A STUDY OF SOLID WASTE COLLECTION SYSTEMS COMPARING ONE-MAN WITH MULTI-MAN CREWS

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Since technological innovation in refuse disposal has been relatively sparse, and since the entire concept of solid waste management is quite new, --the conclusions and evaluations presented should be considered as preliminary in nature.

A STUDY OF SOLID WASTE COLLECTION SYSTEMS COMPARING ONE-MAN WITH MULTI-MAN CREWS

Final Report

This report (SW-9c) was written for
the Bureau of Solid Waste Management
by Ralph Stone and Company, Inc., Engineers
Los Angeles, California
under Contract No. PH 86-67-248

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FOREWORD

An estimated 800 million pounds of solid wastes of all types are generated in the United States every day. The cost for handling and disposing of this vast quantity of waste materials is also very large. A recent study indicates that Americans spend $4.5 billion annually for solid waste management, and that even this sum is inadequate to insure against environmental pollution from solid waste sources.

Approximately 75 percent of the cost of solid waste management is attributable to the collection process, and the present study of a one-man collection system was funded by the Bureau of Solid Waste Management under Contract No. PH 86-67-248, for the purpose of examining one means for reducing collection costs and improving the level of community sanitation services.

--RICHARD D. VAUGHAN, *Director*

Bureau of Solid Waste Management

PREFACE

Recently, collection systems have been reported for curbside collection of residential refuse in Southern California and other areas wherein one man acts as both driver and loader. These sytems normally utilize right-hand drive, side-loading packer vehicles. Reports indicated that substantial reductions in the overall costs of providing collection service were possible using this new system. It was not known whether the apparent savings were due to the smaller crew size or to a combination of equipment, collection methodology, routing characteristics, haul distances, and personnel. Accordingly, the Solid Wastes Program, United States Public Health Service, authorized Ralph Stone and Company, Inc., Engineers, to study and report on one-man refuse collection operations. Ralph Stone was the Project Director, with able support of Robert P. Stearns, Project Engineer. Anthony Svane, Harjeet Singh, Helen Friedland, and other staff personnel provided technical assistance.

The prime purpose of the study was to define the nature of the possible savings, if any, due to a one-man crew; to compare the efficiency of the one-man crew with two- and three-man crews; and to project the future use of the one-man system for refuse collection. In addition, a catalog of the equipment available for one-man operation was compiled.

ACKNOWLEDGMENTS

We wish to express our appreciation to representatives from the Public Health Service's solid wastes program for their encouragement, guidance, and assistance in the conduct of this study. In particular, we wish to thank Mr. John Kennedy, Project Officer, for his assistance which has aided immeasurably in the compilation, interpretation, and presentation of the information within this report.

We would also like to take this opportunity to express thanks to the many engineers and administrators of cities, private refuse collection firms, and refuse equipment manufacturers who also participated in this study. Numerous cities and private collection firms have supplied complex background information necessary for this study, including information on ordinances, costs, tonnages collected, and other relevant facts.

Many manufacturers of refuse collection equipment were equally helpful; they supplied us with brochures describing available equipment and responded to our specific questions. Additionally, we received information from many public cleansing authorities in Europe.

Summary refuse collection data presented within this report would not have been possible without the generous assistance of over two hundred cities located throughout the nation. Detailed summary information of their refuse collection operations, ordinances governing refuse collection, man-hours, tonnage collected, costs, injury rates, and other relevant data is presented in the report. The excellent cooperation received illustrates the current high level of interest on the part of public and private agencies in refuse collection operations.

--RALPH STONE

TABLE OF CONTENTS

TABLE OF CONTENTS - CONTINUED

LIST OF TABLES

LIST OF TABLES - CONTINUED

LIST OF FIGURES

LIST OF FIGURES - CONTINUED

LIST OF FIGURES - CONTINUED

LIST OF PHOTOGRAPHS

APPENDICES

ABSTRACT

This report summarizes research into the relative functional and cost efficiencies of the one-man crew when compared to alternative two- or three-man crews for the collection of refuse.

Four basic analytical techniques were used: comprehensive field surveys; nationwide survey data analysis; time-motion studies; and a mathematical model.

The comprehensive field surveys were applied to four municipal collection systems and two private-firm collection systems. They were supplemented by abbreviated field surveys in selected cities throughout the United States. The comprehensive surveys analyzed four one-man crews, one two-man crew, and one three-man crew. Care was taken to eliminate extraneous factors not related to crew-size efficiencies which might influence the data and distort the results. Detailed observations and records were made of significant measurable factors relating to equipment, containers, productive and nonproductive time, man-hours, and collection techniques. Movie film and video tape records, direct physical observations, and statistical analysis were applied to evaluate relative efficiency based on crew size, and to determine the influence of basic factors on that efficiency.

The time-motion studies compared field times in three cities with Methods-Time-Measurement (or MTM) values developed under controlled laboratory conditions. Preliminary analysis for fatigue effects were examined in relationship to loading height and total container weight; and standard collection times were developed for varying collection locations, techniques, and equipment.

A mathematical model was designed to permit simulation of the refuse collection system. The model is a formula which expresses the interrelationships among the variables affecting collection time and system cost. Nomographs were developed which can be used to project the possible effects of varying truck volumes, refuse quantities, densities, times, crew-sizes, and route sizes.

Tables and charts have been prepared to support and illustrate the information developed, and the conclusions and recommendations which have been based thereon.

CONCLUSIONS

The following conclusions were based on the field studies and time and motion analyses described in this report. The conditions, limitations, and assumptions governing specific data and its analysis are defined in the related sections of the text.

1. For curbside collection of refuse, one-man crews were more efficient than multi-man crews; the productivity of the one-man crew was greater than that of the multi-man crew when measured in terms of route man-hours per ton.

2. The one-man crew was similarly more efficient than the multi-man crew for alley collection of refuse.

3. Multi-man crews were more efficient for backyard carryout collection of refuse.

4. Under specified assumptions for important route factors and costs of equipment and labor, the unit cost of refuse collection by the one-man crew was 25 to 45 percent less than the two-man crew and 35 to 50 percent less than the three-man crew.

5. Although multi-man crews required less equipment of equal size than the one-man crews, this had a negligible effect on unit collection costs when the combined equipment operating, amortization, and labor costs were compared for one-man and multi-man collection.

6. In residential or light commercial curb or alley collection, the work load was not excessive for one-man operation.

7. With existing collection equipment designs, side-loading compactor vehicles were the most suitable type of one-man operated equipment for curbside and alley refuse collection operations.

8. Significant savings in curbside collection time were achieved by the use of disposable containers such as paper or plastic bags.

9. Industrial time standards developed for production control and design were found applicable to evaluating the task of refuse collection.

10. Based on preliminary human factors studies, the weight of the refuse container and contents was more important in the rate of collection personnel performance degradation than vehicular loading height.

11. Various complex refuse collection system interrelations affect optimum crew size, equipment, and cost benefits.

The following conclusions were based on the national survey data described in this report.

1. The predominate (1968) practice of refuse collection used by a sample of 234 cities involved the use of rear-loading packer vehicles with three-man crews for curb and/or alley collection.

2. Only a limited number of small cities used one-man crews for refuse collection.

3. In a sample of 234 cities, unit operating costs for collection of refuse generally increased with the size of the city.

The following conclusions are based on the study as a whole.

1. Public refuse collection systems in general have been slower than private collection systems to adopt new refuse collection technology such as smaller crew sizes, certain low-cost or high-efficiency equipment types, and related system modifications.

2. If labor costs and the incidence and severity of collection labor strikes continue to increase, the one-man collection system may become more common, particularly in private collection firms and in smaller cities.

3. Current municipal collection systems are frequently characterized by: personnel with limited skills and work experience; high absenteeism; absence of promotion opportunity; and lack of public recognition of the collection worker's contribution.

4. As the cost-benefits associated with the one-man crew are sensitive to excessive absenteeism and poor work habits, the one-man collection system generally requires a higher level of responsibility, performance, and loyalty on the part of both collection and supervisory personnel.

5. Successful implementation of a one-man collection system will probably require: higher personnel standards; higher salary rates; potential upward mobility in the job structure; employees with a sense of personal pride and responsibility; and engineering evaluation of route structure and equipment requirements.

6. There is an immediate need for improvement in the design and application of specific equipment for refuse collection tasks. The combination of packer body and conventional truck chassis does not provide for an optimum man-machine relationship.

7. Many existing collection systems can be significantly improved by engineering design of collection methodology, including crew and truck sizes.

8. Increased awareness by collection system administrators concerning potential cost savings and improved human factors can lead to the demand for and use of better equipment designs.

9. Careful planning and engineering of the collection system can realize maximum public health protection, cost savings, improved service and reduction in the frequency of labor strikes and other personnel difficulties.

RECOMMENDATIONS

A. General

1. Collection managers should upgrade the quality of their personnel to the caliber required for potential advancement to positions as truck drivers, mechanical equipment operators, supervisors, clerks, and other skilled jobs, following experience and training programs.

2. Personnel policies in a municipal collection service, particularly under Civil Service regulations, should encourage advancement in the service or reassignment to other municipal departments as needed.

3. Private firms and municipalities initiating a refuse collection system incorporating curbside or alley collection should weigh the possible advantages of the one-man crew.

4. Existing private and municipal operations should review the possibility of reducing crew sizes if multi-man crews are presently performing curbside and/or alley collections.

5. Municipalities and private collection operations should establish work and time standards for their collection crews, and periodic checks to determine compliance should be instituted.

6. When equipment purchases are planned by the administrators of a collection operation, the potential effects of equipment size and design on efficiency should be evaluated.

B. Specific

Based on results of the current study, it is recommended that the United States Public Health Service, Solid Wastes Program sponsor additional engineering study in the following areas:

1. The formulation of orderly collection system modification plans to achieve increased efficiency through reduced crew sizes in harmony with organized labor requirements, local political factors, and the need for higher levels of service.

2. The development of time standards, similar to those developed herein for curbside collections, for other commonly used collection methodologies including variations of backyard collection, set-out, and set-out set-back methods.

3. Comprehensive human factor studies of the interrelationships between basic work activities, efficiency and safety, and equipment design to establish work and equipment guidelines for the reduction of the present relatively high rate of injury to collection personnel.

4. Engineering studies of collection equipment characteristics and performance to establish guidelines for equipment design and manufacture in relationship to collection efficiency and human factor requirements.

5. Use of the extensive statistical data accumulated from this study's field surveys in a computer simulation program to further verify the advantages of the one-man collection system, and to prepare additional illustrative design figures and nomographs to aid the collection system administrator in improving his operation.

6. Expansion of the engineering methodologies developed herein by additional studies of refuse collection to reduce labor unrest and improve socio-economic environmental effects. This can lead to the reduction of strikes, the promotion of labor-management harmony, higher collection efficiencies, and better environmental sanitation.

SUMMARY

The cities of America--indeed of the world--cannot afford to take their refuse collection systems for granted. Few other activities are so intimately concerned with the public health, community aesthetics, and personal contact with the citizen, his home, and his pocketbook. Only constantly rising standards of productivity can compensate for the demands of a steadily advancing wage structure. The urgency of the problem is hardly diminished by the socio-economic implications of the high minority race representation in many American collection systems.

Refuse collection is big business. Because governmental agencies are commonly involved, this fact is frequently overlooked. Like other major industries, refuse collection systems can benefit from in-depth studies of equipment, methodology, and labor relations--in short, of all factors relating to efficient operation and high employee morale. It is believed significant progress has been made as the result of the study described herein and other studies funded by the Solid Wastes Program of the United States Public Health Service.

This study has been primarily concerned with determining the relative efficiency of the one-man collection crew whose single member serves the dual function of driver and collector. The following methods were used to compare the efficiency of the one-man crew with that of the two-, and three-man crews: extensive field studies, time and motion studies, a mathematical model, and controlled laboratory study.

In the field studies, precautions were taken to ensure the gathering of reasonably comparable data. For curbside collection, the two- and three-man crews studied failed to speed collection time sufficiently over that achieved by the one-man crew to compensate for the additional man-hours involved. The travel time between stops was approximately equal for all three crew sizes. Since driving the truck is the only essential labor function between stops, travel-time is usually non-productive time for the second and third members of the larger crews. An exception does exist, however, when routes with narrow alleys or cul de sacs make operation of a conventional large-capacity truck difficult without the guidance of an additional crew member during backing and other tight maneuvering of the vehicle.

At present, the conventional rear-loading packer is believed to be the most efficient refuse collection equipment currently available for packing refuse. The side-loading vehicle, however, is more efficient for use in one-man curbside collection operations, primarily because it locates the driver immediately adjacent to both loading and container locations. The TRAC, or Truck Rear Actuated Control device, was designed to permit one-man operation of the conventional rear-loading truck. In its present experimental form, it appears to have certain disadvantages for heavy-duty all-weather use. As a concept, however, it illustrates both the possibility and the need to produce better equipment specifically designed for refuse collection.

Motion-Time-Measurement, or MTM, industrial time standards were used as an additional tool for the comparative study of different collection methodologies. Recorded field collection time data were supported by the MTM results when proper allowance was made for fatigue and delay factors which had not been assigned standard values, indicating that industrial MTM methods were indeed suitable for collection efficiency studies. The field studies, verified by the MTM time and motion analyses, indicated that the one-man crew was more efficient than either the two- or three-man crews for curbside and alley collection methods. Using the MTM standards, all three crew sizes were found approximately equal for modified curbside collection in which both sides of the street are collected at each collection stop. Similar theoretical analysis indicates that backyard collections may be accomplished more efficiently with the two- and three-man crews, particularly when large capacity trucks are assumed.

A mathematical model was designed to simulate refuse collection using the three crew sizes under a variety of assumed field conditions. Basically, the model makes it possible to calculate the probable time and cost effects of various changes in collection methodology. Using designated values for system parameters, the model was used to project unit costs of collection, services collected per crew, and to evaluate the effect of truck size, for each of the three crew sizes under alternative methods of collection. The model was also used to test design data based on the assumption that two- and three-man crews were respectively one-third and two-thirds faster per collection stop than the one-man crew. The resulting performance and unit cost curves were not supported by this study's field and time-motion data, indicating that the assumptions were not valid.

The use of disposable containers such as plastic or paper sacks was found to enable a significant reduction in collection time, ranging from 15 to as much as 50 percent, depending on the number of containers replaced by the bags. An estimate indicates the cost savings resulting from reduced collection time and elimination of conventional containers may compensate for as much as half the cost of both the disposable containers and their holders. Additional studies in Inglewood, California, have been initiated to verify these potential savings and to evaluate disposable container systems.

In preliminary laboratory studies, loading height of the collection vehicle did not have a significant effect on collector performance degradation. However, an increase in performance degradation due to loading height did appear in association with cumulative loads in excess of 5000 lb. Container weight, on the other hand, was found to have an important effect on performance. The critical load-weight point based on these preliminary studies fell within the range of 45 to 60 lb per container. Further study is necessary to define the point more accurately; such information would be useful since maximum container weight is usually established by municipal ordinance and should be related to the efficiency and welfare of the collection employee. Other collection factors which have a major impact on accidents, injuries, and man's ability to perform the refuse collection task are recommended for further study.

Based on an analysis of sample data from 234 cities, the cities represented provide municipal rather than private refuse collection service; use a three-man crew; designate a combination of curb and alley collection location; and use rear-loading packer equipment. Less than 3 percent of the cities reported the use of the one-man crew, and in descending order of preference, these one-man crews used side-loading, front-bucket, and rear-loading equipment. Twice as many cities used three-man crews as did two-man crews, but several cities used four-man, five-man, and even larger-sized crews, usually in conjunction with yard carryout service. The reported accident rate was higher in the smaller cities. The median city's collection cost per ton was approximately $10 for small and medium-sized cities, and $13 for larger cities with populations in excess of one half million. Reported cost data indicated wide variation among cities in both cost efficiency and accurate accounting. In fact, one of the most interesting conclusions to be drawn from an analysis of the same data is that many American cities have no way of accurately determining the productivity of their collection dollar simply because they fail to record adequate refuse quantity and manpower data.

Improved engineering design of the conventional refuse collection system is both possible and desirable. In curbside or alley collection, where route conditions present no special problems and adequate supervision is available, the one-man crew has been found to be the most economical for refuse collection. In residential or light-commercial areas, the workload is not excessive for one-man collection. In addition, having sole responsibility for a specific route can encourage greater pride and improved work habits. One-man collection does require a responsible attitude on the part of the collector and careful selection of qualified personnel on the part of the governmental or private collection agency. However, both the employee and the community as a whole would certainly benefit if the status of the refuse collector and his essential contribution to the public good received the recognition they deserve.

I. INTRODUCTION AND PURPOSE

Recent (1968) strikes of sanitation workers in the Cities of Atlanta, Baltimore, New York, Memphis, Paris, Los Angeles, Santa Monica, and others have dramatized the importance of refuse collection to the physical and economic welfare of the urban community. The general public was also alerted to the costs involved in municipal refuse collection - many for the first time. An important problem is whether collector manpower requirements can be reduced to compensate for higher pay and increased manpower quality while maintaining a high level of service.

Although, the unit cost of refuse collection does not generally appear to be excessively high, the magnitude of service required quickly expands the total costs to a high figure. Collection and disposal of an estimated 125 million tons of urban refuse produced in the United States each year costs approximately $3 billion per annum. Since collection represents about 70 to 80 percent of this cost, refuse collection is currently at least a $2 billion industry. Furthermore, not only is the per capita quantity of solid waste expected to increase, but the total population and industry of the country is expected to double within the next fifty years. Improvements in collection efficiency can thus be expected to achieve savings of many millions of dollars.

In recent years, extensive study has been devoted to improved refuse disposal techniques and the development of new disposal methods which incorporate refuse reclamation. However, little concentrated effort has been expended to understand and improve refuse collection. In short, large funds have been expended to finance research directed towards reduction of disposal costs, while even greater potential savings from reductions in collection costs have been in large part neglected.

Since most of the population increase will probably continue to be in urbanized areas, it is reasonable to expect a constant acceleration in both the area concentration and absolute quantity of solid wastes. In other words, it will become increasingly necessary to think of managing refuse in terms of mass production, mass collection, and mass disposal. Not only can the smaller cities anticipate future possibilities of growth and experience based on patterns found in the larger municipalities, but all jurisdictions should have access to as much factual information as possible in order to enable intelligent decisions and prevent costly errors.

Recently, a few collection systems have been employed for <u>curbside collection</u> of residential refuse wherein one man acts as both driver and loader. (When words or phrases which are included in the Glossary first appear, they are underlined). Unofficial reports indicated that substantial reductions in the overall costs of providing collection service were possible using this new system. It was not known whether the apparent savings were due to the smaller crew size or to a combination of equipment, collection methodology, routing characteristics, haul distances, and personnel used by these systems. Ralph Stone and Company, Inc., Engineers, was therefore authorized by the Solid Wastes Program, United States Public Health Service, to study and report on one-man refuse collection operations.

The prime purpose of the study was to define the nature and extent of the possible savings, if any, due to a one-man crew; to compare the efficiency of the one-man crew with two- and three-man crews; and to project the future use of the one-man system for refuse collection. In addition, a catalogue of the equipment available for one-man operation was to be compiled.

II. DETAILED APPROACH

Refuse collection is a complex system to analyze, primarily because it involves both men, equipment, and levels of service plus the possibility for numerous variations in secondary factors which are difficult to quantify but have a direct bearing on the overall efficiency of the system. Some of these factors are: collection methodology; quantity, nature, and method of storage of the refuse; location of pickup point; equipment type and characteristics of operation; road factors; service density; route topography; climatic factors; and a broad category termed, for lack of a better description, human factors. Human factors include morale, motivation, fatigue, and other psychological and physiological factors which influence the time required to complete a given work task.

For any given refuse collection system, some or all of these tangible and intangible factors will have significant but perhaps unknown effects upon the efficiency of collection. Thus, merely comparing overall system costs and performance rates of numerous operating systems utilizing various sized crews cannot define the true nature and cause of differences which may occur in efficiency. Analysis of comparable aspects of existing systems, however, can provide valuable information, and various systems were analyzed to disclose interrelationships which might affect relative efficiency. Extensive field surveys of collection operations were conducted.

Comparisons were limited, however, to easily definable factors to assure a high degree of comparability. Thus, comparisons were made of such factors as the incremental time per stop, rather than of overall man-hours per ton and other typical descriptors which are highly variable and are influenced by haul distances, truck sizes, and other methodology alternatives.

Because present day experience with the one-man collection system has been limited primarily to curbside collection, this method received the most intensive study. However, preliminary analysis of the applicability of one-man collection systems to backyard and alley collections has also been completed.

Mathematical and theoretical approaches were also used to examine the refuse collection operation under simulated controlled conditions, thus removing the effect of secondary factors. The mathematical approach involved the description of the refuse collection system by formula. Industrial engineering motion-time analysis methods were used for the theoretical approach. Thus, three complementary approaches were used to define the relative efficiency of the one-man versus two- or three-man crews: 1) the conduct of comprehensive field surveys of selected municipal and private collection operations and the analysis of field and sample data covering nationwide refuse collection operations; 2) the industrial engineering time and motion analysis, which was confined to the on-route collecting time, to verify the validity of the field survey data and to define theoretical times for collecting the refuse based on various equipment designs, collection methodology, locations of the refuse, and number in the crew; and 3), the mathematical model, which, when supplied with various combinations of collection time, travel time, truck capacity, crew sizes, haul time, labor and equipment costs, and other route factors, permitted estimates of the average level of efficiency and projections of system costs.

A. Field Surveys and Analysis

1. General

In comparing the relative efficiency of refuse collection crews, the time to collect the refuse from each service stop is very important. Assuming that containers do not require two men for lifting and that collection equipment can be operated by one man, the incremental time at each service stop is the most important single factor determining relative efficiency of different size crews. During all time spent for travel, lunch, relief, and at the disposal site, the relative efficiency varies inversely with the crew size, except when loader members of the multi-man crew are productively employed for other work while the collected refuse is being hauled for disposal. Occasional instances were noted where loaders were used for sweeping gutters, carrying emptied containers from the curb to the storage location in the backyard, and carrying loaded containers from the backyard location to the curb for subsequent collection. At least one private firm assigned the haul and disposal time period as the lunch period for the loaders. Other minor time considerations, such as unloading at the disposal site, may also affect the relative efficiency - but not to a significant degree.

In addition, it was thought there might be a significant difference in driving time between service stops for one-, two-, and three-member crews, because positioning equipment in relation to container location might be more important for the one-man crew. Desirable equipment types for collection operations using various crew sizes for alternative collection methodology are discussed in Section D of this report.

At any given curbside service stop, apart from differences in personnel ability, the collection time depends primarily on the number and types of containers placed for collection. Therefore, the field surveys of various municipal and private firm collection operations included this information in order to correlate the time per stop with the number and type of containers at each service stop.

A standard form designed for use in the field surveys is contained in Appendix A. Page 1 of the form includes a description of the collection operation being surveyed.

2. Field Study Program

A program was initiated in July 1967 to undertake comprehensive field surveys of selected refuse collection operations located in California. These field surveys were intended to enable evaluation of the following:

a. Statistical distribution of collection time for various crew sizes and collection methodologies.

b. Statistical distribution of travel time between collection stops.

c. Mean quantity of refuse per service stop and an estimate of its standard deviation.

d. Time and motion, employing motion picture films and television video tape recordings of the refuse collection operation for subsequent analysis.

e. Number and type of containers at each service stop and the corresponding collection time.

