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PRODUCTION EFFICIENCY STUDY ON RUBBER-TIRED SCRAPERS

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PRODUCTION EFFICIENCY STUDY ON RUBBER-TIRED SCRAPERS

By

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PREFACE

The Production Efficiency Study presented in this report is another in a series of equipment productivity studies to be published by the Production-Cost Study Program. It is but one element in a broad program of field research on highway construction and maintenance methods, operational efficiency, and costs. This program is administered as a part of the Demonstration Projects Program in Region 15 of the Federal Highway Administration. The activities of the Production-Cost Study Program are geared to needs expressed by the highway construction industry. For guidance, the program relies on a technical advisory committee composed of representatives from the Federal Highway Administration, U.S. Forest Service, and the Highway Equipment Committee of the Highway Research Board. Members include highway engineers, equipment manufacturers, private contractors, and representatives from various concrete and asphalt industries.

The Production-Cost Study Program is not new to the Federal Highway Administration; its history can be traced back to the early 1920's. The program was instituted to assist the highway industry in analyzing its various operations regarding time utilization and operational efficiency, and to provide the necessary training in construction operations for Junior Highway Engineers. Except for a brief period of approximately 10 years, the program continued to function until 1966, when it was discontinued because of personnel shortages.

In 1970, the Highway Research Board's Special Committee on Highway Equipment approached the Federal Highway Administration with the idea of reactivating the program. An extensive survey was conducted throughout all segments of the highway industry. The responses were enthusiastic and unanimously in favor of the resumption of such activities and, in 1971, the Production-Cost Study Program was resumed.

The main objective of the program today remains unchanged--to assist the highway industry in identifying and evaluating time utilization and operational efficiency of various types of construction and maintenance equipment and operations.

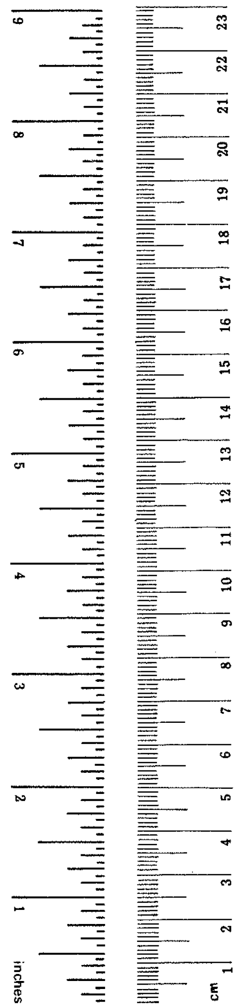
The Federal Highway Administration is indebted to the various segments of the highway industry for its support of this program and, in particular, to the private contractors on whose projects the field studies are conducted.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

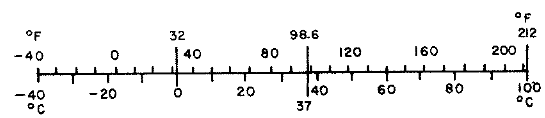
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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SUMMARY

Forty-three rubber-tired scrapers of various types and sizes were studied on eleven separate highway construction projects throughout the United States. These field studies were conducted in order to determine the productive capabilities of the machines under various conditions. Supplementary pusher studies were also conducted to aid in evaluating the scraper operations.

The types of scrapers studied included standard, elevating, twin-engine and push-pull (tandem). Heaped capacities of the machines studied ranged in size from 20 cubic yards (15 cubic metres) to 54 cubic yards (41 cubic metres). The materials excavated were categorized as either common earth or rock. Haul roads were classified according to overall condition and to percent of grade.

Productive work time (the time the scraper was actually engaged in its designated function of excavating and transporting material) averaged 69 percent of the Total Work Time Studied (TWTS). Minor delays--those lasting less than 15 minutes--occurred consistently throughout all the operations and totaled 13 percent of the TWTS; the most significant of the minor delays was the wait for pusher delay. This particular type accounted for 6 percent of TWTS, or approximately 50 percent of all minor delay time. The remainder of the TWTS, 18 percent, was attributed to major delays--those delays lasting 15 minutes or more. In order to discount localized weather conditions, all weather delays were excluded from the study time.

The various components of the productive cycle--loading, dumping, turning and traveling--were isolated and analyzed. Loading was categorized according to the loading method employed and the type of material excavated. Dumping was categorized according to the size and number of engineers of the scraper. Turning operations were found to be relatively constant for all types and sizes of scrapers. Travel time, the most time-consuming segment of the productive cycle, was categorized according to the type and heaped capacity of the scraper and the net grade and overall condition of the haul road.

The scraper "wait for pusher time," the largest minor delay type, was analyzed separately from the remaining minor delays. The amount of scraper wait for pusher time was found to be largely dependent upon the ratio of scrapers to pushers and the overall scraper productive cycle time.

Repairs to the scraper units were by far the most time-consuming and frequently occurring type of major delay; these delays accounted for 67 percent of the total major delay time. Shutdown delays, delays where the work force was dismissed or transferred to another operation, accounted for approximately 75 percent of all major delays.

In order to enable a contractor to analyze his own operations, a scraper field data collection sheet--along with an efficiency study form--has been included in Appendix A. A method for utilizing this report as an estimating guide is described and included in Appendix B of this report. Appendix C illustrates the impact major and minor delays can have on the productivity of a scraper operation.

Results of these field studies have produced findings of considerable interest which should assist contractors in better understanding the productive capabilities of their scraper fleet. Hopefully, this better understanding will be converted to increased efficiency and, subsequently, lower unit bid prices.

I. INTRODUCTION

Background

The rubber-tired scraper has long been associated with the earthmoving phase of highway construction. Under appropriate field conditions and supervisory control, this machine has proved to be a most efficient and economical means of excavating and transporting material.

Admittedly, the scraper is a compromise of the best features of several more-specialized pieces of equipment; the power shovel or the front-end loader might excavate material at a faster rate, or the off-highway truck might surpass the scraper in hauling speed. Nevertheless, the scraper's ability to incorporate all the components of the total earthmoving cycle into one machine gives it a distinct advantage under suitable conditions. Since the individual scraper is relatively independent of other scrapers in a fleet, a breakdown of one machine does not cause the overall operation to be shut down; another advantage over more specialized earth digging equipment.

One obvious goal of efficiently managing scraper operations is to obtain the maximum production at the least cost. A contractor's investment in his scraper fleet is considerable; idle or inefficiently operated equipment is costly in terms of both time and money. It is therefore to the owner's benefit to make maximum use of new developments in methods and techniques.

Purpose and Scope

This report presents the results of field studies conducted on the operational capabilities of many different types and sizes of scrapers. These studies were conducted to evaluate the performance and productivity of the scrapers and also to categorize and measure the many types of delays which occur in the course of the operations. Because of their integral relationship with the performance of the scrapers, the operations of the track-type pushers were also examined and evaluated, although to a lesser degree than the scrapers.

These studies focused primarily on the scrapers themselves and did not attempt to examine the performance of auxiliary equipment such as drills, rippers, or compactors, although it was recognized that such equipment also played an important role in the total process of earthmoving.

The format of the presentation is designed primarily for use by a highway contractor's field supervisory personnel in evaluating the performance of their operating fleet. This report might also be used as an aid to contractors, State highway departments, or other agencies for estimating purposes and predicting scraper performance under given field conditions. It should be noted, however, that the use of this data for estimating purposes on a particular project should be combined with the estimator's own experience and knowledge of the situation at hand.

II. DEFINITION OF TERMS

TOTAL WORK TIME STUDIED (TWTS)--Total work time during which all scraper operations were timed with a stopwatch. TWTS is the sum of the following:

1. Productive Time--Time during which the scraper was used for its intended purpose.

2. Delay Time--Any interruption of productive work. Delay time is further classified as:

a. Major Delay--Any interruption of work lasting 15 or more minutes. Major delays are further classified as:

(1) Major shutdown delays--Those major delays during which the contractor's labor force is dismissed or transferred to other operations, thereby reducing the cost of that delay.

(2) Major operating delays--Those major delays during which the contractor's labor force remains on hand anticipating resumption of work. Labor costs continue undiminished during this type of delay.

b. Minor Delay--Any interruption of work lasting less than 15 minutes.

NET WORK TIME STUDIED (NWTS)--Total work time studied (TWTS) minus major delay time--or productive time plus minor delay time.

The interrelationship of the above terms is further illustrated in the following sketch:

<table>
<tr><td colspan="3">TWTS</td></tr>
<tr><td colspan="2">NWTS</td><td rowspan="2">Major Delays</td></tr>
<tr><td>Productive Time</td><td>Minor Delays</td></tr>
</table>

PRODUCTIVE CYCLE--The operations required for a scraper to perform all the elements of one complete cycle of excavating and delivering a load of material from the cut area to the fill area and returning to the cut. Five basic time elements make up the scraper cycle. They are:

1. Load Time--The time beginning when the cutting edge of the scraper penetrates the material to be excavated and continuing until the apron is drawn shut or the scraper cutting edge is raised from a digging position, whichever occurs first.

[Assist Time (applicable only to push-pull scrapers)--The time required to aid in either push- or pull-loading a second scraper. For the front scraper, the time from completion of loading until commencement of either haul or turn; for the rear scraper, the time from completion of either return or turn until commencement of loading. This also includes the time required to maneuver into contact and link up with the front scraper. Included as part of load time.]

2. Haul Time--The time required to transport the load from the cut to the fill, commencing upon the completion of loading or turning after loading and continuing until the beginning of discharge of the load or the turn prior to discharge.

3. Dump Time--The time required to dump, starting when the apron begins to raise and continuing until the bowl is emptied.

4. Return Time--The time required for the scraper to travel from the point where discharging or the turn after discharging is completed to the point where loading or the turn prior to loading begins.

5. Turn Time--The time required for the scraper to negotiate a change in direction prior to or immediately following loading, dumping, hauling, or returning. Turns are considered to begin when the tractor commences the movement which results in a change in direction of travel, and continues until the new direction of travel has been established or another operation commences. (A slight deviation in direction of travel during another element of the cycle was not considered a turn).

TRAVEL TIME--The sum of haul time plus return time.

PRODUCTIVE EFFICIENCY--The ratio of productive time to TWTS, expressed as a percentage.

STUDY PERIOD--The total period of the study from the first day through the last.

LOADING DISTANCE--The distance traveled during load time.

HAULING DISTANCE--The distance traveled during haul time.

DUMPING DISTANCE--The distance traveled during dump time.

RETURNING DISTANCE--The distance traveled during return time.

HAULING SPEED (Loaded)--The speed of the scraper during haul time.

RETURNING SPEED (Empty)--The speed of the scraper during return time.

LOAD SIZE--The amount of excavated material loaded in the scraper bowl estimated in loose cubic measure.

EQUIPMENT RATIO--The ratio of the number of scrapers operating to the number of pushers.

III. STUDY METHODS

From July 1974 through January 1976, data pertaining to scraper operations was collected on eleven different highway projects throughout the United States. Twenty-three thousand cycles of 43 scrapers of various types and sizes were timed and analyzed. This represented more than 3,800 machine-hours of operating time.

Projects selected for study were chosen primarily for the suitability of the operation to the study techniques employed. Study teams were for the most part limited to four people, and studies generally lasted anywhere from 4 to 6 weeks. Because of these constraints, projects with sporadic or intermittent operations were not considered for study, nor were projects whose physical layouts made it impractical to cover the entire scraper cycle. A further constraint was to study operations that were reasonably repetitious in nature. It was not felt that these restrictions were unwarranted or overly exclusive. It is believed that the projects chosen for study were quite representative of those which a contractor would most likely encounter on a typical project.

Two basic methods of study were employed. One was a random period method in which the work week was divided into equal time periods, from which several were selected for observation. Over the course of a project, approximately 70 percent of the total work time was actually observed and recorded. The second method employed was the all-day study method in which observers recorded the entire operation from the start of the contractor's work shift until either the end of the shift or the shutdown of the scraper operations, whichever occurred later. It was felt that either method provided a sampling of the contractor's operation sufficient for the data analysis presented in this report.

Data pertaining to time utilization, productivity, and performance characteristics of the scrapers was recorded by observers stationed in both the cut and fill areas. Synchronized stopwatches were used to record the cumulative times at the beginning and end of each cycle element. Travel distances were estimated by using existing stationing; all load sizes were estimated by the observers in the cut.

Delay times were recorded when a scraper stopped during or between any of the productive cycle elements, or when it was apparent that a scraper slowed abnormally during a cycle element. When necessary, an additional observer was stationed along the haul road to record any delays which might occur during the haul and return cycle elements. Causes of all delays were determined as accurately as was possible by the observers.

In addition to the scraper studies, occasional spot studies were conducted on pusher operations. These spot studies were spaced randomly throughout the work shift and varied from a half-hour to an hour or more in duration.

During the course of the studies certain data was considered constant, i.e., it remained unchanged for all cycles of a particular operation. Examples included the condition of the haul road and the type of material excavated. These factors later became the parameters under which the various cycle elements were grouped for analysis and comparison. Listed below are the criteria under which the basic parameters were defined and later isolated:

A. Type of Scraper--Scrapers were first classified according to their basic configuration and method of operation:

   1. Type 1 - standard, single-engine, push-loaded scraper.

   2. Type 2 - elevating (self-loading) scraper with which material is excavated and loaded by means of vanes attached to a moving belt system. No pusher is required.

   3. Type 3 - twin-engine scraper equipped with hook-and-bail attachments which allow two scrapers to link together and assist one another while loading in tandem.

   4. Type 4 - twin-engine, push-loaded scraper. Includes scrapers equipped with hook-and-bail when they are not actually loading in tandem.

B. Size of Scraper--Scraper types were further subdivided according to their heaped capacity:

1. capacity < 25 cubic yards heaped.
   (capacity < 19 cubic metres)

2. 25 ≤ capacity < 35 cubic yards heaped.
   (19 ≤ capacity < 27 cubic metres)

3. 35 ≤ capacity < 45 cubic yards heaped.
   (27 ≤ capacity < 34 cubic metres)

4. capacity ≥ 45 cubic yards heaped.
   (capacity ≥ 34 cubic metres)

C. Type of Material--material excavated was subdivided into two categories:

1. Common earth--from loose, free-flowing earth to a well-graded mixture of earth and sandstone, shale, or other easily rippable materials. Contains adequate fines to fill voids. Also includes clay, hardpan, or lightly cemented granular materials.

2. Rock--from poorly graded earth-rock particles to sharp "block type" particles usually less than 24 inches in diameter. Contains a minimum percentage of fines to fill voids.

D. Grade of Haul Road--Haul roads were subdivided according to the net percent grade as measured in the direction of haul from the cut to the fill:

1. Favorable grade--net grade more than 1 percent downgrade.

2. Negligible grade--net grade between 1 percent downgrade and 1 percent upgrade.

3. Unfavorable grade--net grade more than 1 percent upgrade.

E. Condition of Haul Road--The overall condition of the haul road was also subdivided into three categories:

1. Good condition--firm, relatively smooth and dry grade.

2. Fair condition--firm, partially wet, rough, or rutted grade.

3. Poor condition--soft or spongy, mostly wet, rough, or rutted grade.

Other variables noted will be described in later sections.

IV. BREAKDOWN OF TWTS

The combined study time of the studies included in this report amounted to more than 3,800 machine-hours and included observations of more than 23,000 individual scraper cycles. This Total Work Time Studied (TWTS) was divided into 2 major categories: 1) productive time--time during which the scrapers performed designated functions of excavating and transporting material, and 2) delay time--time during which the scrapers were not engaged in productive work. Delays were further subdivided into major delays--delays 15 or more minutes in duration, and minor delays--delays less than 15 minutes in duration. Because of their unpredictability, weather delays were excluded from TWTS.

Major delays lasted anywhere from 15 minutes to several days and were mainly attributed to equipment breakdowns and repairs and to managerial decisions not to use the equipment. Major delays were found to be highly unpredictable in frequency and duration from job-to-job.

Minor delays were found to be much more predictable in both frequency and duration. Typical minor delays were the wait for pusher and start late-quit early delays. Although minor delays normally lasted less than a minute, they occurred frequently enough to have a marked effect on the operation. This effect becomes even more pronounced when comparing minor delays as a percentage of NWTS rather than as a percentage of TWTS.

Table 1 presents the overall breakdown of the TWTS of all the studies. Major delays accounted for 18 percent of all time studied while minor delays amounted to 13 percent. The remaining 69 percent of the time was left for actual scraper production.

Table 1. Breakdown of Scraper TWTS

Item	Percent of TWTS	Percent of NWTS
TWTS	100	
Major Delays	-18	
NWTS	82	100
Wait for Pusher Delays	- 6	- 7
Other Minor Delays	- 7	- 8
Productive Time	69	85

Theoretically, a reduction in delay time should result in a corresponding increase in the productive rate (see Appendix C); however such is not always the case. For example, a decrease in traffic delays would probably result in faster cycles, but may well increase wait delays in the cut, thus resulting in little net gain in production efficiency. Nevertheless, the elimination of delays will result, although not always directly proportionally, in a more efficiently-run operation with corresponding increases in productivity.

V. PRODUCTIVE CYCLE

The typical scraper productive cycle, as illustrated in Figure 1, is composed of 5 distinct cycle elements:

A. Loading

B. Hauling

C. Dumping

D. Returning

E. Turning in the Cut or Fill

The elements may not in practice occur in the exact order shown; for example, the scraper might load before turning in the cut.

In this section each individual productive cycle element is discussed in detail. The haul and return cycle elements are combined into a single "travel" element for reasons which are explained later. In addition, because some wait for pusher time is almost inevitable on every cycle, this minor delay is also discussed. It should be noted, though, that "wait for pusher" is indeed a minor delay and not an element of the productive cycle.

Loading

Loading conditions played a major role in determining which type of scraper waste was to be used on a project. For example, push-loaded scrapers were more suitable for loading rock than elevating scrapers. From the field studies conducted, it was determined that many of these conditions were easily quantifiable, while many others were intangible and therefore difficult to quantify. Typical examples of intangible factors were the condition and grade of the loading area, the condition of the scraper and/or the pusher, the skill of the operator, and the amount of supervision exercised by management. Although it was realized that a combination of all these intangible factors had a definite effect on loading times, it was difficult to isolate each. It is felt that a contractor would be better able to weigh the effects of those factors as they pertain to his particular projects.

