.5	79	98.8
87,000	1	1.3	80	100.0

[1]Gross Weight Classes are 1000 pound ranges, for example the 80,000 class contains the range from 80,000 to 80,999.

Table 22. Distribution of Gross Weights for Treatment Producer B (Mill #1)

History Period

Weight Class[1]	Frequency	Percent	Cumulative Frequency	Cumulative Percent
65,000	1	2.0	1	2.0
72,000	1	2.0	2	4.0
73,000	1	2.0	3	6.0
74,000	2	4.0	5	10.0
75,000	1	2.0	6	12.0
76,000	2	4.0	8	16.0
77,000	2	4.0	10	20.0
78,000	2	4.0	12	24.0
79,000	1	2.0	13	26.0
80,000	3	6.0	16	32.0
81,000	6	120	22	44.0
82,000	5	10.0	27	54.0
83,000	5	10.0	32	64.0
84,000	4	8.0	36	72.0
85,000	5	10.0	41	82.0
86,000	5	10.0	46	92.0
88,000	3	6.0	49	98.0
89,000	1	2.0	50	100.0

Study Period

Weight Class[1]	Frequency	Percent	Cumulative Frequency	Cumulative Percent
71,000	1	1.1	1	1.1
73,000	2	2.2	3	3.3
74,000	1	1.1	4	4.4
75,000	2	2.2	6	6.7
76,000	4	4.4	10	11.1
77,000	10	11.1	20	22.2
78,000	9	10.0	29	32.2
79,000	9	10.0	38	42.2
80,000	12	13.3	50	55.6
81,000	13	14.4	63	70.0
82,000	4	4.4	67	74.4
83,000	6	6.7	73	81.1
84,000	3	3.3	76	84.4
85,000	7	7.8	83	92.2
86,000	2	2.2	85	94.4
87,000	2	2.2	87	96.7
88,000	2	2.2	89	98.9
89,000	1	1.1	90	100.0

[1]Weight Classes are 1000 pound ranges, for example the 80,000 class contains the range from 80,000 to 80,999.

Table 23. Distribution of Gross Weights for Treatment Producer C (Mill #1)

History Period

Weight Class[1]	Frequency	Percent	Cumulative Frequency	Cumulative Percent
76,000	3	6.0	3	6.0
77,000	3	6.0	6	12.0
78,000	6	12.0	12	24.0
79,000	3	6.0	15	30.0
80,000	4	8.0	19	38.0
81,000	4	8.0	23	46.0
82,000	4	8.0	27	54.0
83,000	9	18.0	36	72.0
84,000	3	6.0	39	78.0
85,000	2	4.0	41	82.0
86,000	3	6.0	44	88.0
87,000	1	2.0	45	90.0
88,000	1	2.0	46	92.0
89,000	1	2.0	47	94.0
90,000	1	2.0	48	96.0
92,000	2	4.0	50	100.0

Study Period

Weight Class[1]	Frequency	Percent	Cumulative Frequency	Cumulative Percent
74,000	1	2.0	1	2.0
75,000	6	11.8	7	13.7
76,000	6	11.8	13	25.5
77,000	2	3.9	15	29.4
78,000	5	9.8	20	39.2
79,000	6	11.8	26	51.0
80,000	5	9.8	31	60.8
81,000	6	11.8	37	72.5
82,000	5	9.8	42	82.4
83,000	5	9.8	47	92.2
84,000	1	2.0	48	94.1
85,000	1	2.0	49	96.1
87,000	2	3.9	51	100.0

[1]Weight Classes are 1000 pound ranges, for example the 80,000 class contains the range from 80,000 to 80,999.

Table 24. Distribution of Gross Weights for Treatment Producer D (Mill #1)

History Period

Weight Class[1]	Frequency	Percent	Cumulative Frequency	Cumulative Percent
74,000	2	4.0	2	4.0
75,000	1	2.0	3	6.0
76,000	1	2.0	4	8.0
77,000	3	6.0	7	14.0
78,000	1	2.0	8	16.0
79,000	4	8.0	12	24.0
80,000	7	14.0	19	38.0
81,000	6	12.0	25	50.0
82,000	6	12.0	31	62.0
83,000	6	12.0	37	74.0
84,000	5	10.0	42	84.0
85,000	4	8.0	46	92.0
86,000	1	2.0	47	94.0
87,000	1	2.0	48	96.0
89,000	1	2.0	49	98.0
92,000	1	2.0	50	100.0

Study Period

Weight Class[1]	Frequency	Percent	Cumulative Frequency	Cumulative Percent
75,000	1	1.4	1	1.4
76,000	2	2.7	3	4.1
77,000	3	4.1	6	8.1
78,000	6	8.1	12	16.2
79,000	13	17.6	25	33.8
80,000	9	12.2	34	45.9
81,000	6	8.1	40	54.1
82,000	8	10.8	48	64.9
83,000	6	8.1	54	73.0
84,000	6	8.1	60	81.1
85,000	10	13.5	70	94.6
86,000	2	2.7	72	97.3
87,000	2	2.7	74	100.0

[1]Weight Classes are 1000 pound ranges, for example the 80,000 class contains the range from 80,000 to 80,999.

Table 25. Distribution of Gross Weights for Treatment Producer E (Mill #1)

History Period

Weight Class[1]	Frequency	Percent	Cumulative Frequency	Cumulative Percent
69,000	1	2.0	1	2.0
74,000	1	2.0	2	4.0
75,000	2	4.0	4	8.0
76,000	2	4.0	6	12.0
77,000	3	6.0	9	18.0
78,000	6	12.0	15	30.0
79,000	4	8.0	19	38.0
80,000	8	16.0	27	54.0
81,000	4	8.0	31	62.0
82,000	5	10.0	36	72.0
83,000	6	12.0	42	84.0
84,000	4	8.0	46	92.0
86,000	2	4.0	48	96.0
87,000	1	2.0	49	98.0
88,000	1	2.0	50	100.0

Study Period

Weight Class[1]	Frequency	Percent	Cumulative Frequency	Cumulative Percent
68,000	1	0.6	1	0.6
70,000	1	0.6	2	1.2
72,000	4	2.4	6	3.6
73,000	1	0.6	7	4.1
75,000	5	3.0	12	7.1
76,000	6	3.6	18	10.7
77,000	8	4.7	26	15.4
78,000	4	2.4	30	17.8
79,000	10	5.9	40	23.7
80,000	21	12.4	61	36.1
81,000	12	7.1	73	43.2
82,000	18	10.7	91	53.8
83,000	13	7.7	104	61.5
84,000	21	12.4	125	74.0
85,000	6	3.6	131	77.5
86,000	17	10.1	148	87.6
87,000	10	5.9	158	93.5
88,000	4	2.4	162	95.9
89,000	2	1.2	164	97.0
90,000	4	2.4	168	99.4
94,000	1	0.6	169	100.0

[1]Weight Classes are 1000 pound ranges, for example the 80,000 class contains the range from 80,000 to 80,999.

Table 26. Distribution of Gross Weights for Control Producer F (Mill #1)

History Period

Weight Class[1]	Frequency	Percent	Cumulative Frequency	Cumulative Percent
71,000	1	2.0	1	2.0
74,000	1	2.0	2	4.0
75,000	8	16.0	10	20.0
77,000	5	10.0	15	30.0
78,000	5	10.0	20	40.0
79,000	2	4.0	22	44.0
80,000	3	6.0	25	50.0
81,000	3	6.0	28	56.0
82,000	6	12.0	34	68.0
83,000	5	10.0	39	78.0
84,000	5	10.0	44	88.0
85,000	3	6.0	47	94.0
86,000	3	6.0	50	100.0

Study Period

Weight Class[1]	Frequency	Percent	Cumulative Frequency	Cumulative Percent
55,000	1	1.1	1	1.1
68,000	2	2.1	3	3.2
70,000	1	1.1	4	4.3
71,000	3	3.2	7	7.4
72,000	3	3.2	10	10.6
73,000	6	6.4	16	17.0
74,000	4	4.3	20	21.3
75,000	4	4.3	24	25.5
76,000	10	10.6	34	36.2
77,000	4	4.3	38	40.4
78,000	7	7.4	45	47.9
79,000	4	4.3	49	52.1
80,000	11	11.7	60	63.8
81,000	5	5.3	65	69.1
82,000	3	3.2	68	72.3
83,000	5	5.3	73	77.7
84,000	5	5.3	78	83.0
85,000	5	5.3	83	88.3
86,000	3	3.2	86	91.5
87,000	4	4.3	90	95.7
89,000	2	2.1	92	97.9
90,000	1	1.1	93	98.9
91,000	1	1.1	94	100.0

[1]Weight Classes are 1000 pound ranges, for example the 80,000 class contains the range from 80,000 to 80,999.

Table 27. Distribution of Gross Weights for Control Producer G (Mill #1)

History Period

Weight Class[1]	Frequency	Percent	Cumulative Frequency	Cumulative Percent
41,000	1	2.0	1	2.0
66,000	1	2.0	2	4.0
67,000	2	4.0	4	8.0
69,000	1	2.0	5	10.0
70,000	1	2.0	6	12.0
71,000	2	4.0	8	16.0
72,000	2	4.0	10	20.0
73,000	2	4.0	12	24.0
74,000	3	6.0	15	30.0
75,000	3	6.0	18	36.0
76,000	2	4.0	20	40.0
77,000	3	6.0	23	46.0
78,000	6	12.0	29	58.0
79,000	4	8.0	33	66.0
80,000	4	8.0	37	74.0
81,000	5	10.0	42	84.0
82,000	1	2.0	43	86.0
83,000	3	6.0	46	92.0
84,000	1	2.0	47	94.0
85,000	1	2.0	48	96.0
86,000	1	2.0	49	98.0
87,000	1	2.0	50	100.0

Study Period

Weight Class[1]	Frequency	Percent	Cumulative Frequency	Cumulative Percent
70,000	1	1.5	1	1.5
73,000	1	1.5	2	2.9
74,000	2	2.9	4	5.9
75,000	1	1.5	5	7.4
76,000	2	2.9	7	10.3
77,000	1	1.5	8	11.8
78,000	5	7.4	13	19.1
79,000	2	2.9	15	22.1
80,000	9	13.2	24	35.3
81,000	8	11.8	32	47.1
82,000	3	4.4	35	51.5
83,000	10	14.7	45	66.2
84,000	7	10.3	52	76.5
85,000	7	10.3	59	86.8
86,000	5	7.4	64	94.1
87,000	5	1.5	65	95.6
88,000	3	4.4	68	100.0

[1]Weight Classes are 1000 pound ranges, for example the 80,000 class contains the range from 80,000 to 80,999.

Table 28. Distribution of Gross Weights for Control Producer H (Mill #1)

History Period

Weight Class[1]	Frequency	Percent	Cumulative Frequency	Cumulative Percent
70,000	1	2.0	1	2.0
73,000	1	2.0	2	4.0
76,000	5	10.0	7	14.0
77,000	3	6.0	10	20.0
78,000	3	6.0	13	26.0
79,000	7	14.0	20	40.0
80,000	5	10.0	25	50.0
81,000	7	14.0	32	64.0
82,000	8	16.0	40	80.0
83,000	1	2.0	41	82.0
84,000	4	8.0	45	90.0
85,000	3	6.0	48	96.0
86,000	1	2.0	49	98.0
87,000	1	2.0	50	100.0

Study Period

Weight Class[1]	Frequency	Percent	Cumulative Frequency	Cumulative Percent
75,000	1	0.8	1	0.8
76,000	3	2.5	4	3.3
77,000	2	1.7	6	5.0
78,000	5	4.2	11	9.2
79,000	10	8.3	21	17.5
80,000	12	10.0	33	27.5
81,000	10	8.3	43	35.8
82,000	16	13.3	59	49.2
83,000	11	9.2	70	58.3
84,000	17	14.2	87	72.5
85,000	9	7.5	96	80.0
86,000	8	6.7	104	86.7
87,000	7	5.8	111	92.5
88,000	6	5.0	117	97.5
89,000	3	2.5	120	100.0

[1]Weight Classes are 1000 pound ranges, for example the 80,000 class contains the range from 80,000 to 80,999.