Beginning in early July 1967, contacts were made to request permission from selected cities and private firms to conduct a series of field surveys of collection operations. Four cities and two private collection firms located in California were chosen for detailed field study. Two private firms and two of the cities used one-man collection systems. The remaining two cities utilized two- and three-man crews respectively. Both private firms and three of the municipalities were located in Southern California. In accordance with administrative requests, and in order to obtain maximum cooperation, identities have been withheld. Throughout the report, the following designations will be used:

Municipality A: Southern California - One-Man Crew

Municipality B: Southern California - Two-Man Crew

Municipality C: Southern California - Three-Man Crew

Municipality D: Central California - One-Man Crew

Private Firm X: Southern California - One-Man Crew

Private Firm Y: Southern California - One-Man Crew

System variables were partially controlled by choosing systems with similar climates; service areas; and ordinances governing refuse containers, preparation of refuse for collection, and materials suitable for collection. Curbside collections were made from one side of the street with the truck returning in the opposite direction to collect refuse from the other side of the street. Table I contains selected comparative information including a summary of the ordinances governing refuse collection by each private firm and in each municipality.

In addition to the detailed field surveys, abbreviated field surveys of municipal and private collection operations were made at other locations throughout the country as described in Table II. Motion picture film and video tape studies were made of municipal and private operations. Movie films were subsequently edited to provide visual comparisons between alternative collection methodologies.

Detailed field surveys for Municipalities A, B, and C were scheduled concurrently during three periods of the year. The first series was completed during August of 1967. The second series began in December and was completed by early February 1968. A third and final series was started in March and completed in April 1968.

Municipality D and Firms X and Y were surveyed during the winter and spring period only. Winter surveys commenced in late October 1967 and were completed in early February 1968. The spring series began in February 1968 and was completed in April 1968.

In most instances, the surveys involved the study of the operations of two or more crews for an elapsed time period of two weeks. Rather than make a random survey of a large number of crews for short time periods of one or two days, the operations of a few well-chosen crews were studied for a longer time period (two weeks).

TABLE 1

SUMMARY OF COLLECTION PRACTICES
SELECTED CITIES AND PRIVATE FIRMS

Collection Agency	A	B	C	D	X	Y
Residential Refuse Collected	Combined	Combined	Combined	Combustible Rubbish (less garbage)	Combined	Combined
Quantity Limit	No Limit	No Limit	No Limit	No Limit	No Limit	No Limit
Collection Location	Curb or Alley	Curb or Alley	Curb or Alley	Curb-side	Curb or Alley	Curb or Alley
Container Size						
Max. Vol (Gal)	20-40	20-45	32	30	45	45
Max. Wt (Lb)	60	80	75	70	70	70
Collection Frequency (Per Week)	1	1	1	1	2	2
Truck Size (Cu Yd)	35	25	20	24	20	20
Crew Size	1	2	3	1	1	2,1
State	California	California	California	California	California	California

TABLE II

SUMMARY OF COLLECTION PRACTICES
SUPPLEMENTAL CITIES AND PRIVATE FIRMS

Collection Agency	1	2	3	4	5	6
Residential Refuse Collected	Mixed	Combined	Combined	Combined	Combined, less garden refuse	Combined
Quantity Limit	No Limit	No Limit	No Limit	No Limit	No Limit	No Limit
Collection Location	Curb-side	Back-yard	Curb or Alley	Curb or Alley	Back-yard	Curb or Alley
Container Size						
Max. Vol (Gal)	2 cu ft	27	30	50	--	32
Max. Wt (Lb)	100	75	--	80	--	50
Collection Frequency (Per Week)	2-6	1	2	1	1	2
Truck Size (Cu Yd)	16	20	17	25	25	20,25
Crew Size	3	3,4	2	2	3	3,2
State	New York	Ohio	Cali-fornia	Cali-fornia	Cali-fornia	Cali-fornia

TABLE II (Continued)

Collection Agency	7	8	9	10	11	12
Residential Refuse Collected	Combined, less garden refuse	Combined, less garden refuse	Combustible (less garbage)	Combustible (less garbage)	Combined	Combined, less garden refuse
Quantity Limit	No Limit	No Limit	--	No Limit	No Limit	—
Collection Location	Curb/ Alley or Backyard	Curb or Alley	Curb or Alley	Back-yard	Curb or Alley	Back-yard
Container Size						
Max. Vol (Gal)	--	30	--	--	--	32
Max. Wt (Lb)	--	75	--	--	--	100
Collection Frequency (Per Week)	1	2	1&2	2	1	2
Truck Size	Varies	20	25	25	25	20
Crew Size	5	3	5	4	3,2	4,5
State	Ohio	Arizona	British Columbia	Florida	California	Georgia

TABLE II (Continued)

Collection Agency	13	14
Residential Refuse Collected	Combined	Combined
Quantity Limit	No Limit	No Limit
Collection Location	Curb or Alley	Curb or Alley
Container Size		
Max. Vol (Gal)	--	--
Max. Wt (Lb)	--	--
Collection Frequency (Per Week)	1	2
Truck Size	20	20
Crew Size	4	3
State	Illinois	Pennsyl-vania

Short term surveys of a collection crew's operations, especially those involving detailed time studies, may temporarily affect the work rate of the crew. Such short term effects are probably nullified when the same crew is studied over a longer period of time.

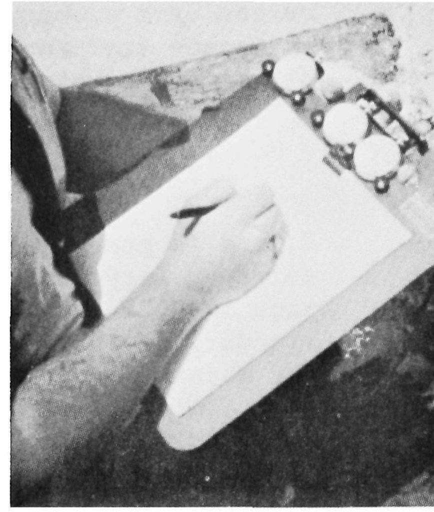
The field survey was conducted by Company staff who followed and recorded the collection operations of a single crew during the entire work day during each day of the two-week survey series. Normally, one crew was studied for the first week and a different crew for the second week. At each service stop, the number and type of containers, collection time, the travel time to the next stop, and the elapsed time and its cause for any measurable delays were noted. Examples of such delays were lost time due to tagging illegal containers, operation of the packer cycle at the stop, cleanup of spilled refuse containers, and so forth. Many other delays could not be recorded due to their extremely short duration or difficulty in determining the precise moment they began. This category would include the effect of a parked car, wiping off perspiration, removing lids from containers, and numerous other occurrences. Supplemental video tape studies were used to measure this type of lost time.

To facilitate the use of the data forms and to record the incremental collection and travel times for each stop, timing boards typically used for industrial time and motion studies were employed. Photograph I illustrates the timing board which enables accurate recording of the times of consecutive operations; for example, the collection of refuse from one collection stop and the travel to the next collection stop.

Routes selected for detailed field study in Municipalities A, B, C, and D, and Firms X and Y, were based on the following criteria: curbside collection of residential refuse (some alley collections were also included); predominately single family residential service area; average income area; minimum number of route obstructions, such as cul de sacs, dead end alleys, and construction; and level topography.

These desirable route characteristics were chosen to make technical data as comparable as possible. In addition, defining the route and service conditions enabled the data to be compared with data from other cities with similar conditions. Projections of results to other common practices, such as backyard collection, are included in a later section of this report.

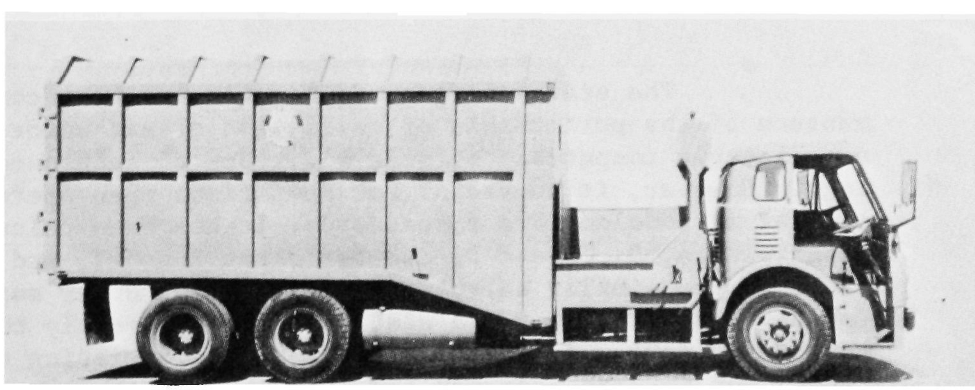
Typical crews were selected for detailed study following discussions with collection system managers. When available, prior records of crew performance were consulted to aid in crew selections. The nature and general purpose of the survey was explained to the crews, and their support in obtaining meaningful results was requested. Crews were instructed to complete their routes in a normal manner. A copy of the data for each day of the detailed field surveys is enclosed as a separate Attachment A to this report.



PHOTOGRAPH I.
FIELD SURVEY
TIMING BOARD

PHOTOGRAPH II
EQUIPMENT - MUNICIPALITY B

PHOTOGRAPH III
EQUIPMENT - MUNICIPALITY C.



PHOTOGRAPH IV.
EQUIPMENT - MUNICIPALITY A

Each day's survey data for a particular crew was summarized on the data summary form included as Appendix B. Copies of the data summaries are provided in separate Attachment B and were the basis for detailed analysis to evaluate refuse collection practices.

3. Results - Field Surveys

The field survey data is summarized in Tables III, IV, and V, and is graphically presented in Figures 1 through 26. Table III contains summary information on the mean quantity of refuse per service stop and the estimate of its standard deviation. The estimate of the standard deviation of the load mean quantity of refuse per service stop was obtained by the following procedure: the total number of services collected (SC) in each truck load of net weight (W) was determined. The load mean quantity of refuse per service stop ($\bar{q}$) for each load was calculated from the following:

$$(\bar{q})_i = \frac{W_i}{(SC)_i} \qquad i = 1, 2..n, \text{ load number}$$

The mean refuse quantity per service stop ($\bar{Q}$) for each field survey period and for the composite was calculated from the following:

$$\bar{Q} = \frac{\sum_{i=1}^{n} W_i}{\sum_{i=1}^{n} (SC)_i}$$

The standard deviation of the load mean refuse quantity per stop was calculated from the following:

$$S = \sqrt{\frac{\sum_{i=1}^{n} (\bar{q}i - \bar{Q})^2}{n}}$$

The statistic man-minutes/ton has been commonly used as a measure of the performance of collection crews; unfortunately, it is not directly comparable between all types of refuse collection methodology. However, it is useful for comparison when operations using similar methodology are considered. It has been calculated for Municipalities A, B, C, and D, and for Firms X and Y, and is tabulated in Table IV. A similar calculation for certain other surveys is shown in Table V. In order for the statistic to be directly comparable between the systems surveyed, the mean and standard deviation of the quantity of refuse per service stop and the distribution of containers would have to be equal. Table IV and Figures 1 and 2 illustrate the similarity in

TABLE III

FIELD SURVEY SUMMARY DATA - DETAILED SURVEYS

Collection Agency / Season	Mean Refuse Quantity (Lb/Stop)	Load Standard Deviation (Lb/Stop)	Surveys Included
Municipality A			
Summer	80.75	8.43	8/67
Winter	65.1	11.74	12/67
Spring	88.23	11.46	4/68
Composite	77.11	14.25	
Municipality B			
Summer	83.02	6.47	8/67
Winter	81.70	16.87	1/68 - 2/68
Spring	78.86	15.62	4/68
Composite	81.25	13.38	
Municipality C			
Summer	71.99	4.60	8/67
Winter	69.04	9.16	1/68
Spring	76.28	20.25	3/68 - 4/68
Composite	73.20	14.07	
Municipality D			
Winter	53.86	6.71	11/67 - 2/68
Spring	59.35	9.03	3/68 - 4/68
Composite	56.87	8.74	
Firm X			
Winter	81.19	12.41	10/67
Spring	93.68	25.71	2/68 - 4/68
Composite	88.07	22.19	
Firm Y			
Winter	56.26	11.91	11/67 - 2/68
Spring	66.38	23.28	4/68
Composite	60.54	18.26	

TABLE IV

ROUTE MAN-MINUTES PER TON

Agency	Crew Size	Mean Man-Minutes/Ton	Standard[1] Deviation
Municipality A	1	26.25	4.64
Municipality B	2	43.00	9.89
Municipality C	3	63.53	7.33
Municipality D	1	37.57	8.70
Firm X	1	33.84	7.36
Firm Y	1	39.05	10.37

(1) Standard Deviation of Mean Man-Minutes/Ton

TABLE V

FIELD SURVEY SUMMARY DATA - ABBREVIATED SURVEYS (1)

City or Private Firm	Quantity of Refuse Per Collection Stop (Lb)		Man-Minutes Per Ton	
	Mean	SD	Mean	SD(2)
1	33.71	5.10	119.95	25.99
3	62.60	23.22	113.96	36.05
4 (one-man)	70.12	4.81	25.66	2.77
4 (two-man)	82.44	10.31	38.18	5.11
5 (P) (3)	110.19	--	103.34	--
6	126.28	12.86	115.81	34.28

(1) Field Surveys conducted for one week or less.

(2) Standard Deviation of the Mean.

(3) Private Firm

Municipalities A, B, and C and, to a lesser degree, in Municipality D and Firms X and Y. To remove the effect of haul time, volumetric capacity of equipment, and other factors affecting each municipality and private firm, man-minutes/ton were calculated only for the time interval during which the crews were on the collection route, including travel time between stops. Break time, lunch time, and other nonproductive periods were excluded from the calculations. The inclusion of nonproductive time, haul, and disposal time, would all have the effect of increasing each respective man-minute per ton figure; however, to a much greater degree for the two- and three-man crew for reasons previously noted.

Figures 1 and 2 illustrate the statistical distribution of cans and total items at the service stop, respectively. Figures 3 through 7 illustrate the approximate statistical distribution of the collection time for one through five cans respectively from the curbside location for the three indicated municipal collection studies. These data were determined following a total of six weeks of detailed field survey in each city. The plots were constructed by joining the mid-interval points of histograms constructed from the field data.

As indicated by these figures, the disparity in average collection time between crews for equal numbers of cans increases as the number of cans increases. This would be the expected result since the second or third crew man becomes more effective when there are two or more cans at the service stop. However, note the similarity in the shape of the curves regardless of the number of cans. Typically, the driver member of the two-man crew is instructed to leave the cab to aid the loader only if three or more items are to be loaded at a service stop. In the three-man operation surveyed, the driver always remained in the cab of the truck. Therefore, assuming personnel and route factors were equal, the only differences expected between crews in Figures 3 and 4 would be those due to the work procedure at the service stop.

In both the two- and three-man crews, the receiving hopper and the loader are located at the rear of the packer truck. For the one-man crew, the surveyed operation used a side-loading packer equipped with right-hand drive. Photographs II, III, and IV illustrate collection operations in each instance.

Figure 8 illustrates the overall average collection time per stop, based on all field study data, regardless of the number of items at the stop.

Figure 9 illustrates the average collection time for one through seven cans at the curb location by Municipalities A, B, and C. A least squares line has been calculated to represent the data. Figure 9 is, therefore, a plot representing the mean time values from Figures 3 through 7. The data indicates that for the conditions and crews sampled in these three municipalities, the increased rate of handling

AGENCY	MEAN NO. OF CANS PER STOP
Municipality A	2.45
Municipality B	2.65
Municipality C	2.70

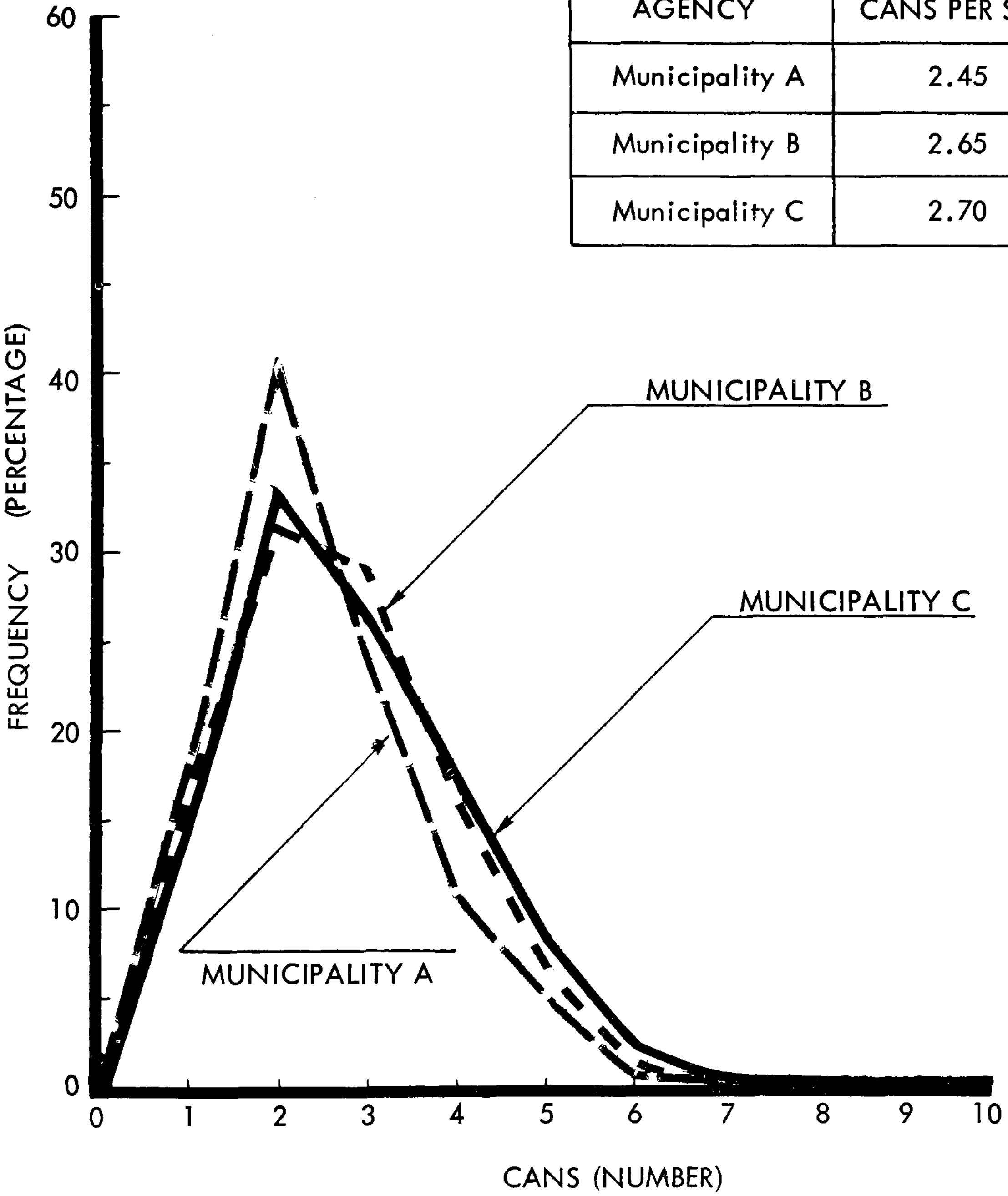


FIGURE 1
DISTRIBUTION
CANS
AT COLLECTION STOP

AGENCY	MEAN NO. OF ITEMS PER STOP
Municipality A	3.40
Municipality B	3.55
Municipality C	4.01