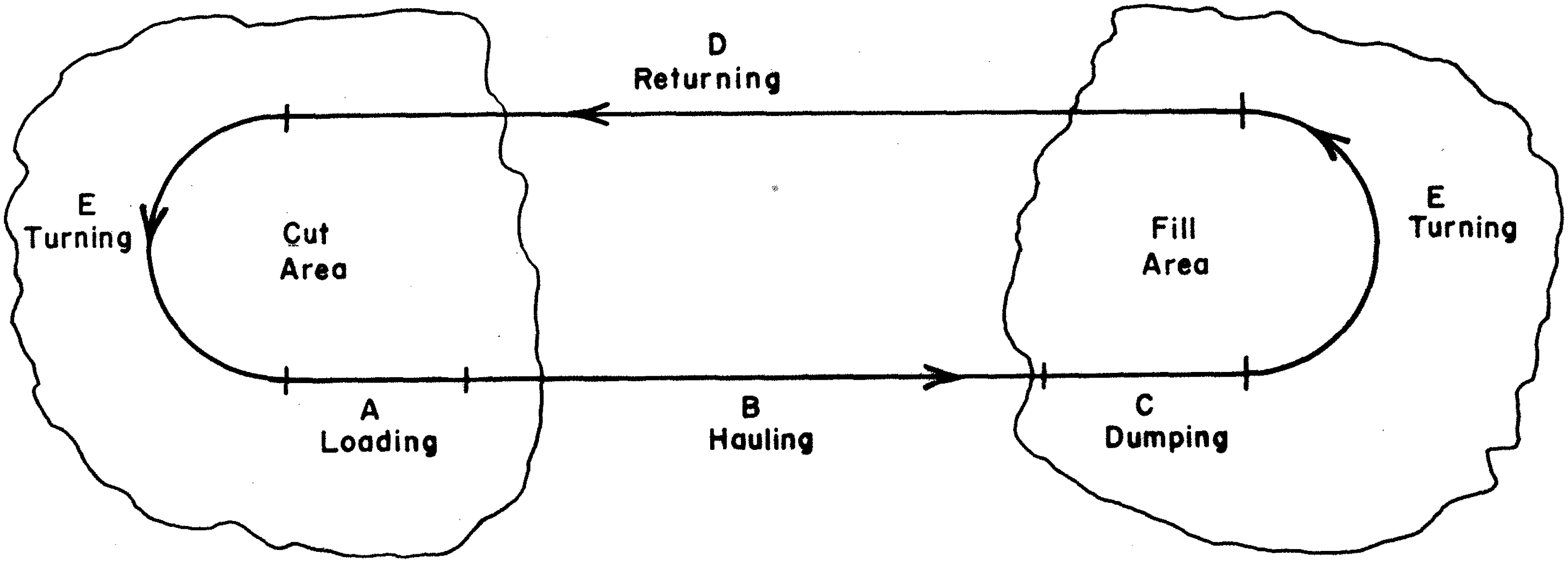

Figure 1. Elements of the Scraper Productive Cycle

Classifying the load times according to the size of the scraper indicated no significant difference. The larger scrapers, even though obtaining larger loads, loaded equally as fast as the smaller scrapers. The phenomenon could possibly have been attributed to the additional loading horsepower, in both the scraper and pusher, which was usually utilized in loading the larger sized scrapers. Those factors by which the loading data was eventually grouped and analyzed were the loading method employed and the type of material excavated.

The various loading methods observed included loading with a single pusher, loading with two pushers operating in tandem, push-pull loading and self-loading (elevating). For those scrapers which were push-loaded, no significant difference in time was recorded when push-loading a twin-engine scraper versus a single-engine scraper. Logically it would seem that the twin-engine scraper would have been push-loaded faster than a single-engine scraper. However, it is believed that little additional traction was provided to the rear wheels of the twin-engine scrapers because of the uplifting force provided by the pusher on the rear of the scraper.

As previously described, the type of material excavated was classified as either common earth or rock. Initially, it was felt that common earth should have been further subdivided into a "loose earth" and a "firm earth" category. However, in comparing the loading times no appreciable difference was indicated.

Table 2 summarizes the loading times and their respective loading distances according to the loading method employed and the type of material excavated. It should be noted that the times shown for push-pull loading include both the load time and the assist time. (see Definition of Terms)

Table 2. Scraper Loading Times and Distances

Loading Method Employed	Value	Material			
		Common Earth		Rock	
		Time (Min.)	Dist. Ft(M)	Time (Min.)	Dist. Ft(M)
Single Pusher	Average	0.85	125 (38)	1.00	150 (46)
	Std. Dev.	0.30	-	0.28	-
Tandem Pushers	Average	0.76	125 (38)	0.77	100 (30)
	Std. Dev.	0.22	-	0.20	-
Push-Pull	Average	1.83	400 (122)	1.46	300 (91)
	Std. Dev.	0.38	-	0.29	-
Self-Loading (Elevating)	Average	1.84	400 (122)	-	-
	Std. Dev.	0.34	-	-	-

As was expected, loading with tandem pushers was generally faster than loading with single pushers. In most cases, common earth was loaded at a faster rate than rock; however, this was not the case in push-pull loading. This exception leads to the next observation: not only was loading time important, but also the size of load obtained. These two factors combined determined the production rates. Table 3 shows the ranges of load sizes obtained as percentages of available heaped capacity for each loading method and type of material encountered.

Table 3. Scraper Load Sizes as Percent of Heaped Capacity

	Loading Method Employed			
Material	Single Pusher	Tandem Pushers	Push-Pull	Self-Loading (Elevating)
Common Earth	82-83	84-89	83-87	93-98
Rock	77-83	80-82	72-76	-

Examination of Table 3 shows that tandem pushers produced greater loads on the average than single pushers. It also can be seen that, in general, smaller loads were obtained in rock than in common earth. This could possibly explain the above-mentioned differences in loading times between common earth and rock for push-pull loading. Not only was push-pull loading less effective in rock, but increased wear on the machines usually resulted. The self-loading (elevating) scraper achieved near-capacity loads as a result of the unique loading method it employed.

To illustrate the value of Tables 2 and 3, the following example is presented:

> A contractor chooses to use a fleet of scrapers of 30 CY capacity in a rock material. He expects to use tandem pushers on this operation. What will be the average time it takes to load the scraper and what can the contractor expect to be the average load size?
>
> Table 2 shows that for tandem pushing in a rock material he can expect an average load time of 0.77 minutes. Table 3 indicates that he may expect an average load size of approximately 81 percent of the heaped capacity of the scraper, or 24 loose cubic yards. These two figures can then be used to aid him in determining an overall production rate for his operation.

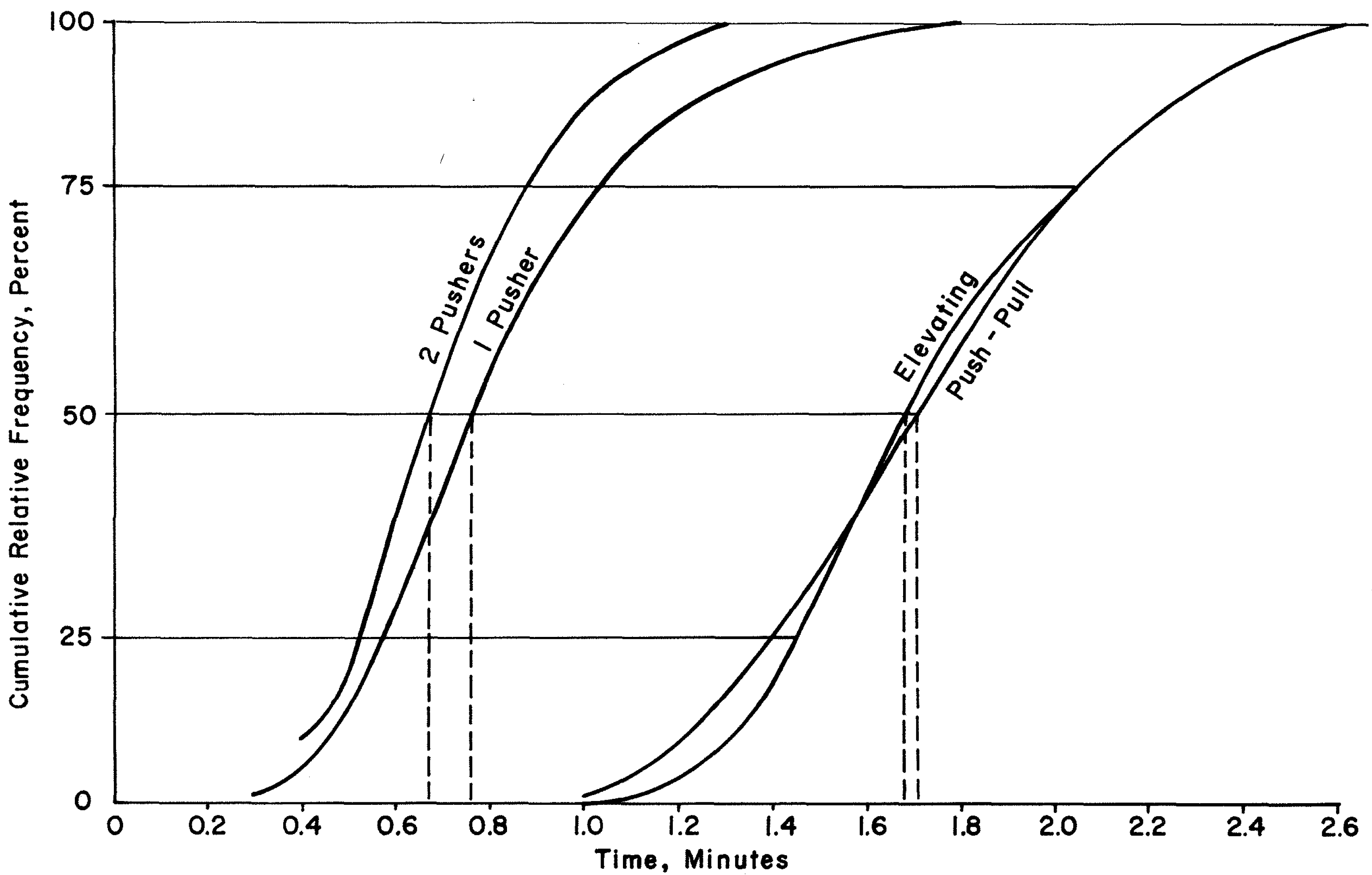

Figure 2. Cumulative Distributions of Loading Time - Common Earth Material

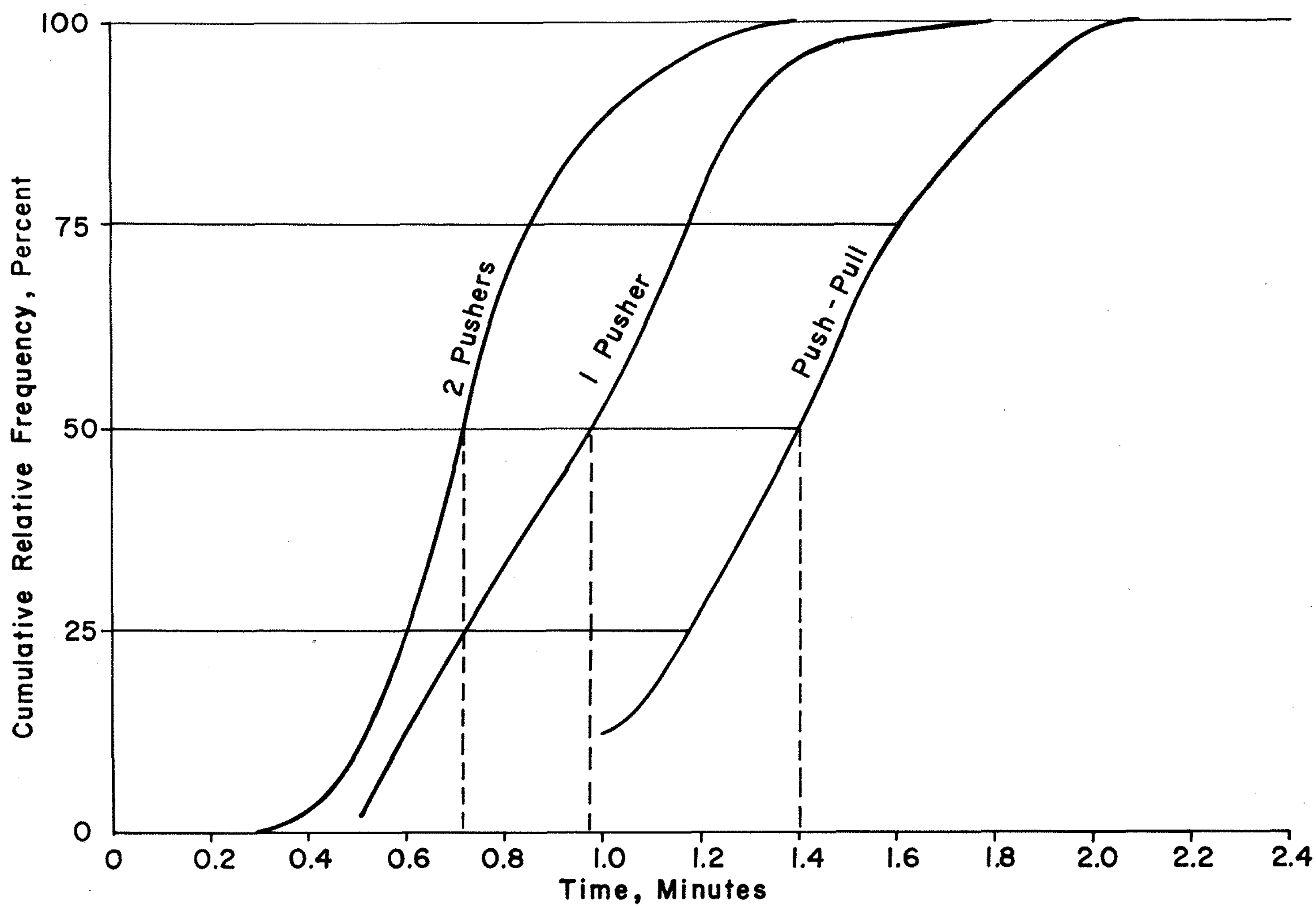

Figure 3. Cumulative Distributions of Loading Time - Rock Material

Figures 2 and 3 show the relative cumulative frequency curves for loading times in common earth and rock. The median values were obtained from the 50th percentile of these graphs. The mid-range for the load times is also illustrated between the 25th and 75th percentiles.

Several observations which were made during the loading operations are presented as follows:

1. Material classified in this report as common earth was more easily loaded when reasonably moist.

2. Hard clay materials and other tight soils should be ripped prior to loading. Loading the material in the unripped state usually resulted in increased load times and added wear on the machines.

3. Loading should be conducted downgrade and toward the fill when possible. However, if a choice must be made between the two, the following decision criteria should be followed:

    a. Loading should be directed toward the fill on slight to moderate uphill grades.

    b. Loading should be conducted downgrade on unusually steep grades regardless of the direction of fill.

4. An excessive amount of time was spent trying to overfill scraper bowls. This amounted to much wasted effort and, consequently, lowered scraper efficiency.

5. Scrapers that need to be push-loaded should not attempt to load without the pusher. Not only is a minimal load obtained, but more wear on the machines results. The time a scraper spends loading without a pusher would be better utilized in locating the best position to minimize pusher maneuver time.

6. In many cases, the use of an experienced cut foreman greatly increases loading performance. The resulting increase in production attained more than justifies the added expense.

Dumping

Basically, three distinct methods of dumping were observed on the scraper operations. These three methods are illustrated in Figure 4. Generally, the physical characteristics of a particular project dictated which method was most appropriate.

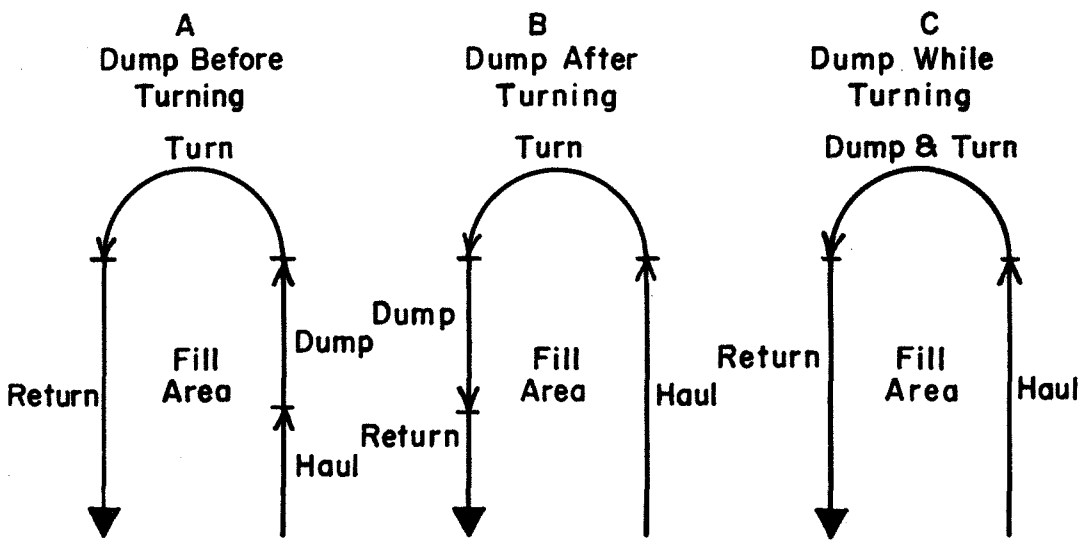

Figure 4. Dumping Methods

Method A, the most commonly observed, utilized the momentum of the haul speed to carry the scraper through the dump and subsequent turn. Higher dumping speeds reduced the possibility of the scraper becoming stuck in the dumped material. Dumping by this method also permitted a more even spread of material than the other methods, thereby requiring less effort on the part of the spreading and compacting equipment.

Method B ordinarily was used when it was necessary to negotiate a turn prior to entering the fill area. Dumping by this method generally increased the dump time and the chances of being slowed or bogged while dumping.

Method C was generally used in fills where access or manueverability was limited, such as backfilling over culverts or constructing embankments for bridge abutments. This method had the advantage of placing the material more closely to the designated area; however, many scrapers became bogged down in doing so. When dumping while turning became necessary, increased dumping times along with an uneven spread of the material were observed.

From analysis of the data collected, it was found that variations in dump times occurred for scrapers of different types and sizes. Scrapers were classified as either single-engine scrapers (which included the standard and elevating types), or twin-engine scrapers (which included push-pull and standard twin-engine types). Table 4 shows the average dumping times as observed for the various types and sizes of scrapers. In some cases, particularly when wet material was being dumped, it was more difficult to eject the load, and dump times were higher than the average. Also, the average times encompass the many different physical conditions of the fill area itself. In particularly marshy areas, the dump times were generally much higher; on the other hand, under excellent fill conditions dump times were lower.

Table 4. Scraper Dump Times (Min.)

SIZE	TYPE			
	SINGLE ENGINE		TWIN-ENGINE	
	AVERAGE	STD. DEV.	AVERAGE	STD. DEV.
< 25	0.30	0.13	NO DATA AVAILABLE	
25-34	0.37	0.13	0.26	0.07
35-44	0.44	0.13	0.28	0.07
> 44	NO DATA AVAILABLE		0.29	0.07

Table 4 shows that twin-engine scrapers dumped faster than single-engine scrapers of equal size. This was attributed to the increased power and traction that the twin-engine scrapers had over those with a single engine. A second observation is that for each type of scraper, as was expected, the dump time increased with increasing size.

Figures 5 and 6 show the cumulative relative frequency distributions of dump times for both single- and twin-engine scrapers. Each figure includes the curves for the combined averages of all three dumping methods (A, B, and C).