Table 29. Distribution of Gross Weights for Control Producer I (Mill #1)

History Period

Weight Class[1]	Frequency	Percent	Cumulative Frequency	Cumulative Percent
78,000	2	4.0	2	4.0
79,000	4	8.0	6	12.0
80,000	2	4.0	8	16.0
81,000	5	10.0	13	26.0
82,000	11	22.0	24	48.0
83,000	9	18.0	33	66.0
84,000	5	10.0	38	76.0
85,000	3	6.0	41	82.0
86,000	3	6.0	44	88.0
87,000	2	4.0	46	92.0
88,000	3	6.0	49	98.0
89,000	1	2.0	50	100.0

Study Period

Weight Class[1]	Frequency	Percent	Cumulative Frequency	Cumulative Percent
59,000	1	1.4	1	1.4
75,000	3	4.1	4	5.5
76,000	2	2.7	6	8.2
77,000	3	4.1	9	12.3
78,000	4	5.5	13	17.8
79,000	5	6.8	18	24.7
80,000	9	12.3	27	37.0
81,000	10	13.7	37	50.7
82,000	12	16.4	49	67.1
83,000	6	8.2	55	75.3
84,000	4	5.5	59	80.8
85,000	3	4.1	62	84.9
86,000	6	8.2	68	93.2
87,000	1	1.4	69	94.5
88,000	3	4.1	72	98.6
91,000	1	1.4	73	100.0

[1]Weight Classes are 1000 pound ranges, for example the 80,000 class contains the range from 80,000 to 80,999.

Table 30. Distribution of Gross Weights for Control Producer J (Mill #1)

History Period

Weight Class[1]	Frequency	Percent	Cumulative Frequency	Cumulative Percent
76,000	1	2.0	1	2.0
77,000	2	4.0	3	6.0
78,000	2	4.0	5	10.0
80,000	2	4.0	7	14.0
81,000	4	8.0	11	22.0
82,000	5	10.0	16	32.0
83,000	7	14.0	23	46.0
84,000	10	20.0	33	66.0
85,000	5	10.0	38	76.0
86,000	7	14.0	45	90.0
87,000	1	2.0	46	92.0
88,000	1	2.0	47	94.0
89,000	3	6.0	50	100.0

Study Period

Weight Class[1]	Frequency	Percent	Cumulative Frequency	Cumulative Percent
63,000	1	1.1	1	1.1
68,000	2	2.2	3	3.3
70,000	1	1.1	4	4.4
71,000	1	1.1	5	5.6
72,000	1	1.1	6	6.7
73,000	1	1.1	7	7.8
74,000	1	1.1	8	8.9
75,000	3	3.3	11	12.2
76,000	2	2.2	13	14.4
77,000	6	6.7	19	21.1
78,000	6	6.7	25	27.8
79,000	7	7.8	32	35.6
80,000	2	2.2	34	37.8
81,000	8	8.9	42	46.7
82,000	10	11.1	52	57.8
83,000	8	8.9	60	66.7
84,000	10	11.1	70	77.8
85,000	6	6.7	76	84.4
86,000	8	8.9	84	93.3
87,000	3	3.3	87	96.7
88,000	1	1.1	88	97.8
89,000	1	1.1	89	98.9
90,000	1	1.1	90	100.0

[1]Weight Classes are 1000 pound ranges, for example the 80,000 class contains the range from 80,000 to 80,999.

Appendix D. Graphic Plots of Cumulative Relative Frequency for Mill #1

Figure 18: Cumulative Percent Frequency of Gross Weights for Treatment Producer A

Figure 19: Cumulative Percent Frequency of Gross Weights for Treatment Producer B

Figure 20: Cumulative Percent Frequency of Gross Weights for Treatment Producer C

Figure 21: Cumulative Percent Frequency of Gross Weights for Treatment Producer D

Figure 22: Cumulative Percent Frequency of Gross Weights for Control Producer E

Figure 23: Cumulative Percent Frequency of Gross Weights for Control Producer F

Figure 24: Cumulative Percent Frequency of Gross Weights for Control Producer G

Figure 25: Cumulative Percent Frequency of Gross Weights for Control Producer H

Figure 26: Cumulative Percent Frequency of Gross Weights for Control Producer I

Figure 27: Cumulative Percent Frequency of Gross Weights for Control Producer J

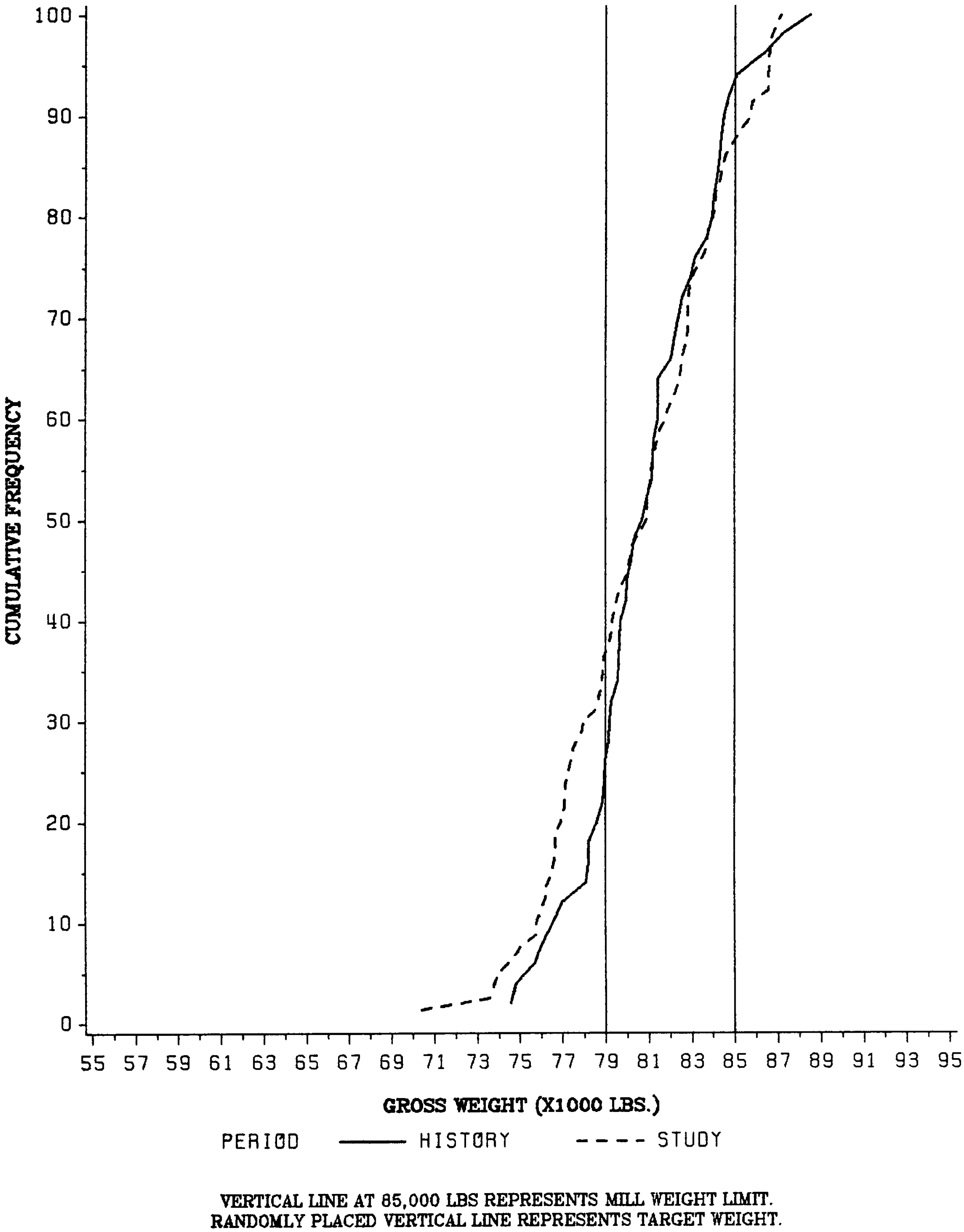


Figure 18. Frequency Plot of Gross Weights for Treatment Producer A (Mill #1)

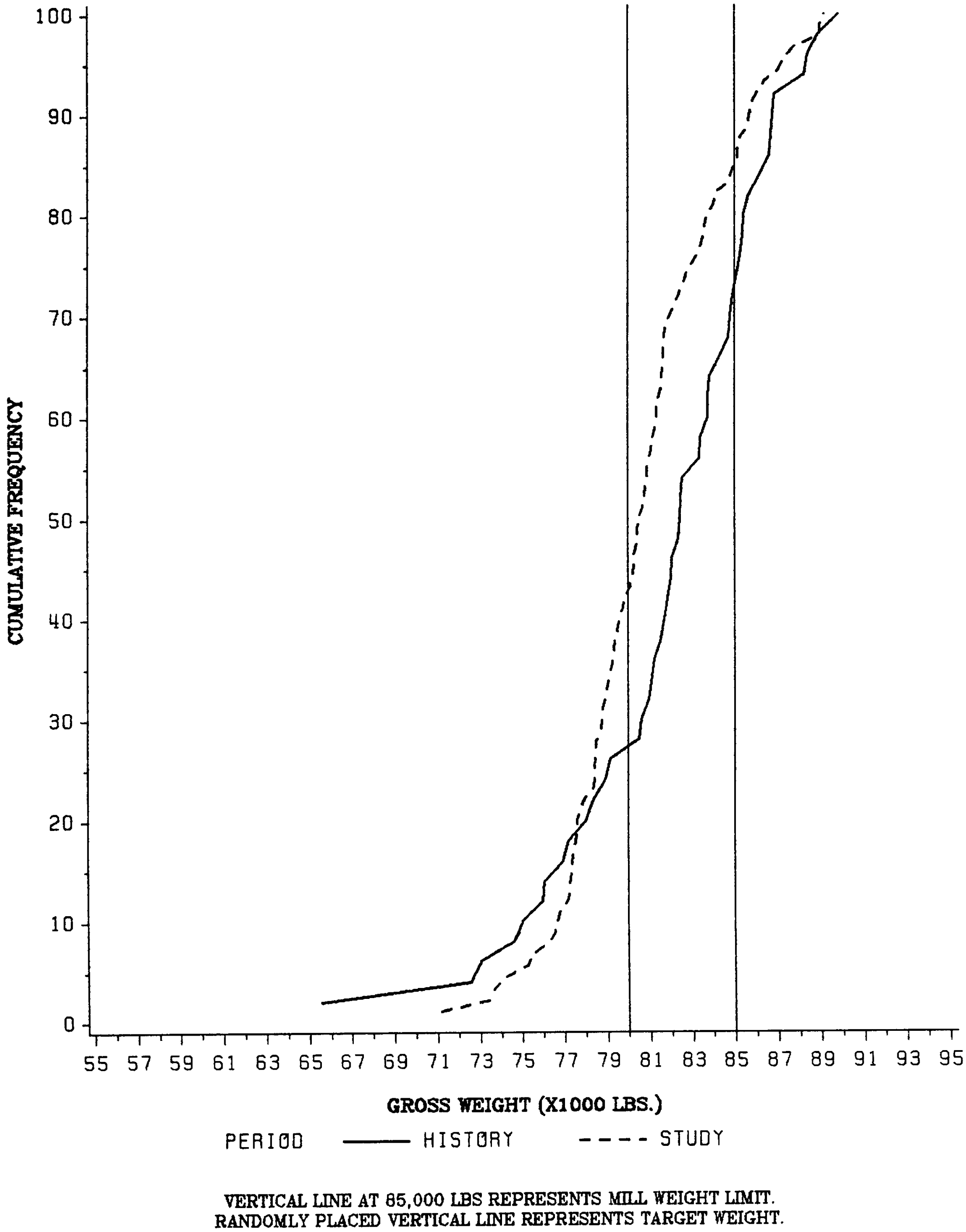


Figure 19. Frequency Plot of Gross Weights for Treatment Producer B (Mill #1)