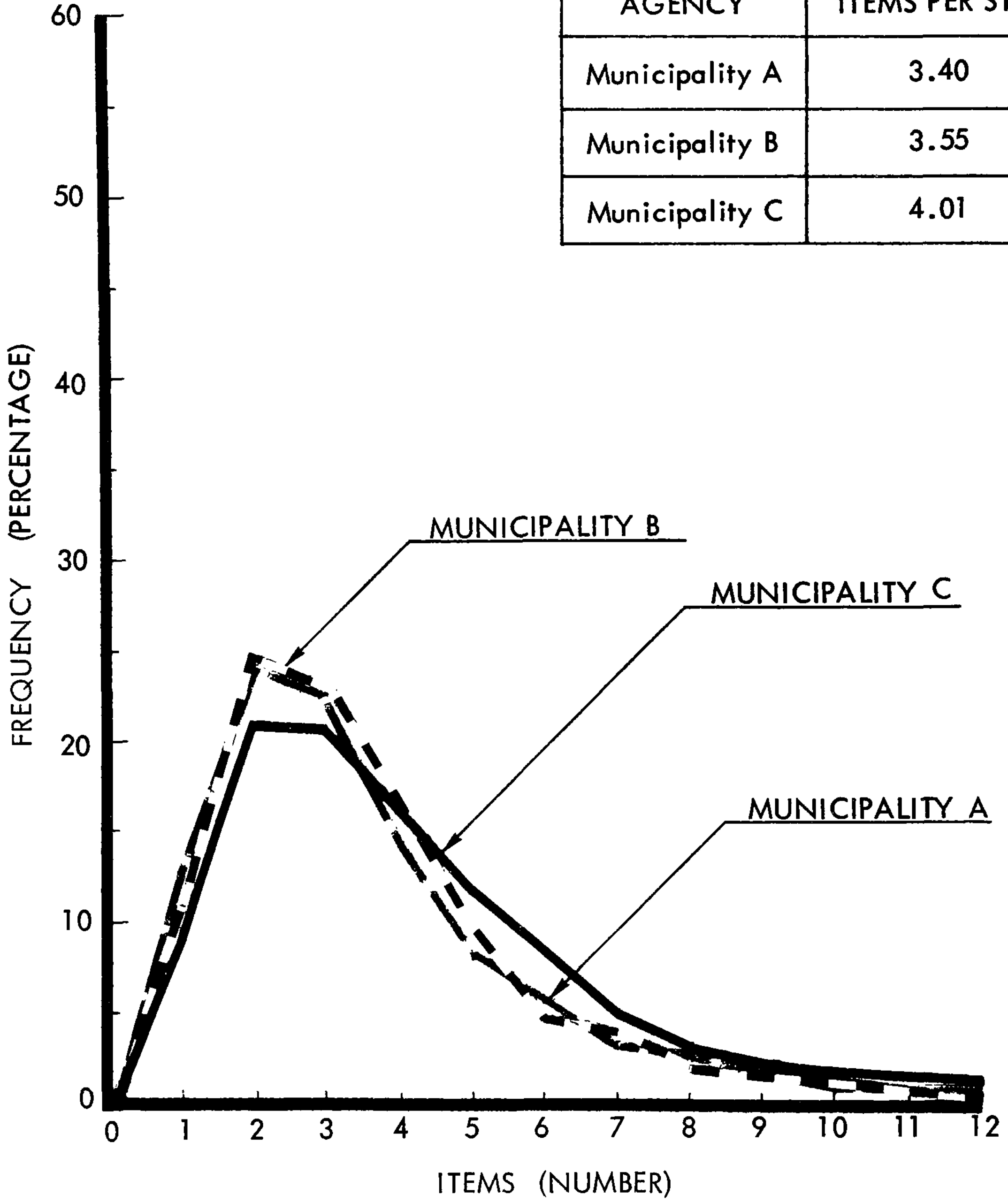
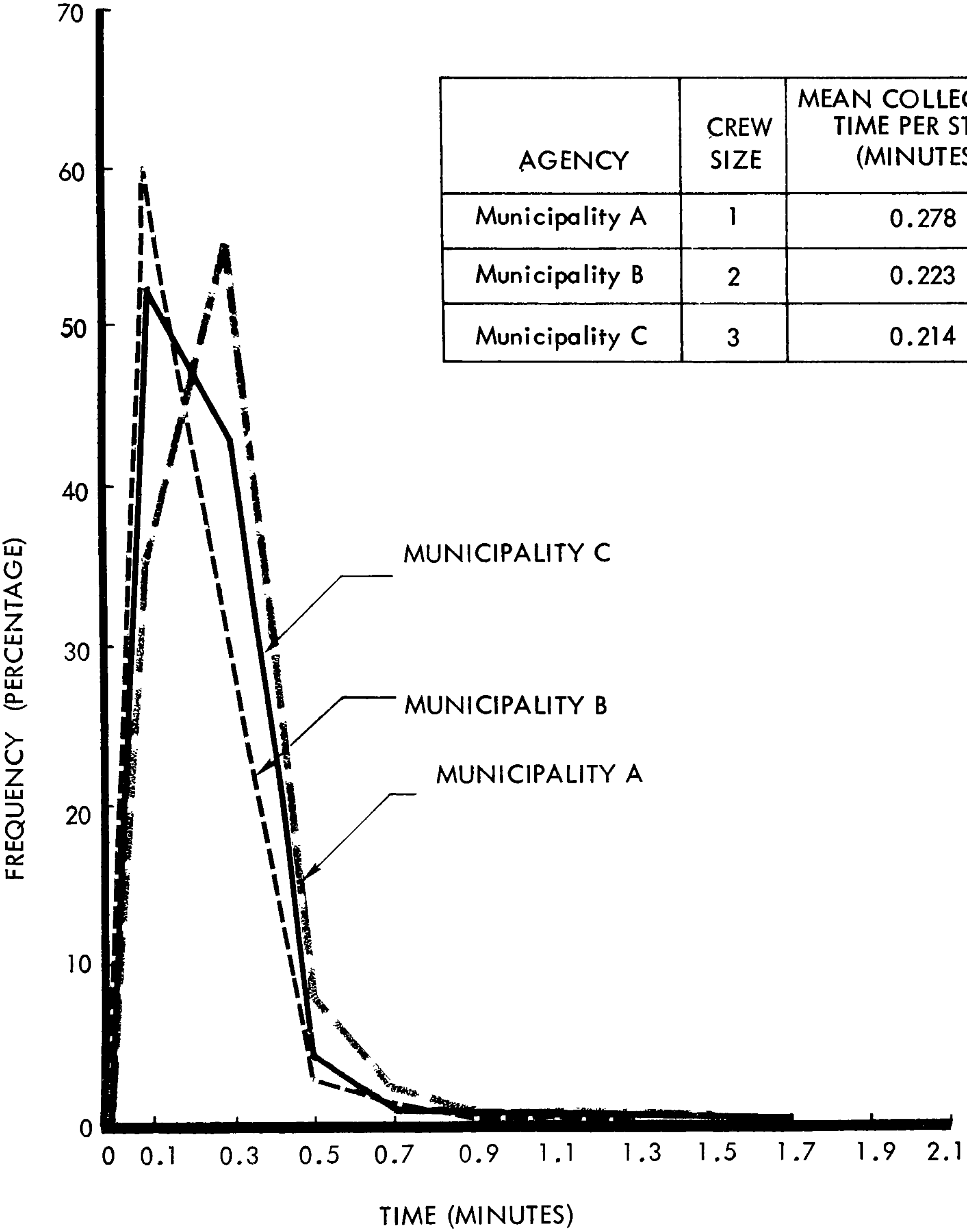
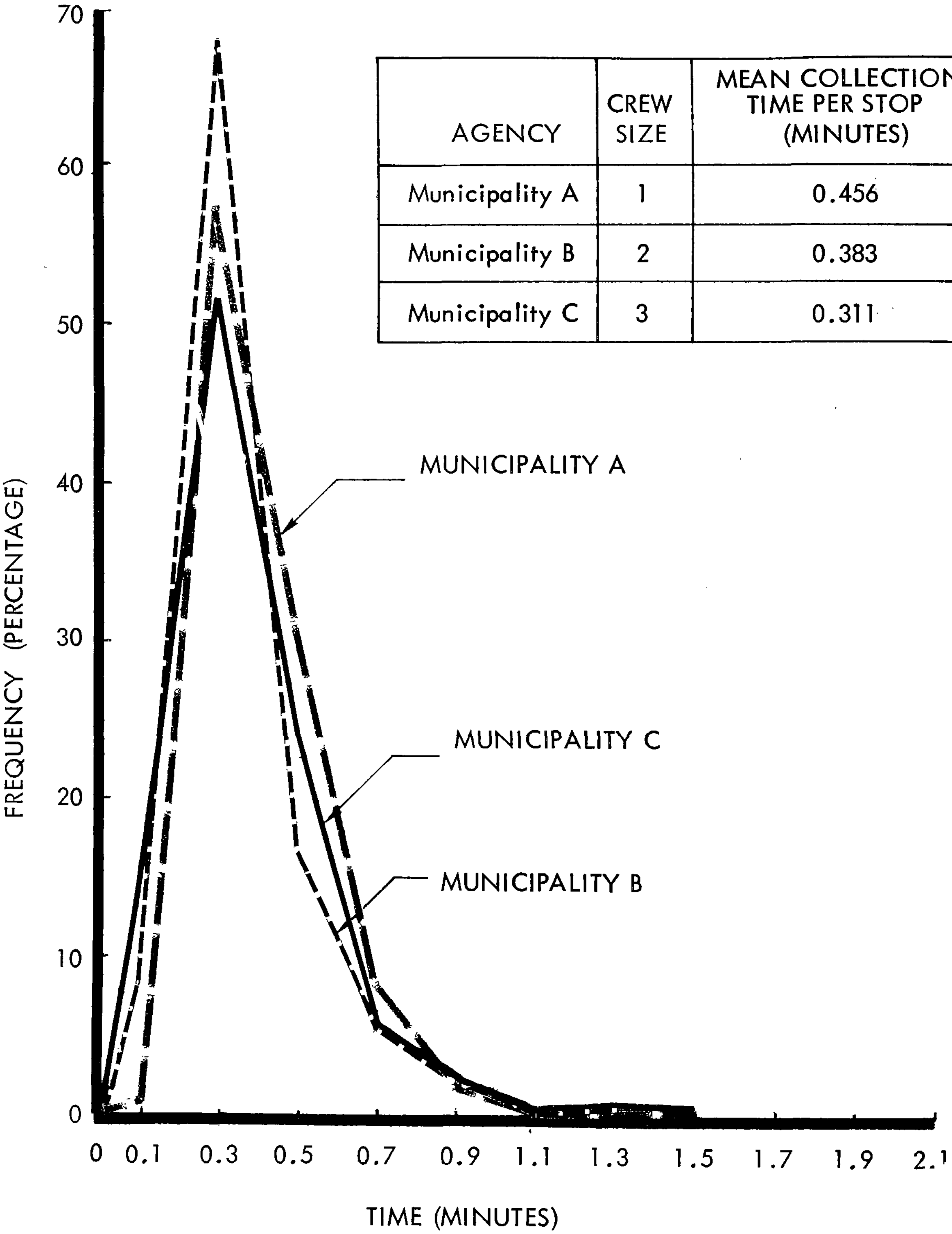


FIGURE 2
DISTRIBUTION
ITEMS AT COLLECTION STOP



AGENCY	CREW SIZE	MEAN COLLECTION TIME PER STOP (MINUTES)
Municipality A	1	0.278
Municipality B	2	0.223
Municipality C	3	0.214

FIGURE 3
DISTRIBUTION
COLLECTION TIME
ONE CAN



AGENCY	CREW SIZE	MEAN COLLECTION TIME PER STOP (MINUTES)
Municipality A	1	0.456
Municipality B	2	0.383
Municipality C	3	0.311

FIGURE 4
DISTRIBUTION
COLLECTION TIME
TWO CANS

AGENCY	CREW SIZE	MEAN COLLECTION TIME PER STOP (MINUTES)
Municipality A	1	0.620
Municipality B	2	0.558
Municipality C	3	0.454

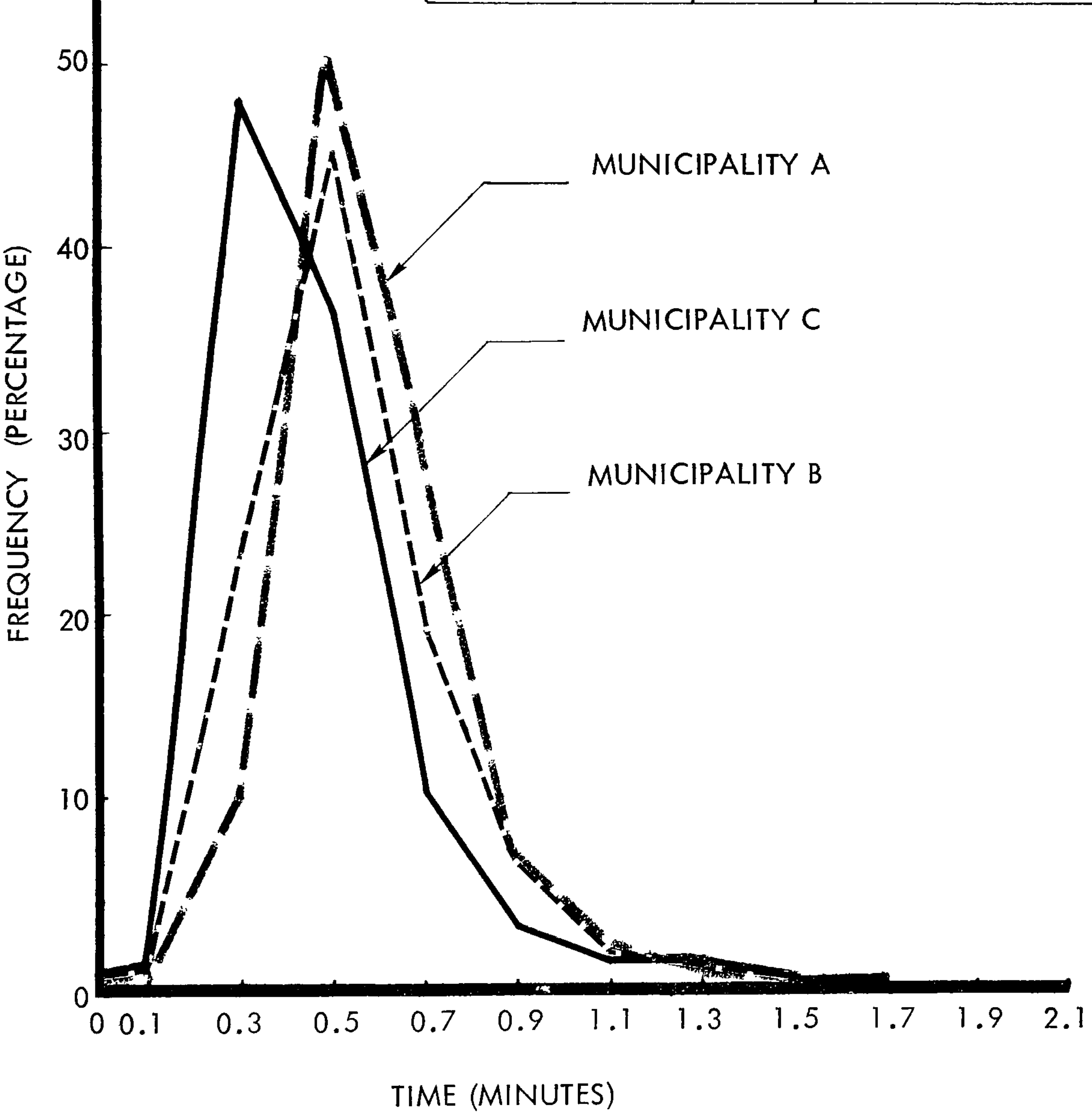


FIGURE 5
DISTRIBUTION
COLLECTION TIME
THREE CANS

AGENCY	CREW SIZE	MEAN COLLECTION TIME PER STOP (MINUTES)
Municipality A	1	0.793
Municipality B	2	0.705
Municipality B	3	0.558

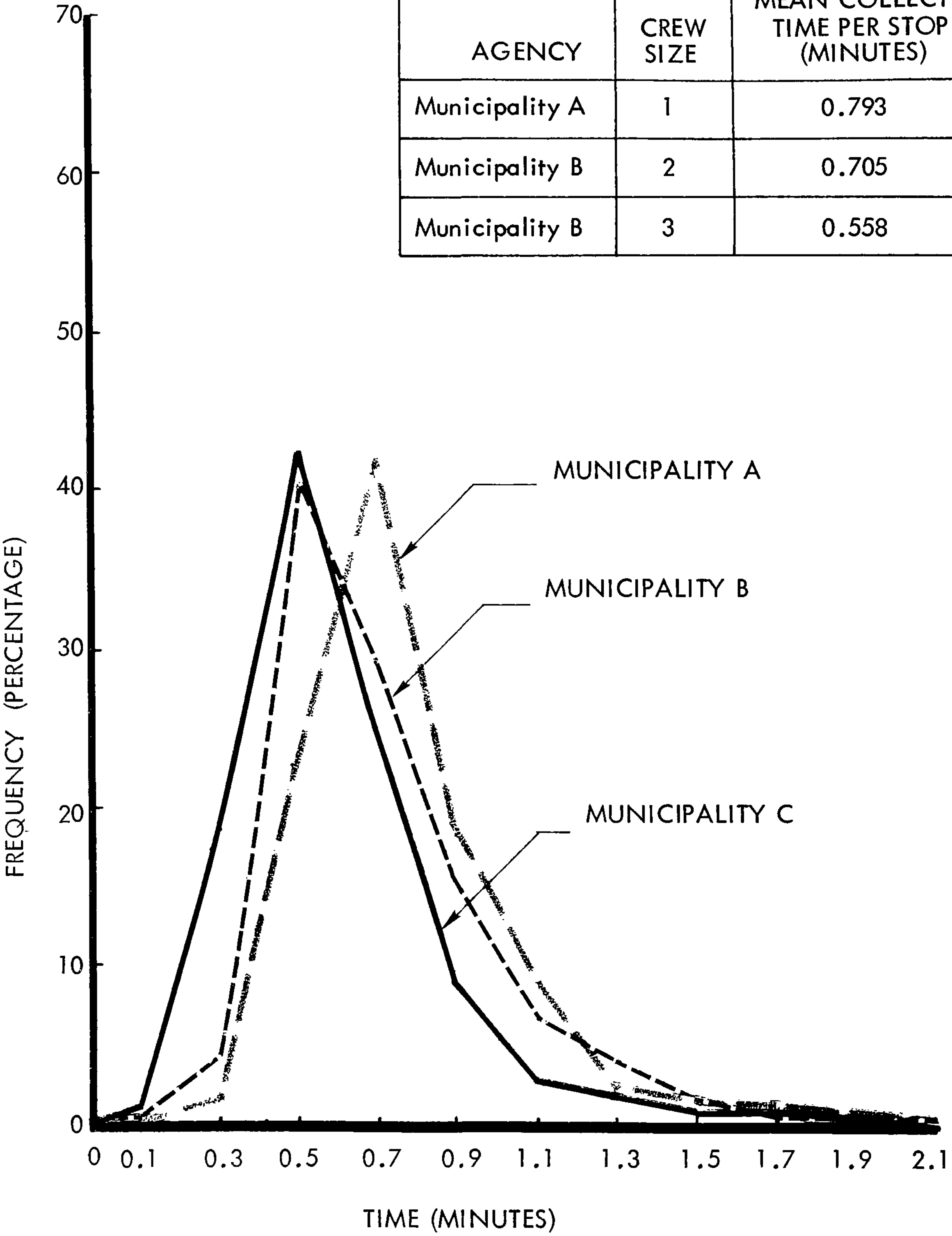
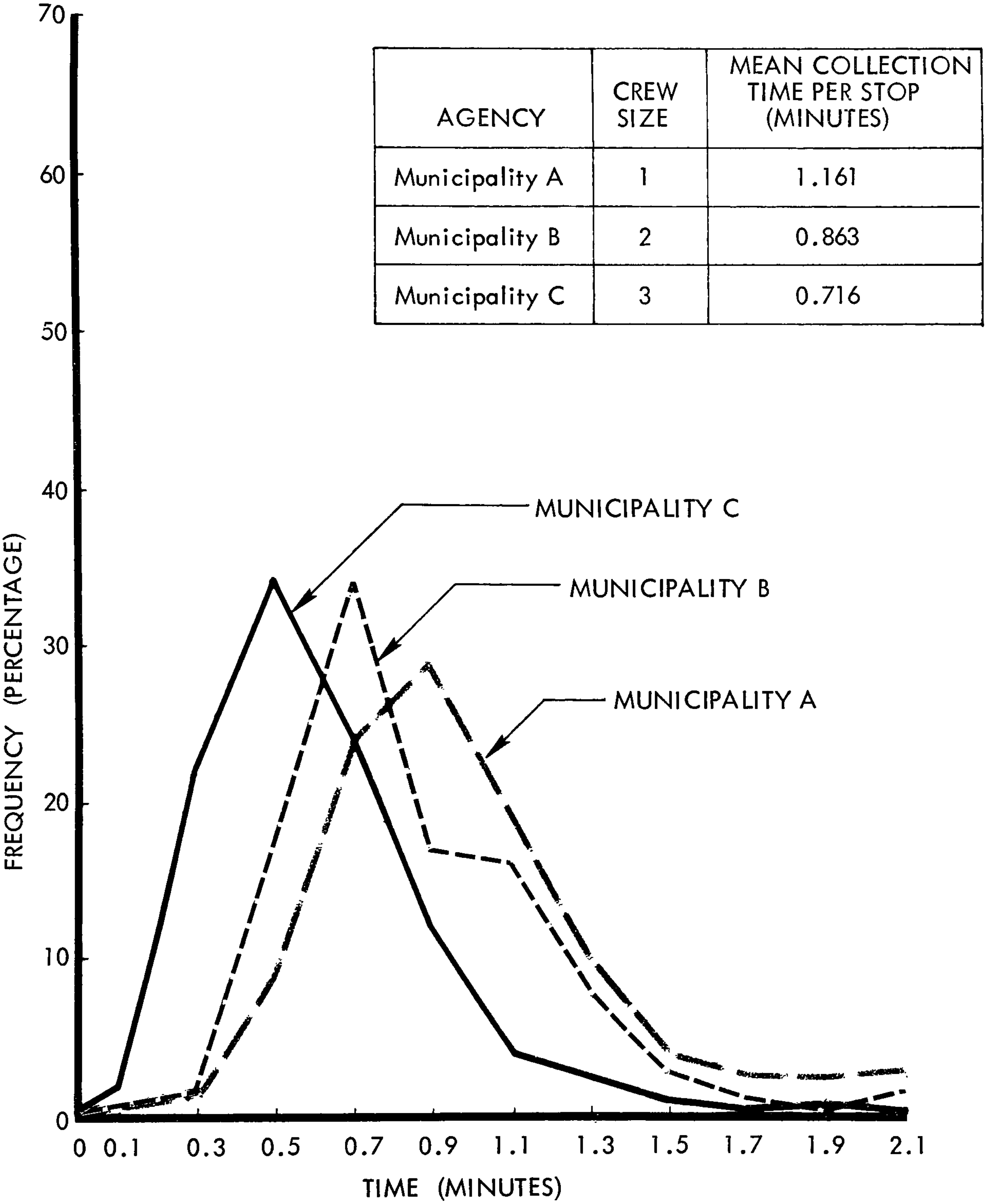
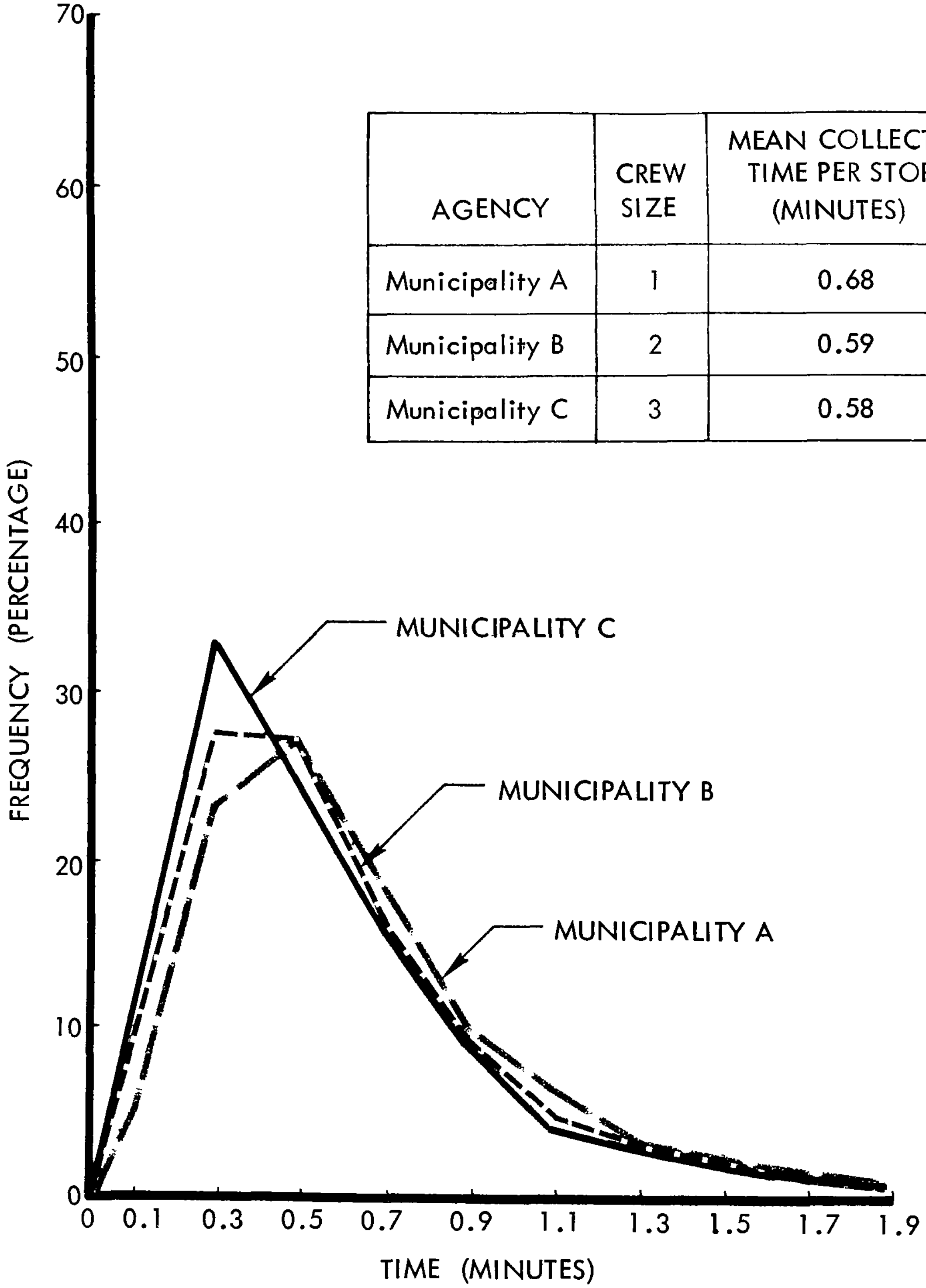


FIGURE 6
DISTRIBUTION
COLLECTION TIME
FOUR CANS



AGENCY	CREW SIZE	MEAN COLLECTION TIME PER STOP (MINUTES)
Municipality A	1	1.161
Municipality B	2	0.863
Municipality C	3	0.716