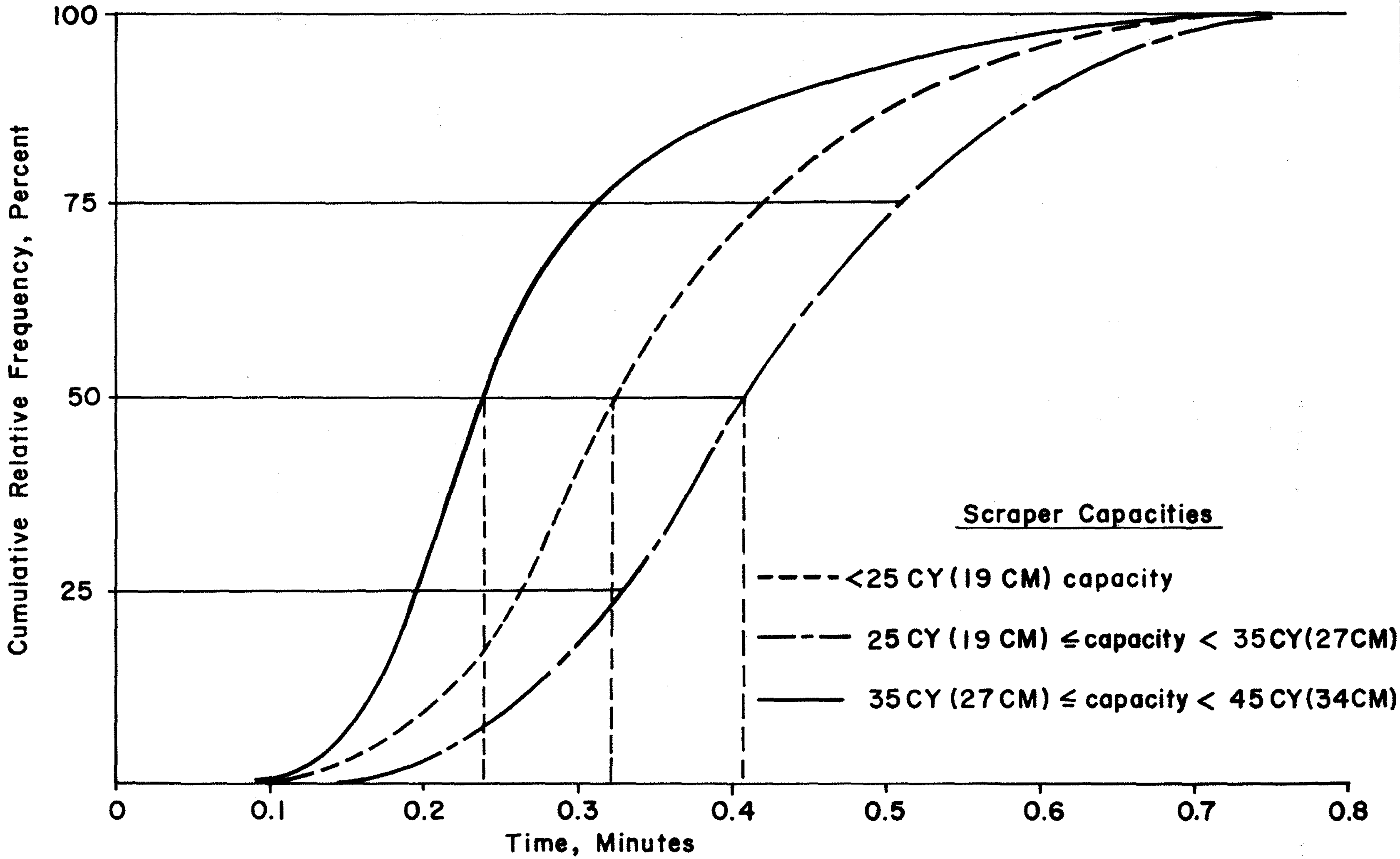

Figure 5. Cumulative Distributions of Dumping Time - Single Engine Scrapers (Type 1 and 2)

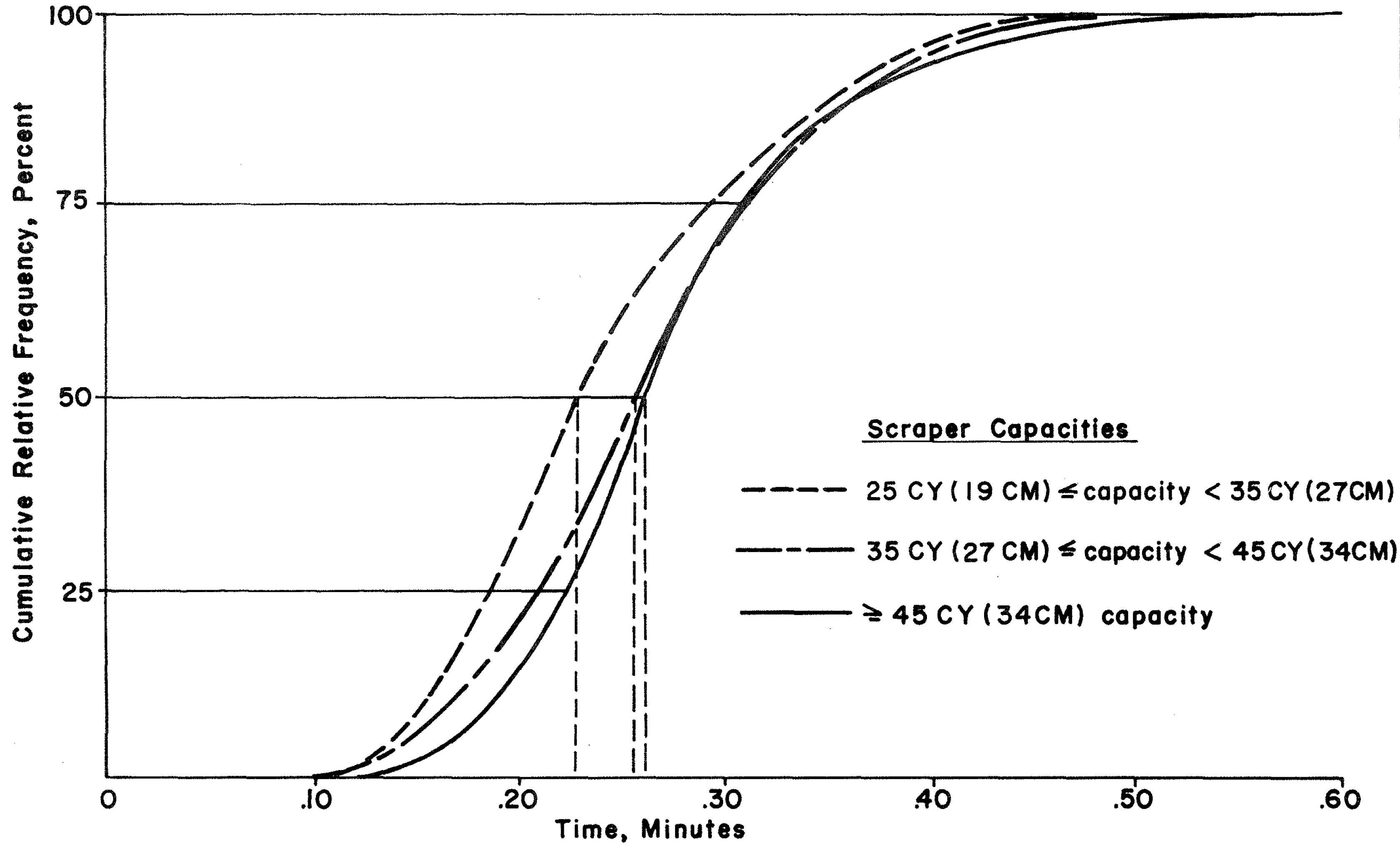

Figure 6. Cumulative Distributions of Dumping Time - Twin Engine Scrapers (Type 3 and 4)

It was interesting to note the value of a spotter in achieving a more efficient fill operation. The spotter provided better coordination of the scrapers with the spreading and compacting equipment. Part of the spotter's job was to keep the scrapers dumping in a specific location and pattern. As each scraper entered the fill area, the spotter would direct the operator to dump his load at the end of the preceding spread until the end of the fill was reached. Another spread was then started parallel to the first. By instructing the scrapers to dump in this manner, compacting equipment could work on the dumped material without interfering with the scrapers. The spotter also directed the scrapers so that maximum benefit from the scrapers' tire compaction could be utilized. It was also noticed that a spotter kept the scrapers constantly on the move while maintaining a constant check on grade and could properly slope the fill area to provide adequate drainage in case of rain. On operations without a spotter in the fill, it was observed that much time was wasted by the scraper operators trying to guess where to dump; there also appeared to be a general congestion of equipment in the fill area.

Turning

Typically, scrapers must negotiate a change in direction at the two extreme points on their traveled route. A scraper entering the cut must turn either prior to or after loading to be in proper position for traveling to the fill area. Similarly, upon reaching the fill it must again turn before or after dumping to be oriented for the return to the cut. It is also quite possible for the scraper to operate by any number of variations, such as turning partially in the cut, loading, and then completing its turn. Configurations actually used on an operation may vary according to the preferences of the contractor or his operators and to the physical characteristics of the project itself.

Occasionally, there was no distinct isolated turn element apparent in the cycle. Changes in direction might have been incorporated directly into the loading or dumping cycle elements. When such cases arose on the operations studied, turn times were recorded as having zero duration; these were later eliminated from the analysis of data, so the graphs shown represent only those cycles in which there was a distinct turn element.

Figure 7 shows the cumulative distribution of observed turn times in the cut. This curve includes all types and sizes of scrapers studied, as it was determined by analysis of the data collected that the variations in these two factors had little effect on turn times. The overall average turn time in the cut was 0.30 minutes. The standard deviation--a measure of how widely individual times were dispersed about the mean--was 0.12 minutes.

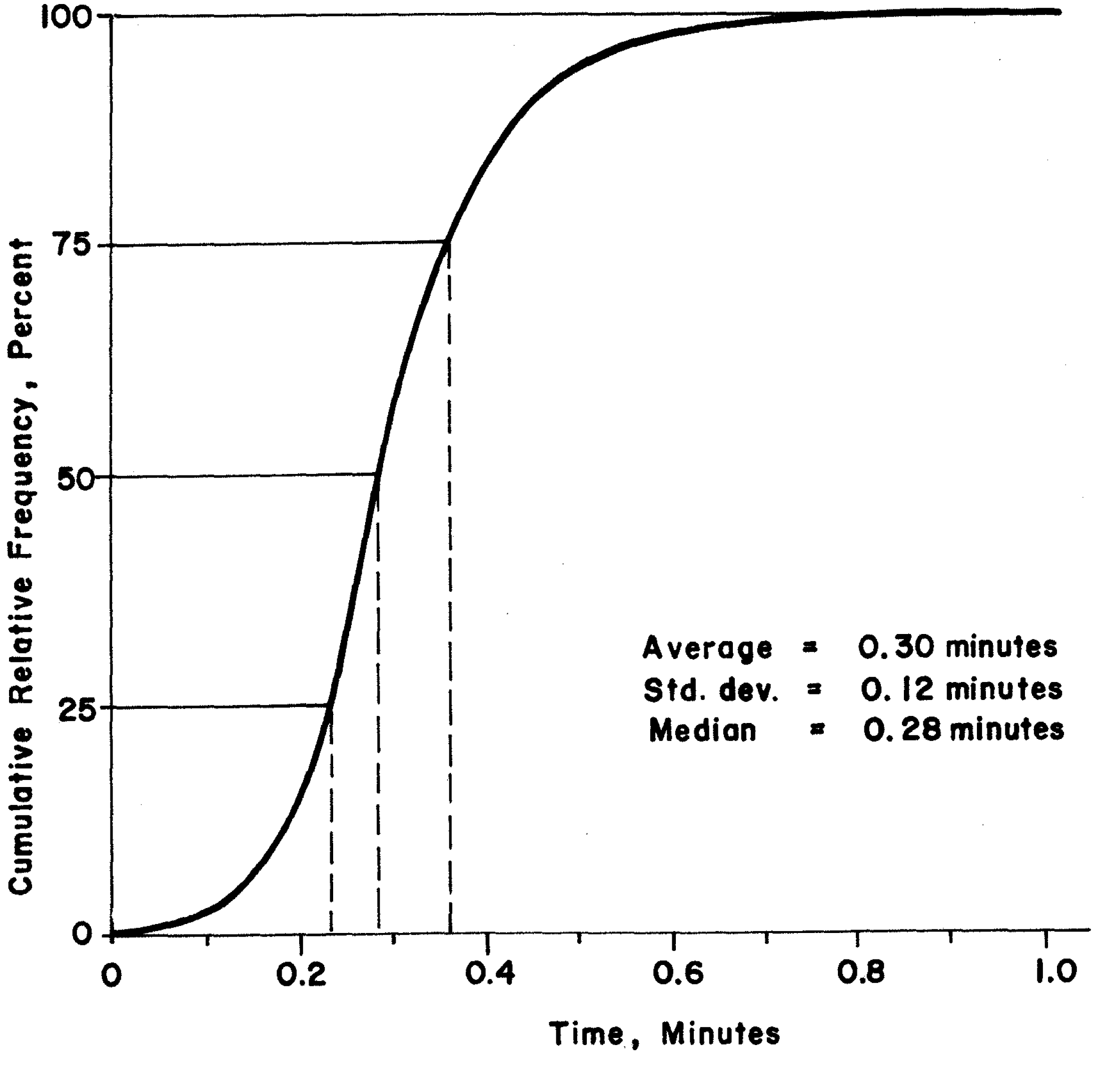

Figure 7. Cumulative Distribution of Turn Times in the Cut

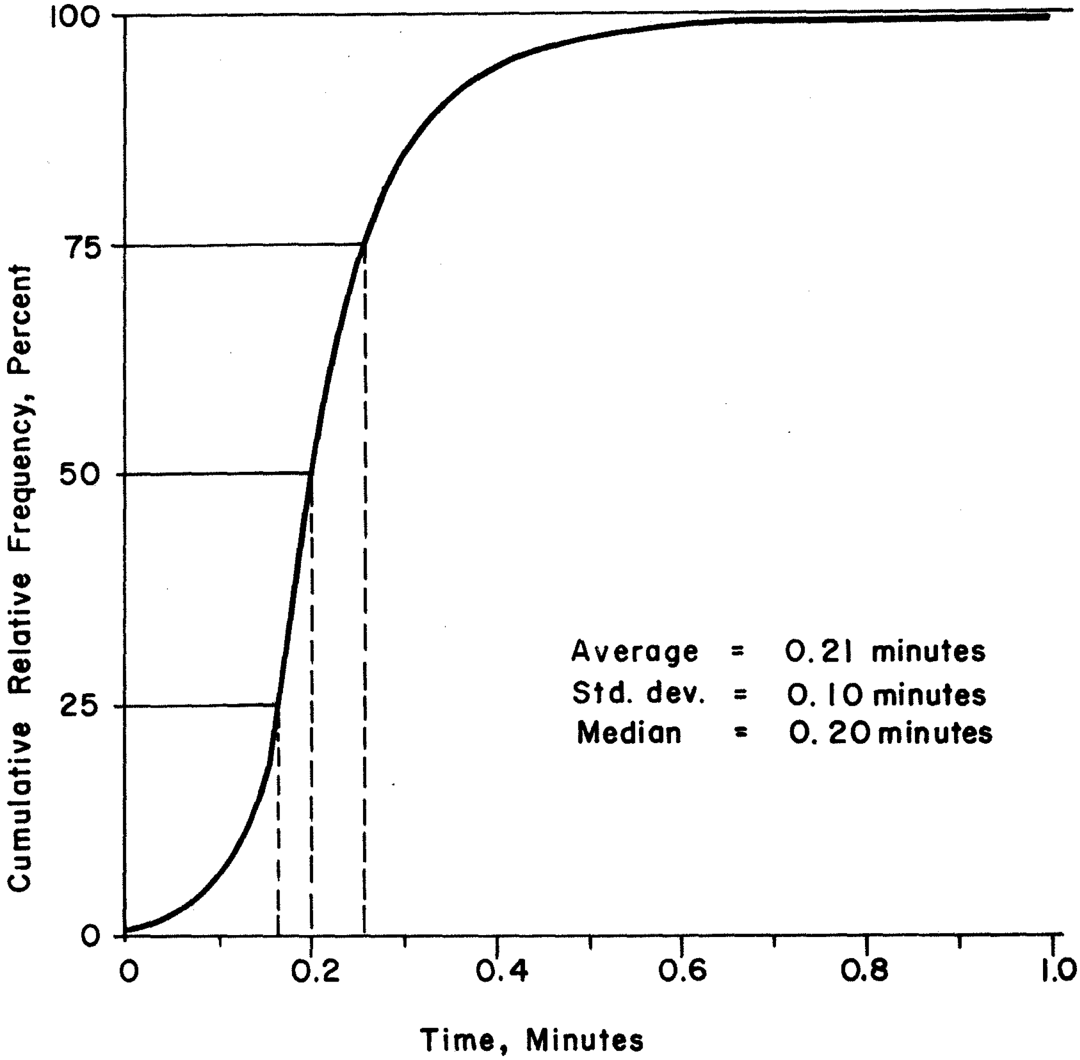

Figure 8. Cumulative Distribution of Turn Times in the Fill

Similarly, Figure 8 shows the cumulative distribution for turn times in the fill. The average was found to be 0.21 minutes with a standard deviation of 0.10 minutes.

It is not unusual to find this difference between the averages of the respective times. Field observations noted that the congestion of traffic which usually existed in the cut area, along with the necessity of spotting the scrapers carefully for loading, normally required that the scraper operators slow their machines considerably before commencing their turn. Conversely, the loose, uncompacted state of the material in the fill and the desire for a uniform spread of dumped material required operators to attempt to maintain a fairly high rate of speed while dumping. This speed was carried into the turn element, and machines were able to complete their turns much more rapidly.

Special attention should be drawn to the fact that the above distributions represent the results of studies made under many different field conditions. The actual times observed on a particular project may vary. A highly efficient operation might, for example, result in turn averaging faster than the overall mean, perhaps at the 25th percentile or lower. Conversely, a contractor might find his operation is averaging times higher than the mean, for example the 75th percentile. Nevertheless, the rather steep slopes of the curves in the region around the means would indicate that average field times would not vary greatly from the observed averages.

Traveling

Two of the most significant elements of the total productive cycle in determining the total productive cycle time are the haul and return elements. Unfortunately, they are also the elements which are subject to the most variation from project-to-project and even from cycle-to-cycle on the same project. As haul lengths increase, haul and return times comprise a larger portion of the total cycle; thus, the need to accurately predict haul and return and to exercise careful supervision and control over the many factors affecting these times becomes more important with increasing distances between the cut and fill areas.

Haul and return have previously been defined as two separate elements in the scraper productive cycle; they were, in fact, recorded as such in the field studies. However, in predicting travel times, a contractor will normally be reasonably sure of only the length of haul and not necessarily that of return.

Return distances, while typically approximating haul distances, vary somewhat according to the sequences of loading, dumping, and turning followed. To illustrate, should a scraper turn before loading and after dumping, the return distance will be greater than the haul distance. This case is shown in Figure 9a. Or, should the scraper turn after loading and before dumping, the return distance will be shorter, as shown in Figure 9b. Methods employed on a project may vary from time-to-time according to many factors, thus opening the return length to some degree of unpredictability. In addition, it is quite possible that a scraper will not follow the same road on the return that it did on the haul. Figure 10 shows the distribution established for the difference between return lengths and haul lengths. While, on the average, the return length exceeded the haul length by 400 feet, the variation possible from job-to-job may be difficult to predict.

As previously pointed out, for the purposes of this report haul time and return time were combined into one "travel time." Figures 11 through 21 have been prepared to show that the combined time of haul plus return can be estimated by knowing the one-way haul distance from the cut to the fill. The shaded portion of the curves indicates the range of haul lengths for which data was actually available. However, on the basis of the data collected, these curves could reasonably be extrapolated beyond this range in order to provide some basis for determining travel times for other haul lengths. The dashed portion of the curves represents this zone of extrapolation.

The left-hand portions of the graphs exhibit a nonlinear relationship between times for different haul lengths of comparatively short hauls. This is attributed to the distance required for the scraper to accelerate to and decelerate from its maximum travel speed. As the haul length increases, the curve becomes flatter until eventually the scraper reaches a maximum speed and begins to travel at a constant rate. Beyond this point any additional increases in haul length result in a corresponding linear increase in travel time.

Travel times were logically dependent upon several isolated variables--type and size of scraper and the net grade and condition of the haul road. Scraper types 3 and 4 were included in the same category because their basic design configurations were identical; there was no reason to suspect significantly different performance on the haul and return elements. Since all the possible combinations of variables were not encountered in the course of the studies, several "gaps" appear in the number of curves provided.