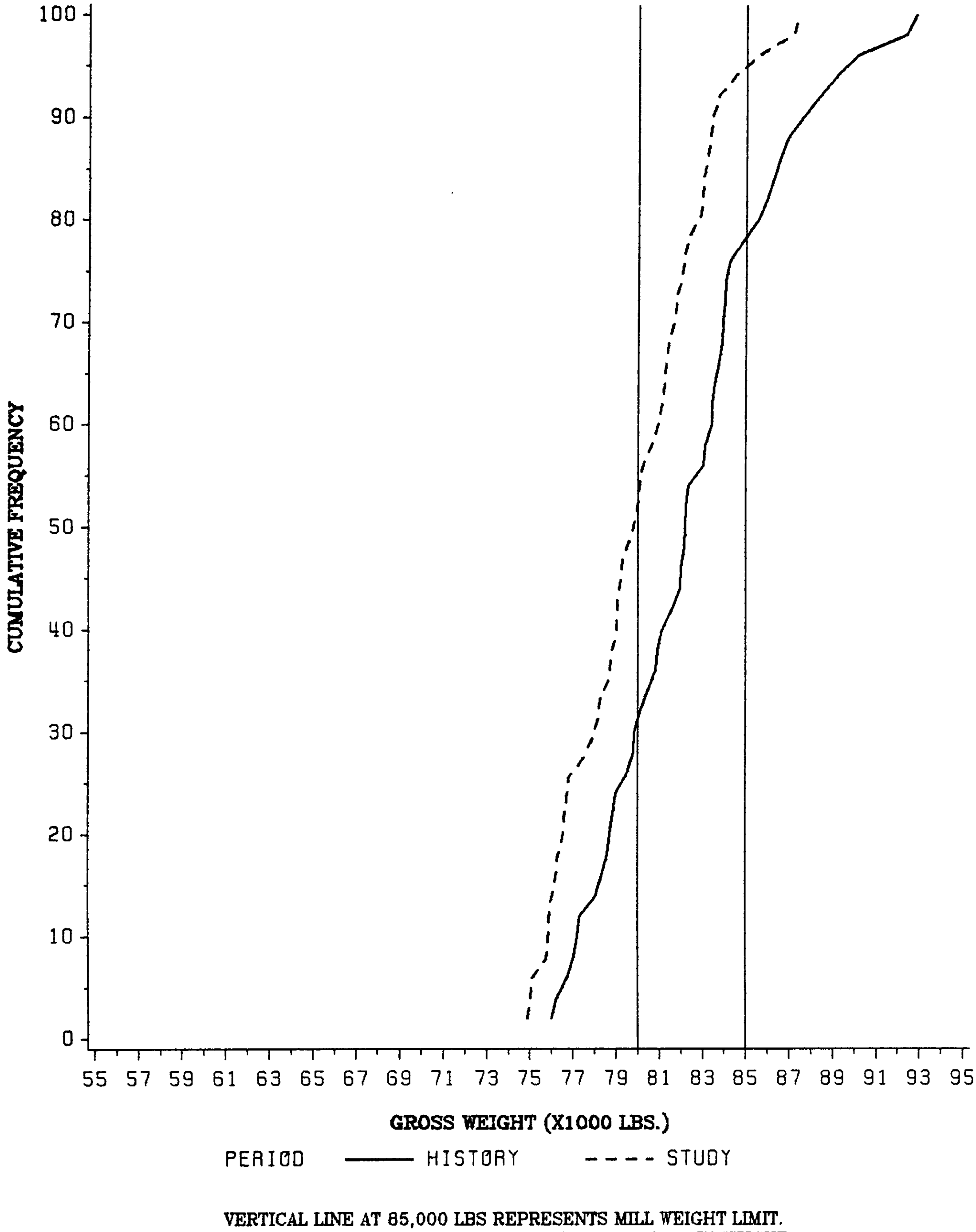
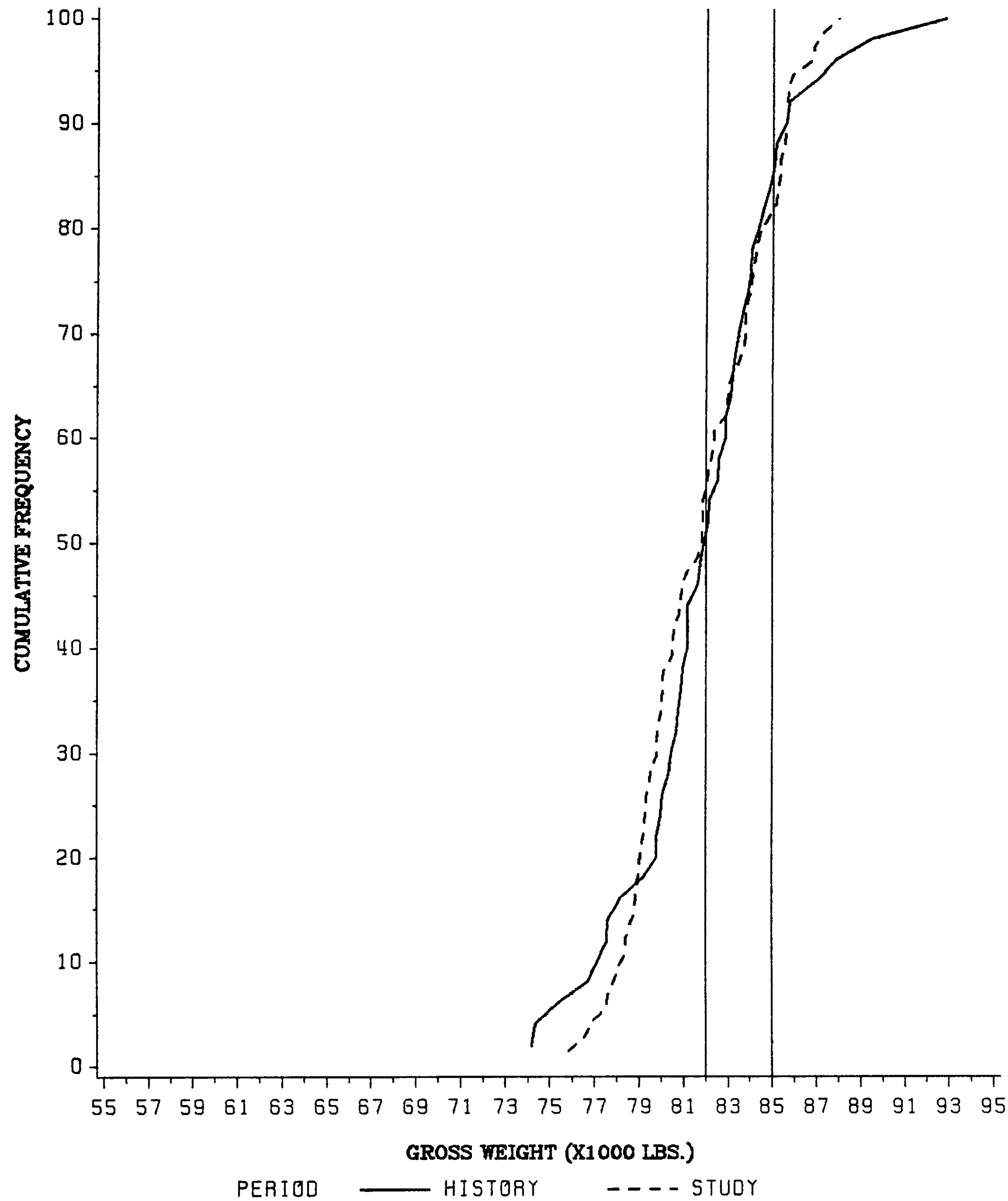


Figure 20. Frequency Plot of Gross Weights for Treatment Producer C (Mill #1)



VERTICAL LINE AT 85,000 LBS REPRESENTS MILL WEIGHT LIMIT.
RANDOMLY PLACED VERTICAL LINE REPRESENTS TARGET WEIGHT.

Figure 21. Frequency Plot of Gross Weights for Treatment Producer D (Mill #1)

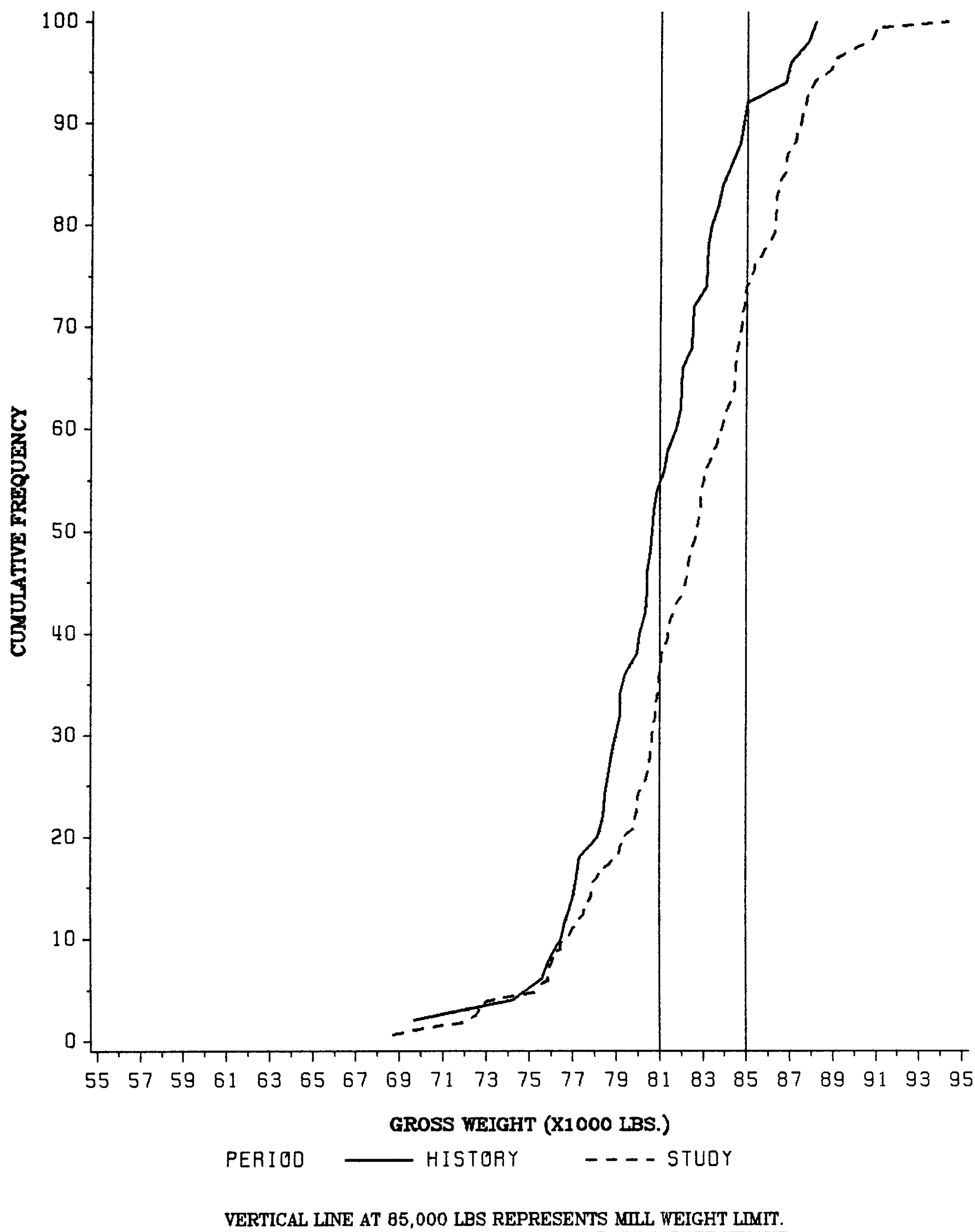


Figure 22. Frequency Plot of Gross Weights for Treatment Producer E (Mill #1)

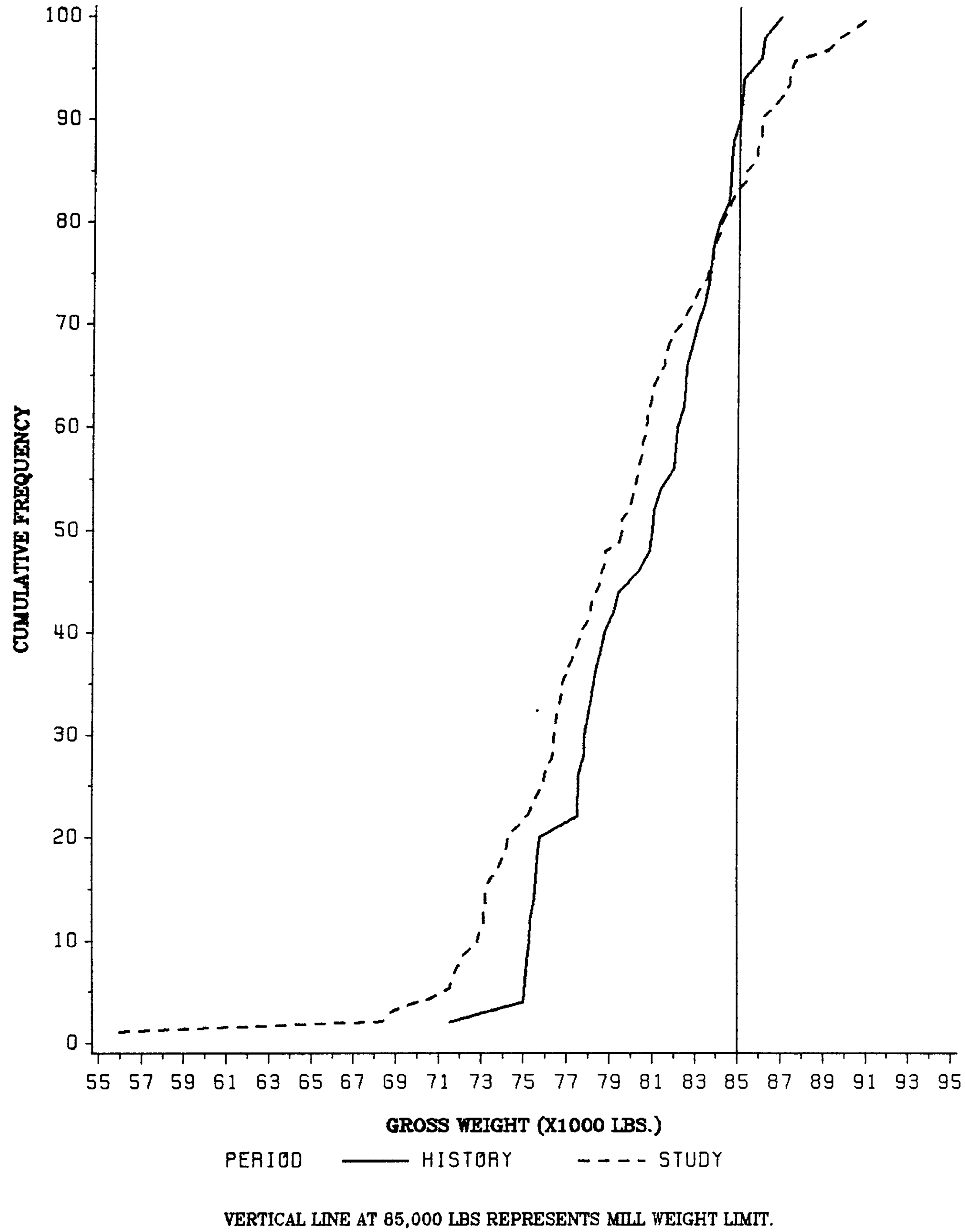


Figure 23. Frequency Plot of Gross Weights for Control Producer F (Mill #1)