FIGURE 7
DISTRIBUTION
COLLECTION TIME
FIVE CANS



AGENCY	CREW SIZE	MEAN COLLECTION TIME PER STOP (MINUTES)
Municipality A	1	0.68
Municipality B	2	0.59
Municipality C	3	0.58

FIGURE 8
DISTRIBUTION
COLLECTION TIME
PER STOP

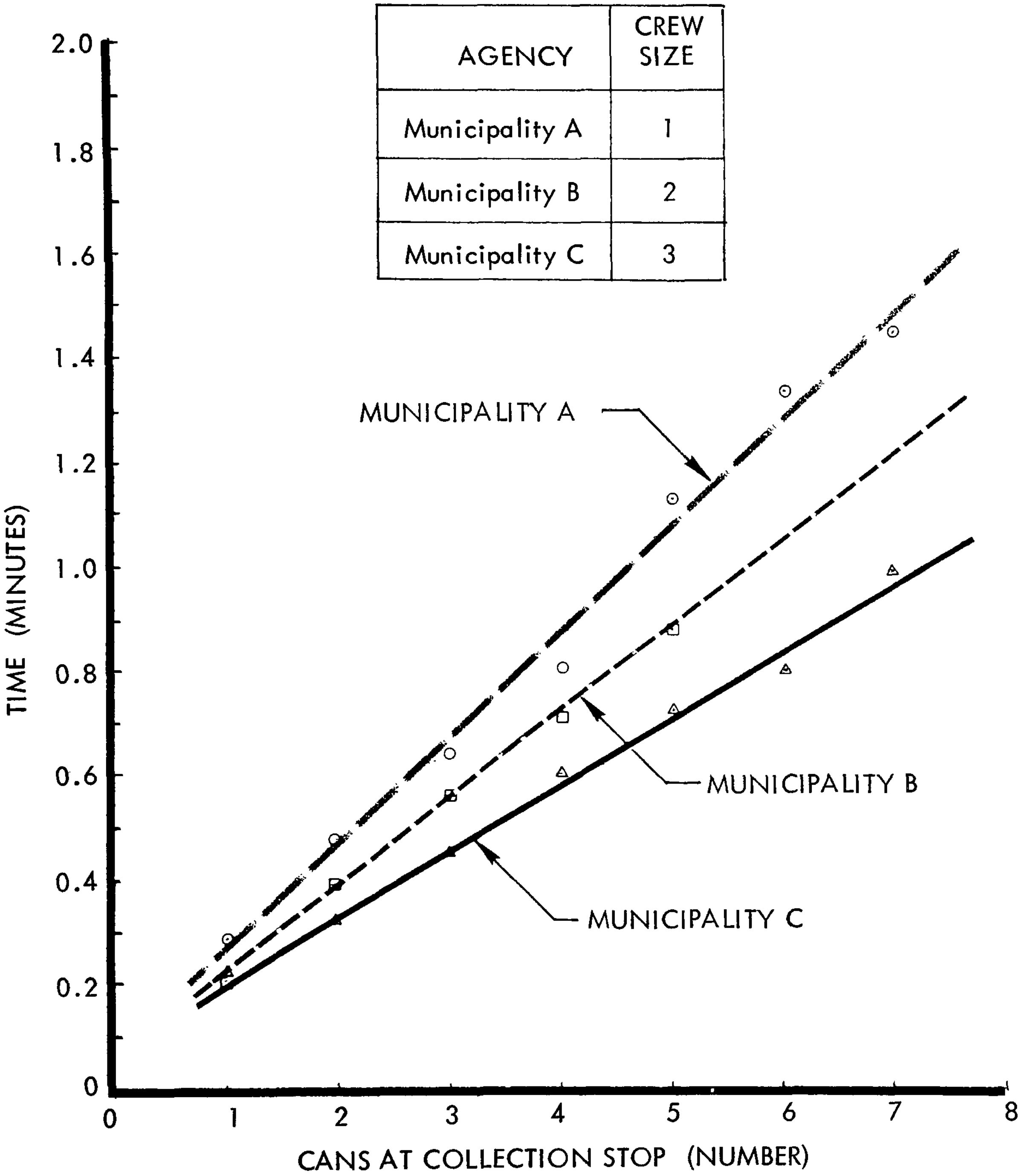


FIGURE 9
FIELD SURVEY
AVERAGE COLLECTION TIME
PER STOP

containers possible at each collection stop with multi-man crews is not sufficient to compensate for the associated increased man-hours -- double in the case of the two-man crew, and triple in the case of the three-man crew. Figure 10 is a similar plot of average collection time for disposable items.

Figure 11 illustrates the distribution of the travel time between stops. No significant difference in travel time between stops appears to result from the addition of a man who acts solely or primarily as a driver. Lot widths in the surveyed areas were about the same, averaging about 50 ft. Collection equipment participating in the studies was equipped with automatic transmission. Film studies of Municipality A indicated that the drivers consistently set the brakes and stepped from the cab before the equipment had completely stopped, which perhaps accounted for the slightly less mean travel time recorded for the municipality. Although several hundred service stops are made each day, the differences illustrated are not considered important in total time; e.g., a difference of 0.02 minutes per collection stop would only total 6 minutes per day if 300 stops were made by the crew. In efficiency comparisons using the mathematical model presented in Section D, the travel time between curbside service stops was assumed constant at 0.17 minutes.

Figures 12 through 19 illustrate the statistical distributions of cans, total items, and collection times for Firms X and Y and for Municipality D. Figures 20 through 25 illustrate the collection time per stop and the average collection time for stops composed of from one to seven cans for Municipalities 1 through 6 where the abbreviated surveys were conducted.

The following general comments can be made by studying Figures 20 through 25. Increasing the crew size usually reduces the mean collection time per stop by some amount, causing the distribution of collection time to become skewed more to the left part of the curves. Increasing the frequency of collection did not result in any apparent decrease in the collection time per stop (see Figures 20 and 21). Figure 22 illustrates the differences in collection time occurring between a backyard and curbside set-out system. Other variable factors between the two Municipalities may have contributed to their differences; however, a considerable range would be expected. Figure 23 illustrates differences that do occur between two municipalities, even though from Table II, the operation appears to be somewhat similar. Figure 24 illustrates the curbside collection time for a four-man crew. Comparison with Figure 9 indicates that only minor time differences occur between the four- and the three-man crews for comparable collection stops, thus continuing the trend shown on Figure 8. Figure 25 illustrates the collection time for stops composed of from 1 to 7 cans by Municipalities 4 and 3. Note the apparent similarity between the two crews of Municipality 4 with the same size crews of Municipalities A and B on Figure 9.

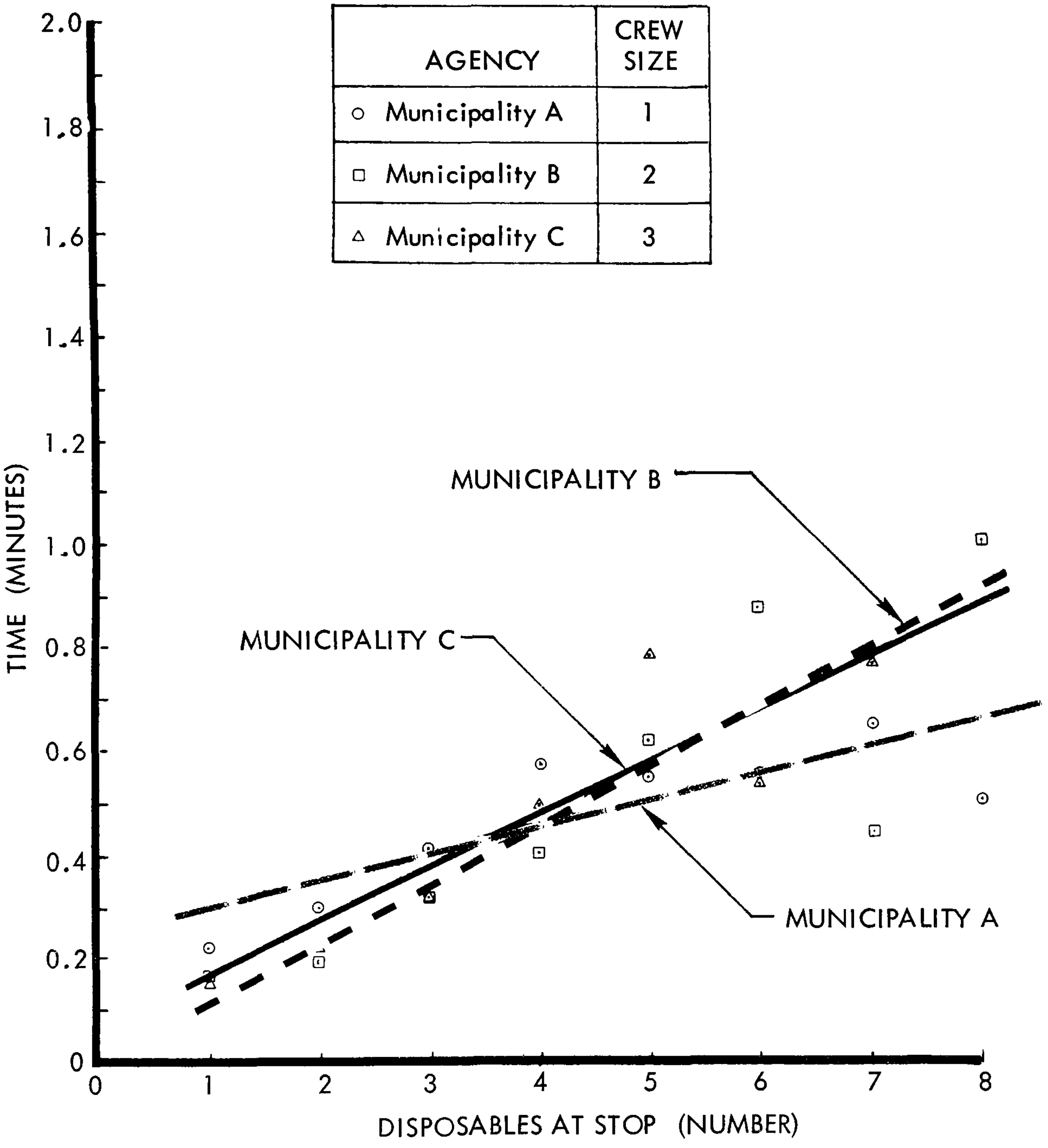


FIGURE 10
FIELD SURVEY
AVERAGE COLLECTION TIME
DISPOSABLES ONLY

AGENCY	CREW SIZE	MEAN TRAVEL TIME PER STOP (MINUTES)
Municipality A	1	0.153
Municipality B	2	0.170
Municipality C	3	0.174

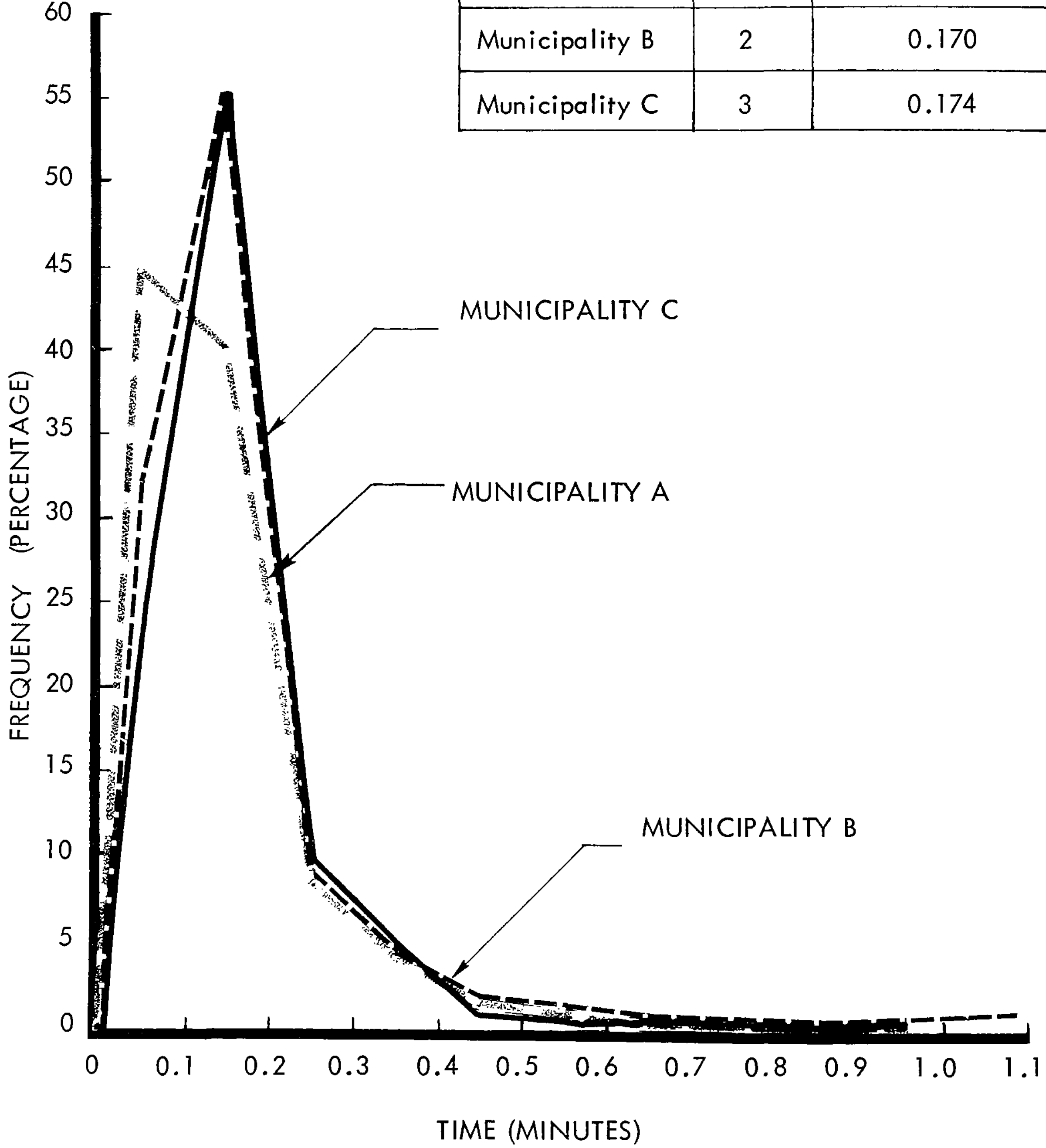


FIGURE 11
DISTRIBUTION
TRAVEL TIME BETWEEN
COLLECTION STOPS

AGENCY	MEAN NO. OF CANS PER STOP	CREW SIZE
Municipality D	1.79	1

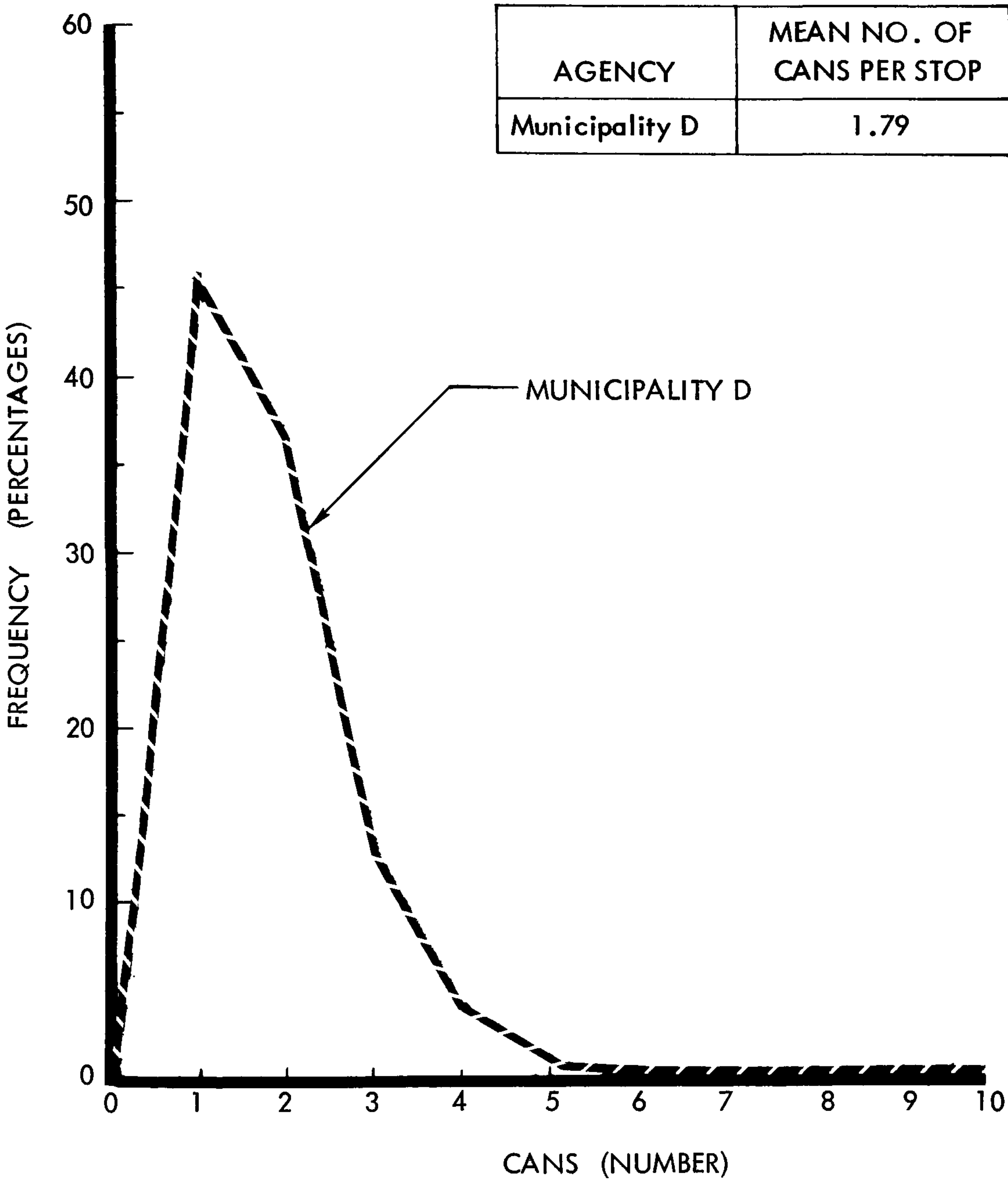
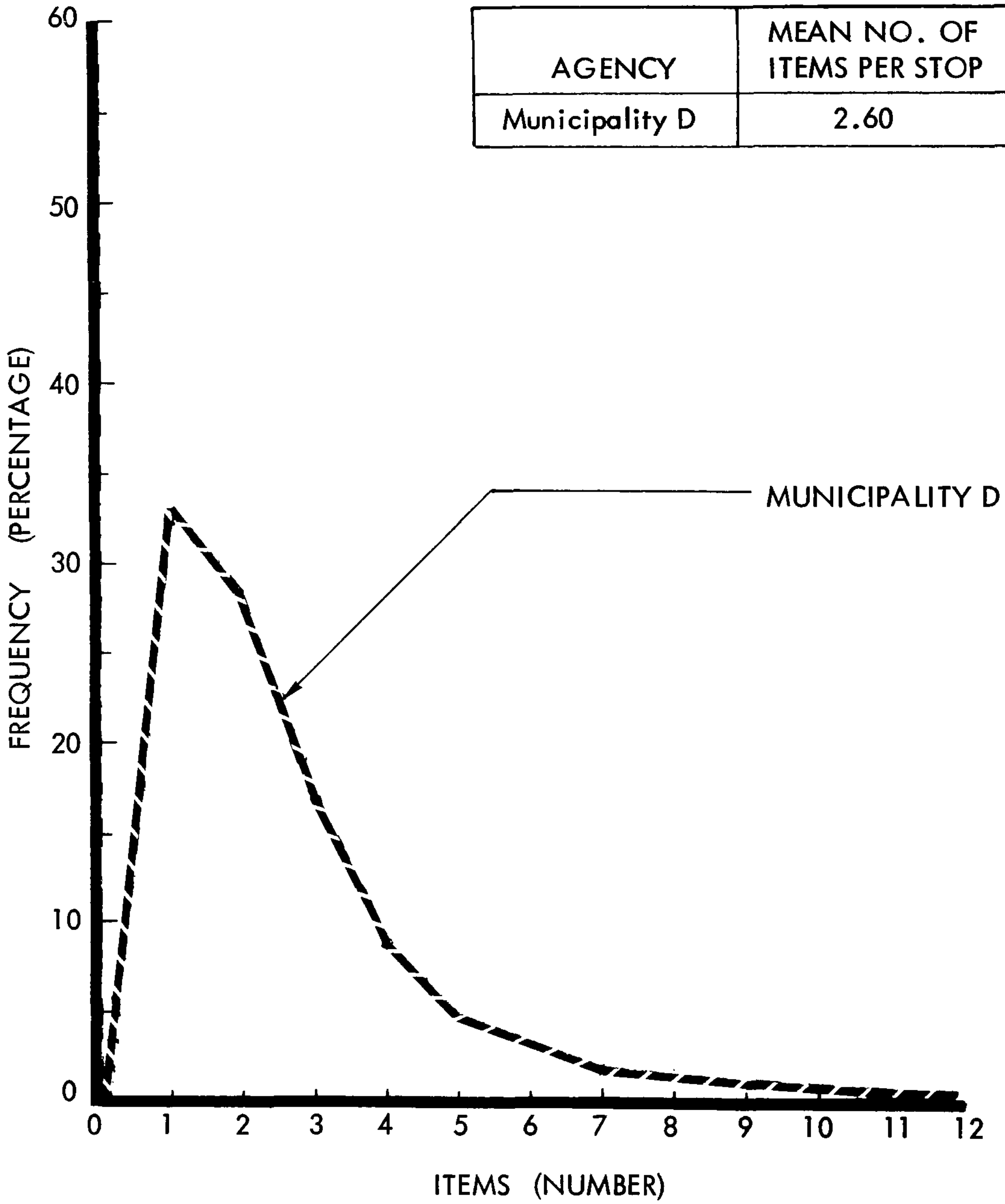
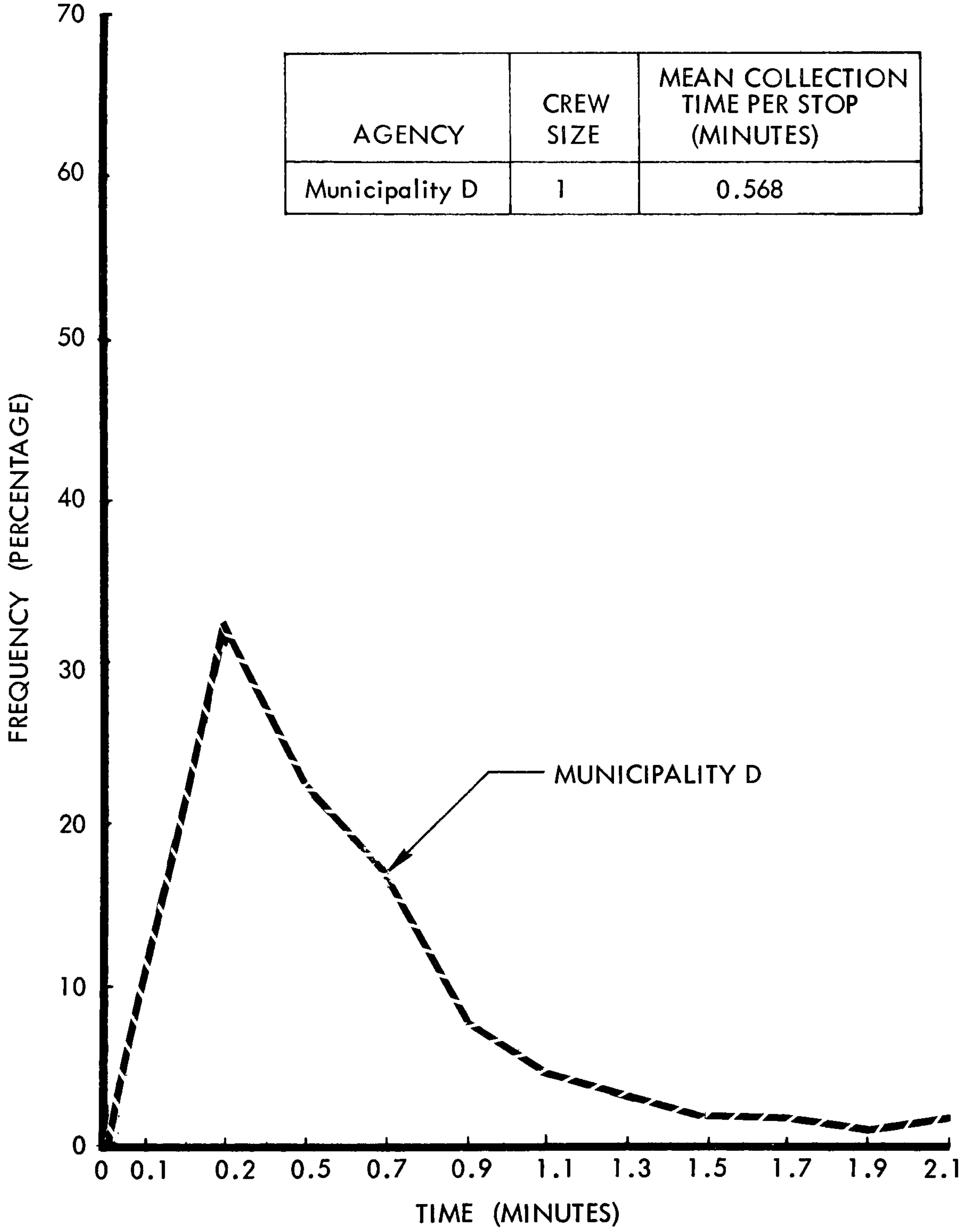