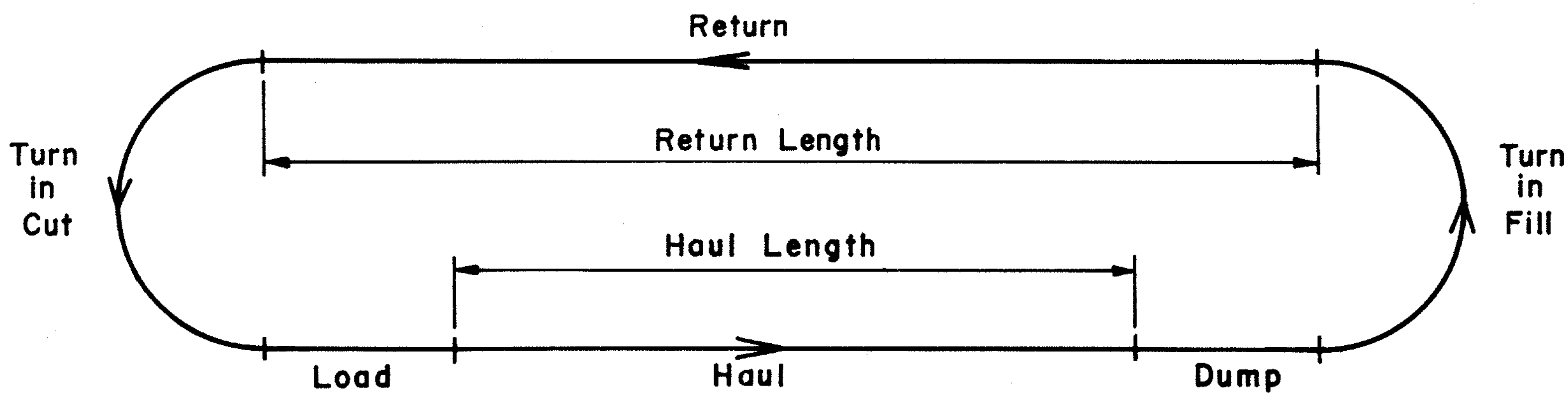

Figure 9a. Case I: Return Length > Haul Length

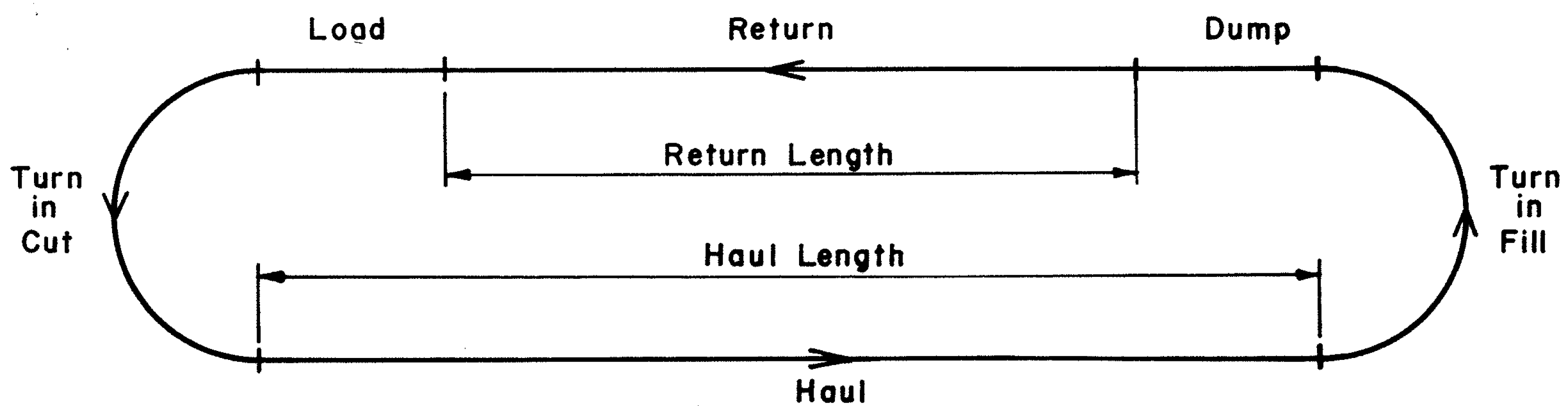

Figure 9b. Case II: Return Length < Haul Length

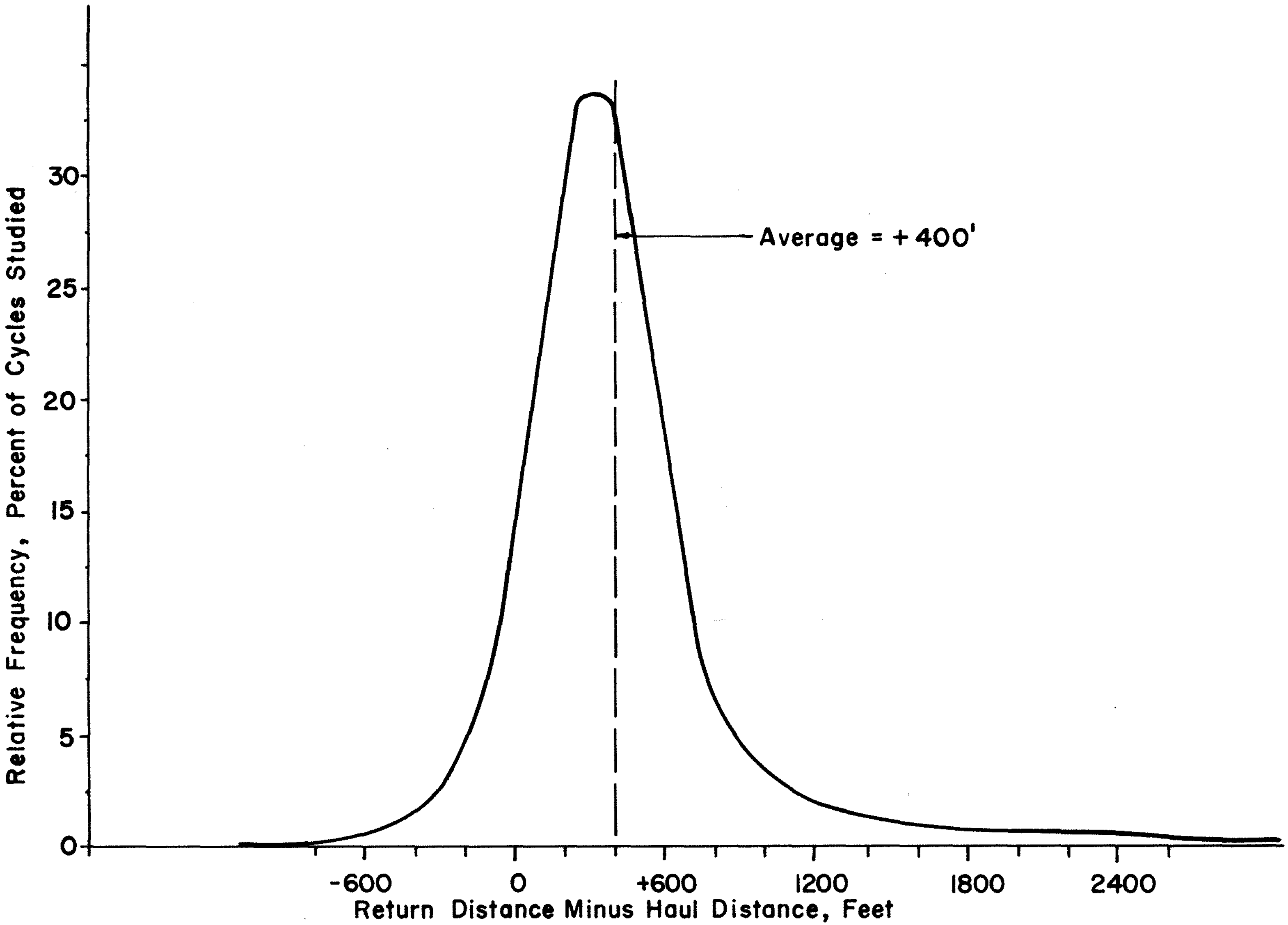

Figure 10. Relationship Between Haul Distance and Return Distance

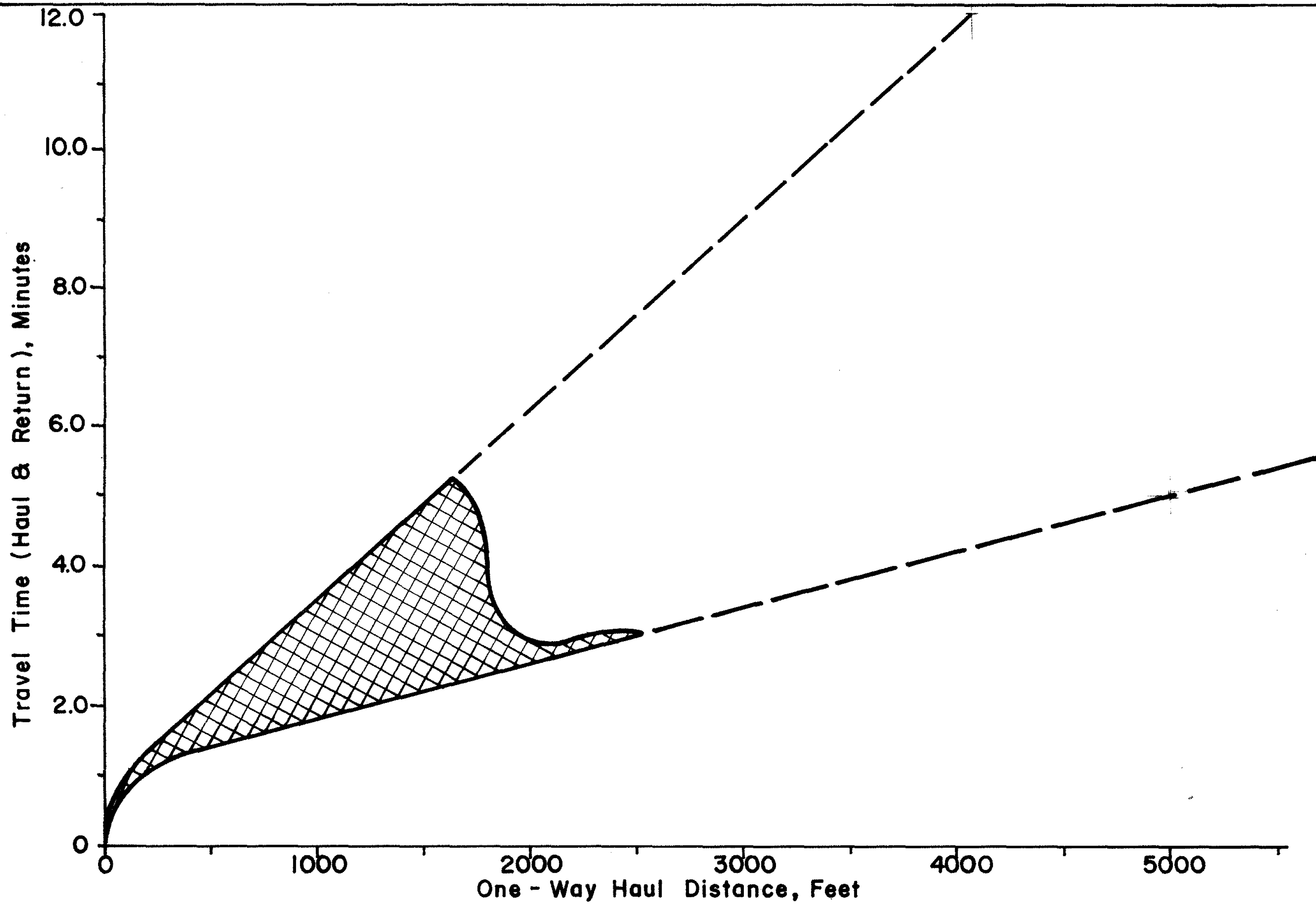

Figure 11. Travel Times (Type I Scrapers, Capacity < 25 CY, Favorable Grade)

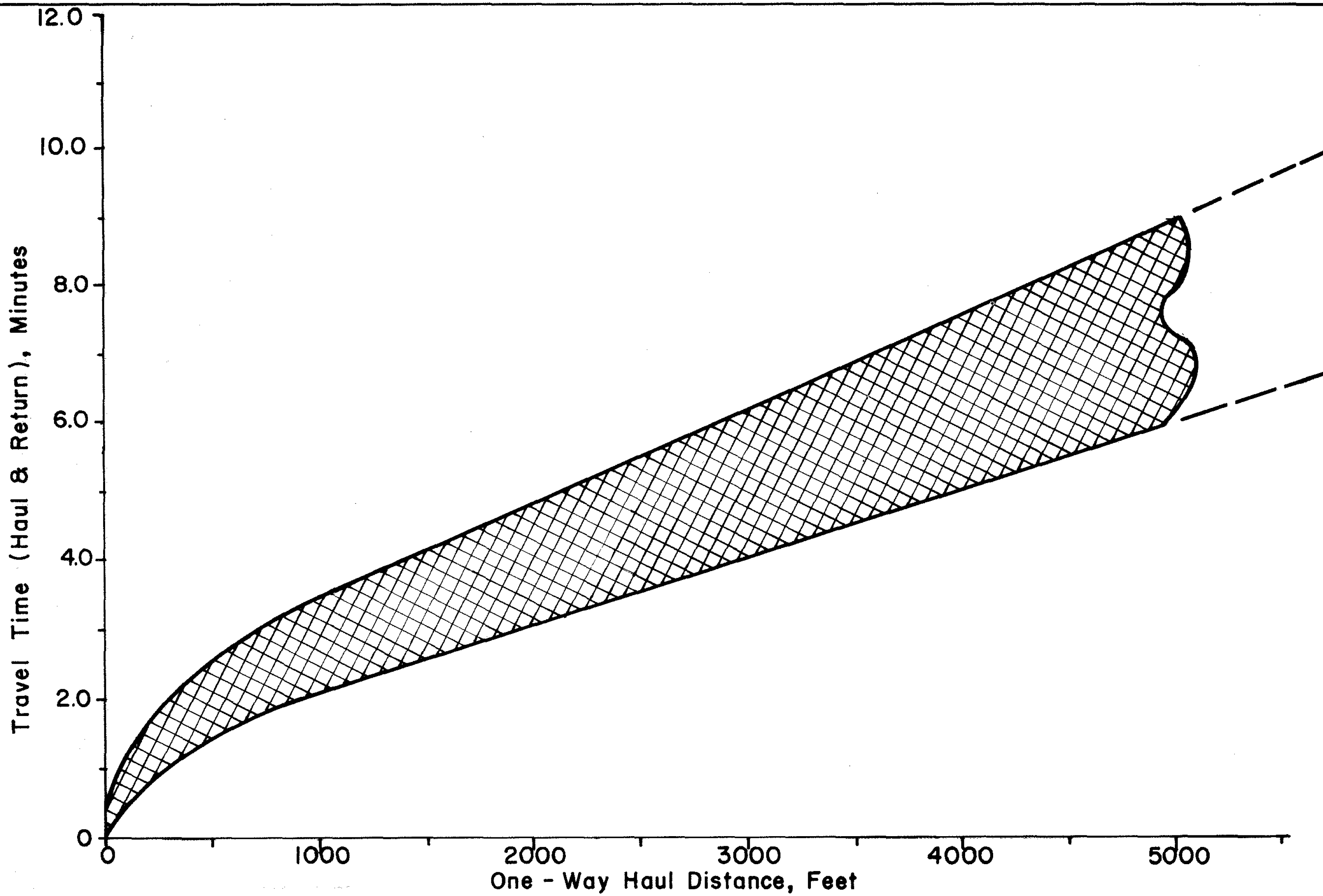

Figure 12. Travel Times (Type I Scrapers, Capacity < 25CY, Negligible Grade)

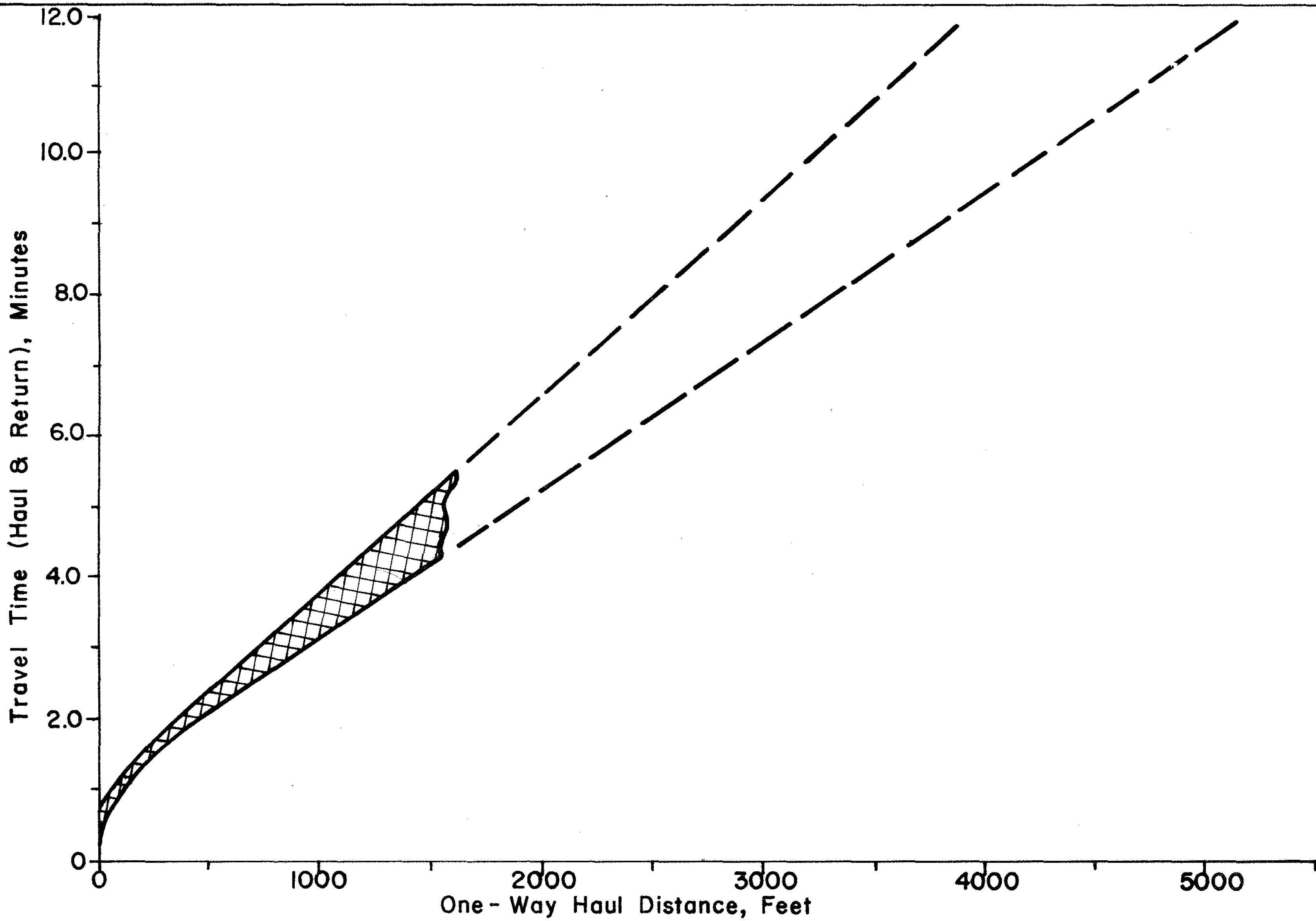

Figure 13. Travel Times (Type I Scrapers, 25 CY ≤ Capacity < 35 CY, Favorable Grade)