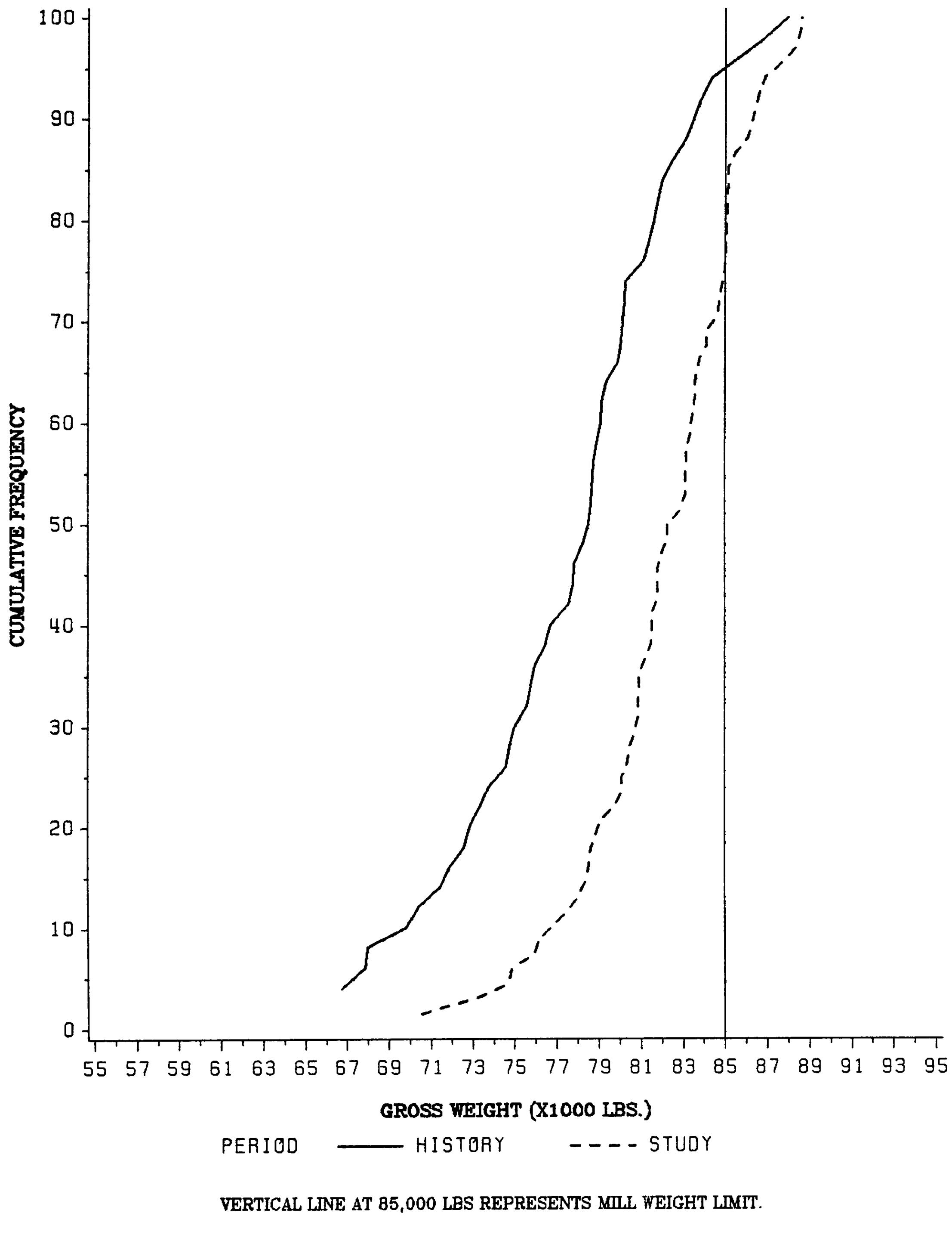


Figure 24. Frequency Plot of Gross Weights for Control Producer G (Mill #1)

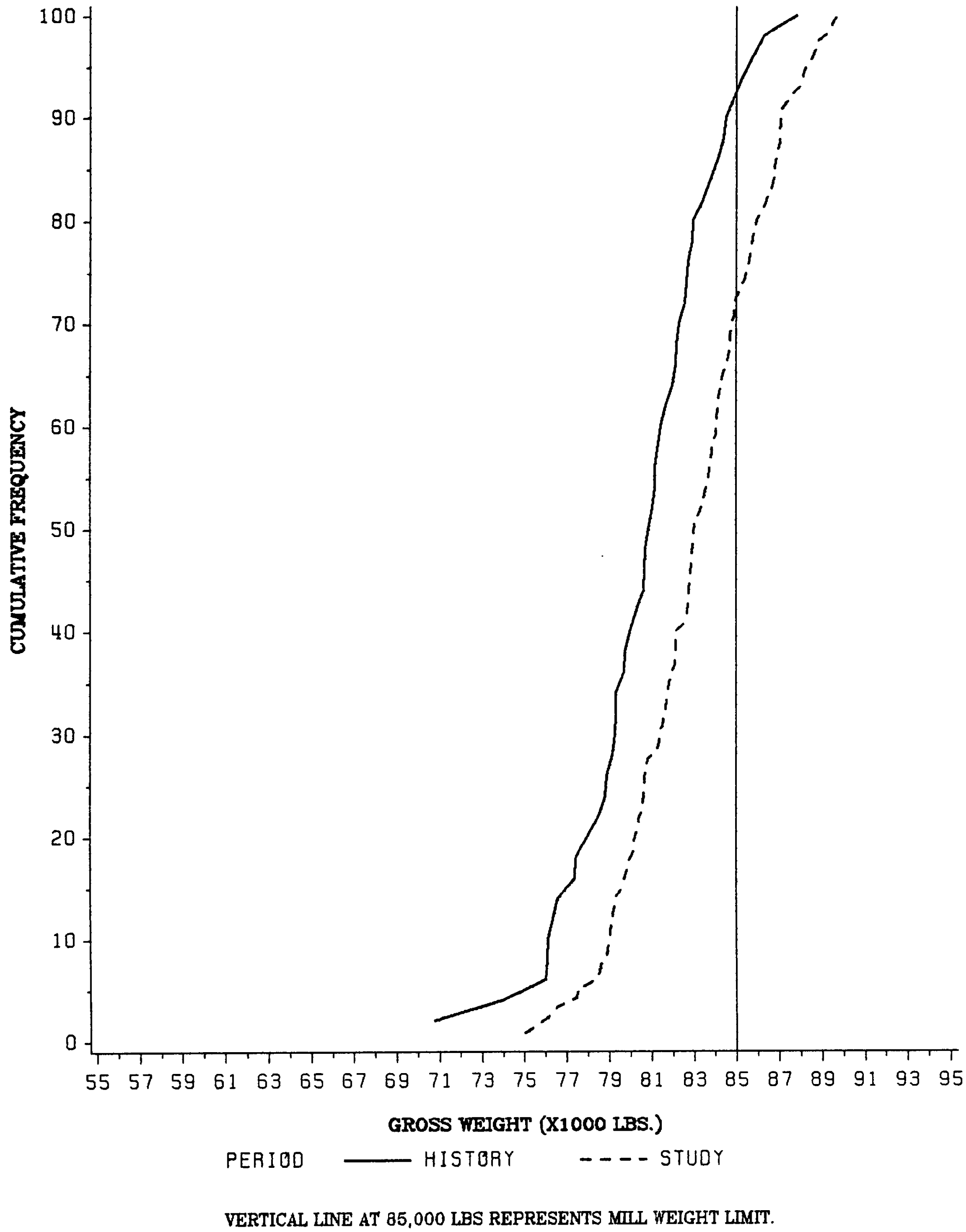


Figure 25. Frequency Plot of Gross Weights for Control Producer H (Mill #1)

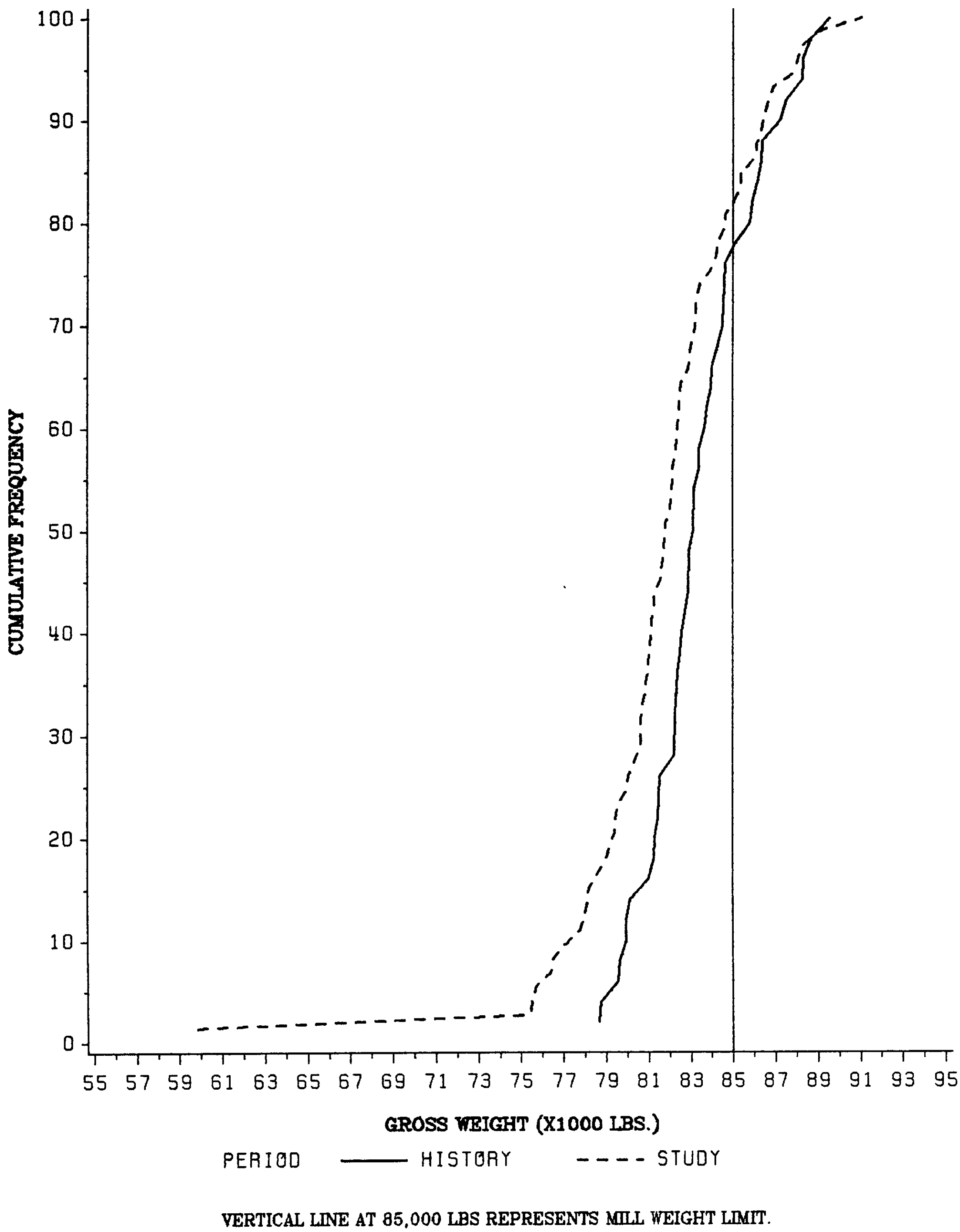


Figure 26. Frequency Plot of Gross Weights for Control Producer I (Mill #1)