FIGURE 12
DISTRIBUTION
CANS
AT COLLECTION STOP



AGENCY	MEAN NO. OF ITEMS PER STOP	CREW SIZE
Municipality D	2.60	1

FIGURE 13
DISTRIBUTION
ITEMS AT COLLECTION STOP



AGENCY	CREW SIZE	MEAN COLLECTION TIME PER STOP (MINUTES)
Municipality D	1	0.568

FIGURE 14
DISTRIBUTION
COLLECTION TIME
PER STOP

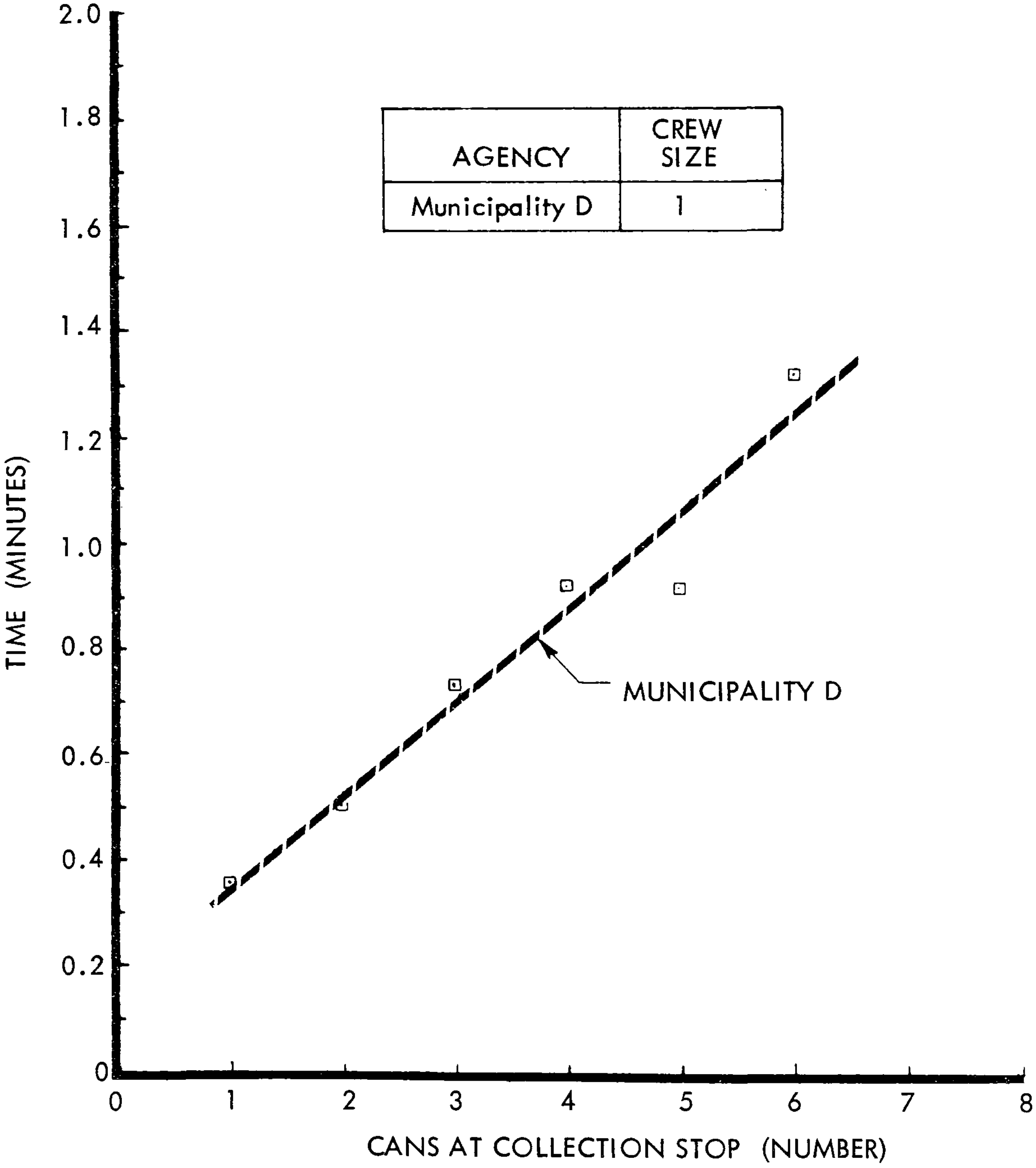


FIGURE 15
AVERAGE
COLLECTION TIME

AGENCY	MEAN NUMBER OF CANS PER STOP	CREW SIZE
Firm X	2.74	1
Firm Y	2.07	1

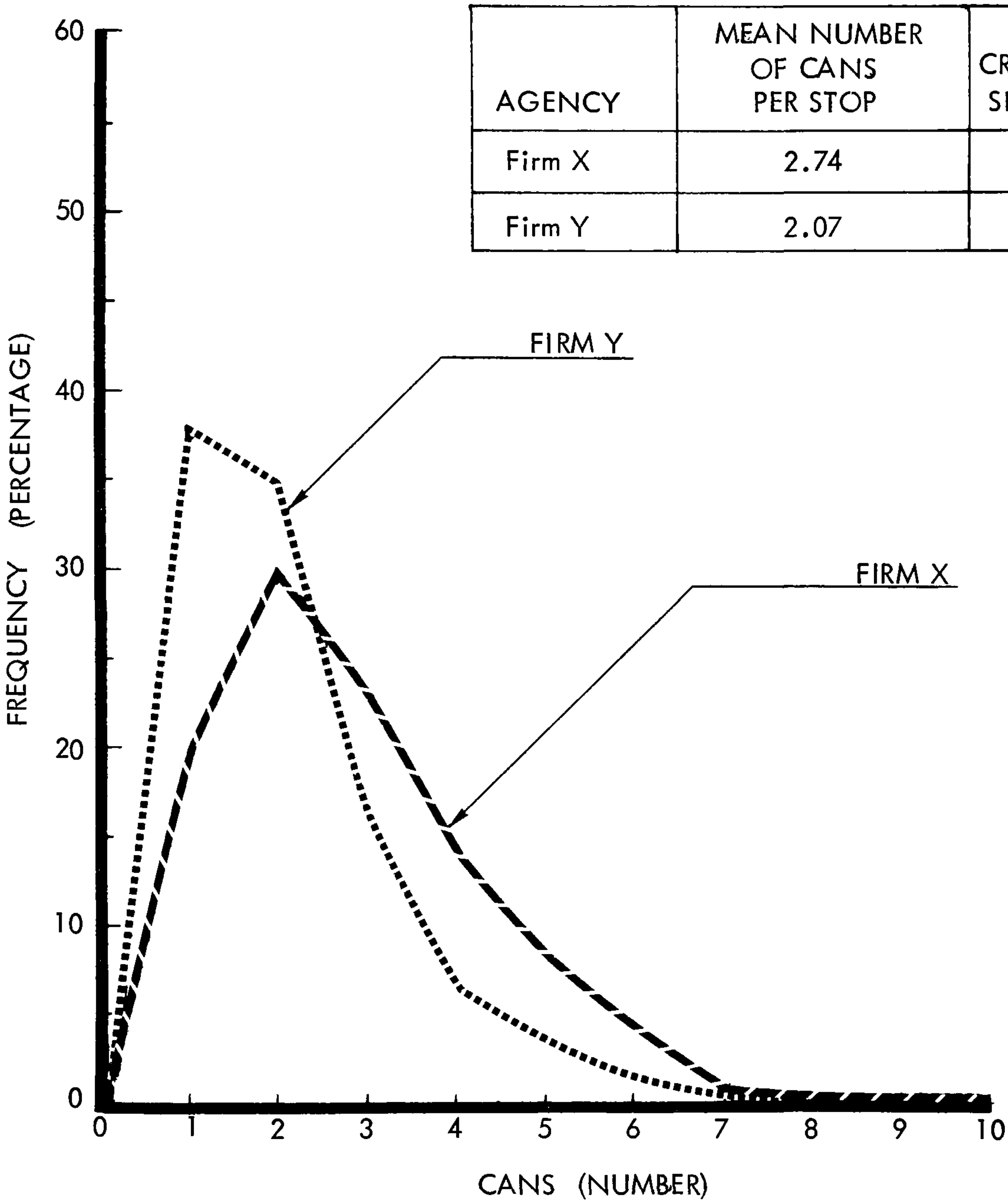
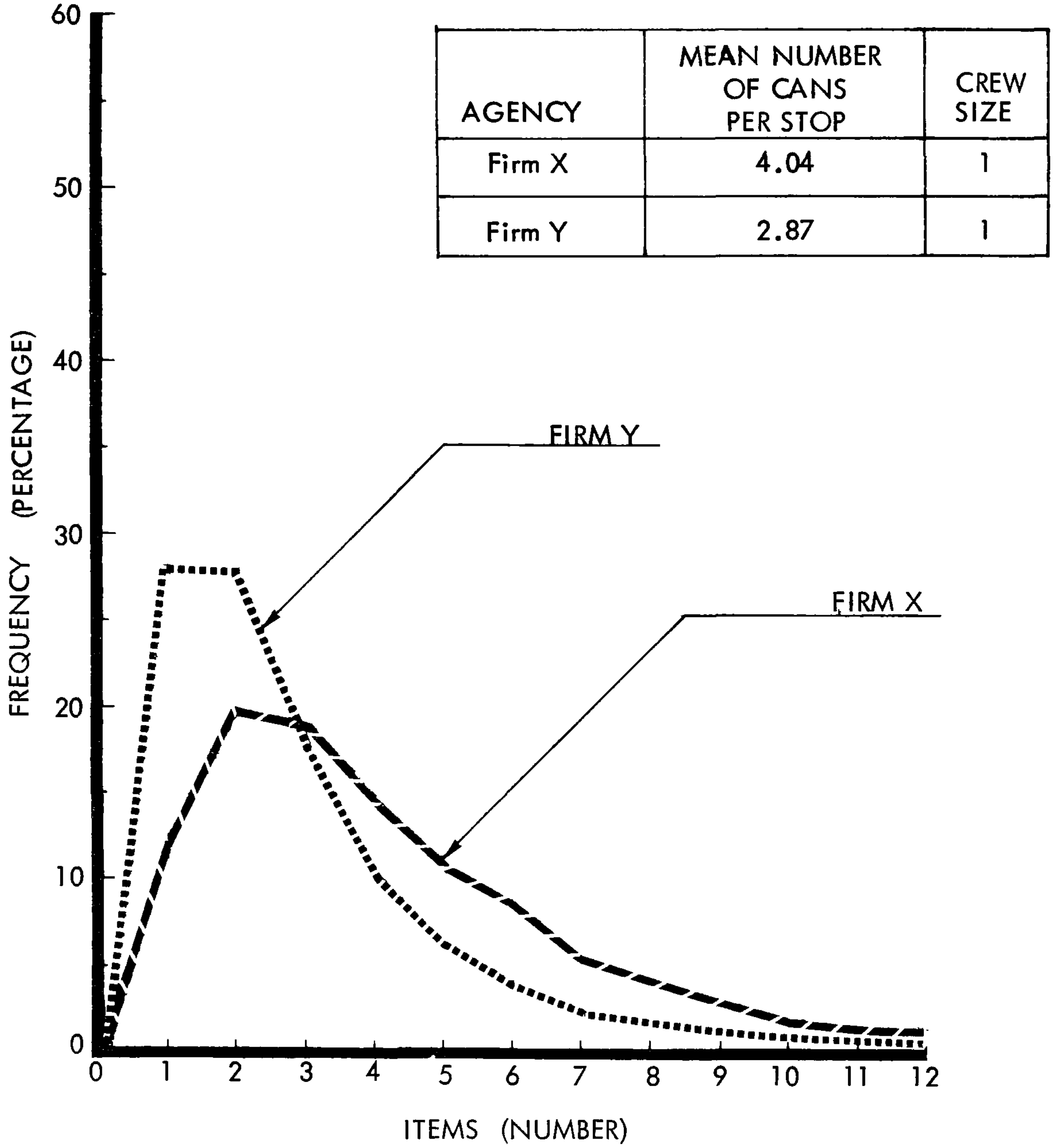
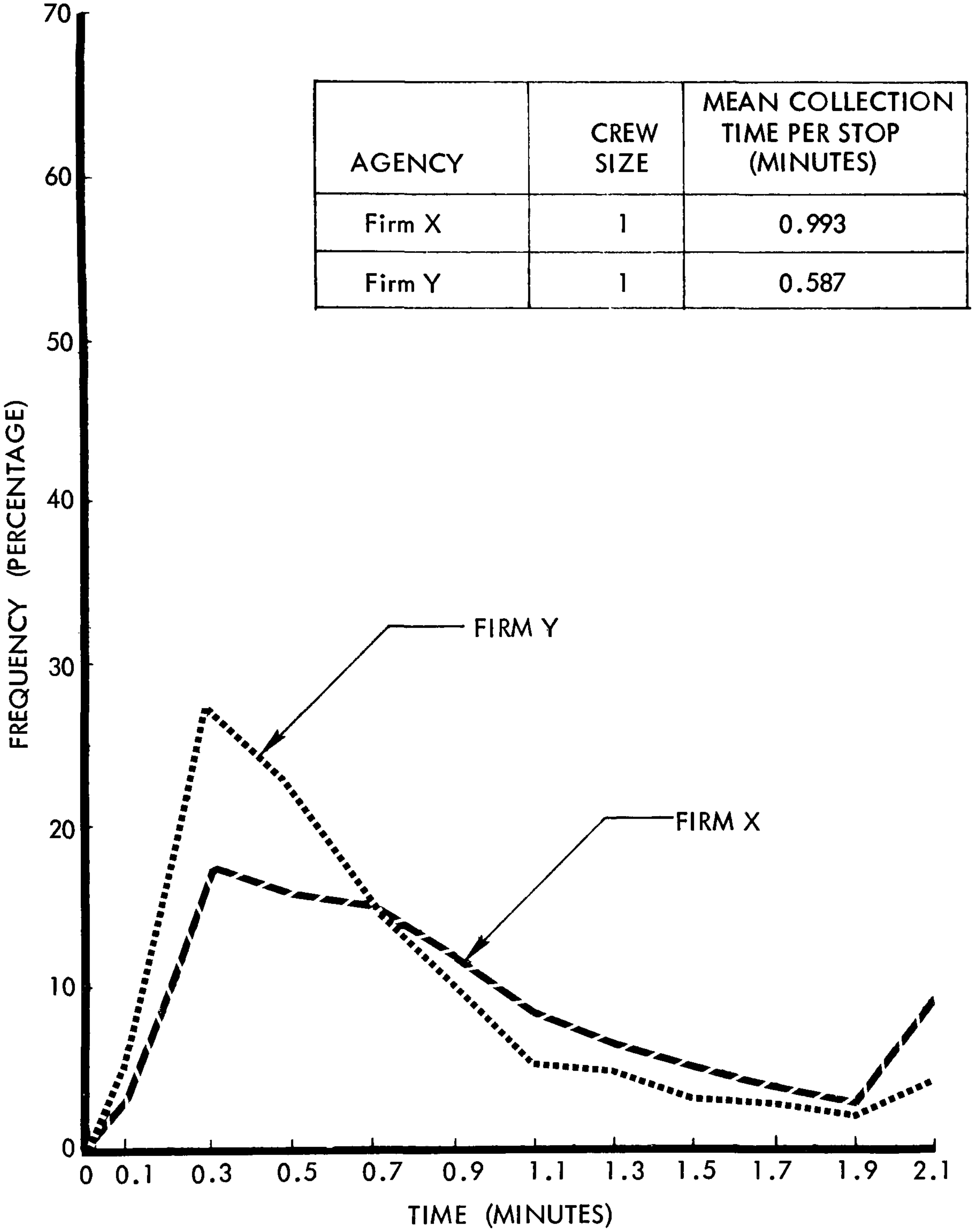


FIGURE 16
DISTRIBUTION
CANS
AT COLLECTION STOP



AGENCY	MEAN NUMBER OF CANS PER STOP	CREW SIZE
Firm X	4.04	1
Firm Y	2.87	1

FIGURE 17
DISTRIBUTION
ITEMS PER COLLECTION STOP



AGENCY	CREW SIZE	MEAN COLLECTION TIME PER STOP (MINUTES)
Firm X	1	0.993
Firm Y	1	0.587

FIGURE 18
DISTRIBUTION
COLLECTION TIME
PER STOP

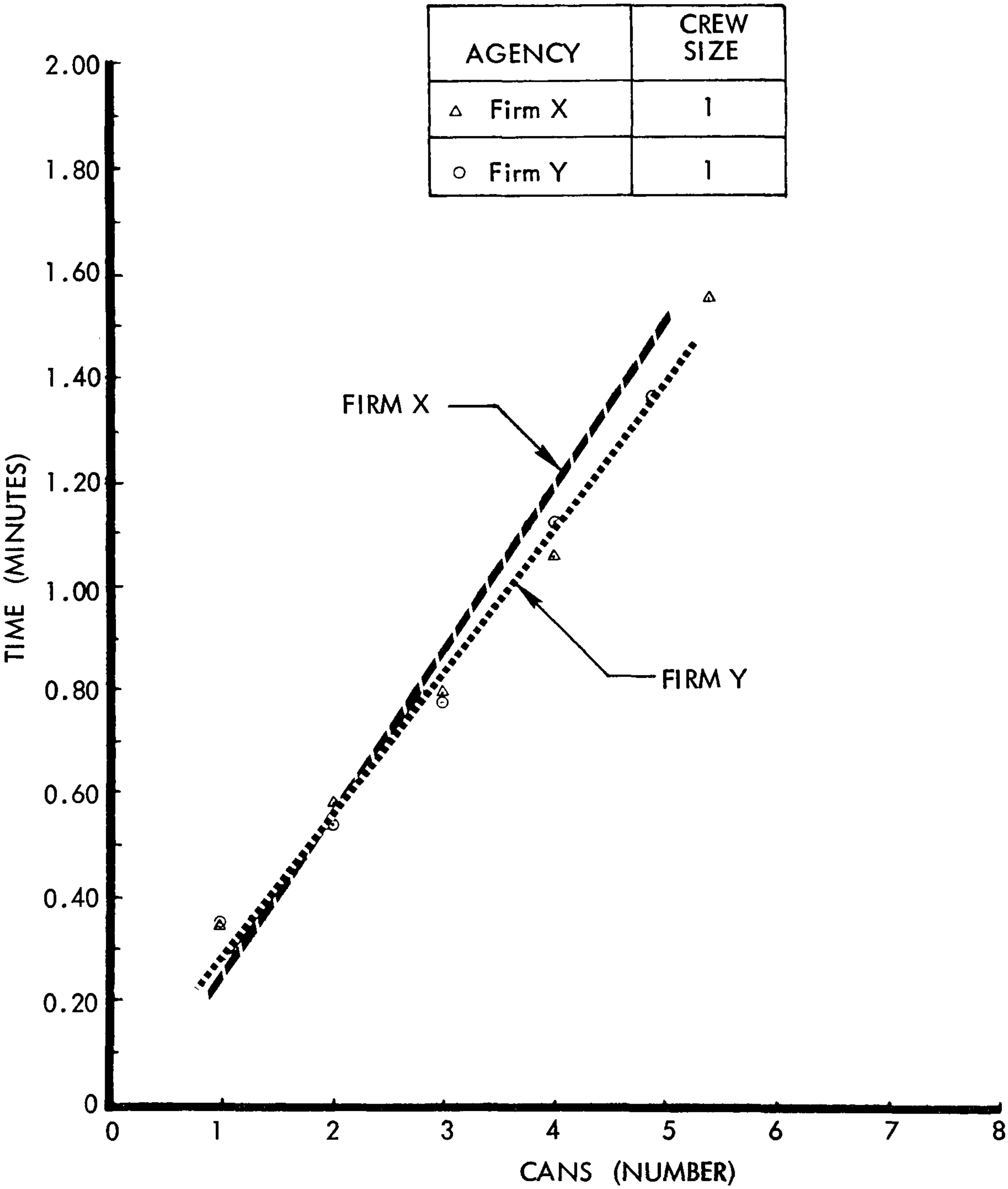


FIGURE 19
AVERAGE
COLLECTION TIME
PER STOP

AGENCY	SIZE	MEAN COLLECTION TIME PER STOP (MINUTES)
Municipality 1	3	0.531
Municipality 6	3	0.925