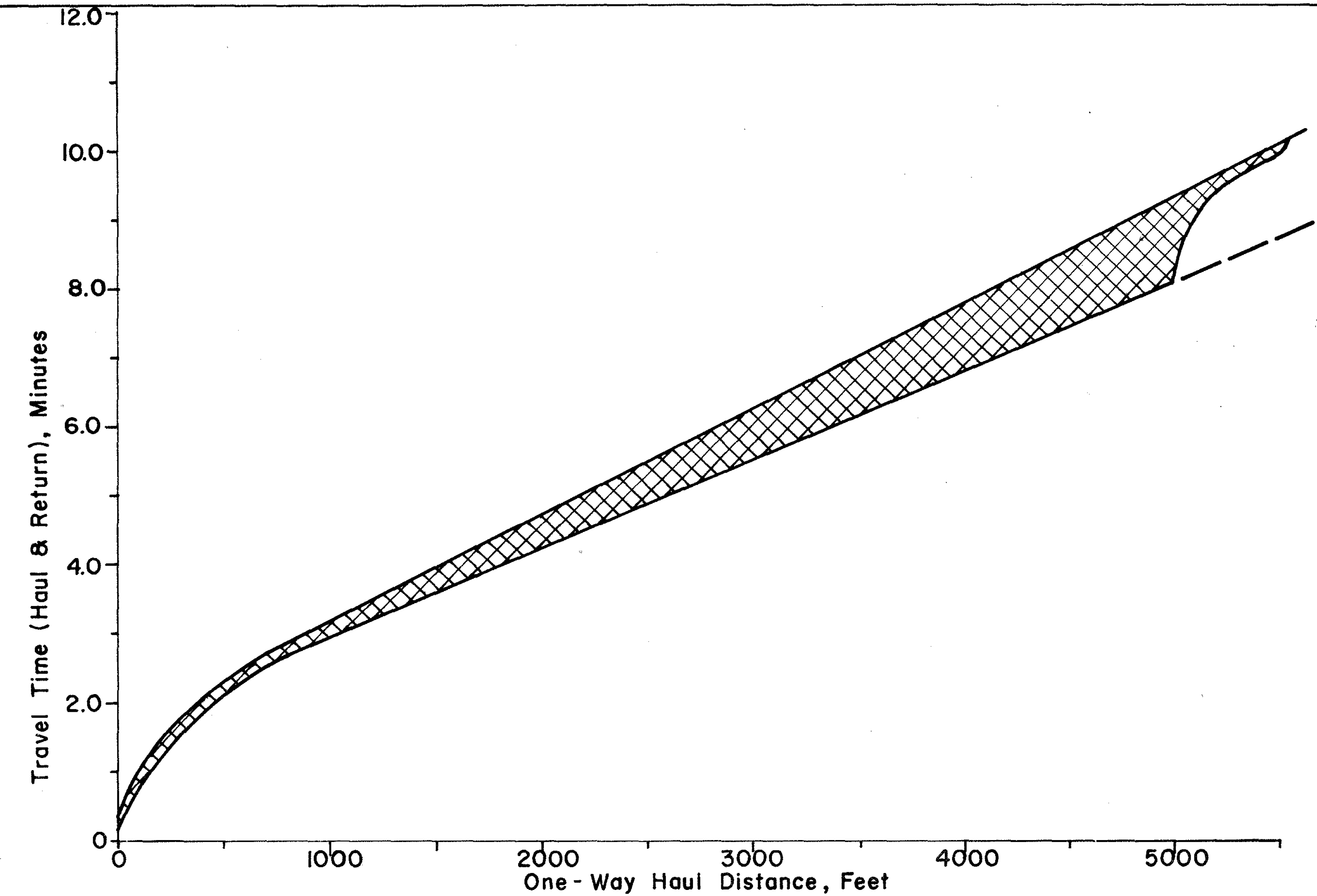

Figure 14. Travel Times (Type I Scrapers, 25 CY ≤ Capacity < 35 CY, Negligible Grade)

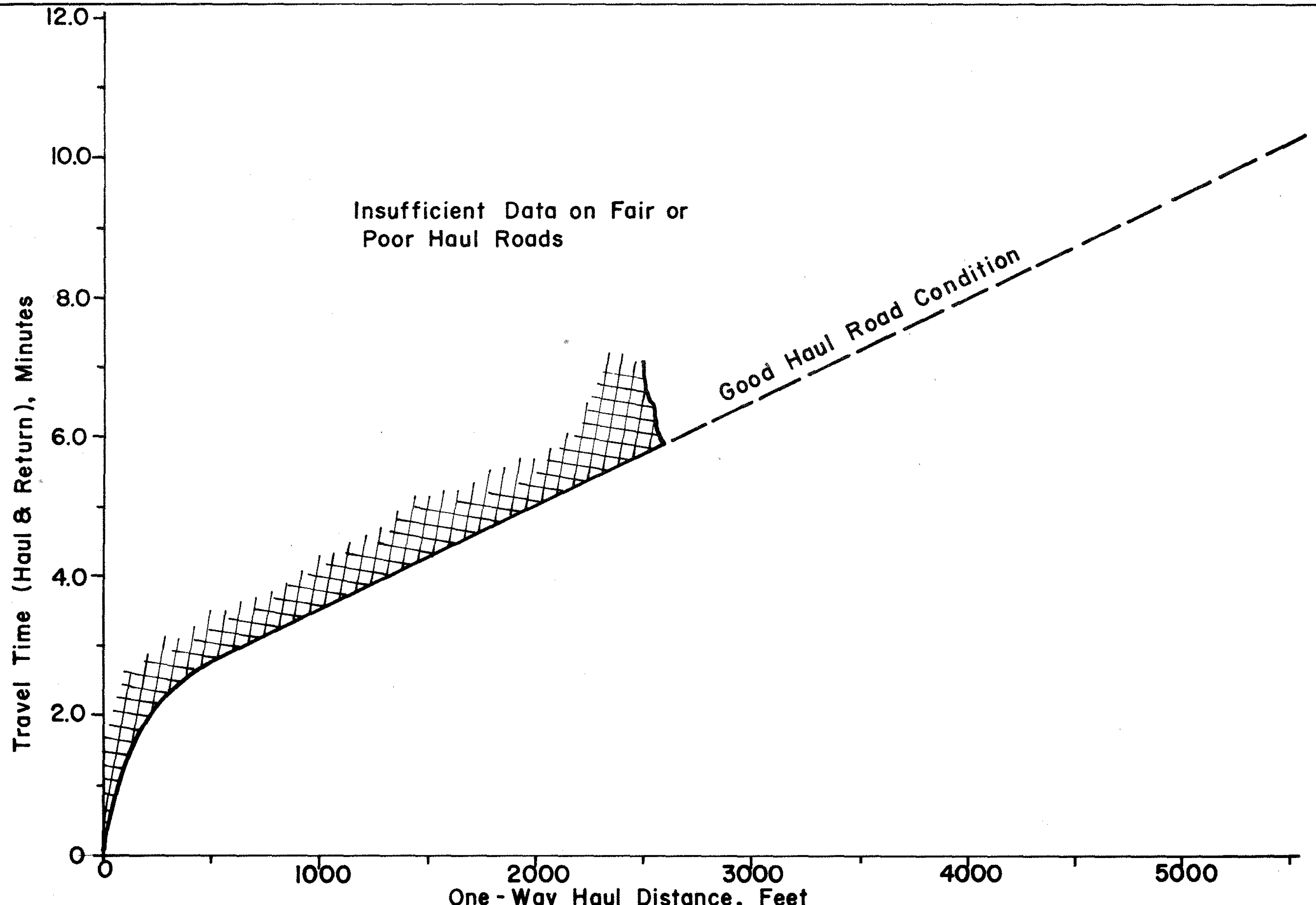

Figure 15. Travel Times (Type I Scrapers, 25 CY ≤ Capacity < 35 CY, Unfavorable Grade)

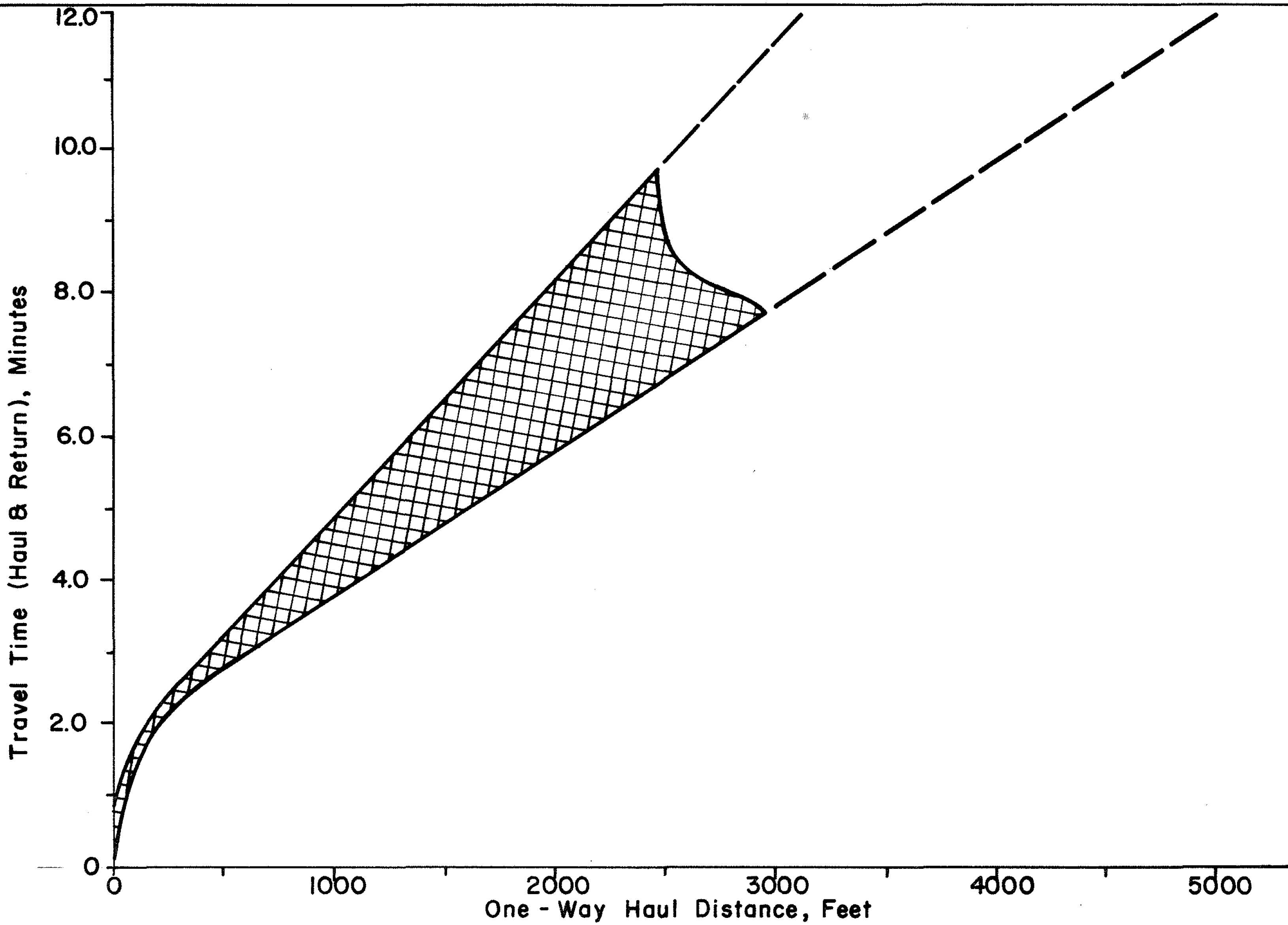

Figure 16. Travel Times (Type I Scrapers, 35 CY ≤ Capacity < 45 CY, Favorable Grade)

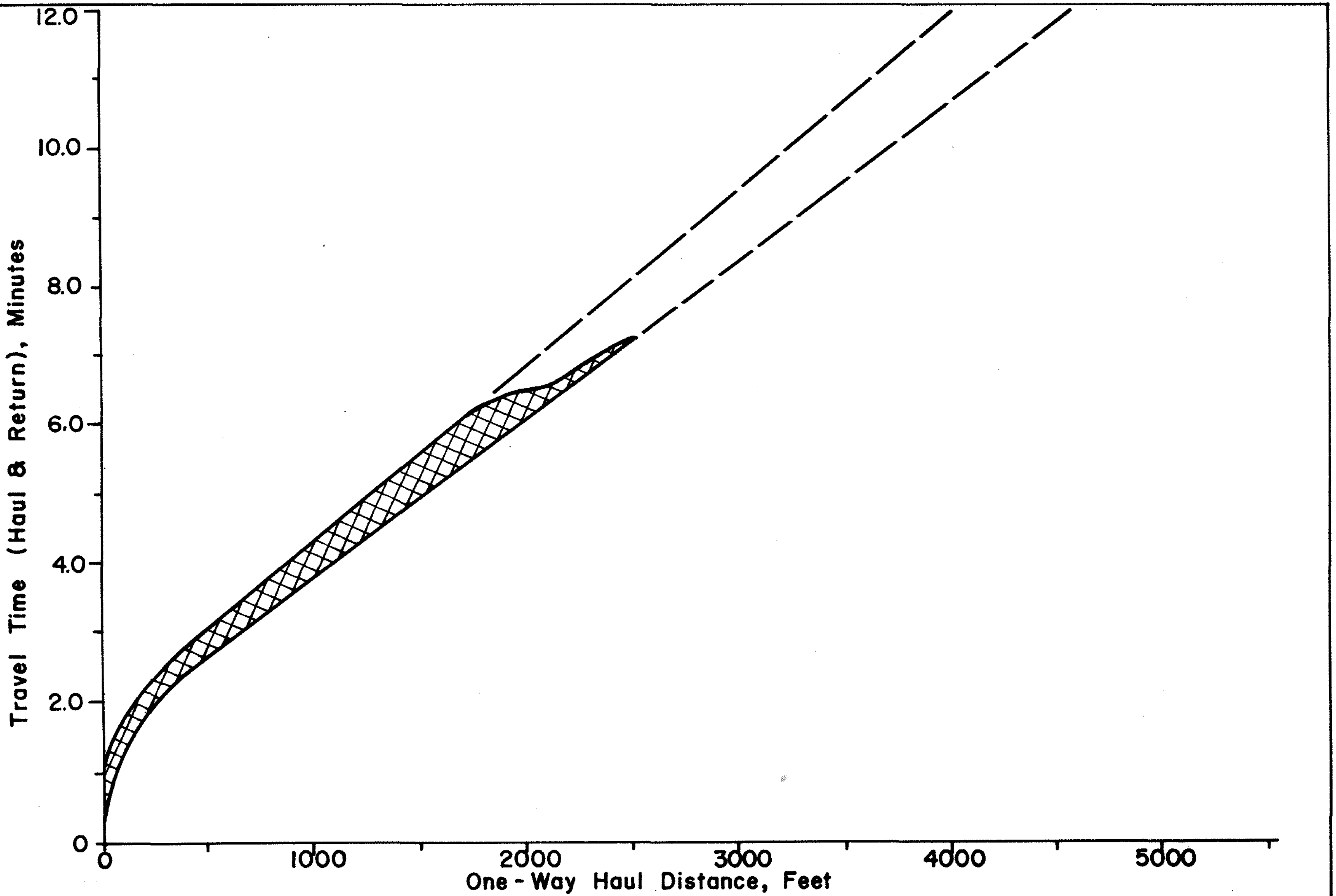

Figure 17. Travel Times (Type I Scrapers, 35 CY ≤ Capacity < 45 CY, Negligible Grade)

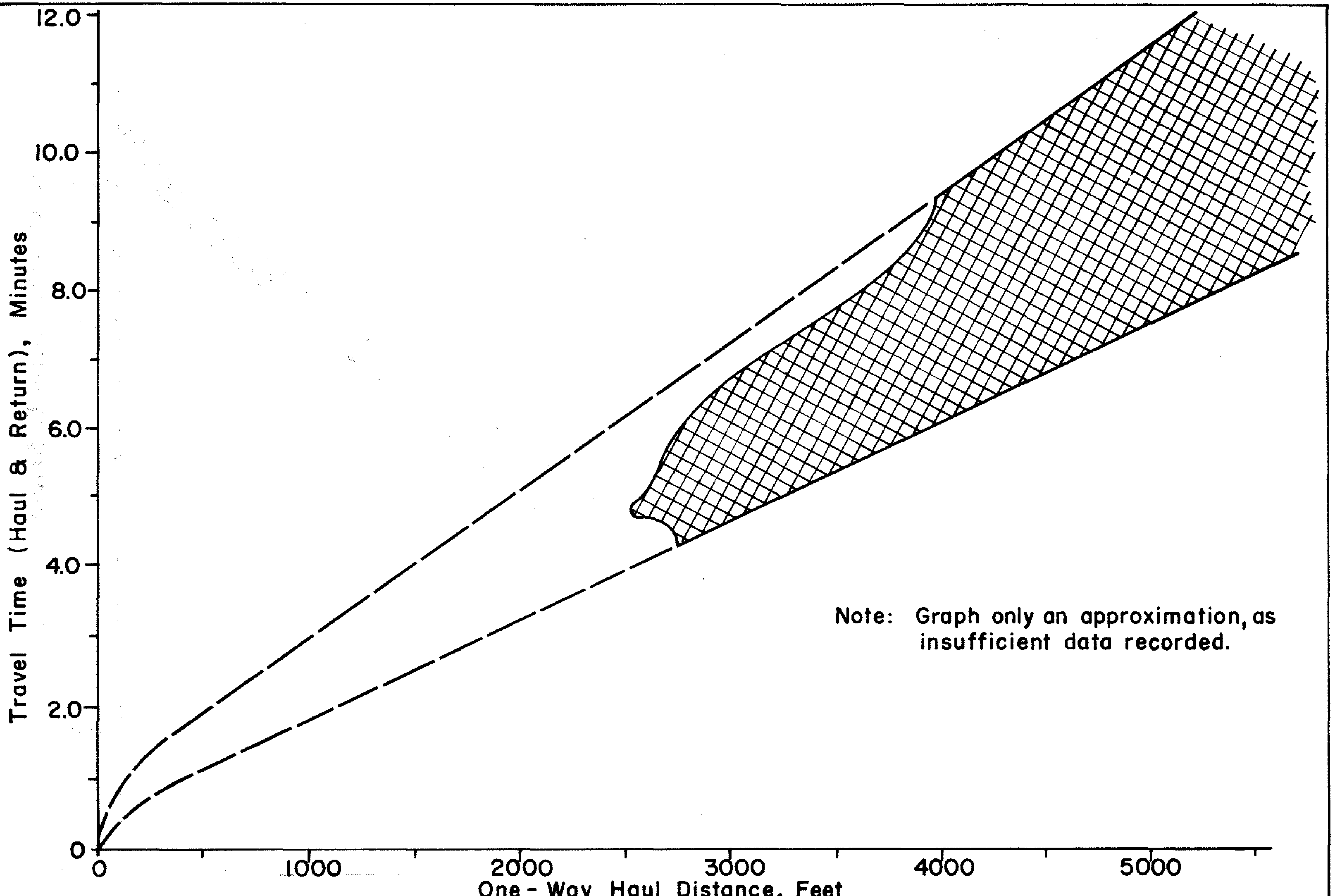

Figure 18. Travel Times (Type 2 Scrapers, 25 CY ≤ Capacity < 35 CY, Negligible Grade)