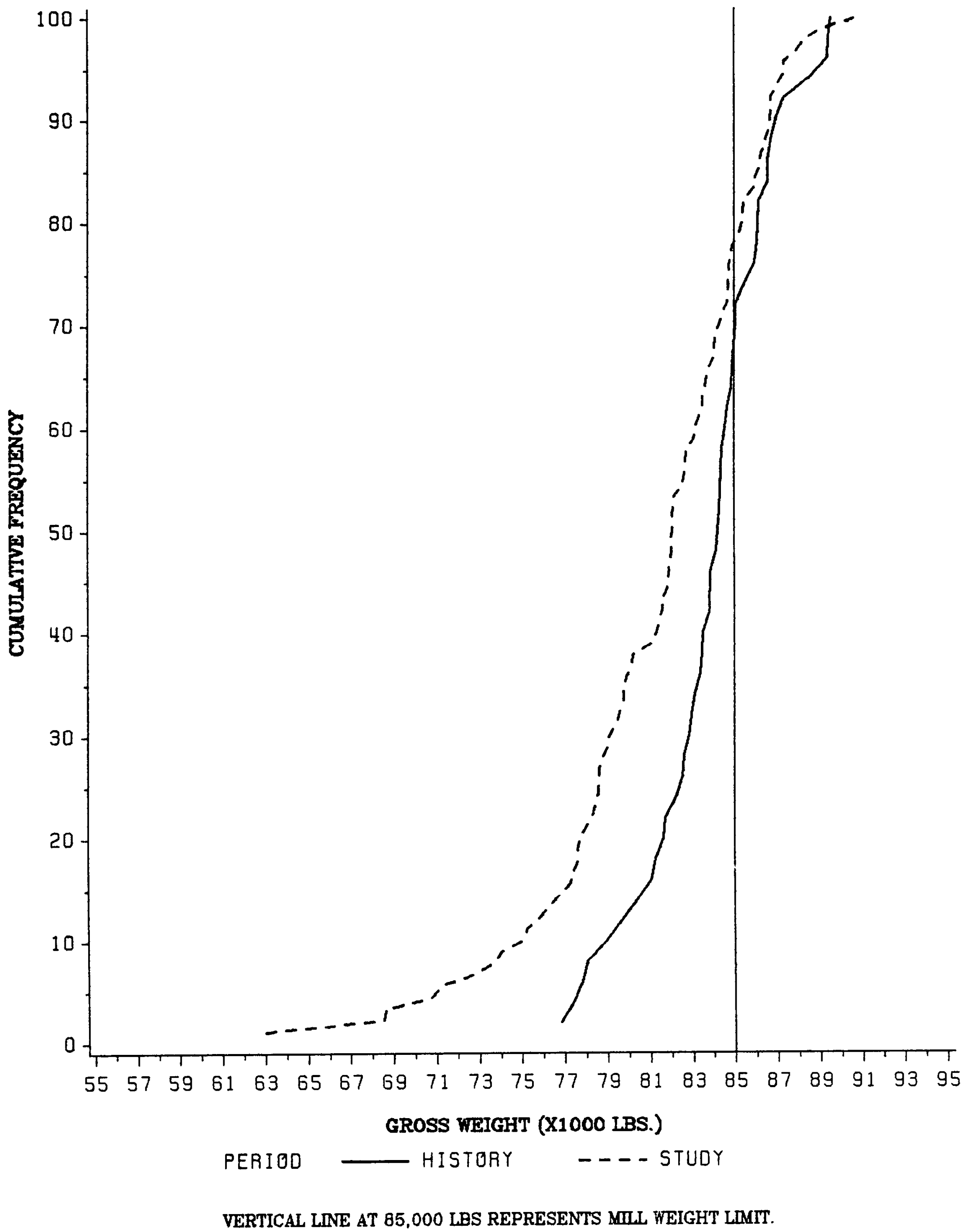


Figure 27. Frequency Plot of Gross Weights for Control Producer J (Mill #1)

Appendix E. Frequency Distributions for Mill #2 Producers

Table 31: Distribution of Gross Weights for Treatment Producer A

Table 32: Distribution of Gross Weights for Treatment Producer C

Table 33: Distribution of Gross Weights for Treatment Producer D

Table 34: Distribution of Gross Weights for Treatment Producer E

Table 35: Distribution of Gross Weights for Control Producer F

Table 36: Distribution of Gross Weights for Control Producer H

Table 37: Distribution of Gross Weights for Control Producer I

Table 38: Distribution of Gross Weights for Control Producer J

Table 31. Distribution of Gross Weights for Treatment Producer A (Mill #2)

History Period

Weight Class[1]	Frequency	Percent	Cumulative Frequency	Cumulative Percent
65,000	1	2.0	1	2.0
66,000	2	4.0	3	6.0
69,000	3	6.0	6	12.0
70,000	6	12.0	12	24.0
71,000	2	4.0	14	28.0
72,000	5	10.0	19	38.0
73,000	5	10.0	24	48.0
74,000	6	12.0	30	60.0
75,000	4	8.0	34	68.0
76,000	3	6.0	37	74.0
77,000	2	4.0	39	78.0
78,000	2	4.0	41	82.0
79,000	1	2.0	42	84.0
80,000	3	6.0	45	90.0
81,000	2	4.0	47	94.0
82,000	2	4.0	49	98.0
84,000	1	2.0	50	100.0

Study Period

Weight Class[1]	Frequency	Percent	Cumulative Frequency	Cumulative Percent
63,000	1	1.4	1	1.4
65,000	1	1.4	2	2.8
66,000	2	2.8	4	5.6
67,000	2	2.8	6	8.5
68,000	3	4.2	9	12.7
69,000	3	4.2	12	16.9
70,000	3	4.2	15	21.1
71,000	2	2.8	17	23.9
72,000	6	8.5	23	32.4
73,000	10	14.1	33	46.5
74,000	3	4.2	36	50.7
75,000	7	9.9	43	60.6
76,000	9	12.7	52	73.2
77,000	4	5.6	56	78.9
78,000	3	4.2	59	83.1
79,000	1	1.4	60	84.5
80,000	6	8.5	66	93.0
81,000	2	2.8	68	95.8
82,000	2	2.8	70	98.6
85,000	1	1.4	71	100.0

[1]Weight Classes are 1000 pound ranges, for example the 80,000 class contains the range from 80,000 to 80,999.

Table 32. Distribution of Gross Weights for Treatment Producer C (Mill #2)

History Period

Weight Class[1]	Frequency	Percent	Cumulative Frequency	Cumulative Percent
69,000	1	2.0	1	2.0
70,000	2	4.0	3	6.0
71,000	6	12.0	9	18.0
72,000	7	14.0	16	32.0
73,000	4	8.0	20	40.0
74,000	6	12.0	26	52.0
75,000	5	10.0	31	62.0
76,000	4	8.0	35	70.0
77,000	7	14.0	42	84.0
78,000	1	2.0	43	86.0
79,000	3	6.0	46	92.0
80,000	1	2.0	47	94.0
81,000	1	2.0	48	96.0
82,000	1	2.0	49	98.0
83,000	1	2.0	50	100.0

Study Period

Weight Class[1]	Frequency	Percent	Cumulative Frequency	Cumulative Percent
64,000	1	0.9	1	0.9
66,000	1	0.9	2	1.9
67,000	3	2.8	5	4.7
68,000	4	3.7	9	8.4
69,000	5	4.7	14	13.1
70,000	14	13.1	28	26.2
71,000	12	11.2	40	37.4
72,000	12	11.2	52	48.6
73,000	14	13.1	66	61.7
74,000	15	14.0	81	75.7
75,000	7	6.5	88	82.2
76,000	6	5.6	94	87.9
77,000	2	1.9	96	89.7
78,000	7	6.5	103	96.3
79,000	1	0.9	104	97.2
80,000	1	0.9	105	98.1
81,000	2	1.9	107	100.0

[1]Weight Classes are 1000 pound ranges, for example the 80,000 class contains the range from 80,000 to 80,999.

Table 33. Distribution of Gross Weights for Treatment Producer D (Mill #2)

History Period

Weight Class[1]	Frequency	Percent	Cumulative Frequency	Cumulative Percent
67,000	2	4.0	2	4.0
68,000	1	2.0	3	6.0
69,000	1	2.0	4	8.0
70,000	3	6.0	7	14.0
71,000	6	12.0	13	26.0
72,000	1	2.0	14	28.0
73,000	6	12.0	20	40.0
74,000	12	24.0	32	64.0
75,000	5	10.0	37	74.0
76,000	1	2.0	38	76.0
77,000	3	6.0	41	82.0
78,000	1	2.0	42	84.0
79,000	2	4.0	44	88.0
80,000	3	6.0	47	94.0
81,000	3	6.0	50	100.0

Study Period

Weight Class[1]	Frequency	Percent	Cumulative Frequency	Cumulative Percent
62,000	1	1.0	1	1.0
64,000	2	1.9	3	2.9
65,000	1	1.0	4	3.8
66,000	3	2.9	7	6.7
67,000	1	1.0	8	7.6
68,000	3	2.9	11	10.5
69,000	3	2.9	14	13.3
70,000	4	3.8	18	17.1
71,000	8	7.6	26	24.8
72,000	10	9.5	36	34.3
73,000	7	6.7	43	41.0
74,000	12	11.4	55	52.4
75,000	16	15.2	71	67.6
76,000	12	11.4	83	79.0
77,000	8	7.6	91	86.7
78,000	8	7.6	99	94.3
79,000	2	1.9	101	96.2
80,000	2	1.9	103	98.1
82,000	1	1.0	104	99.0
85,000	1	1.0	105	100.0

[1]Weight Classes are 1000 pound ranges, for example the 80,000 class contains the range from 80,000 to 80,999.

Table 34. Distribution of Gross Weights for Treatment Producer E (Mill #2)

History Period

Weight Class[1]	Frequency	Percent	Cumulative Frequency	Cumulative Percent
67,000	1	2.0	1	2.0
69,000	1	2.0	2	4.0
70,000	1	2.0	3	6.0
71,000	2	4.0	5	10.0
72,000	5	10.0	10	20.0
73,000	2	4.0	12	24.0
74,000	10	20.0	22	44.0
75,000	7	14.0	29	58.0
76,000	4	8.0	33	66.0
77,000	4	8.0	37	74.0
78,000	8	16.0	45	90.0
79,000	2	4.0	47	94.0
80,000	2	4.0	49	98.0
82,000	1	2.0	50	100.0

Study Period

Weight Class[1]	Frequency	Percent	Cumulative Frequency	Cumulative Percent
66,000	1	1.3	1	1.3
68,000	2	2.6	3	3.9
69,000	4	5.2	7	9.1
70,000	1	1.3	8	10.4
71,000	2	2.6	10	13.0
72,000	3	3.9	13	16.9
73,000	5	6.5	18	23.4
74,000	11	14.3	29	37.7
75,000	11	14.3	40	51.9
76,000	10	13.0	50	64.9
77,000	8	10.4	58	75.3
78,000	11	14.3	69	89.6
79,000	1	1.3	70	90.9
80,000	2	2.6	72	93.5
82,000	4	5.2	76	98.7
84,000	1	1.3	77	100.0

[1]Weight Classes are 1000 pound ranges, for example the 80,000 class contains the range from 80,000 to 80,999.

Table 35. Distribution of Gross Weights for Control Producer F (Mill #2)

History Period

Weight Class[1]	Frequency	Percent	Cumulative Frequency	Cumulative Percent
68,000	1	2.0	1	2.0
70,000	1	2.0	2	4.0
71,000	3	6.0	5	10.0
72,000	3	6.0	8	16.0
73,000	4	8.0	12	24.0
74,000	6	12.0	18	36.0
75,000	6	12.0	24	48.0
76,000	3	6.0	27	54.0
77,000	5	10.0	32	64.0
78,000	2	4.0	34	68.0
79,000	5	10.0	39	78.0
80,000	4	8.0	43	86.0
81,000	3	6.0	46	92.0
83,000	2	4.0	48	96.0
85,000	2	4.0	50	100.0

Study Period

Weight Class[1]	Frequency	Percent	Cumulative Frequency	Cumulative Percent
68,000	3	2.8	3	2.8
69,000	1	0.9	4	3.7
70,000	3	2.8	7	6.5
71,000	5	4.7	12	11.2
72,000	2	1.9	14	13.1
73,000	4	3.7	18	16.8
74,000	8	7.5	26	24.3
75,000	12	11.2	38	35.5
76,000	19	17.8	57	53.3
77,000	8	7.5	65	60.7
78,000	10	9.3	75	70.1
79,000	9	8.4	84	78.5
80,000	6	5.6	90	84.1
81,000	4	3.7	94	87.9
82,000	6	5.6	100	93.5
83,000	7	6.5	107	100.0

[1]Weight Classes are 1000 pound ranges, for example the 80,000 class contains the range from 80,000 to 80,999.