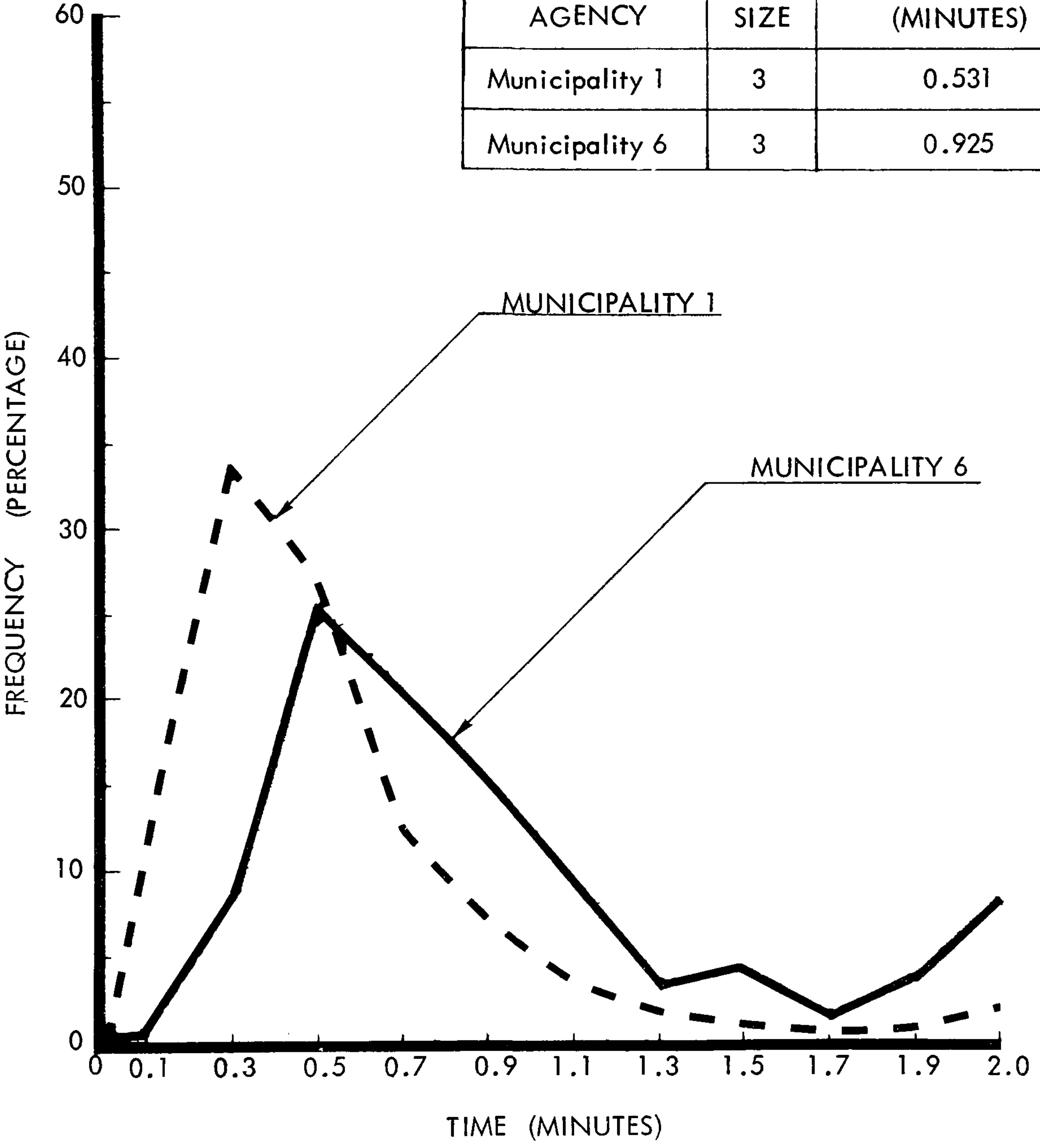


FIGURE 20
DISTRIBUTION
COLLECTION TIME
PER STOP

AGENCY	CREW SIZE	MEAN COLLECTION TIME PER STOP (MINUTES)
Municipality 3	2	0.763
Municipality 4	1	0.620
Municipality 4	2	0.491

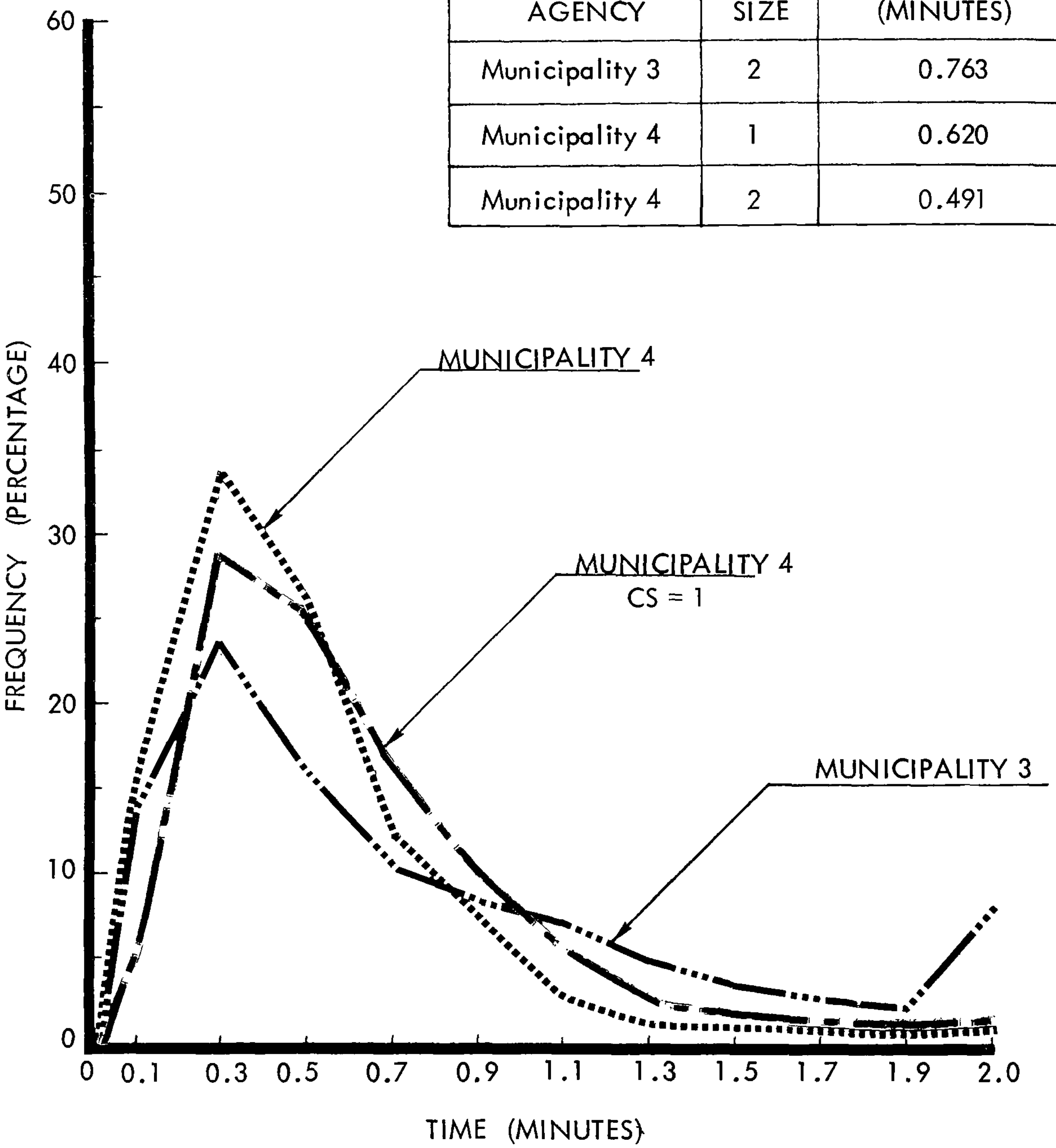
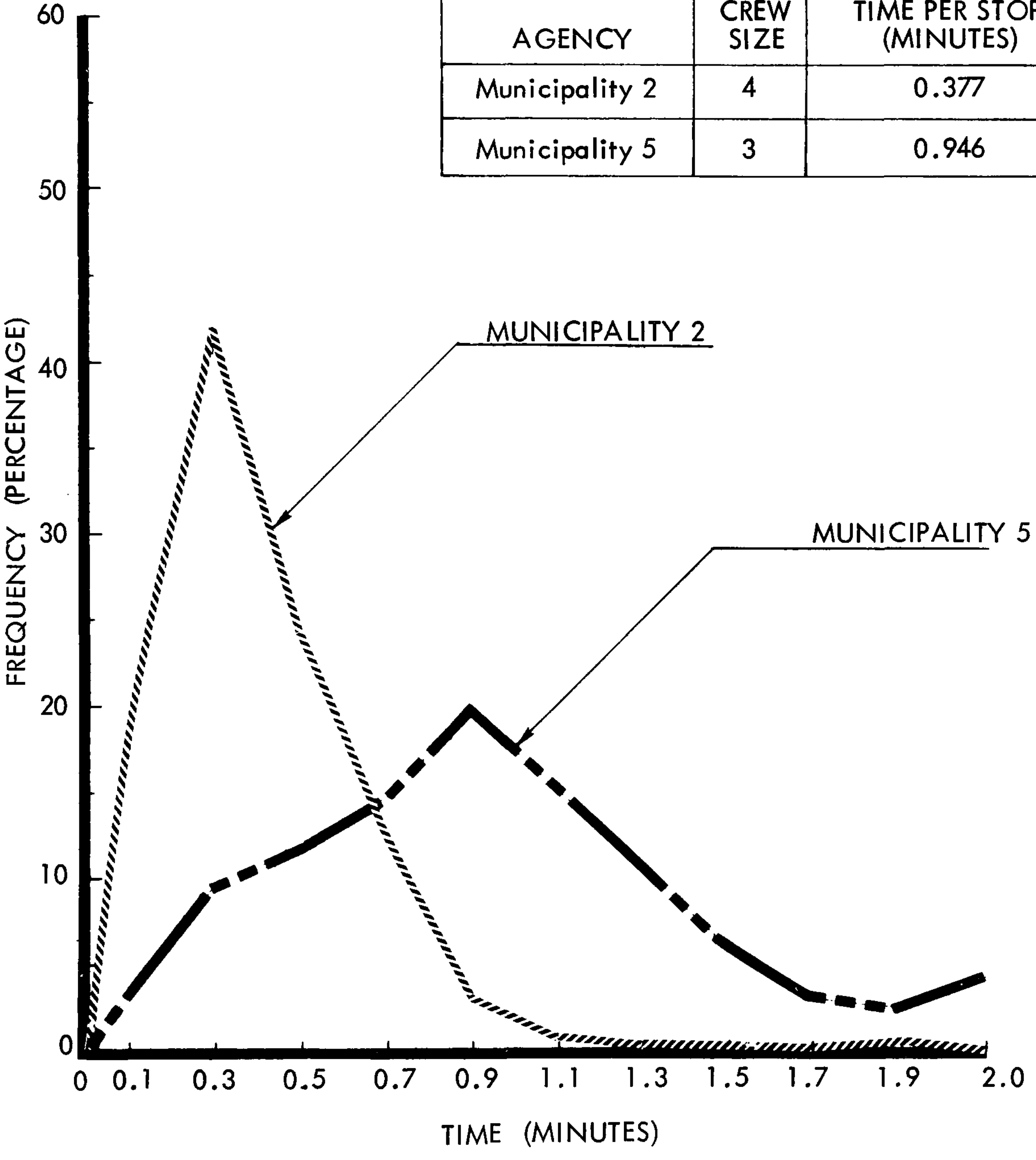


FIGURE 21
DISTRIBUTION
COLLECTION TIME
PER STOP



AGENCY	CREW SIZE	MEAN COLLECTION TIME PER STOP (MINUTES)
Municipality 2	4	0.377
Municipality 5	3	0.946