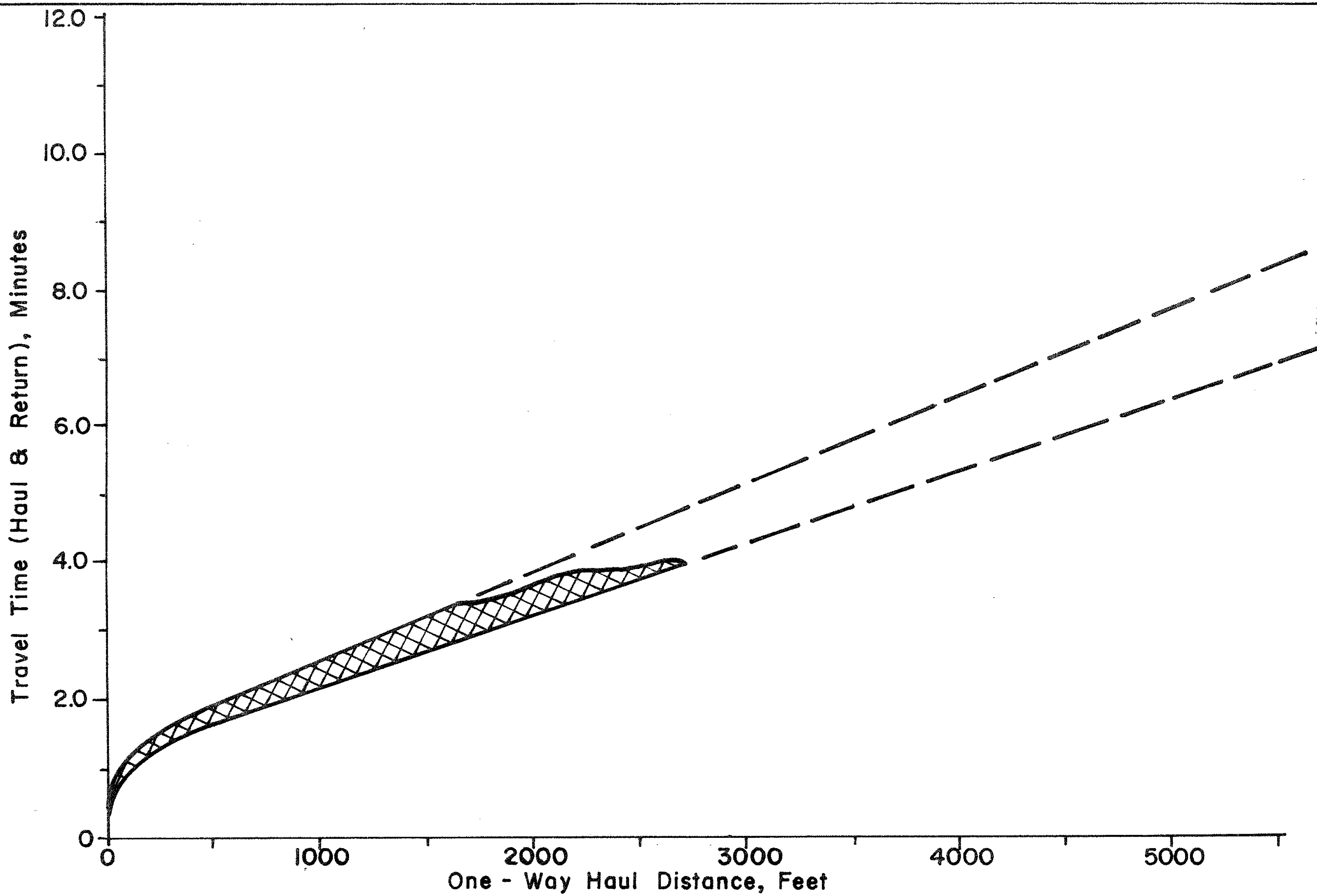

Figure 19. Travel Times (Types 3 and 4, 35 CY ≤ Capacity < 45 CY, Favorable Grade)

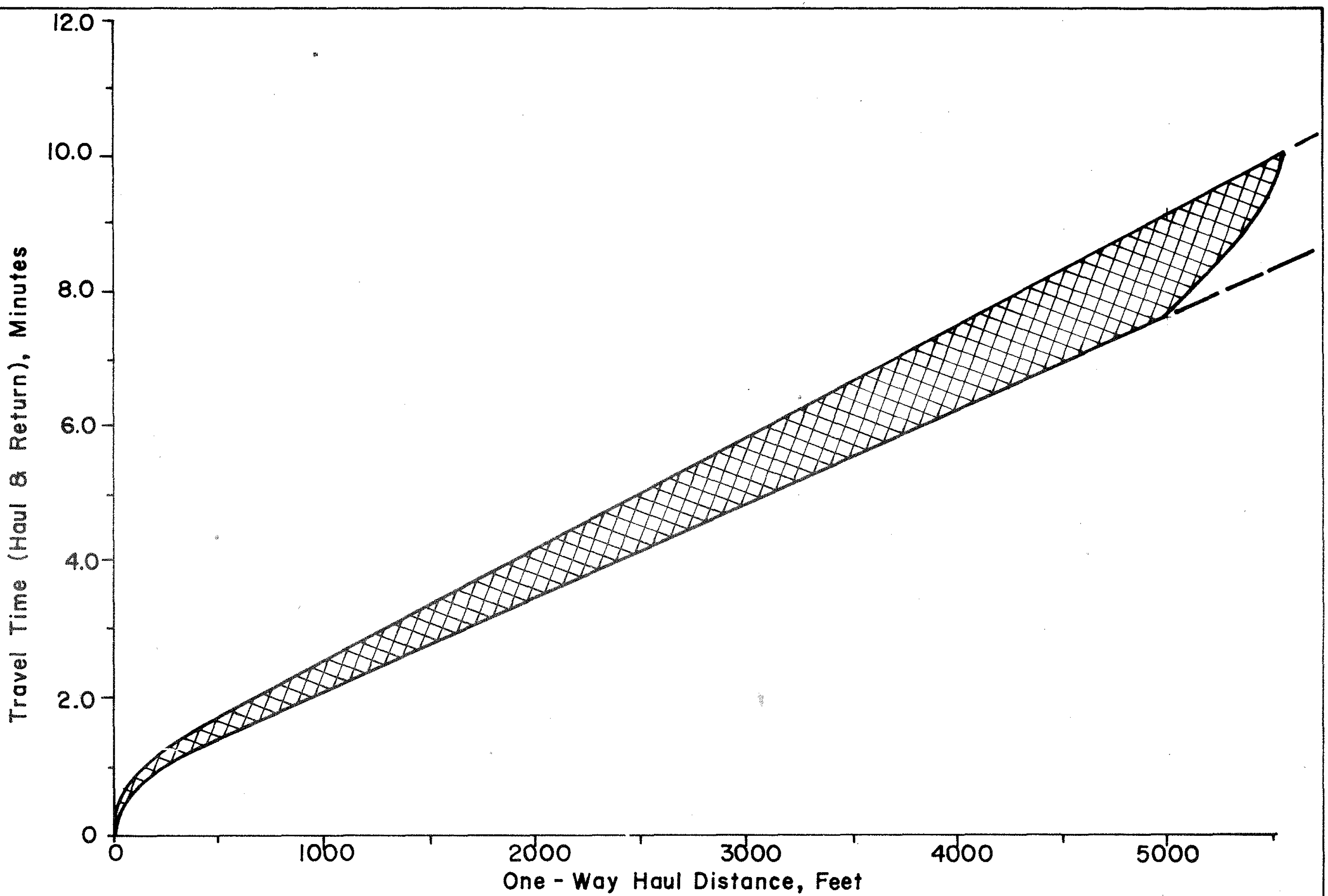

Figure 20. Travel Times (Types 3 and 4, 35 CY ≤ Capacity < 45 CY, Negligible Grade)

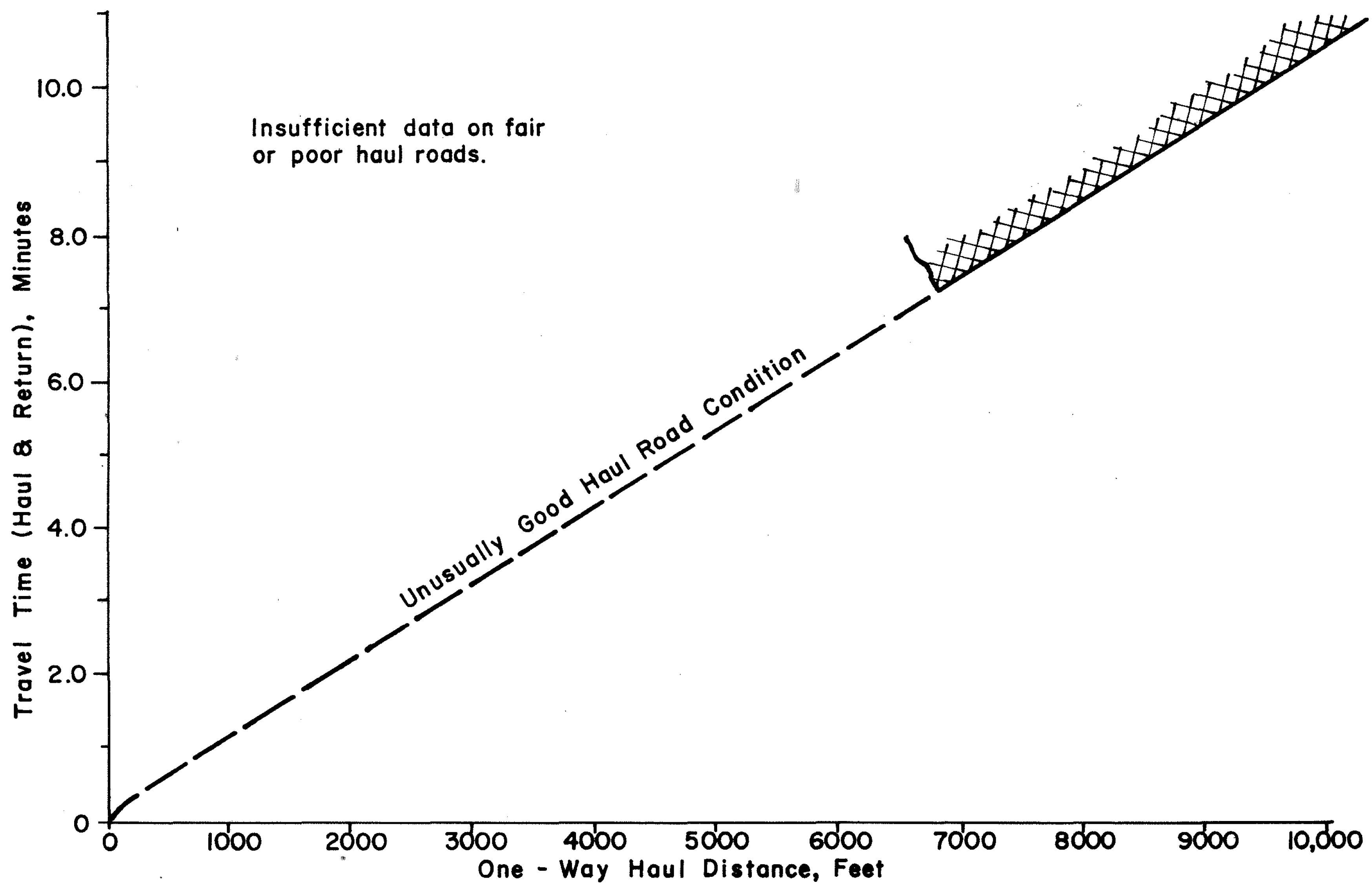

Figure 21. Travel Times (Types 3 and 4, Capacity ≥ 45 CY, Negligible Grade)

To demonstrate the use of Figures 11 through 21, let us assume we are confronted with the following situation:

> A contractor using standard, push-loaded scrapers with a heaped capacity of 20 cubic yards (15 cubic metres) wishes to determine an average travel time given a haul length, i.e., the one-way distance from the cut to the fill, of approximately 4000 feet (1219 metres). From profiles of the project, he knows that the net grade of the haul road will be negligible.

To determine his travel time, he would first turn to Figure 12 (type 1 scrapers, capacity less than 25 cubic yards, negligible grade). The shaded area shown represents the range of average travel times of typical projects, with the lower boundary indicating times taken under better haul road conditions and the upper boundary indicating those of poorer conditions. Entering the horizontal axis with the haul distance of 4000 feet, the total time for the haul and return elements combined can be read from the vertical axis. For example, should the contractor assume that the haul road will be firm, dry and well-maintained, i.e., "Good," the average travel time would be 5.20 minutes. Or, should the haul road generally be in a somewhat poorer condition, the average travel time for the same haul length could increase to as much as 7.55 minutes. It is left to the individual to decide upon a "best" estimate between the two extremes based on his knowledge of what the actual haul road conditions will be.

It should be noted that Figure 21 indicates rather low travel times for a scraper of this particular type and size. This was the result of an unusually good condition of the haul road; in fact, haul roads encountered on this operation were by far the best maintained of any operation studied. Conditions for this curve might well be considered "excellent" rather than merely good. It was necessary to have such good haul conditions in order to maintain an economical production rate on this particular project. Figure 21 should not be considered to be a typical travel time curve for this type and size of scraper.

Previously it was mentioned that several factors can affect the actual performance achieved on a particular operation. These more "intangible" factors involve the planning and management of the job more than the actual physical conditions encountered--a situation which is very difficult to quantify. The ratio of scrapers to pushers (discussed later in further detail) appears to significantly influence travel times. When there were too many scrapers for the pusher(s) to handle efficiently, the scrapers tended to "bunch up" in the cut, with several waiting simultaneously to be loaded. Scraper operators, upon seeing this situation, seemed to reduce speeds; apparently there is a psychological tendency to travel at lower speeds rather than wait idly, even though neither action will affect the production rate (it is recognized, however, that an advantage of traveling slower would be to reduce wear on the equipment.) Conversely, for an ample number of pushers, operators tended to "race" their machines at higher than normal speeds. This may lead to increased production but at the same time may increase equipment wear and expose the operation to greater danger of accidents. The same situation is true, although to a somewhat lesser extent, in the event of mismatching scrapers and compaction equipment in the embankment areas.

The configuration of the haul roads also had a marked influence on travel times. In many cases, sections of a haul road were too narrow to allow hauling and returning units to pass one another without slowing appreciably. In fact, some haul roads were limited (in some sections) to one-way travel only; the empty returning scrapers usually yielded the right-of-way to the loaded scrapers. Areas where haul roads intersected with roads used by public or contractor traffic often caused operators to be cautious and reduce speed. Time lost in decelerating and accelerating for the above cases cost the scraper in longer travel times.

Extremely steep downgrades, while categorized as being favorable, often resulted in longer travel times, as operators had to downshift to keep speeds from being excessive.

Job supervision also influenced travel times. On jobs where there was minimum supervision or where production rates were not considered critical, operators worked more at their own pace; sometimes this meant lower speeds, longer travel times, and less production. Conversely, when earthmoving was a more critical activity, scrapers appeared to perform closer to maximum efficiency.

Wait for Pusher

Wait for pusher has been defined as the time during which a scraper is in position in the cut to begin loading but must remain idle while waiting for a pusher to assist. Although this is actually unproductive delay time, some wait time is inherent in most scraper cycles, if only because of the time required by the pusher to maneuver into position to begin its assist. For this reason, this element has been included in our discussion of productive cycle elements. In practice, one should not consider wait for pusher when computing the scraper productive cycle. Wait times are included in TWTS under the category of minor delays.

A scraper may have to wait for a pusher for any of several other reasons as well. The pusher may be engaged in assisting other scrapers to load. The use of pushers to perform other tasks such as ripping, maintenance of the cut area or haul road, or moving boulders could cause additional wait time. While waiting for the pusher, scraper operators typically either sat idly or performed incidental activities such as receiving instructions, inspecting his machine, drinking water, etc. Regardless, this delay was noted as an interruption of the productive use of the scraper.

One of the most important decisions confronting the contractor is selection of the proper scraper-pusher fleet to minimize the overall costs of this idle wait time. Logically, a single pusher is less expensive to operate than two units, but if the number of scrapers served by this one pusher is too large, the scrapers will spend an inordinately amount of time waiting in a queue for the pusher. Conversely, a pusher for each scraper would theoretically result in a minimum wait time for the scrapers, but the costs for the pushers waiting idly for a scraper might again be prohibitive. The problem then is to balance the ratio of scrapers to pushers to achieve minimum cost for the total system.

Figures 22 and 23 show the average wait for pusher time as a function of the scraper total productive cycle time.

The number of pushers used was actually defined as the number of independent pusher teams, i.e., two pushers operating independently in assisting scrapers would be considered as two separate teams. If, however, the two were used in tandem to assist a single scraper, they were considered as being one single pusher team.

From the curves shown in these two figures, it can be seen that average wait times tend to approach a minimum as productive cycle times increase. As mentioned previously, some time was consumed by the pusher in maneuvering into position behind the scraper; additionally, pushers often were used to perform other functions such as trimming cut slopes, ripping material, etc., which also resulted in some additional wait time. Scrapers also contributed to this wait time by their tendency to travel in groups rather than be spaced evenly throughout the cycle. Several scrapers often arrived almost simultaneously at the cut, causing a wait queue to form. Thus, it is obvious that a certain minimum amount of wait time can never be eliminated in any field operation. The use of Figures 22 and 23 as an aid to fleet selection will be discussed in Appendix B.

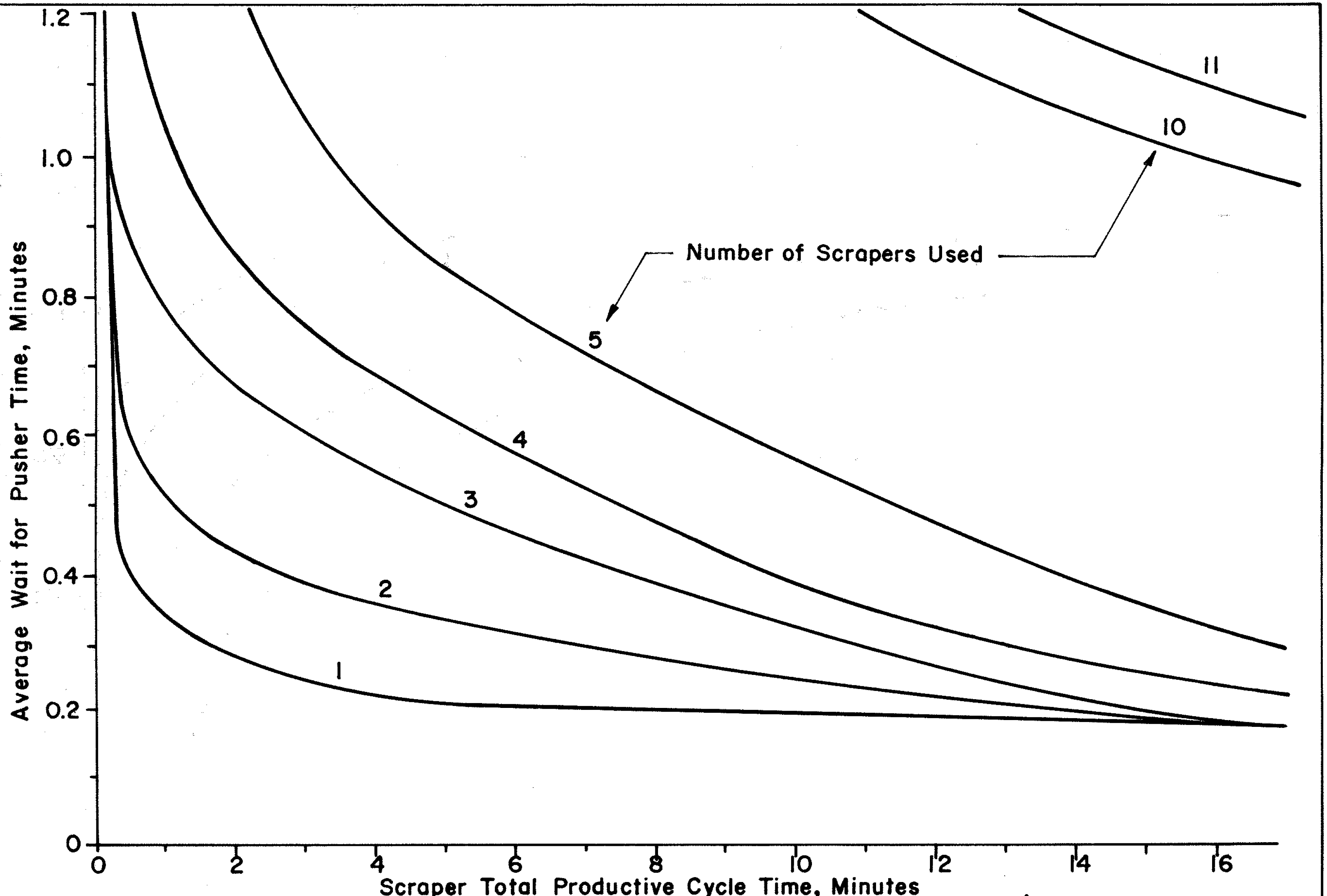

Figure 22. Relationship of Wait Time to Scraper Productive Cycle (One Pusher)