Table 36. Distribution of Gross Weights for Control Producer H (Mill #2)

History Period

Weight Class[1]	Frequency	Percent	Cumulative Frequency	Cumulative Percent
69,000	2	4.0	2	4.0
70,000	2	4.0	4	8.0
71,000	1	2.0	5	10.0
72,000	4	8.0	9	18.0
73,000	3	6.0	12	24.0
74,000	10	20.0	22	44.0
75,000	8	16.0	30	60.0
76,000	4	8.0	34	68.0
77,000	2	4.0	36	72.0
78,000	3	6.0	39	78.0
79,000	4	8.0	43	86.0
80,000	3	6.0	46	92.0
81,000	1	2.0	47	94.0
82,000	2	4.0	49	98.0
85,000	1	2.0	50	100.0

Study Period

Weight Class[1]	Frequency	Percent	Cumulative Frequency	Cumulative Percent
62,000	1	1.0	1	1.0
65,000	1	1.0	2	2.0
68,000	1	1.0	3	2.9
69,000	2	2.0	5	4.9
70,000	6	5.9	11	10.8
71,000	6	5.9	17	16.7
72,000	10	9.8	27	26.5
73,000	5	4.9	32	31.4
74,000	6	5.9	38	37.3
75,000	4	3.9	42	41.2
76,000	13	12.7	55	53.9
77,000	12	11.8	67	65.7
78,000	11	10.8	78	76.5
79,000	4	3.9	82	80.4
80,000	8	7.8	90	88.2
81,000	2	2.0	92	90.2
82,000	4	3.9	96	94.1
83,000	4	3.9	100	98.0
84,000	2	2.0	102	100.0

[1]Weight Classes are 1000 pound ranges, for example the 80,000 class contains the range from 80,000 to 80,999.

Table 37. Distribution of Gross Weights for Control Producer I (Mill #2)

History Period

Weight Class[1]	Frequency	Percent	Cumulative Frequency	Cumulative Percent
67,000	1	2.0	1	2.0
68,000	6	12.0	7	14.0
69,000	4	8.0	11	22.0
70,000	5	10.0	16	32.0
71,000	8	16.0	24	48.0
72,000	12	24.0	36	72.0
73,000	2	4.0	38	76.0
74,000	4	8.0	42	84.0
75,000	3	6.0	45	90.0
76,000	2	4.0	47	94.0
77,000	1	2.0	48	96.0
78,000	1	2.0	49	98.0
79,000	1	2.0	50	100.0

Study Period

Weight Class[1]	Frequency	Percent	Cumulative Frequency	Cumulative Percent
66,000	1	1.1	1	1.1
67,000	3	3.2	4	4.3
68,000	7	7.4	11	11.7
69,000	6	6.4	17	18.1
70,000	11	11.7	28	29.8
71,000	6	6.4	34	36.2
72,000	6	6.4	40	42.6
73,000	21	22.3	61	64.9
74,000	12	12.8	73	77.7
75,000	10	10.6	83	88.3
76,000	2	2.1	85	90.4
77,000	8	8.5	93	98.9
78,000	1	1.1	94	100.0

[1]Weight Classes are 1000 pound ranges, for example the 80,000 class contains the range from 80,000 to 80,999.

Table 38. Distribution of Gross Weights for Control Producer J (Mill #2)

History Period

Weight Class[1]	Frequency	Percent	Cumulative Frequency	Cumulative Percent
68,000	1	2.0	1	2.0
69,000	1	2.0	2	4.0
70,000	3	6.0	5	10.0
72,000	8	16.0	13	26.0
73,000	4	8.0	17	34.0
74,000	5	10.0	22	44.0
75,000	7	14.0	29	58.0
76,000	2	4.0	31	62.0
77,000	3	6.0	34	68.0
78,000	3	6.0	37	74.0
79,000	4	8.0	41	82.0
80,000	2	4.0	43	86.0
81,000	4	8.0	47	94.0
83,000	1	2.0	48	96.0
85,000	1	2.0	49	98.0
87,000	1	2.0	50	100.0

Study Period

Weight Class[1]	Frequency	Percent	Cumulative Frequency	Cumulative Percent
67,000	1	1.0	1	1.0
68,000	1	1.0	2	2.0
69,000	3	2.9	5	4.9
70,000	3	2.9	8	7.8
71,000	3	2.9	11	10.8
72,000	5	4.9	16	15.7
73,000	5	4.9	21	20.6
74,000	8	7.8	29	28.4
75,000	11	10.8	40	39.2
76,000	10	9.8	50	49.0
77,000	6	5.9	56	54.9
78,000	10	9.8	66	64.7
79,000	3	2.9	69	67.6
80,000	7	6.9	76	74.5
81,000	6	5.9	82	80.4
82,000	6	5.9	88	86.3
83,000	4	3.9	92	90.2
84,000	2	2.0	94	92.2
85,000	2	2.0	96	94.1
86,000	3	2.9	99	97.1
87,000	2	2.0	101	99.0
88,000	1	1.0	102	100.0

[1]Weight Classes are 1000 pound ranges, for example the 80,000 class contains the range from 80,000 to 80,999.

Appendix F. Graphic Plots of Cumulative Relative Frequency for Mill #2

Figure 28: Cumulative Percent Frequency of Gross Weights for Treatment Producer A

Figure 29: Cumulative Percent Frequency of Gross Weights for Treatment Producer C

Figure 30: Cumulative Percent Frequency of Gross Weights for Treatment Producer D

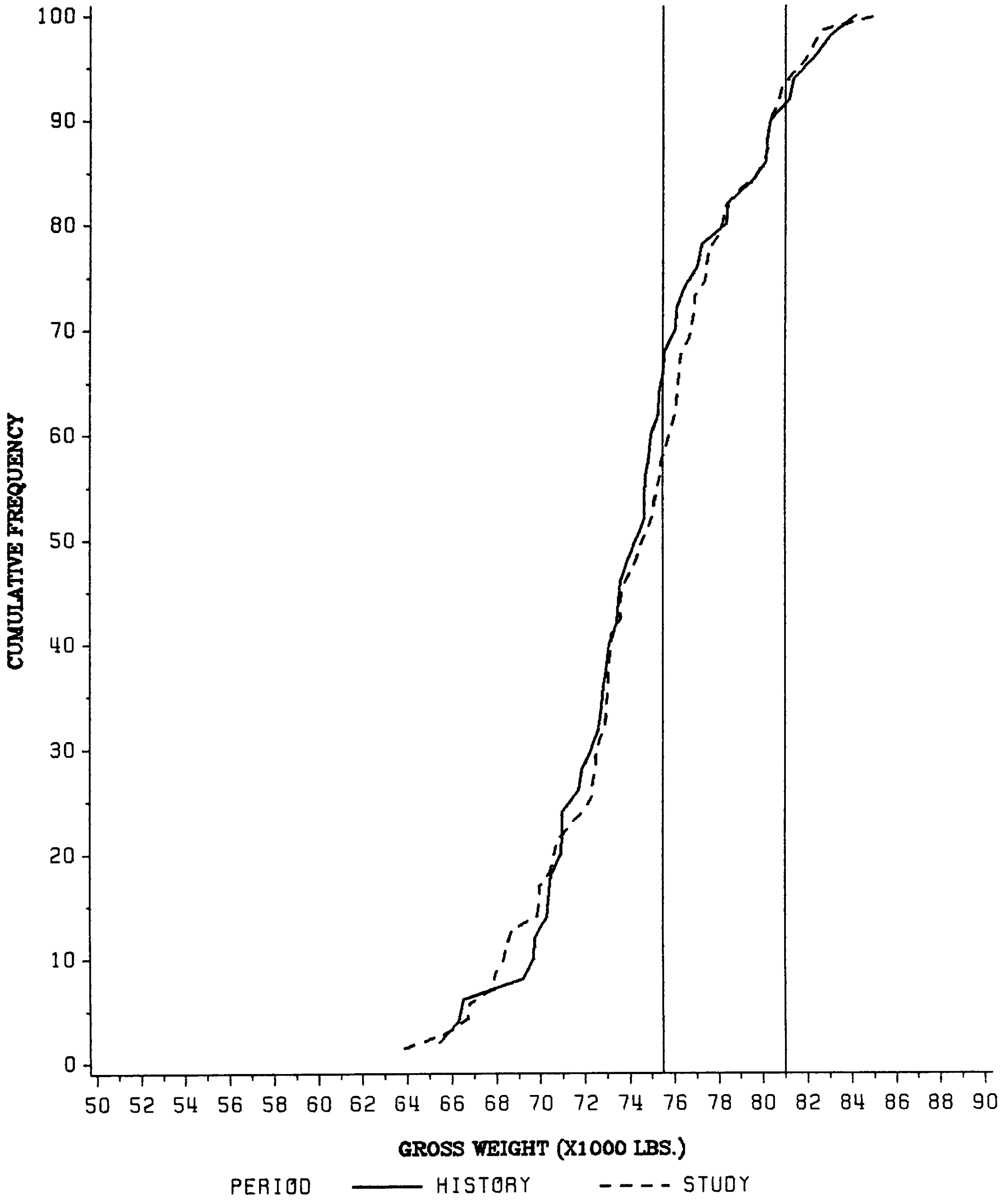
Figure 31: Cumulative Percent Frequency of Gross Weights for Treatment Producer E

Figure 32: Cumulative Percent Frequency of Gross Weights for Control Producer F

Figure 33: Cumulative Percent Frequency of Gross Weights for Control Producer H

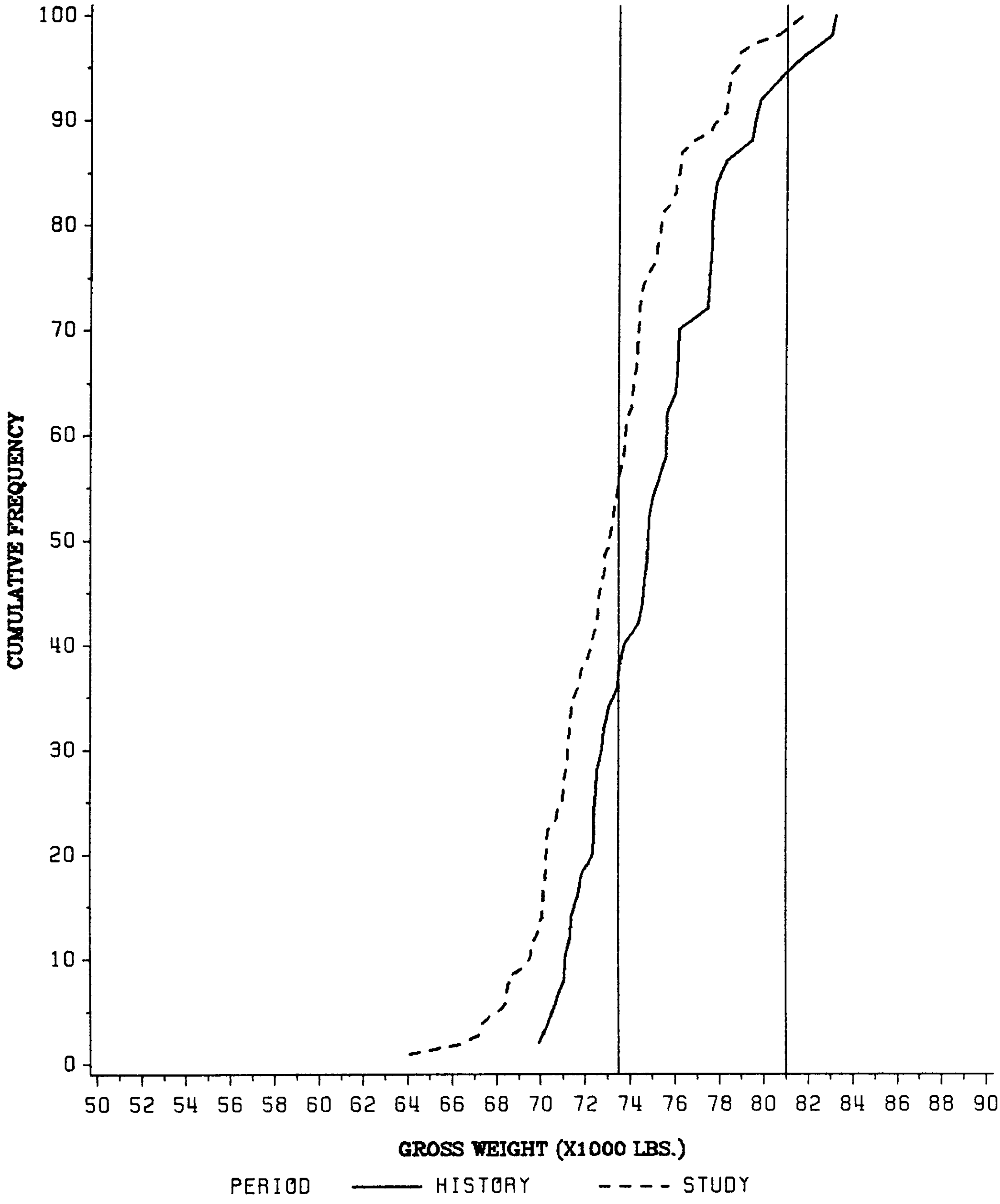
Figure 34: Cumulative Percent Frequency of Gross Weights for Control Producer I