FIGURE 22
DISTRIBUTION
COLLECTION TIME
PER STOP

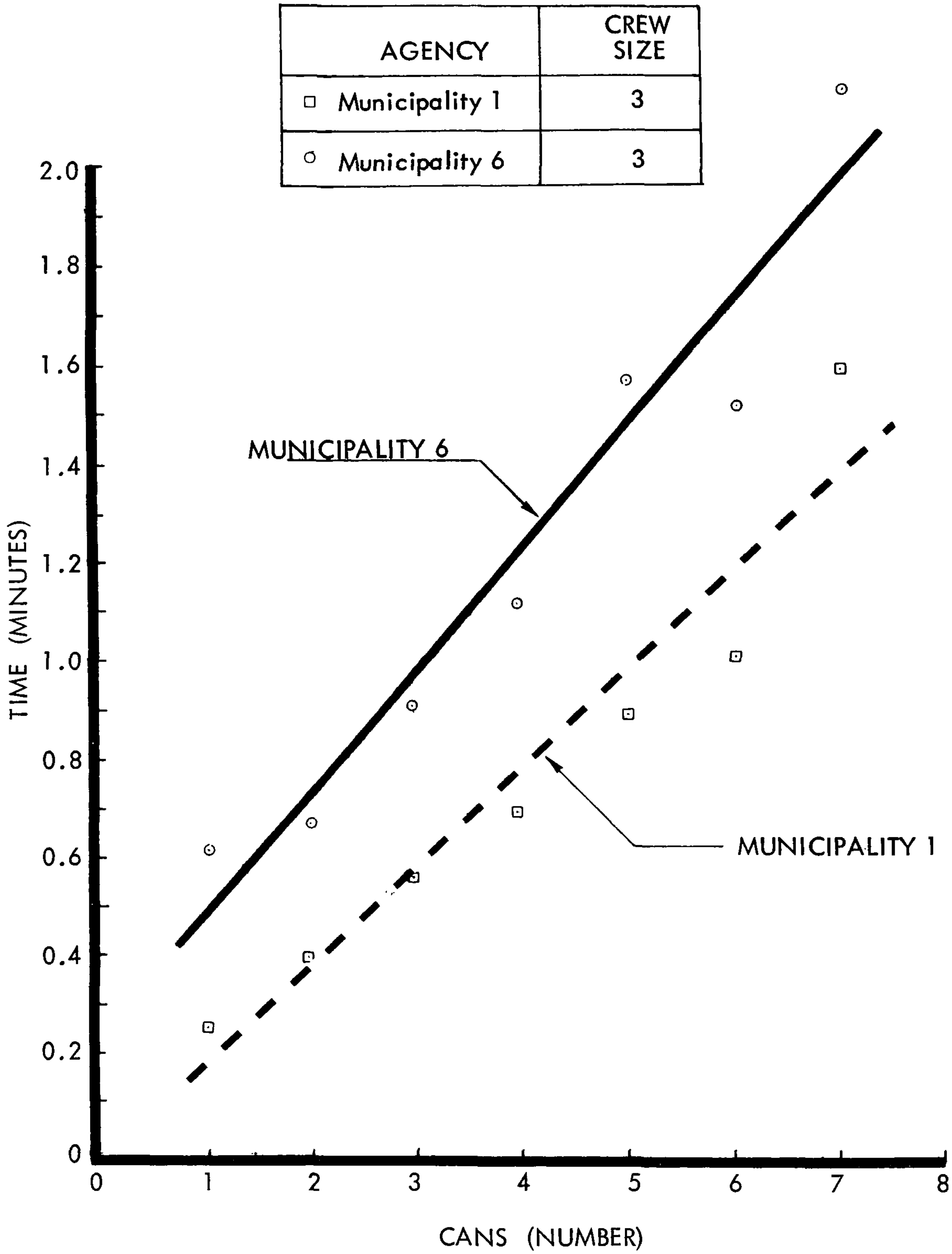


FIGURE 23
AVERAGE
COLLECTION TIME
PER STOP

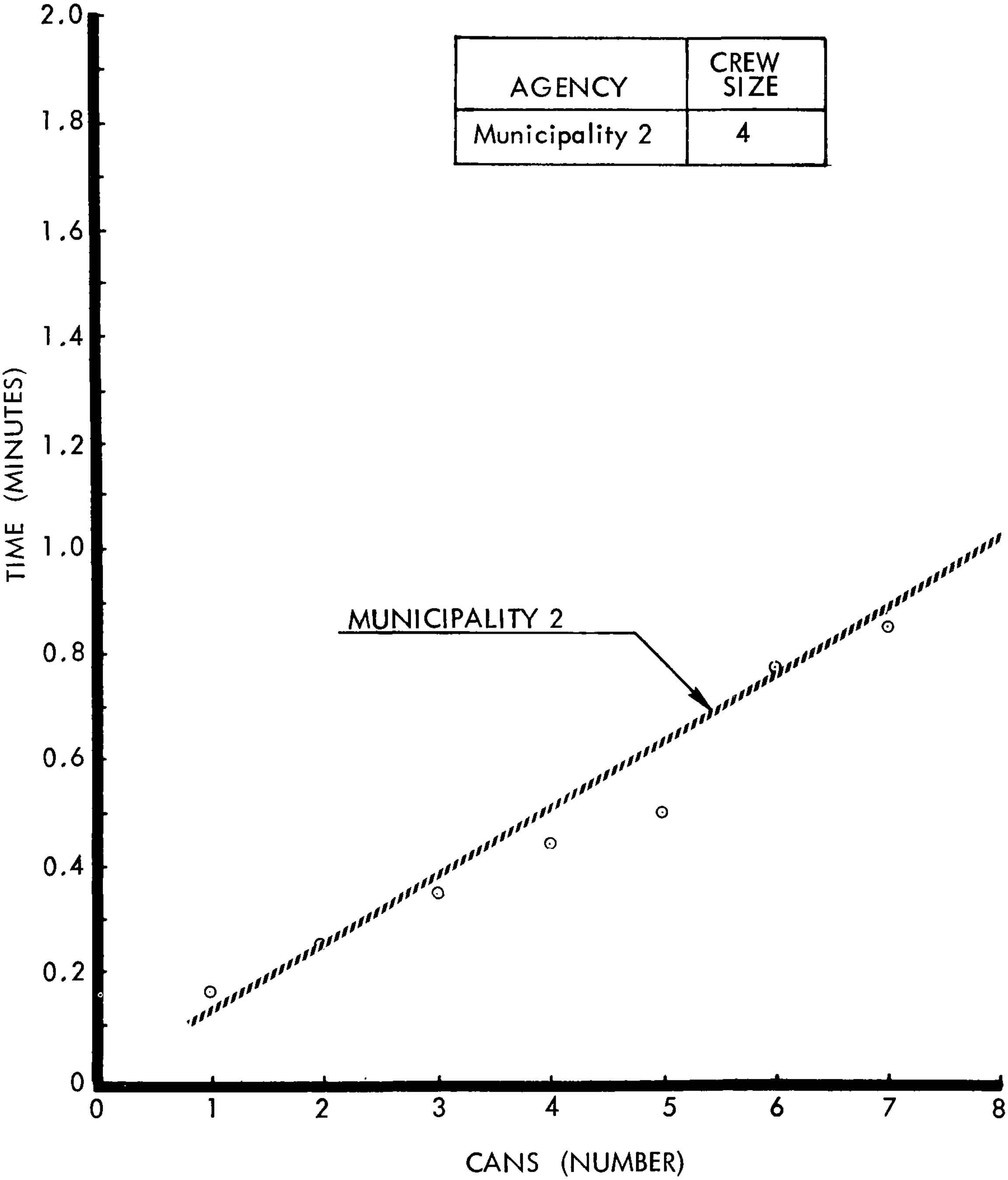


FIGURE 24
AVERAGE
COLLECTION TIME
PER STOP

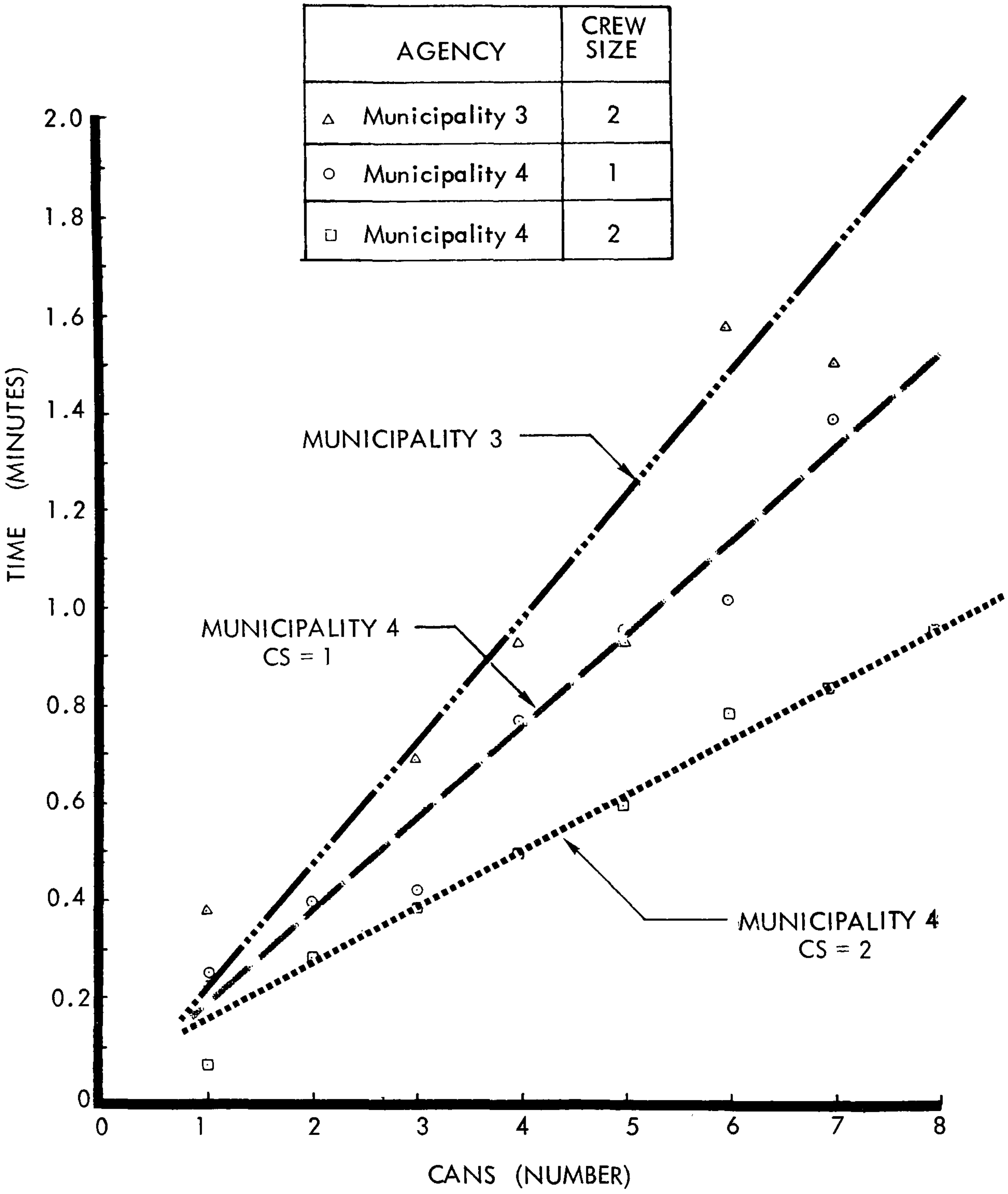


FIGURE 25
AVERAGE COLLECTION TIME
PER STOP

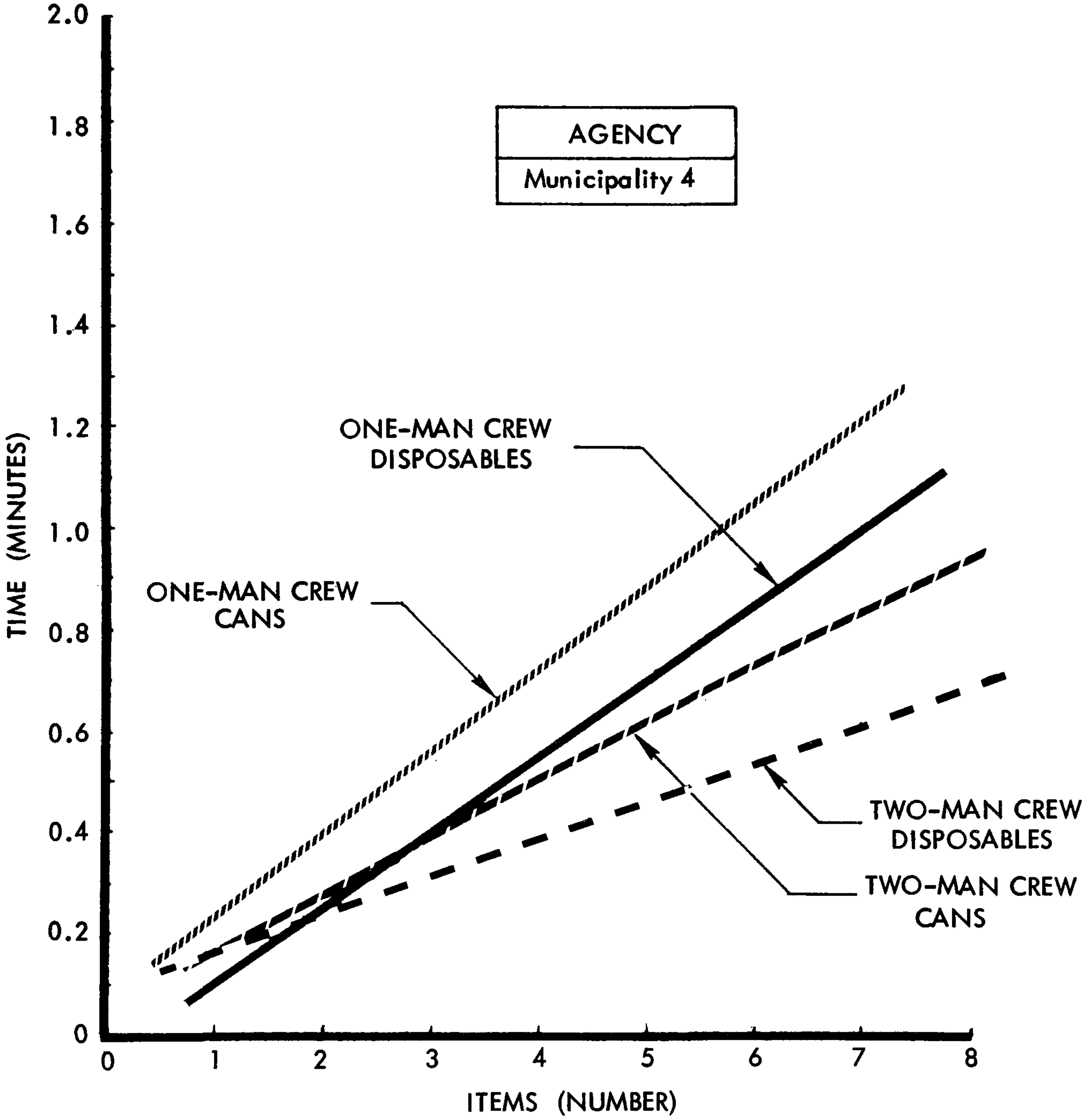


FIGURE 26
COLLECTION TIME -
CANS AND DISPOSABLES

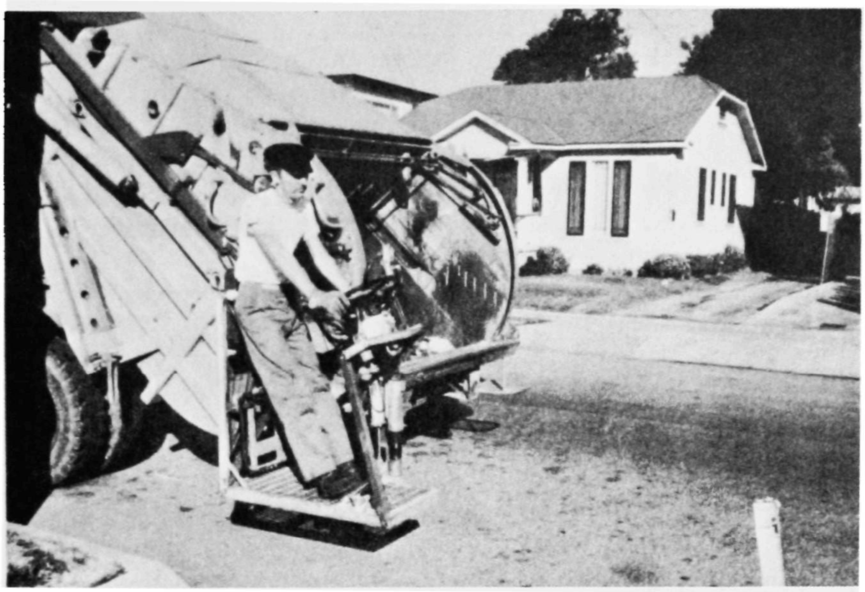
Detailed analysis of the field data indicated that the use of disposable containers, such as bags or sacks, may effect a significant reduction in the collection time per stop. A comparison of Figure 10 with Figure 9 illustrates that the use of disposable containers might enable a 15 to 50 percent reduction in collection time per stop if the conventional containers are replaced by disposable containers on a one-for-one basis. A Public Health Service-sponsored demonstration of the feasibility of improved collection service using disposable bags is now being performed at Inglewood, California.

The concept is illustrated further in Figure 26. Results of two crews operating concurrently in the same municipality on trucks which were identical, except that one was equipped with a "TRAC" (Truck Rear Actuated Control) device to facilitate one-man operation of the conventional rear-loading packer vehicle, are illustrated. The device, illustrated in Photographs V and VI, enables operation of the rear-loading packer from a position adjacent to the loading hopper. The truck travels in reverse during collection, with the operator conveniently located adjacent to both the curbside location of the refuse containers and the loading hopper of the truck. Following completion of the loading phase, the device is disengaged, swung to the storage position behind the vehicle, and the truck proceeds in the normal manner to the disposal site. Municipality 4 has been evaluating the device for approximately one year.

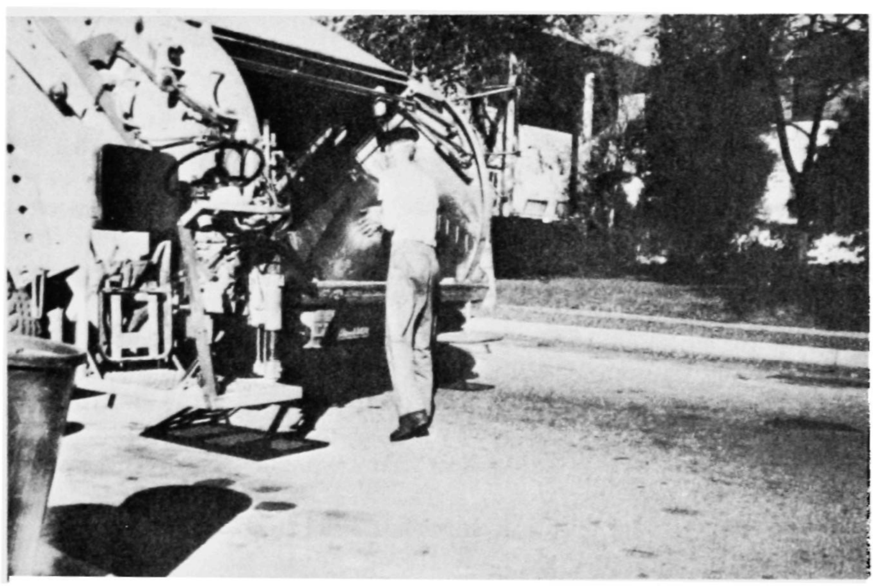
Referring again to Figure 26, in comparing the curves of the time per stop for one man collecting cans using the TRAC unit with the time per stop for the two-man crew collecting cans, potential savings in man-minutes per collection stop range from 30 to 40 percent between the two systems. Note that it is necessary to multiply the collection time per stop for the two-man crew by a factor of two in order to obtain man-minutes per stop. This potential timesaving could be expected to increase when haul time and non-productive time are considered. During extensive studies of the TRAC unit conducted by Municipality 4 and verified by the current studies, the average man-hour saving on the route was about 26 percent. In terms of the total man-hours used during the day, there was a saving of 38 percent. Although the TRAC unit is not fully satisfactory for all-weather heavy-duty use in its present form, the concept underscores the potential savings possible by re-designing the man-machine combination for the collection task.

B. National Survey of Collection Practice

A total of 234 cities in 42 different States, with a total population of 37,397,837, have cooperated in our studies by supplying system data. Copies of the data form are appended to this report (see Appendix D). Figure 27 illustrates the location of these cities in the United States, and Table VI is a tabulation by State. Table VII illustrates the number of responding cities in each population range.



PHOTOGRAPH V.
TRAC - DRIVING



PHOTOGRAPH VI.
TRAC - LOADING

TABLE VI

NUMBER OF CITIES IN EACH STATE
(INCLUDING DISTRICT OF COLUMBIA)
SUPPLYING COLLECTION DATA

Alabama	3	Kentucky	0	North Dakota	3
Alaska	2	Louisiana	0	Ohio	14
Arizona	3	Maine	3	Oklahoma	3
Arkansas	0	Maryland	5	Oregon	9
California	50	Massachusetts	2	Pennsylvania	9
Colorado	1	Michigan	10	Rhode Island	0
Connecticut	3	Minnesota	1	South Carolina	0
Washington D.C.	1	Mississippi	0	South Dakota	2
Delaware	1	Missouri	2	Tennessee	5
Florida	12	Montana	1	Texas	21
Georgia	2	Nebraska	2	Utah	1
Hawaii	2	Nevada	1	Vermont	0
Idaho	1	New Hampshire	1	Virginia	12
Illinois	5	New Jersey	4	Washington	6
Indiana	1	New Mexico	0	West Virginia	1
Iowa	2	New York	8	Wisconsin	10
Kansas	1	North Carolina	3	Wyoming	2
				(Unknown)	3

234 cities responded

42 states represented

TABLE VII

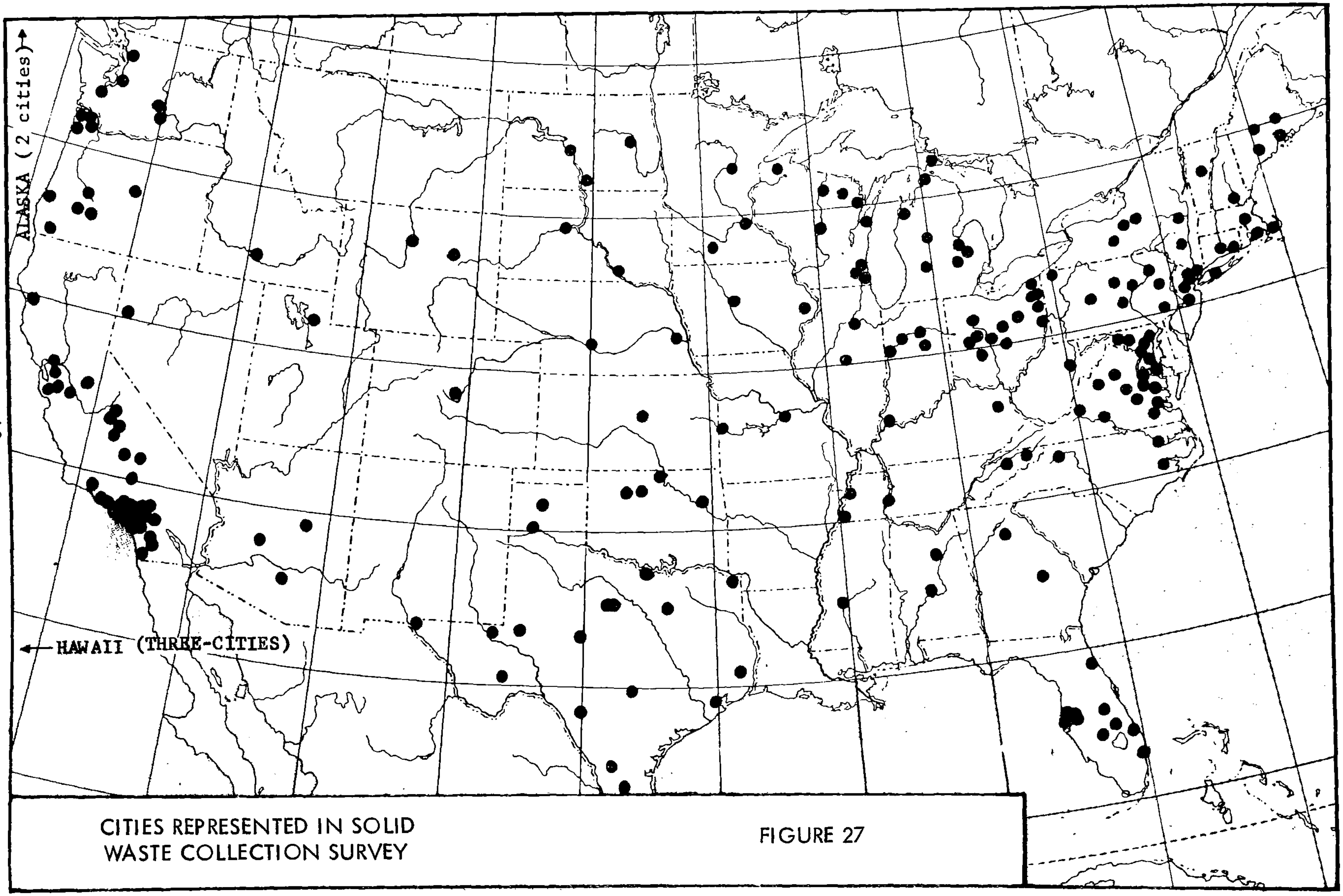
POPULATION REPRESENTED BY 234 CITIES RESPONDING TO DATA SURVEY

Population (1,000's)	No. of Cities	Total Population
10 - 100	179	7,021,153
100 - 500	38	8,266,790
500 and over	17	22,109,874
Total	234	37,397,817

TABLE VIII

TYPE OF COLLECTION SERVICE REPORTED BY RESPONDING CITIES

Population (1,000's)	Municipal	Private	Both
10 - 100	108	59	12
100 - 500	30	5	3
500 and over	13	1	3
Total	151	65	18



CITIES REPRESENTED IN SOLID WASTE COLLECTION SURVEY

FIGURE 27

1. Public vs Private Collection Service

The ratio of cities providing public collection service as opposed to private collection service in the survey sample was approximately two and a half to one. Although cities with populations of less than 100,000 had a ratio of two to one in favor of public collection, the larger cities indicated an even greater preference for public collection over private collection. A number of cities, less than 10 percent of the sample, reported using a combination of public and private collection services.(Table VIII).

2. Type of Equipment

Based on the sample data, rear-loading equipment received the greatest use in refuse collection systems. An analysis of 5018 units of collection equipment revealed that the four leading types in descending order of preference were: rear-loading; side-loading; container; and front bucket (Table IX). However, the last two together comprised less than 5 percent of the total, while side-loaders comprised 8.2 percent. More than 87 percent of the units in this data sample were rear-loading equipment. A number of cities, however, while using them for the major proportion of their collection activities, also reported the need for auxiliary types of equipment for special functions or unusual situations such as spring cleanup or access problems in unusually narrow winding roads. A number of cities used side-loading equipment almost exclusively. The preference for rear-loading equipment was most noticeable in the largest cities with populations greater than half a million. These metropolitan areas reported using 3106 rear-loaders compared with only 96 side-loaders; thus the former comprised 94.5 percent and the latter 3.0 percent of the total units reported by this large-city category.

3. Capacity of Equipment

A sample of 77 cities (Table X) was analyzed to determine the average capacity of collection equipment units based on once a week versus twice a week collection. In the 10,000 to 100,000 population range, there was little difference for the 52 reporting cities. The average capacity per unit was 18.6 cu yd for once a week collection, and 18.5 cu yd for twice a week collection. A greater difference appeared among the 17 cities in the 100,000 to 500,000 population range where equipment for once a week collection averaged 21.4 cu yd, while equipment for twice a week collection averaged 17.8 cu yd; hence, the average unit capacity for once a week collection was approximately 20 percent larger than for twice a week. For the eight largest cities in this sample (those with minimum populations of half a million) there was no important difference in average capacity based on once a week versus twice a week collection. The former was 19.4 cu yd and the latter 18.8 cu yd.

TABLE IX

EQUIPMENT ACCORDING TO TYPE
(NUMBER OF PIECES OF EQUIPMENT)

Population (1,000's)	Rear Loading		Side Loading		Front Bucket		Container		Totals
	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.
10 - 100	586	77.6	128	17.0	34	4.5	7	0.9	755
100 - 500	680	69.5	185	18.9	58	5.9	56	5.7	979
500 and over	3,106	94.5	96	3.0			82	2.5	3,284
Total	4,372	87.2	409	8.2	92	1.8	145	2.8	5,018

TABLE X

AVERAGE CAPACITY OF EQUIPMENT (WEIGHTED BY NO. UNITS) COMPARED WITH SIZE OF CITY FOR ONCE A WEEK AND TWICE A WEEK COLLECTION (77 CITIES)

Population Class (1000's) From	To Less Than	No. Cities	Average Capacity Equipment Once/Week Collection (Cu Yd)	No. Cities	Average Capacity Equipment Twice/Week Collection (Cu Yd)
10-	20	3	17.6	9	18.2
20-	30	6	14.7	5	16.5
30-	40	3	24.5	3	14.0
40-	50	2	15.3	3	17.3
50-	60	4	16.5	3	21.7
60-	70	2	25.5	1	30.0
70-	80	2	16.0	0	-
80-	90	1	18.0	1	18.0
90-	100	2	17.4	2	23.4
Combined Average		25	18.6	27	18.5
100-	200	5	24.5	2	18.9
200-	300	2	17.0	2	15.8
300-	400	2	17.8	3	17.8
400-	500	0	-	1	20.5
Combined Average		9	21.4	8	17.8
500 and over		5	19.4	3	18.77

4. Crew Size

The majority of American sanitation collection equipment represented in the sample was serviced by a three-man crew (Table XI). In fact, the data indicates that the major portion of solid waste was collected by a three-man crew using a rear-loading compactor (Table XII). Less than 3 percent of the cities reported exclusive use of a one-man crew, while an additional 5-1/2 percent used one-man crews as an adjunct to larger crew sizes. Eight cities in the 10,000 to 100,000 population range reported using one-man crews exclusively. Five of these eight cities provided side-loading equipment; two preferred front-buckets; and one used rear loaders. Although this data was based on a small sample, it indicated that side-loading equipment may presently be favored for use by the one-man crew.

Although three-man crews were most typical in the sample, a large number of rear-loading units were serviced by two-man crews. An analysis of 36 larger cities (populations of 100,000 and over) shows that out of 3489 rear loaders, approximately 73.4 percent used three-man crews (Table XIII). In the same sample, 104 side loaders were serviced 57.7 percent by three-man crews and 42.3 percent by two-man crews. This again supports the conclusion that side-loading equipment was more popular for smaller crew sizes than rear-loading equipment.

When crew size was compared with pick-up location (Table XIV), the three-man crew remained the major choice of most cities in the sample for most pick-up points. Based on a study of 136 cities, 54.4 percent of the cities used three-man crews as opposed to 27.9 percent who used two-man crews. Larger crews were used in significant numbers only when yard carryout service was provided by the city. Of the 17 cities using four- or five-man crews, nine provided yard service exclusively, and two used a combination of yard and either curb or alley service.

5. Pick-Up Location

The most common locations designated for municipal refuse collection were a combination of curb and alley. In an analysis of 206 cities (Table XV), 77 provided for curb and alley pick-up; 42 collected at the curb exclusively; 33 provided carry-out service exclusively; 10 provided exclusive alley pick-up; and the remaining 44 combined backyard carryout service with curbside and/or alley pick-up.

6. Frequency of Collection

There was no strong statistical preference for either once or twice a week collection in the sampled cities. In a study of 112 cities, 51 cities, or 45.5 percent, provided once a week residential collection; 55 cities, or 49.1 percent, collected twice a week; and 6 cities, or 5.4 percent, collected three times per week (Table XVI).

TABLE XI

NORMAL CREW SIZE OR SIZES
(BY NO. OF CITIES)

Population (1,000's)	Crew Size (No. of Men, Including Driver)																
	1	2	3	4	5	9	1,2	1,3	2,3	2,4	3,4	3,5	4,5	1,2,3	4,5,6	2,4,5	1,2,3,4
10 to 100	8	31	61	7	5	1	6	7	13	1	2	2	1	2	0	1	0
100 to 500	0	7	13	0	2	0	0	2	2	0	0	0	1	0	0	0	1
500 and over	0	3	6	1	1	0	0	1	1	0	1	0	1	0	1	0	0
Subtotal	8	41	80	8	8	1	6	10	16	1	3	2	3	2	1	1	1
Total	146						46										

TABLE XII

CREW SIZE ACCORDING TO TYPE OF EQUIPMENT

Population (1,000's) (No. of Cities)	No. of Men In Crew	Type of Equipment by Number of Cities		
		Rear Loader	Side Loader	Front Bucket
10 to 100 (89 Cities)	1	1	5	2
	2	17	6	-
	3	43	11	2
	4	3	1	-
	5	4	1	-
	Varying	4	1	2
100 to 500 (29 Cities)	1	-	-	-
	2	6	3	2
	3	10	4	1
	4	1	1	-
	5	1	-	-
500 and over (15 Cities)	1	-	-	-
	2	3	2	-
	3	6	2	-
	4	1	-	-
	5	-	-	-
	Varying	1	-	-
Total		101	37	9

TABLE XIII

TOTAL NUMBER OF UNITS OF EQUIPMENT ACCORDING TO TYPE OF EQUIPMENT AND CREW SIZE (FOR 36 LARGER CITIES)[1]

Population (1,000's) (No. of Cities)	No. of Men in Crew	Rear Loader		Side Loader		Front Bucket	
		No. of Cities	No. of Units of Equipment	No. of Cities	No. of Units of Equipment	No. of Cities	No. of Units of Equipment
100 -	2	6	135	3	33	2	20
500	3	10	271	4	45	1	3
(25 Cities)	5	1	49	-	-	-	-
Subtotal		17	455	7	78	3	23
500	2	3	649	2	11	-	-
and over	3	6	2,289	2	15	-	-
(11 Cities)	4	1	96	-	-	-	-
Subtotal		10	3,034	4	26	-	-
Total		27	3,489	11	104	3	23

(1) The number of cities may not seem to correspond with the data only because any one city may be listed more than once under different types of equipment.