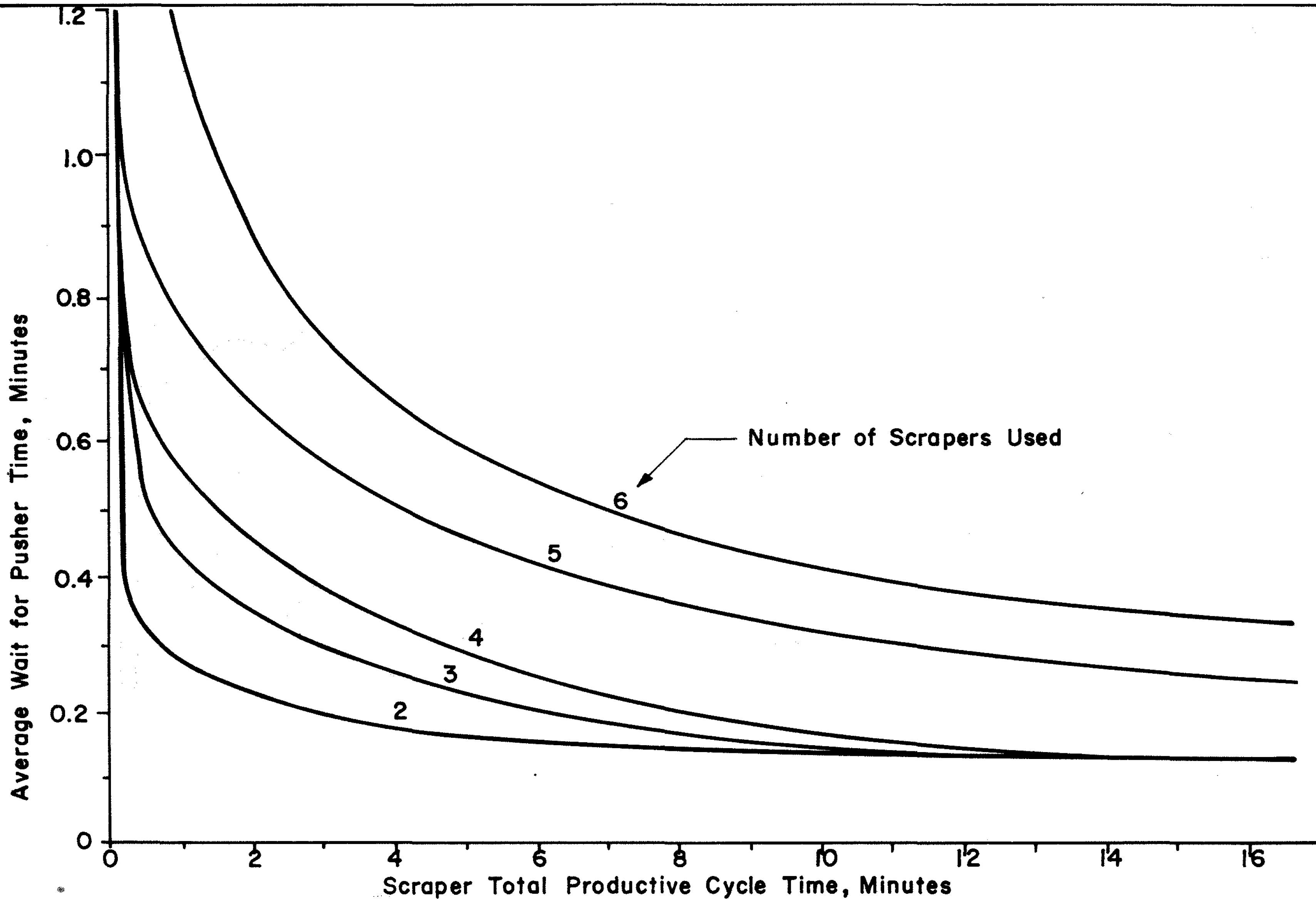

Figure 23. Relationship of Wait Time to Scraper Productive Cycle (Two Pushers Used Independently)

VI. ANALYSIS OF DELAYS

Delays are an inherent part of any major earthmoving operation. They are to be expected to a certain degree and must be taken into consideration when determining production rates. The delays recorded during these studies were classified as either major or minor delays depending on their duration. To facilitate the analysis of scraper delays, they were categorized into one of the following classes:

1. Delays Peculiar to the Operation--maneuvering into position; stuck while loading or dumping; trimming, finishing or cleanup work.

2. Maintenance--refueling, greasing and oiling of scraper units; maintenance of pusher, spreading and/or compacting equipment.

3. Repairs--repairs to scraper power takeoff control unit, motor, transmission, or control system; repairs to pusher, spreading and/or compacting equipment.

4. Inefficiencies--inefficiencies involving scraper operators, pusher operators, grading or dump foreman, or any other supervisory personnel.

5. Correlated Operations--waiting for spreading equipment, scarifying, or ripping; start late-quite early delays.

6. Physical--rock or field stone requiring special attention; physical obstructions; poor or impassable haul road; blasting.

7. Traffic--public and contractor-owned traffic; improving haul road; major moves within limits of project.

8. Miscellaneous Delays--changing operators; personal delays (illness, drink of water, etc.); supervisory instructions; labor shortages.

Major Delays

Major delays, as previously defined, were classified as those delays which were 15 minutes or more in duration. In Section IV, it was pointed out that major delays accounted for approximately 18 percent of scraper TWTS.

Major delays did not occur with any measure of consistency. They usually varied in frequency and duration on a project-to-project basis. Table 5 shows the breakdown of major delays as they occurred on the eleven studied projects. This table is presented for informational purposes only. A contractor might obtain a totally different distribution of major delays on his projects, as major delays are not normally consistent or predictable. The data in Table 5 is separated according to the type of scraper and includes a column containing the averages of all scraper types combined.

As can be seen from Table 5, repairs were by far the most time-consuming and frequently occurring type of major delay; they accounted for 67 percent of the total major delay time. The extent of repair time on each scraper was largely affected by the condition of the machine. Typically, the older the machine, the worse the condition and the greater the amount of repair time required.

Shutdown delays, delays where the work force was dismissed or transferred to another operation, accounted for approximately 75 percent of all major delays.

Minor Delays

Minor delays were classified as those delays which were less than 15 minutes in duration. In Section IV, it was pointed out that minor delays (excluding wait for pusher delays) accounted for approximately 7 percent of TWTS and 8 percent of NWTS. Unlike major delays, minor delays occurred with some measure of consistency. Even though they were normally quite short in duration, they did occur often enough to have a significant effect on the productivity of the scraper operations. It should be noted at this point that elimination of all minor delays on a given project would be virtually impossible. The contractor can only attempt to reduce their frequency and duration to a practical minimum.

Table 6 shows the breakdown of minor delays for each type of scraper as a percent of the minor delay time and as a percent of the total number of occurrences.

Note that wait for pusher delays, although classed as minor delays, were not included in this table since they were analyzed in detail in Section V.

Table 5. Breakdown of Scraper Major Delays

Delay Category	Standard		Elevating		Push-Pull		Tandem		Total	
	% Major Delay Time	% Major Delay Occur.	% Major Delay Time	% Major Delay Occur.	% Major Delay Time	% Major Delay Occur.	% Major Delay Time	% Major Delay Occur.	% Major Delay Time	% Major Delay Occur.
Repairs	67	40	12	13	65	37	74	48	67	28
Miscellaneous	11	8	44	13	–	–	16	11	14	36
Correlated Oper.	10	24	31	40	12	18	5	18	9	16
Maintenance	7	13	–	–	17	27	2	8	6	8
Traffic	3	8	13	34	–	–	1	5	3	6
Delays Peculiar to the Operation	1	5	–	–	–	–	1	7	1	4
Physical	1	1	–	–	6	18	0	1	0	1
Inefficiencies	0	1	–	–	–	–	1	2	0	1
TOTAL:	100	100	100	100	100	100	100	100	100	100

"Correlated Operations," while not the most frequently occurring type of minor delay, accounted for a large portion of the minor delay time. Among the most significant minor delay types was the "start late-quit early" delay, consuming approximately 25 percent of the total minor delay time. The "start late-quit early" delay was defined as the extra time taken at the beginning and end of the work shift and after the lunch break. Minimizing this delay would have significantly increased productivity.

Personal delays, falling within the category "Miscellaneous Delays," were also a significant minor delay type. Many of these delays occurred when the scraper operators stopped to get a drink of water, clean the windshield, etc. Personal delays amounted to approximately 16 percent of the total minor delay time.

Another significant minor delay type was "Scraper Operator Inefficiencies," amounting to nearly 9 percent of the total minor delay time.

Start late-quit early delays, personal delays, and operator inefficiencies were examples of "avoidable delays," or delays which could have been prevented. For example, had the work shifts and lunch breaks been strictly adhered to, start late-quit early delays would have been greatly minimized. Many personal delays, such as stopping to get a drink of water, appeared unnecessary since the scraper operators could easily have been instructed to get a drink of water during the time in which they were waiting for the pusher.

Other minor delays were considered as "unavoidable delays." These were the ones which were bound to occur and thus were unpreventable. They also had a significant effect on the magnitude of the overall minor delay time. A typical example of an "unavoidable delay" was getting stuck while loading or dumping. Approximately 7 percent of the total minor delay time was consumed by this particular type of delay. Other unavoidable minor delays included delays caused by physical obstructions and minor repairs to the scrapers.

In order to maximize the efficiency of scraper operations, it is advisable to concentrate on eliminating or minimizing as many avoidable delays as possible. Among the reasons found to be the cause of such delays were:

1. Inadequate preplanning of a day's work.

2. Lack of project supervision.

3. Lack of adequate communications between supervisory personnel and scraper operators.

4. Use of unskilled and untrained scraper operators.

Table 6. Breakdown of Scraper Minor Delays

Delay Category	Standard		Elevating		Push-Pull		Tandem		Total	
	% Minor Delay Time	% Minor Delays Occur.	% Minor Delay Time	% Minor Delay Occur.	% Minor Delay Time	% Minor Delay Occur.	% Minor Delay Time	% Minor Delay Occur.	% Minor Delay Time	% Minor Delay Occur.
Correlated Opers.	24	8	28	7	22	7	36	20	26	10
Miscellaneous	20	18	32	26	41	32	21	28	21	20
Delays Peculiar to the Operation	19	38	10	25	4	5	12	15	17	34
Inefficiencies	12	14	10	14	15	31	10	19	12	15
Maintenance	10	3	2	3	15	8	9	5	10	3
Traffic	10	16	15	22	3	14	5	9	9	15
Repairs	3	1	1	2	0	2	6	3	3	1
Physical	2	2	2	1	0	1	1	1	2	2
TOTAL:	100	100	100	100	100	100	100	100	100	100

VII. PUSHER STUDY

To obtain maximum load sizes in minimum loading times, most scrapers require the assistance of one or more push tractors.

In order to economize scraper-pusher operations to the fullest extent, the number of pushers must be properly matched with the number of scrapers. To achieve this, in addition to the scraper cycle time, the pusher cycle time must be determined. As studies were conducted on scrapers to determine cycle times, sample studies were randomly taken on pushers throughout the projects and varied from a half-hour to an hour more in duration. Both single and tandem pusher combinations were studied.

The "Productive Cycle Time" for the pusher was considered to be the sum of the following cycle elements:

1. Push Time--Time from contact with the scraper until the scraper lifts its cutting edge.

2. Boost Time--Time during which scrapers were assisted out of the cut, from the end of push time until scraper-pusher contact ceased.

3. Reverse Time--Time consumed in moving from completion of boost on one scraper to beginning of contact maneuver or wait for the next scraper.

4. Contact Maneuver Time--Time for movement needed to position the pusher against the next scraper. This time included the time for the backward swing behind the scraper and the forward movement until contact was made.

Basically, three methods of pusher operations were studied. These three methods are shown in Figure 24.

The backtrack method of push-loading was the most commonly observed. This method offered the advantage of always being able to load in the direction of haul and was also found to be most desirable when the use of a cut foreman was not possible. In this case, the pusher operator usually controlled the cut operations. Occasionally chain-loading was combined with backtrack-loading when excavation was conducted in a long cut. Loading in this manner had the advantage of minimizing pusher reversal time. It was the most economical method to use when possible; however, the cut areas were usually limited in length, making the straight backtrack method the most desirable

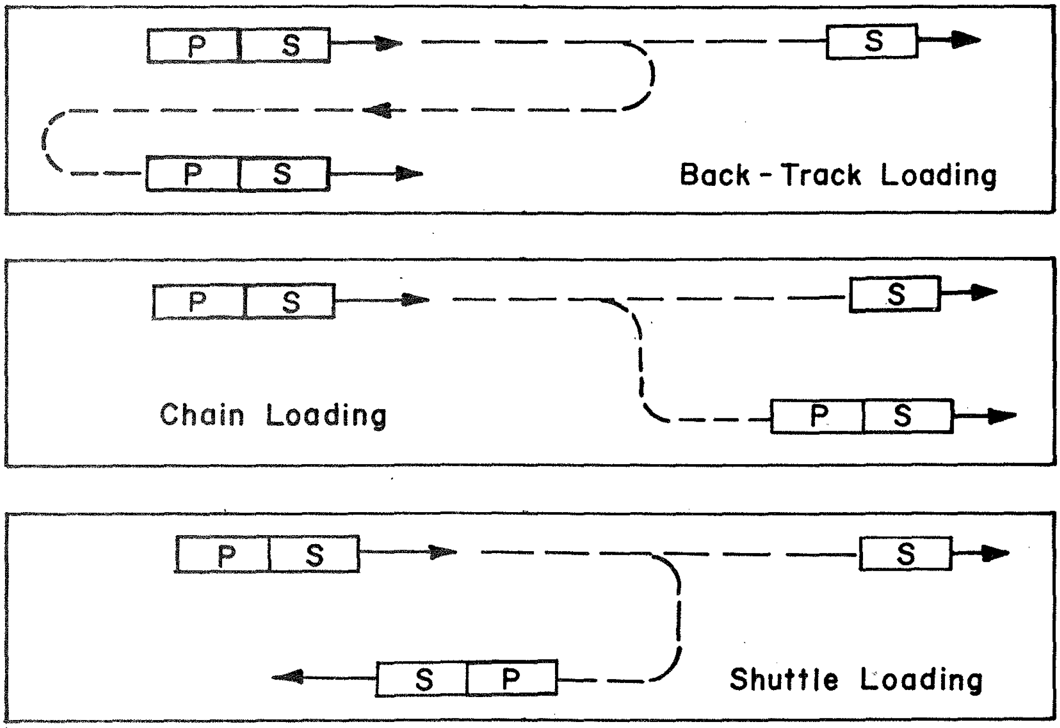

Figure 24. Loading Methods

method to use. Shuttle-loading was the method least frequently observed. In this operation one pusher served two separate scraper fleets--each hauling in opposite directions from the cut. Typically, hauling was limited from one cut area to one fill area--a situation in which shuttle-loading was the least desirable method to use.

Table 7 shows the breakdown of pusher NWTS by individual cycle elements. Average cycle element times were classified into both the single- and tandem-pushing methods.

Table 7. Breakdown of Pusher NWTS

	Average Time (min)		Percent of Pusher Productive Cycle Time		Percent of Pusher NWTS	
Cycle Element	Single	Tandem	Single	Tandem	Single	Tandem
Push	0.82	0.70	55	53	32	39
Boost	0.03	0.04	2	3	1	2
Reverse	0.42	0.42	29	31	16	23
Contact-Maneuver	0.21	0.17	14	13	8	10
Productive Time	1.48	1.33	100	100	57	74
Wait for Scraper Delays	0.92	0.42			36	23
Other Minor Delays	0.17	0.05			7	3
NWTS	2.57	1.80			100	100

As was expected, the element most affected by the use of tandem-pushing as opposed to a single pusher was the push time. Tandem pushers push-loaded faster than single pushers (0.70 minutes as opposed to 0.82 minutes). All other cycle element times remained relatively constant. Tandem pushers were also found to experience less wait time on the average; perhaps the contractors using tandem pushers were more particular in balancing the pusher-scraper fleet, thereby minimizing pusher wait time.

Table 8 shows the breakdown of pusher minor delays. The first column illustrates the minor delays as a percent of the overall minor delay time. The second column illustrates the delays as a percent of the overall minor delay time with the "wait for scraper" delay excluded.

Table 8. Breakdown of Pusher Minor Delays

Minor Delay	Percent of Minor Delay Time	Percent of Minor Delay Time (WFS Delay Excluded)
Wait for scraper (WFS)	85.0	-
Ripping and trimming	3.4	22.6
Personnel inefficiences	3.0	20.1
Pusher maintenance and repair	2.4	16.3
Maintain cut area	1.4	9.3
Supervisory instructions	1.2	7.8
Personal (Drink water, etc.)	1.2	7.7
Scraper or pusher stuck while loading	0.9	6.0
Traffic (contractor and public)	0.5	3.4
Change sites	0.3	2.3
Maneuver into position	0.3	1.9
Start late-quit early	0.3	1.9
Change operators	0.1	0.7
TOTAL:	100.0	100.0

VIII. SUMMARY OF FINDINGS

The significant findings resulting from these field studies are as follows:

1. Productive time amounted to 69 percent of the TWTS (excluding weather delays). Major delay time totaled 18 percent of the TWTS. The remaining 13 percent was attributed to minor delay time.

2. No appreciable difference in loading times was found between push-loading single-engine versus twin-engine scrapers. It was felt that the horsepower of the rear engine in the twin-engine scraper was not effectively used because of the uplifting force provided by the pusher on the rear of the twin-engine scraper being loaded.

3. No difference was discovered in load times according to the size of the scraper. This phenomenon was partially attributable to the additional loading horsepower which was usually provided to the larger sized scrapers.

4. Loading with tandem pushers was faster than with single pushers in both common earth and rock. Greater capacity loads were also produced with tandem pushers. Lesser loads were obtained in rock than in common earth. Increased wear on the machines was also found when loading in rock.

5. Greater speeds and less chance of becoming stuck while dumping were found when the dumping operation preceded the turning maneuver. A more even spread of fill material also resulted, requiring less work of the spreading and compacting equipment.

6. Twin-engine scrapers dumped faster than single-engine scrapers of equal size. Dump time also increased as the size of the scraper increased.

7. Average turn times were found to be 0.30 minutes in the cut and 0.21 minutes in the fill. The difference is attributed to the more congested conditions prevalent in the cut. Also, the operators tended to slow their turn in the cut when they knew they would have to wait for the pusher.

8. Twin-engine scrapers traveled faster than those with only one engine. The size of the scraper appeared to have no clear effect on travel time.

9. Although not as influential as haul distance in influencing travel times, haul road condition and grade nevertheless were found to have a significant effect.

10. Scraper travel time was found to have a curvilinear relationship to haul distance for short distances between the cut and fill. This was due to the distance required for the scraper to accelerate to and decelerate from its maximum travel speed. As the haul length increased, the relationship became more linear until any increase in haul length resulted in a direct linear increase in travel time.