Figure 35: Cumulative Percent Frequency of Gross Weights for Control Producer J



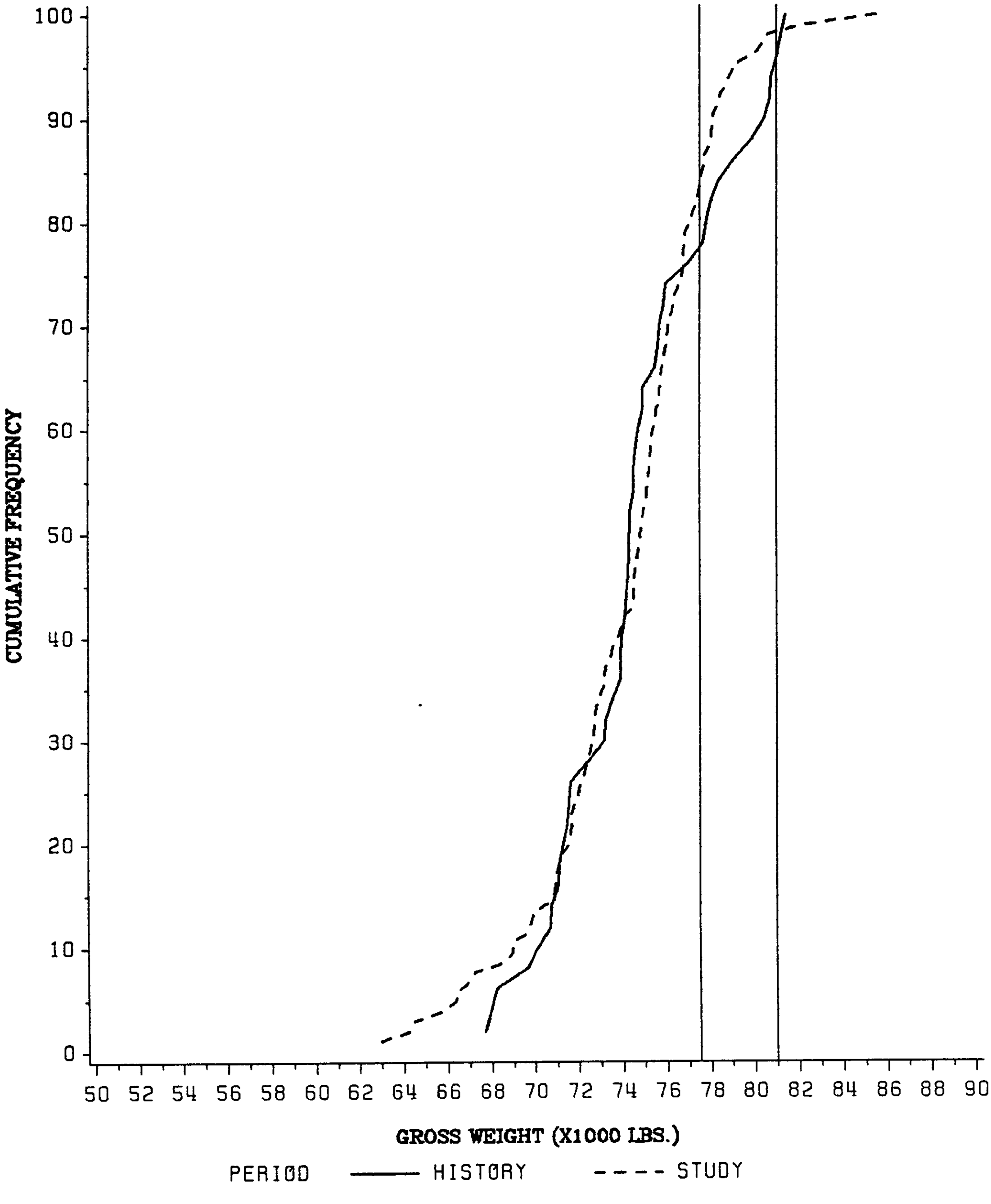
VERTICAL LINE AT 81,000 LBS REPRESENTS MILL WEIGHT LIMIT.
RANDOMLY PLACED VERTICAL LINE REPRESENTS TARGET WEIGHT CLASS CENTER.

Figure 28. Frequency Plot of Gross Weights for Treatment Producer A (Mill #2)



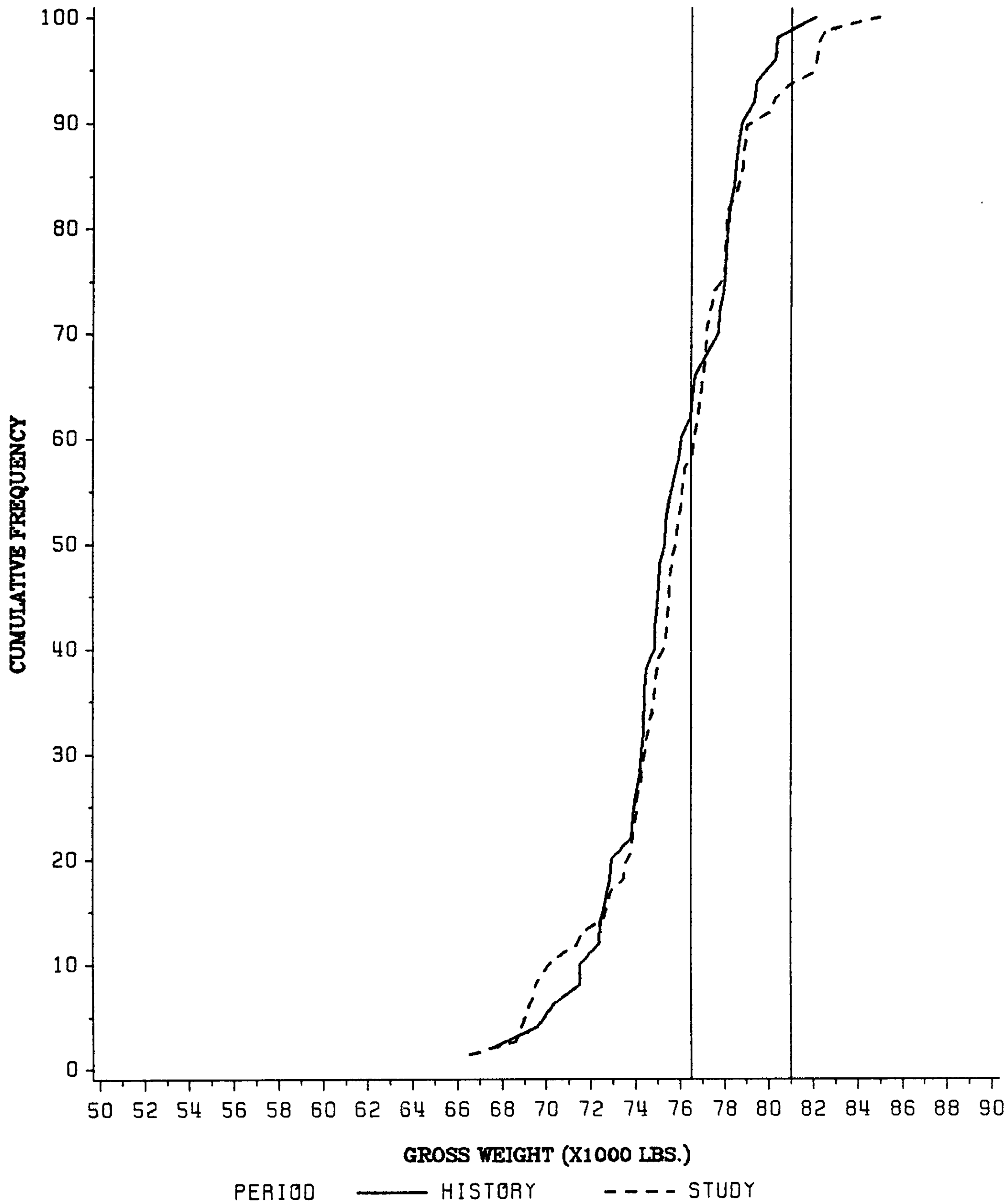
VERTICAL LINE AT 81,000 LBS REPRESENTS MILL WEIGHT LIMIT.
RANDOMLY PLACED VERTICAL LINE REPRESENTS TARGET WEIGHT CLASS CENTER.

Figure 29. Frequency Plot of Gross Weights for Treatment Producer C (Mill #2)



VERTICAL LINE AT 81,000 LBS REPRESENTS MILL WEIGHT LIMIT.
RANDOMLY PLACED VERTICAL LINE REPRESENTS TARGET WEIGHT CLASS CENTER.

Figure 30. Frequency Plot of Gross Weights for Treatment Producer D (Mill #2)



VERTICAL LINE AT 81,000 LBS REPRESENTS MILL WEIGHT LIMIT.
RANDOMLY PLACED VERTICAL LINE REPRESENTS TARGET WEIGHT CLASS CENTER.

Figure 31. Frequency Plot of Gross Weights for Treatment Producer E (Mill #2)

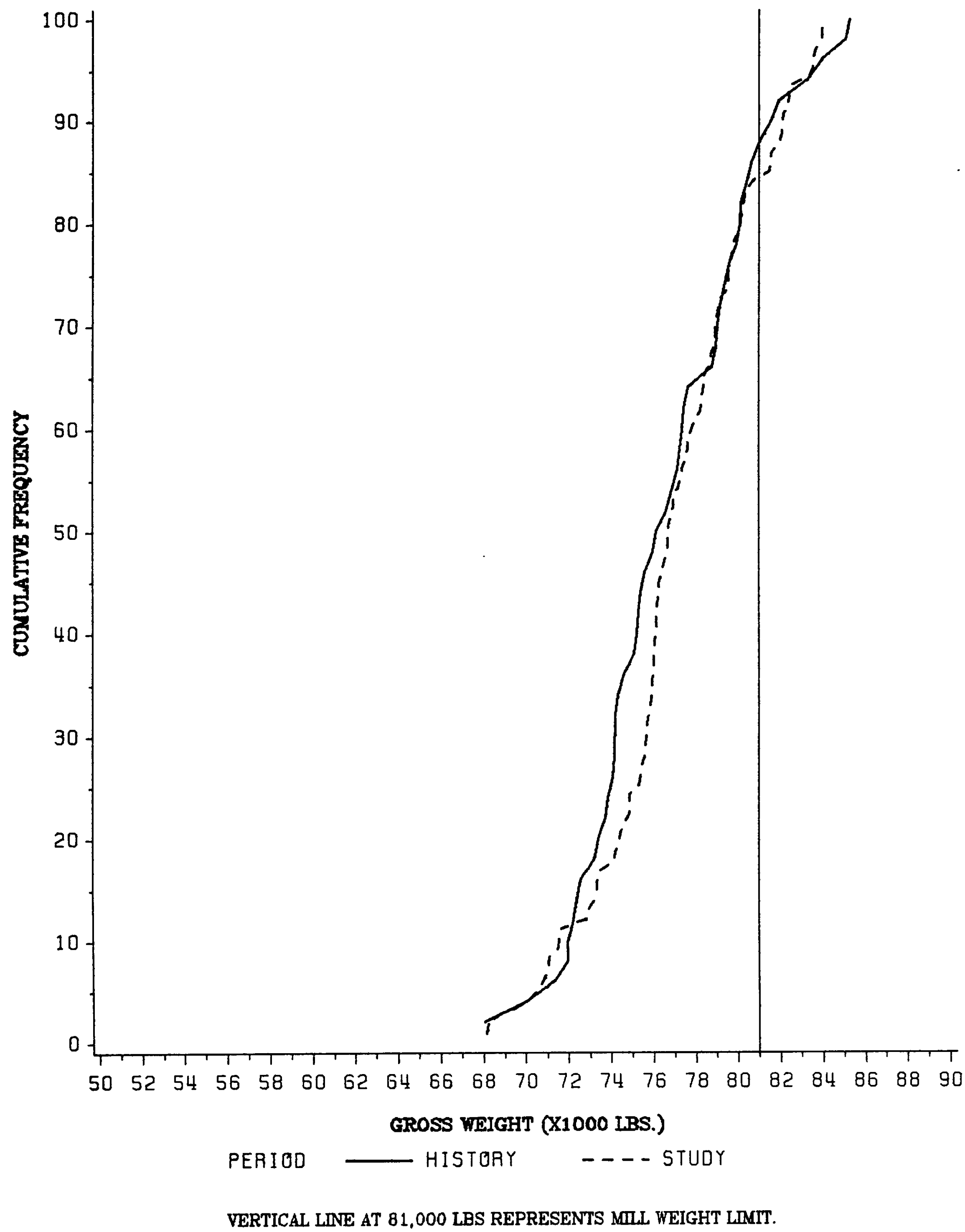


Figure 32. Frequency Plot of Gross Weights for Control Producer F (Mill #2)