11. Given a constant productive cycle time, the average wait for pusher time increased as the scraper to pusher ratio increased. Given a constant ratio, the average wait time decreased with an increasing scraper productive cycle time. It was discovered that no matter what the ratio, a certain amount of scraper wait time was to be expected.

12. Repairs to the scrapers were the most significant form of major delay. They amounted to 67 percent of the total major delay time. The most significant minor delay type (excluding the wait for pusher delay) was the start late-quit early delay, which amounted to nearly 25 percent of the total minor delay time. Other minor delays, considered as "avoidable delays," were personal delays and operator inefficiencies. These totaled another 25 percent of the minor delay time.

13. The most commonly used form of push-loading was the backtrack method, mainly because of the configuration of the cut. Tandem pushers were found to experience less wait time than single pushers; perhaps the contractors using tandem pushers were more particular in balancing the pusher-scraper fleet, thereby minimizing pusher wait time.

IX. CONCLUSIONS

As a result of the field studies, the following conclusions have been developed:

1. Ripping of material before excavating can significantly reduce loading times and, therefore, increase production rates--not only in rock materials but in many hard, dry clay materials as well. In addition, delays pertaining to equipment repairs would be reduced substantially. Costs of ripping versus not ripping involves a detailed analysis for each particular material removed; it is recommended that such an analysis always be made.

2. Loading of scrapers should be done both downgrade and in the direction of haul if at all possible. Downgrade loading results in faster loading times, while loading in the direction of haul both shortens the length of haul and removes the need to turn in the cut with a loaded scraper. Preference should be given to the loading in the direction of haul when the grade in the cut is slight or moderately uphill. Preference should be given to downgrade loading on unusually steep grades no matter what the direction of haul.

3. Single- and twin-engine standard scrapers should not attempt to load without a pusher, as much smaller load sizes were usually obtained. In addition, such practices lead to increased wear on the scraper and, consequently, increased downtime for maintenance and repairs. It is felt that the time would be better spent in waiting for a pusher, as the operator can use this wait time to perform such tasks as receiving instructions or inspecting his machine--tasks which otherwise might cause unnecessary interruptions in the productive cycle.

4. If feasible, full-time supervisory control of operations in the cut should be provided. Reductions in traffic congestion and confusion leads to a more efficient operation and more than compensates for the additional manpower cost.

5. Similarly, a spotter in the fill area results in more efficient management of both scrapers and spreading and compacting equipment. Material is dumped more evenly and in a more orderly fashion. A spotter can foresee possible delays and can institute preventive measures in situations which would hinder the operation.

6. The optimum ratio of scrapers to pushers for a particular situation is not necessarily that which results in the minimum scraper wait for pusher time. The optimum is that which minimizes the overall cost of wait time for both the scraper and the pusher.

7. Many intangible factors can affect the production of a scraper operation. Among the most significant were project supervision and skill of the operators. Other factors included such things as project time schedules, weather conditions, and the extent of the desire to retain full-time employees.

APPENDIX A

Scraper Efficiency Study Format

As an aid to the contractor in analyzing the productive capabilities of his scraper operations, this appendix contains a suggested field study method. The procedure to be described here has been much simplified for use by contractor's personnel and can easily be modified if desired. In addition to the recording of the various cycle elements shown on the data sheets, the following "constant" information should be determined at the time of the study:

1. Overall grade of the haul road--favorable, negligible, or unfavorable, as measured in the direction of haul.

2. Condition of the haul road--good, fair, or poor.

3. Type of material excavated--common earth or rock.

4. Type of scraper studied--standard, elevating, or twin-engine (the example data sheet is not designed for use in studying push-pull scrapers; such modification is left to the user).

5. Size of scraper--heaped capacity in cubic measure.

6. Scraper to pusher ratio--ratio of <u>total</u> number of scrapers operating in the cut to <u>total</u> number of pusher units operating in <u>same</u> cut (two pushers operating in tandem to be considered as one unit).

7. Number of pushers per scraper--the number of pushers (typically one or two) used at one time to load a single scraper.

This "constant" data just described, combined with recorded cycle element times, should be sufficient to allow comparisons of individual study results with those presented in this report.

The data recording sheet shown in Figure 25 is designed to facilitate the recording of the cumulative time at the beginning of each cycle element and in the order in which the elements occur in the scraper cycle. Space is provided for several different combinations; for example, if the turn occurs before loading, the time is to be recorded in column 4; if, however, it occurs <u>after</u> loading, the time should be

PROJECT ______________ SCRAPER STUDY DATA SHEET SHEET ___ OF ____

DATE ______________ OBSERVER __________

CUT ELEMENTS										FILL ELEMENTS						DELAYS		
Scraper No.	Set Distance	Distance from Point 1	Begin Turn	Begin Wait for Pusher	Begin Load	Load Size	Begin Turn	Begin Haul	Distance from Point 1	Distance from Point 2	Begin Turn	Begin Dump	Begin Turn	Begin Return	Distance from Point 2	Begin Delay	End Delay	Delay Description
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)

Figure 25. Example Data Recording Sheet

recorded in column 8. Not all columns would necessarily be used in a typical cycle. The set distance between points 1 and 2 in Figure 26 is a predetermined length over which all scrapers will travel regardless of where they begin to load or dump; this is done to facilitate the computation of the travel distances, as the observer then has only to estimate the distances from the set reference points, i.e., plus or minus X number of feet, rather than attempt to estimate the entire haul or return distance. Typically, these reference points are located at the entrances to the cut and fill areas or at some other convenient location.

In addition to the cycle elements, space is provided for recording the cumulative times at the beginning and end of any delays which might occur during the cycle. Note that it is not necessary to record wait for pusher delays in these columns, as such delays occur so frequently that they are included under column 5 with the element of the scraper cycle. Space is also provided for a description of the cause for the delay if desired.

The user should either record a period of several hours of operation which would fairly represent a typical period or record several smaller periods throughout the work week. If the haul length is relatively short, it is possible for a single observer to record the entire cycle. However, it may be more convenient to have observers in both the cut and the fill to cover different portions of the cycle, particularly if the haul length is long or if several scrapers are being studied simultaneously. The use of multiple observers requires that all watches be synchronized.

Upon completion of the data recording, actual cycle element times are computed by subtracting the time at the beginning of the element from the time at the beginning of the next element. Delay times are subtracted from the appropriate element, and the reduced data is transferred to the cycle element summary sheet shown in Figure 27. Note that both turns in the cut (when there are in fact two turns on a single cycle) are combined into one total cut turn time; the same is true of the fill turn times. Delays less than 15 minutes in duration are listed in the minor delay column; all others are listed in the major delay column. Travel distances are determined by adding the recorded distances from the reference points at each end of the cycle to the set distance. The appropriate elements of the N number of cycles can then be summed at the bottom of the page.

From this summary of the operation, one can then follow the step-by-step procedure outlined on the Performance Evalulation sheet of this appendix to evaluate the productivity of the scraper operation. The letters shown refer to the sums of the respective columns as shown in the reduced data summary sheet of Figure 27.

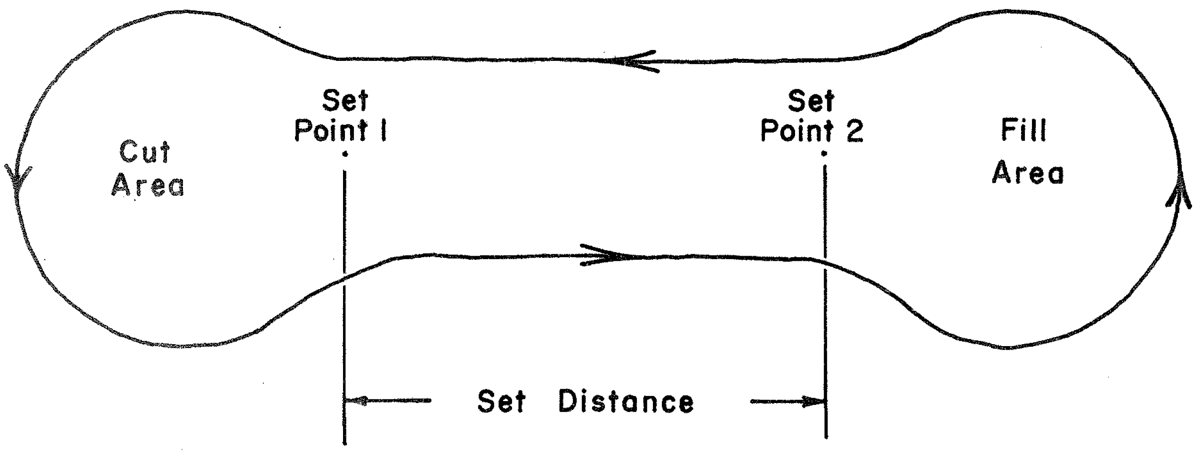

Figure 26. Use of Set Distance in Estimating Travel Distance

PROJECT ________________ SCRAPER STUDY SHEET ___ OF _____

DATE ______________ REDUCED CYCLE ELEMENTS OBSERVER ___________

Cycle No.	Cut Turn Time	Wait Time	Load Time	Load Size	Haul Time	Haul Distance	Dump Turn Time	Dump Time	Return Time	Return Distance	Minor Delays	Major Delays
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
13												
	Σ = (a)	Σ = (b)	Σ = (c)	Σ = (d)	Σ = (e)	Σ = (f)	Σ = (g)	Σ = (h)	Σ = (i)	Σ = (j)	Σ = (k)	Σ = (l)

Figure 27. Example Reduced Data Summary Sheet

PERFORMANCE EVALUATION

PRELIMINARY CALCULATIONS:

A. PRODUCTIVE WORK TIME

Productive Work Time = a + c + e + g + h + i = ______ min.

÷ 60 min./hr.

ANSWER ______ hr.

B. TOTAL MINOR DELAYS

Total Minor Delays = b + k = ______ min.

÷ 60 min./hr.

ANSWER ______ hr.

C. TOTAL MAJOR DELAYS

Total Major Delays = l = ______ min.

÷ 60 min./hr.

ANSWER ______ hr.

EFFICIENCY CALCULATIONS:

D. NWTS Productive Efficiency

Productive Work Time ______ hrs.

NWTS (Productive Work Time + Total Minor Delays) ÷ ______ hrs.

X 100 %

ANSWER ______ %

E. TWTS Productive Efficiency

Productive Work Time ______ hr.

TWTS (NWTS + Total Major Delays) ÷ ______ hr.

X 100 %

ANSWER ______ %

F. Summary

TWTS = __ hr.

NWTS = __ hr.

Productive Work Time (A) = __ hr. Minor Delays (B) = __ hr. Major Delays (C) = __ hr.

OR

TWTS = 100%

NWTS [(A + B) ÷ TWTS] = __ %

Productive Time Time (E) = __ % Minor Delays (B ÷ TWTS) = __ Major Delays (C ÷ TWTS) = __ %

PRODUCTION RATE CALCULATIONS:

G. TWTS Rate

Total Yardage Moved = d

TWTS (A + B + C)

	______	lcy
÷	______	hr.
ANSWER	______	lcy/hr.

H. NWTS Rate

Total Yardage Moved = d

NWTS (A + B)

	______	lcy
÷	______	hr.
ANSWER	______	lcy/hr.

I. Productive Work Rate

Total Yardage Moved = d

Productive Work Time (A)

	______	lcy
÷	______	hr.
ANSWER	______	lcy/hr.

AVERAGE CYCLE ELEMENT CALCULATIONS:

J. Average Cut Turn Time

Total Cut Turn Time = a

Total Number of Cycles Recorded

	______	min.
÷	N	cycles
ANSWER	______	min.

(Remaining cycle elements calculated in similar fashion.)

APPENDIX B

Use of this Report for Estimating Production

This appendix illustrates how the information in this report might be used as an aid in estimating scraper production. The form shown can be used to determine the average scraper and pusher cycle times for a particular project. Also included is a means for determining the fleet production rate of the proposed project both with and without including major delay time.

The contractor or estimator must supply the project conditions and the equipment fleet to be used. Most project conditions may be obtained from either the project drawings or preliminary site investigations. The scraper and pusher cycle element times can be determined from the contents of this report once the project conditions are defined. Once the cycle element times are determined, the expected fleet production rates can be obtained.

In order to provide a more realistic adjusted fleet production rate, the estimator would have to supply a value for major delay time as a percentage of TWTS which is indicative of the particular contractor's fleet. However, it should be noted that any techniques for optimizing the fleet size should be based on the unadjusted production rate obtained without taking major delays into account.

ESTIMATING WORK FORM: SCRAPERS AND PUSHERS

JOB CONDITIONS:

a. Material Type ________

b. Haul Distance ________ Ft.

c. Haul Road Grade ________

d. Haul Road Condition ________

EQUIPMENT:

a. Scrapers

1. Heaped Capacity ________ LCY

2. Type ________

3. Number in Use ________

b. Pushers

1. Type (Single or Tandem) ________

2. Number of Independent Units ________

TOTAL SCRAPER CYCLE TIME

				Reference:
A.	Load Time	________	Min.	Table 2
B.	Dump Time	+ ________	Min.	Table 4
C.	Cut Turn Time	+ ________	Min.	Figure 7
D.	Fill Turn Time	+ ________	Min.	Figure 8
E.	Travel Time	+ ________	Min.	Figures 11-21
F.	Productive Cycle Time	= ________	Min.	
G.	Wait Time	+ ________	Min.	Figures 22-23
H.	Minor Delay Time (Excluding Wait)[1]	+ ________	Min.	Table 1
I.	Total Cycle Time	= ________	Min.	

FLEET PRODUCTION

J.	Cycles per Hr. [60 ÷ I]	________	Cycles/Hr.	
K.	Payload[2]	________	LCY/Cycle	Table 3
L.	Production per Scraper [(J) X (K)]	________	LCY/Hr.	
M.	Fleet Production [(L) X No. Scrapers]	________	LCY/Hr.	
N.	Percent Major Delay Time[3]	________	%	

O. Major Delay Factor

[100% - (N)] ÷ 100 ________

P. Adjusted Fleet Production

[(M) X (O)] ________ LCY/Hr.

Footnotes

[1] The figure for Minor Delay Time can be found as follows:

X = Minor Delay Time, Y = Minor Delay Time as a percent of NWTS

$$X = \frac{Y}{\left(1 - \frac{Y}{100}\right)} \times [\text{Productive Cycle Time (F)}]$$

Y can be found from either Table 1 or from the contractor's records.

[2] The average payload is found by multiplying the scraper heaped capacity by the percentage determined from Table 3.

[3] This percentage assumes a contractor maintains records of major delay time for his own equipment. The percentage is found by:

$$\text{Percentage} = \frac{\text{Total Major Delay Time}}{\text{Total Available Shift Time}} \times 100\%$$

APPENDIX C

Illustration of Effect of Delays on Scraper Productivity

Figure 28 is intended to emphasize the significance of major and minor delays in influencing the productivity of a scraper operation. The nomograph was developed on the basis of the data collected on the eleven projects studied and is not meant to represent any particular project. It is a useful tool, however, in determining the order of magnitude of the effect reductions in delay time might have.

To use the nomograph to determine changes in productivity during TWTS, locate the desired percent decrease in minor delay time of scale A, locate the desired percent decrease in major delay time on scale D, and connect the two points with a straight line. The theoretical percent increase in productivity per hour of TWTS is read at the point where the line crosses scale C.

To determine changes in productivity during NWTS, locate the desired percent decrease in minor delays on scale A and connect it with a straight line to the 100 percent value on scale D. The increase in productivity per hour of NWTS is read at the point where the line crosses scale B.

Following are two examples of the use of Figure 28:

1. Decreases of 40 percent in minor delay time and and 20 percent in major delay time would theoretically increase the productivity of the scraper per hour of TWTS by 13 percent--as shown where the line crosses scale C.

2. A decrease of 30 percent in minor delay time would theoretically increase productivity per hour NWTS by 6 percent--as shown where the line crosses scale B.

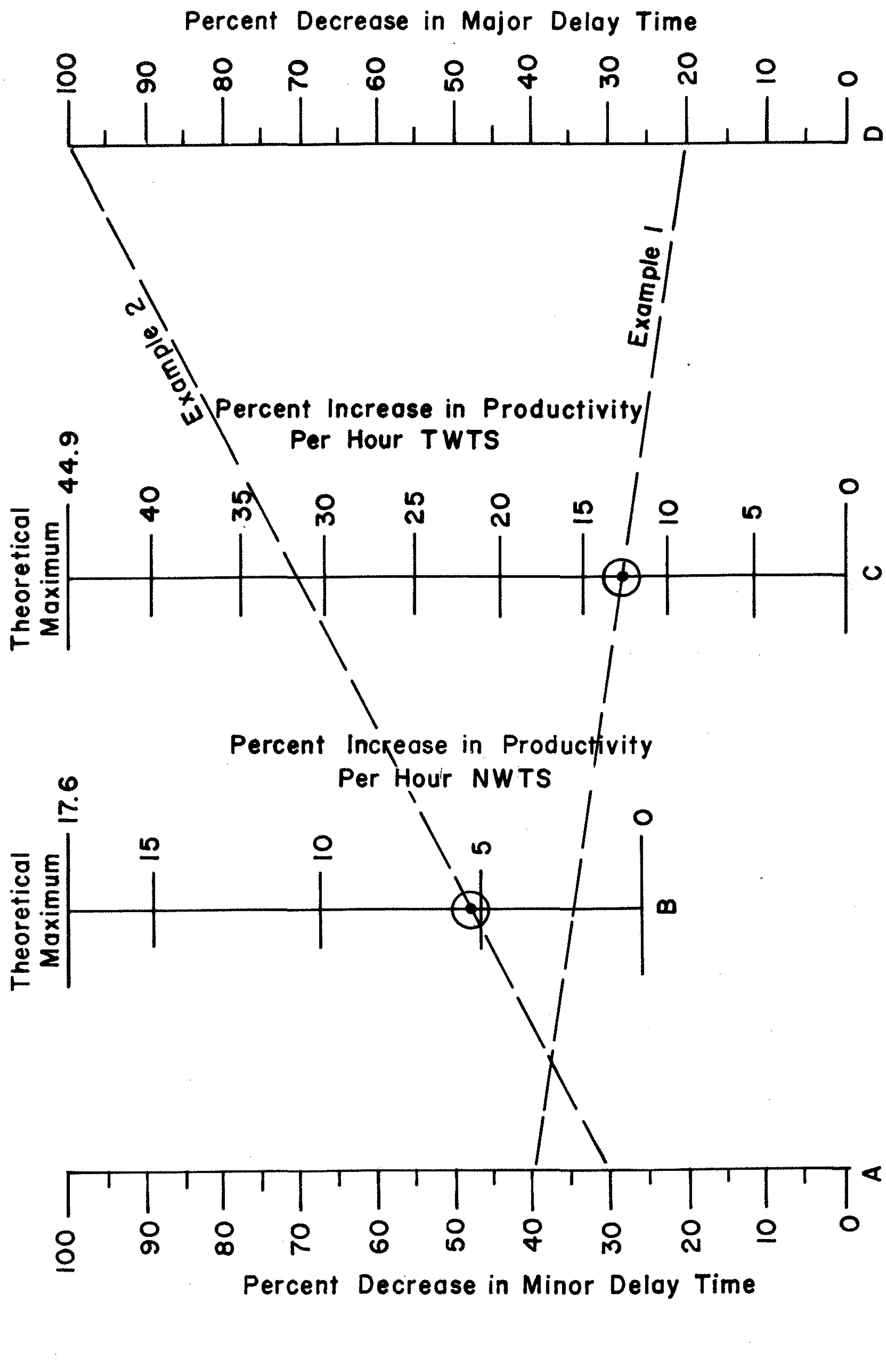

Figure 28. Theoretical Effect of Reductions in Delay Time on Scraper Productivity

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