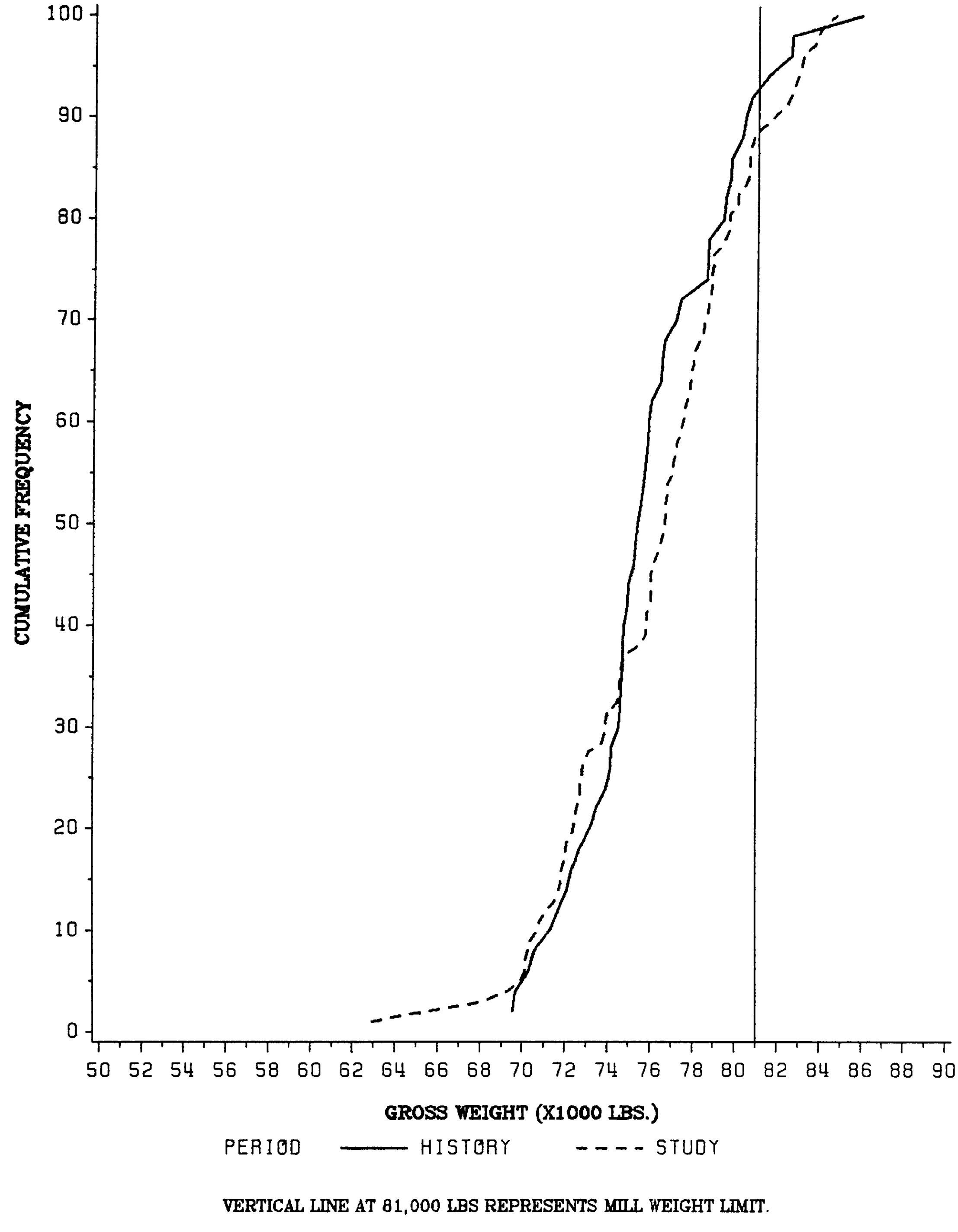


Figure 33. Frequency Plot of Gross Weights for Control Producer H (Mill #2)

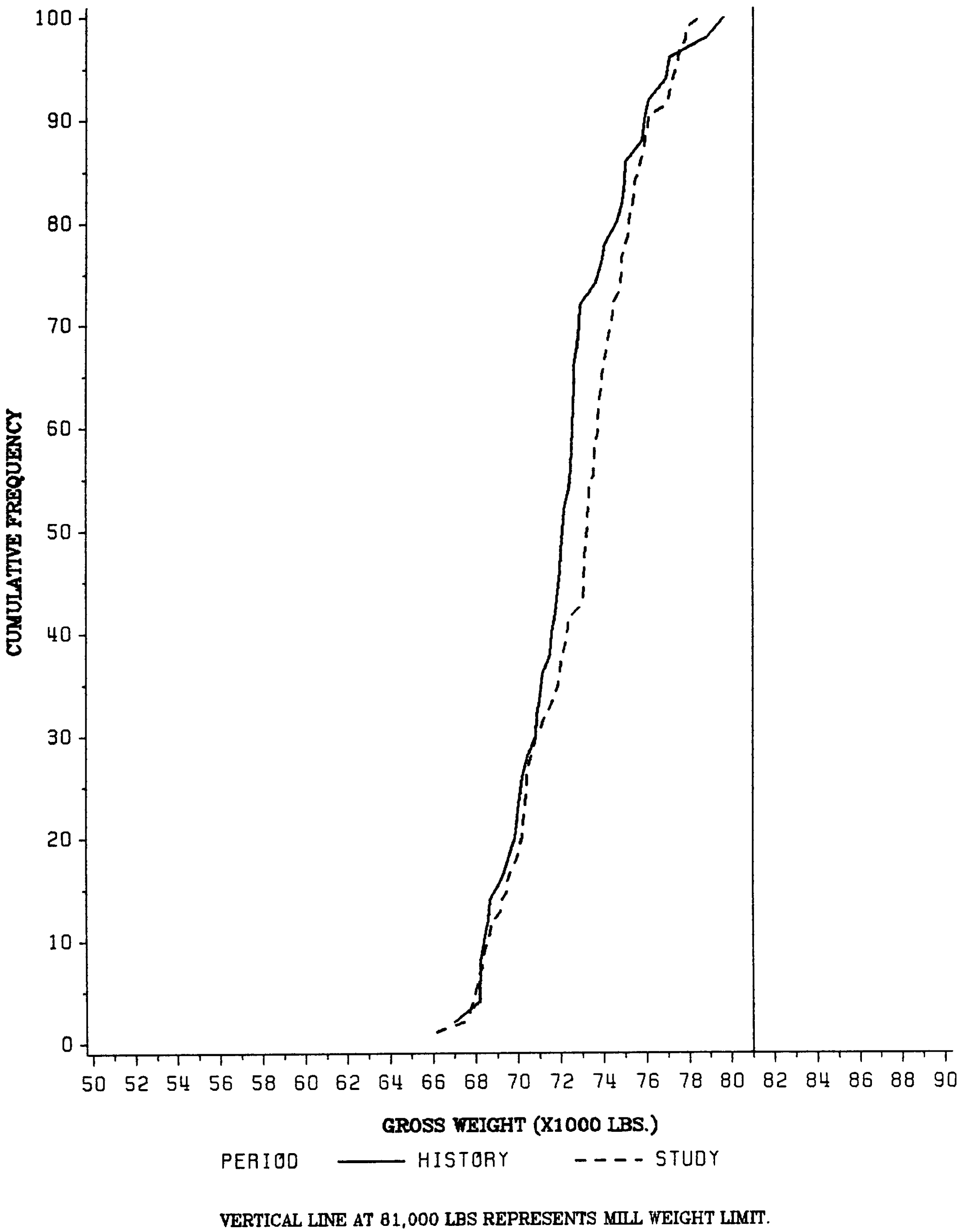


Figure 34. Frequency Plot of Gross Weights for Control Producer I (Mill #2)

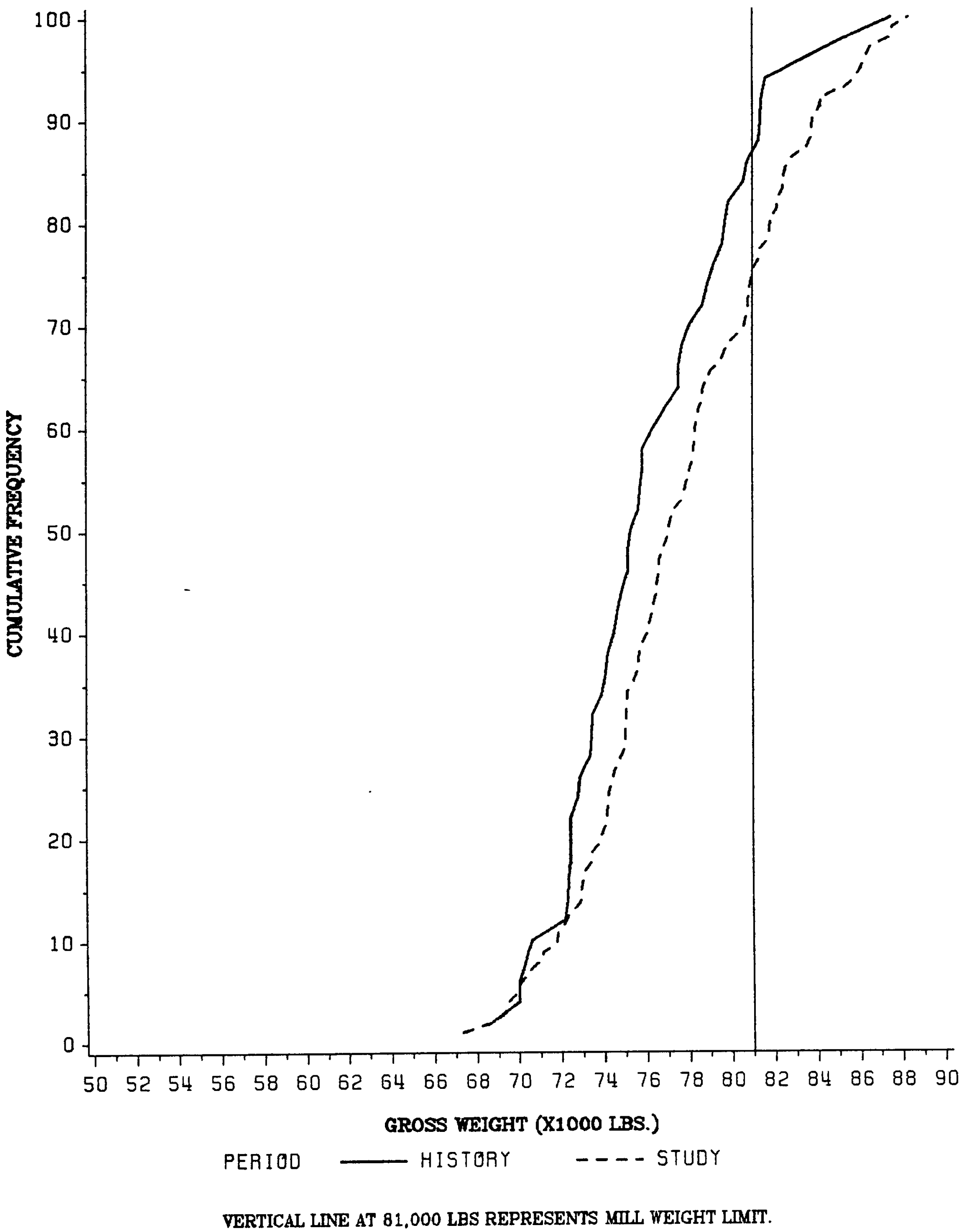


Figure 35. Frequency Plot of Gross Weights for Control Producer J (Mill #2)

The vita has been removed from
the scanned document