TABLE XIV

CREW SIZE BY LOCATION OF PICKUP
(136 CITIES)
(BY NUMBER OF CITIES)

Population (1,000's)	Crew Size	C	A	Y	C&A	Y&A	C&Y	C,A&Y	Total
		Number of Cities							
10 - 100	1	-	1	1	5	-	-	-	7
	2	8	-	3	11	3	1	2	28
	3	17	3	6	20	1	5	2	54
	4	1	-	4	2	-	-	-	7
	5	-	-	4	-	1	-	-	5
	Total	26	4	18	38	5	6	4	101
100 - 500	1	-	-	-	-	-	-	-	0
	2	1	-	-	6	-	-	-	7
	3	2	-	3	5	1	1	1	13
	4	-	-	1	-	-	1	-	2
	5	-	-	-	1	-	-	-	1
	Total	3	0	4	12	1	2	1	23
500 and over	1	-	-	-	-	-	-	-	0
	2	-	-	-	2	-	-	1	3
	3	3	-	-	3	-	1	-	7
	4	-	-	-	1	-	-	-	1
	5	-	-	-	1	-	-	-	1
	Total	3	0	0	7	0	1	1	12
Total		32	4	22	57	6	9	6	136

Note: C = Curb
Y = Yard (or House Carryout)
A = Alley

TABLE XV

COLLECTION LOCATION
(206 CITIES)

Population, (1,000's)	C	A	Y	C&A	Y&A	C&A	C,A&Y
	Number of Cities						
10 - 100	34	9	26	54	13	8	7
100 - 500	6	1	4	15	5	3	4
500 and over	2	0	3	8	1	0	3
Total	42	10	33	77	19	11	14

Note: C = Curb
A = Alley
Y = Yard (or House Carryout)

TABLE XVI

FREQUENCY OF COLLECTION SERVICE
BY SIZE OF CITY (112 CITIES)

Population (1,000's)	Once Per Week		Twice Per Week		Three Times Per Week	
	No. of Cities	Total Population	No. of Cities	Total Population	No. of Cities	Total Population
10 - 100	33	1,422,217	37	1,499,197	2	79,000
100 - 500	10	2,057,000	11	2,196,893	3	452,000
500 and over	8	5,397,180	7	4,564,393	1	114,000
Total	51	8,876,397	55	8,260,483	6	645,000

The slight preference for twice a week collection was primarily in the cities in the 10,000 or 100,000 population range. However, the percentages are similar for cities of all sizes.

7. Lost Time Accidents

A total population of 11,894,787 was represented in the 80 cities reporting their lost time accident experience (Table XVII). These cities reported an average annual total of 1,457 accidents. Based on population served, the incidence of accidents was greatest for cities in the lowest population range of 10,000 to 100,000; it dropped in the medium population range of 100,000 to 500,000; and was lowest for the largest cities with populations of half a million or more. There was one reported lost time accident per population of 6261 in the smaller cities, per population of 8439 in the medium size cities, and per population of 8988 in the largest cities. No information was supplied concerning man-days lost due to accidents. Although there were fewer accidents per city for the smaller cities, the larger cities had a lower accident rate on the basis of population served.

8. Collection Costs

A sample of 166 cities (Table XVIII) reported an annual total of 12,352,319 tons of solid waste at a cost of $217,040,288, or an average of $17.66 per ton. This figure, however, was not representative for any of the three city-size categories. The average collection cost per ton was $9.50 for cities with populations of less than 100,000, $10.20 per ton for cities with populations between 100,000 and 500,000, and $24.05 per ton for cities in the 500,000 and over population range. The last figure, however, reflected the weighting effect of both the huge tonnages and high collection costs of one or two large communities. In order to secure more typical cost figures, the median city in each population range was determined. The figures for the smaller and medium-sized cities remained about the same at $9.90 and $10.64 per ton, respectively; however, the median city in the largest population category had a collection cost per ton of only $12.78 as compared with the above-mentioned weighted figure of $24.05. Collection costs reported are represented by a least squares line in Figure 28.

There were large variations in reported collection costs per ton among the cities in every population category. Calculations based on the information submitted ranged from $1.56 to $80.00 per ton. Some of the more extreme variations were obviously the result of inadequate records - or simple clerical errors. Ignoring these extremes, however, the figures still indicate that wide cost variations are the rule rather than the exception. It is not uncommon for the refuse collection budgets of two cities in the same state with similar economics, levels of service, and populations to vary by 200 percent or more. This would seem to indicate great differences in the cost benefits of different collection systems. Since labor costs are a significant factor in every collection budget, an attempt was made to determine the economic effects of backyard collection service.

TABLE XVII

NUMBER OF LOST TIME ACCIDENTS
(80 CITIES)

Population (1,000's)	No. of Cities	Total Population	Average Number of Accidents Per Year	Population Per Accident
10 - 100	56	2,219,714	354.5	6,261
100 - 500	18	3,607,893	427.5	8,439
500 and over	6	6,067,180	675.0	8,988
Total	80	11,894,787	1,457.0	8,060

TABLE XVIII

ANNUAL SOLID WASTE TONNAGE AND COLLECTION COSTS (166 CITIES)

Population (1,000's)	Tons (Per Annum)	Collection Cost ($ Per Annum)	Average Cost Per Ton ($)	Cost Per Ton For Median City ($)
10 - 100	2,813,819	26,757,188	9.50	9.90
100 - 500	2,803,700	28,605,200	10.20	10.64
500 and Over	6,734,800	161,677,900	24.05	12.78
Total	12,352,319	217,040,288	17.66	

TABLE XIX

AVERAGE ANNUAL COST PER TON COMBINED AVERAGES (39 CITIES)

Population (1,000's)	Curbside Pickup		Backyard Pickup	
	Average Cost Per Ton ($)	No. of Cities	Average Cost Per Ton ($)	No. of Cities
10 - 100	8.61	21	10.71	5
100 - 500	8.92	6	15.78	4
500 and over	20.71	2	14.09	1
Total	9.52	29	13.08	10

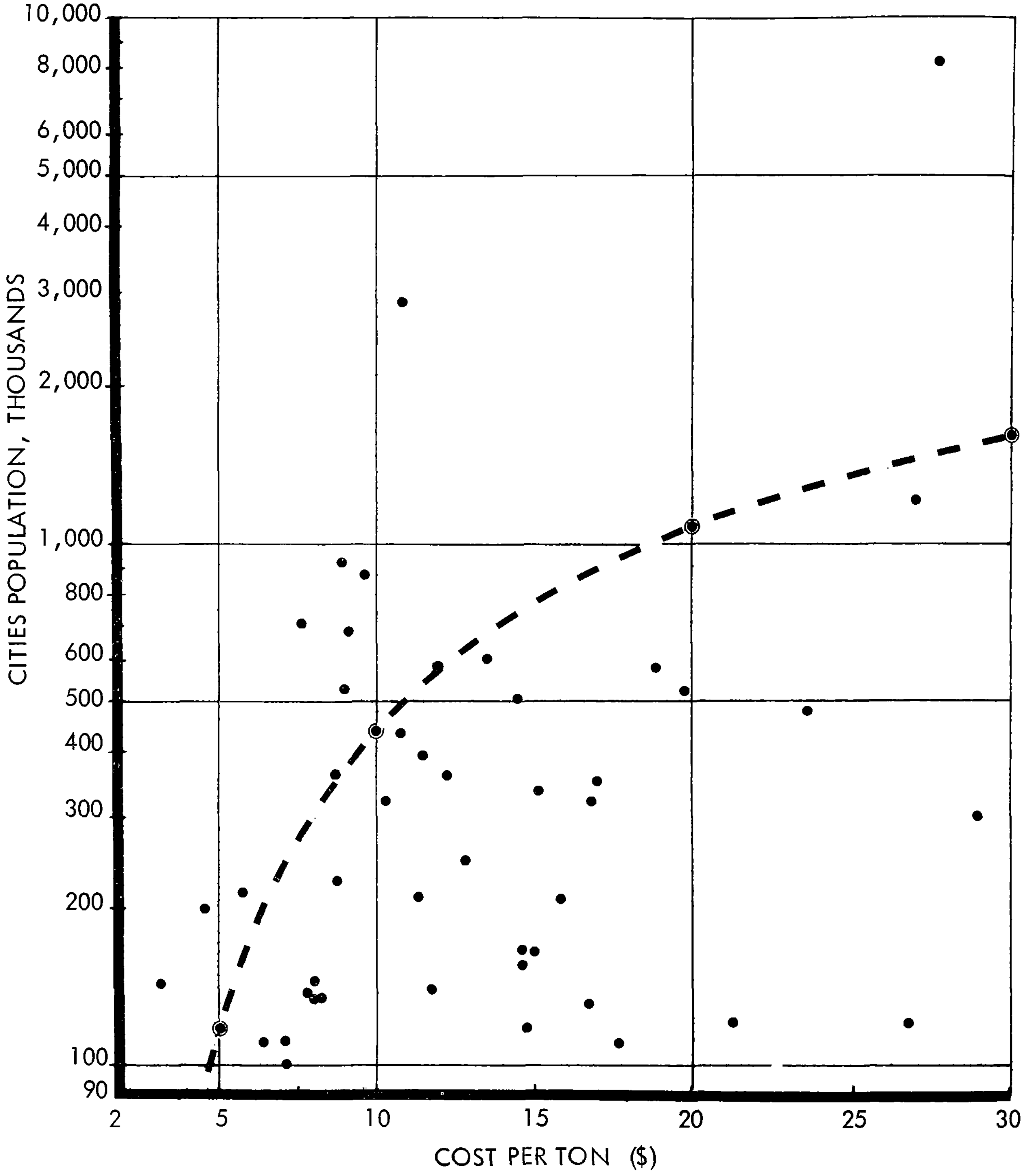


FIGURE 28
COST OF REFUSE COLLECTION
IN 46 CITIES

For once a week residential collection, the average reported cost per ton was $8.60 for six cities with curbside collection and $11.82 per ton for three cities with yard collection service. In other words, the cost for carryout collection averaged about 37 percent higher than for curb collection.

In order to enlarge the sample, further analysis included cities with diversified or unknown weekly collection patterns. In the enlarged sample of 39 cities, 29 cities reported a total average collection cost per ton of $9.52 for curbside collection in contrast with an average cost of $13.08 for 10 cities providing yard collection. For this larger sample, therefore, the increased time and labor costs for carryout service were reflected in about a 37 percent higher collection cost per ton. This indicated that conclusions based on the smaller sample were substantially correct (Table XIX).

C. Time and Motion Analysis

1. General

As indicated in Section II, Detailed Approach, a theoretical approach to the comparison of efficiency between one-, two-, and three-man collection crews was considered important for this study. Although precautions were taken during conduct of the field surveys to ensure reasonable comparability, variations in personnel, equipment, and field conditions did exist, and the data was, therefore, not exactly comparable. A theoretical approach using industrial time and motion study methods was undertaken to eliminate the effects of such differences and to verify the results of the field studies. Comparing the motions required for the various crews to complete similar tasks, and assigning the appropriate time values to each human motion required, resulted in closely comparable time values for collection operations involving alternative crew sizes.

The use of predetermined industrial time standard systems has grown rapidly in recent years. Their use enables a qualified analyst to develop time values for alternative methods of performing a job even though the work task may never have been performed.

"A predetermined time system is an organized body of information, procedures, and techniques employed in the study and evaluation of work elements performed by human power in terms of the method or motions used, their general and specific nature, and conditions under which they occur, and the application of prestandardized or predetermined times which their performance requires."*

MTM (Methods-Time-Measurement) is a system of predetermined times in common industrial engineering use throughout the world. This system can be used by the qualified analyst to predict or measure the time necessary to perform almost any manual task.

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*Karger, Delmar W., and H. Bayha Franklin. Engineered Work Measurement. New York: The Industrial Press, 1959.

Each element of a performed task can be measured in a manner similar to the previously described field studies. However, when measurement is difficult or the operation exists only as a concept, the analyst need only visualize, carefully list the motions, and apply the appropriate MTM values to determine the basic expected time to perform specific refuse collection tasks with different crew sizes. Comparisons can then be made with the time study values obtained by actual field studies. The system was used to assign time values to alternative methods of refuse collection.

The MTM time values are the expected times for a typical, experienced worker to perform the motions required to complete the work task under normal conditions.

To determine the MTM time to move an object from one place to another, it is necessary to determine the length of the move, the weight of the object moved, the use of one or two hands, the type of grasping motion, hand motions before or after the move, and other relevant body motions. The associated MTM time for each movement is then assigned, and the sum of these incremental times is the time for the object to be moved.

The MTM system does not include time values for factors which cannot be standardized, such as fatigue, personal and unavoidable delays. Although developing these latter factors definitively was beyond the scope of the study, some waste time values were developed for refuse collection operations; a preliminary evaluation of their possible effects has been made.

The amount of variation between standard time values developed for the refuse collection task and any given set of actual field data may be quite high. Such variations may be due to one or more of the following: skill of the employee; level of effort; delays; variability within the task; and other allowances.

The primary cause of the delays will usually be found within the task itself. For example, the volume and weight of waste per container may vary greatly. It is possible for one container to be loaded to a weight equal to the combined weight of three other partially loaded refuse containers. When quantities are small, a collector may load two containers simultaneously. (See Photograph VII) In other cases, he may have such difficulty with one can that the actual time exceeds the standard time for two or more cans.

Refuse collectors themselves vary in experience and physical condition. Skill level is dependent on experience and has a significant effect on collection time. Motivation is another important variable. However, when the volume of data is large and adjustments are made for fatigue and delays, the actual performance times should cluster about the standard times with no appreciable difference between the MTM and observed values.

PHOTOGRAPH VII.
COLLECTOR LOADING TWO CANS SIMULTANEOUSLY

Weight affects the loading time of each can. Laboratory tests show that people perform more slowly when moving or carrying heavy weights. Our standards were based on the assumption that the refuse collector carried each can with two hands. Approximately 13 percent was added to the normal walking time to estimate the time required when carrying a loaded container. Similar allowances were made for other body movements involved in the moving of the loaded containers.

2. Analysis - Time and Motion

Based on motion picture and video tape recordings, a list was made of the basic human motions required to perform the refuse collection task in the one-, two-, and three-man collection systems, and the proper MTM values were applied. Where the nature of the process controlled the time (for example, emptying refuse from the can), field study time values were used. The basic motion data was formulated into elements:

a. Dismount from truck.

b. Walk to container location.

c. Grasp and pick up container.

d. Pivot and walk with container to loading location.

e. Dump container contents.

f. Pivot and return with container to storage location.

g. Place container on ground and pivot.

h. Return to cab.

i. Mount truck.

These elements were combined as needed to give expected time values for the collection of one, two,....10 cans for each of the three systems under consideration. The data gathered by the field time studies were compared with the MTM values for the same tasks as a check against each other.

Alternative collection methodologies, such as backyard collection, collection of both sides of the street with one pass of the crew, or systems using different equipment types such as right- or left-hand drive vehicles, can be evaluated by use of the MTM method.

3. Results - Time and Motion Analysis

a. Curbside Collection

Figures 29, 30, and 31 illustrate some of the results of the time and motion analysis. Figure 29 illustrates the standard time to collect one through ten cans from the curbside location for one-, two-, and three-man crews. The shape and relative position of the curves agree reasonably well with the results of the field data shown in Figure 9. The curves of Figure 29 contain no allowances for fatigue, personal and unavoidable delays. Figure 30 shows the standard collection time for disposable containers. As illustrated by comparing Figure 30 with Figure 29, the time and motion study substantiates that savings in collection time are possible for any sized crew through the use of disposable containers.

Figure 31 shows application of the use of MTM values to a comparison of two alternative equipment types with the side-loading right-hand drive type used in Municipality A. The figure is intended to illustrate the effect of driver and loading location on standard times to collect one through ten cans. Such a plot can be used to evaluate the economics of purchasing a truck equipped with a right-hand drive and enables comparison of a rear-loading packer with a side-loading packer.

For simple collection systems, it may be unnecessary to determine the values for fatigue, personal and unavoidable delays. This is particularly true if equipment comparisons are being conducted within a given system, such as the example just cited. When complex systems involving different collection methodology and numbers of personnel are being studied, the possible effect of delays and fatigue must be considered.

Although the form and relative position of the standard collection time curves were very similar to the associated field-measured curves for Municipalities A, B, and C, the difference between the curves in Figures 9 and 29 prompted a preliminary study to evaluate fatigue, personal and unavoidable delays. It will be found in Section D-5 of this report.

b. Backyard Collection

As previously noted, the use of one-man crews has been limited primarily to the collection of refuse from the curb or alley location. On the other hand, for backyard collection, the use of three or more crew members is quite common. As field data were not available for one- or two-man backyard collection systems, MTM standards for backyard collection were developed for the three crew sizes used for comparisons.

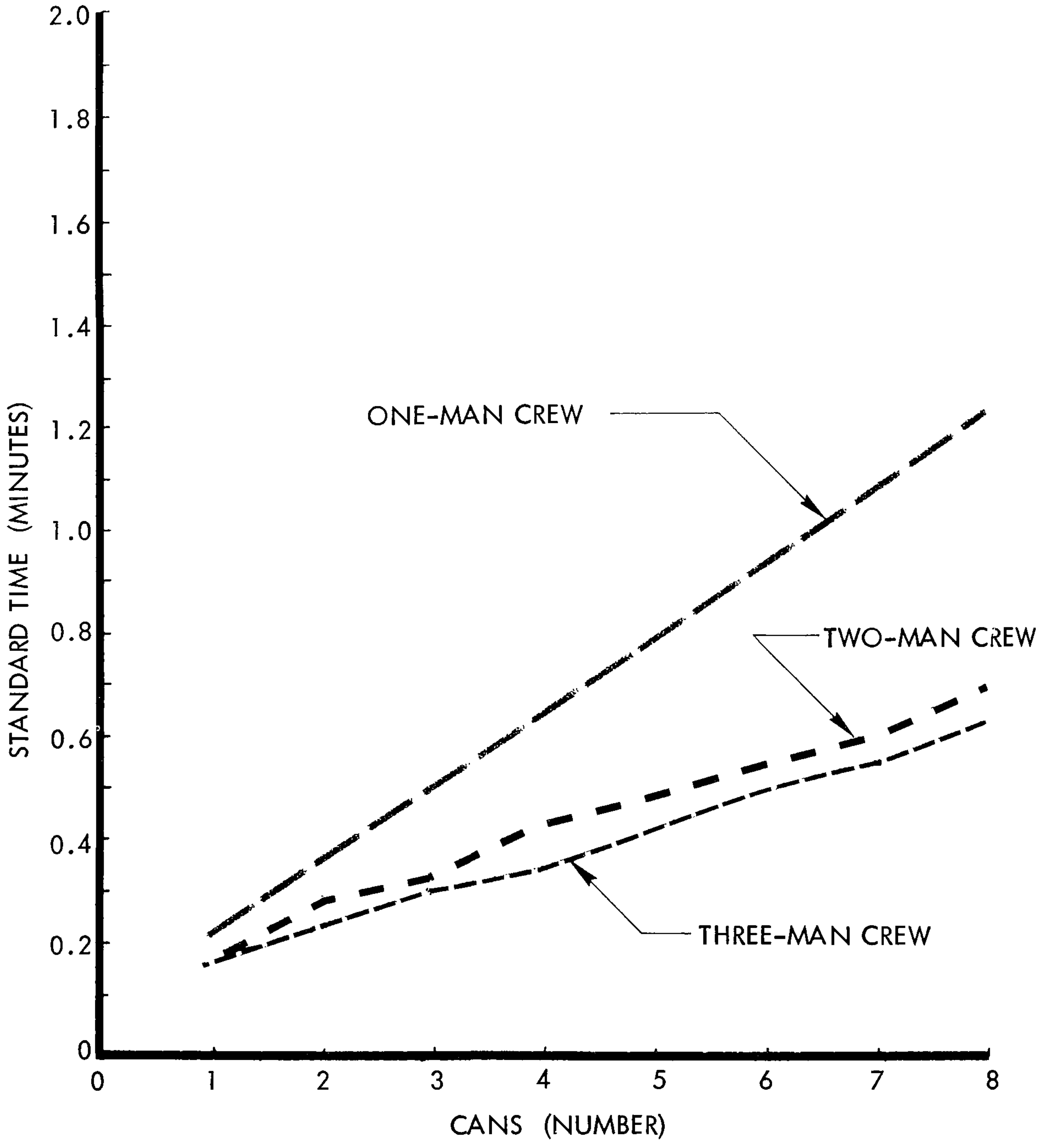


FIGURE 29
STANDARD
COLLECTION TIME
CURBSIDE COLLECTION

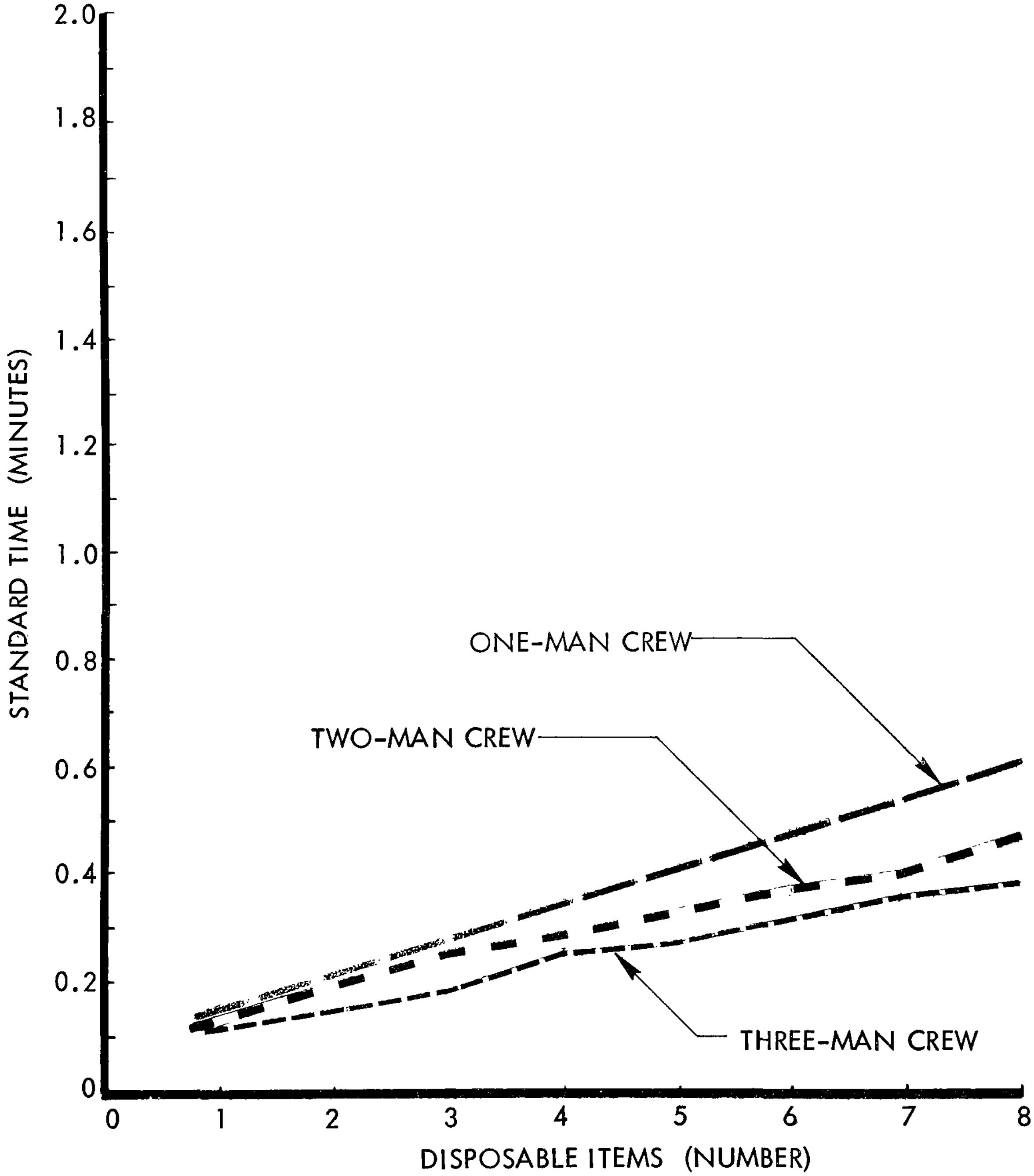


FIGURE 30
STANDARD
COLLECTION TIME - DISPOSABLES
CURBSIDE COLLECTION

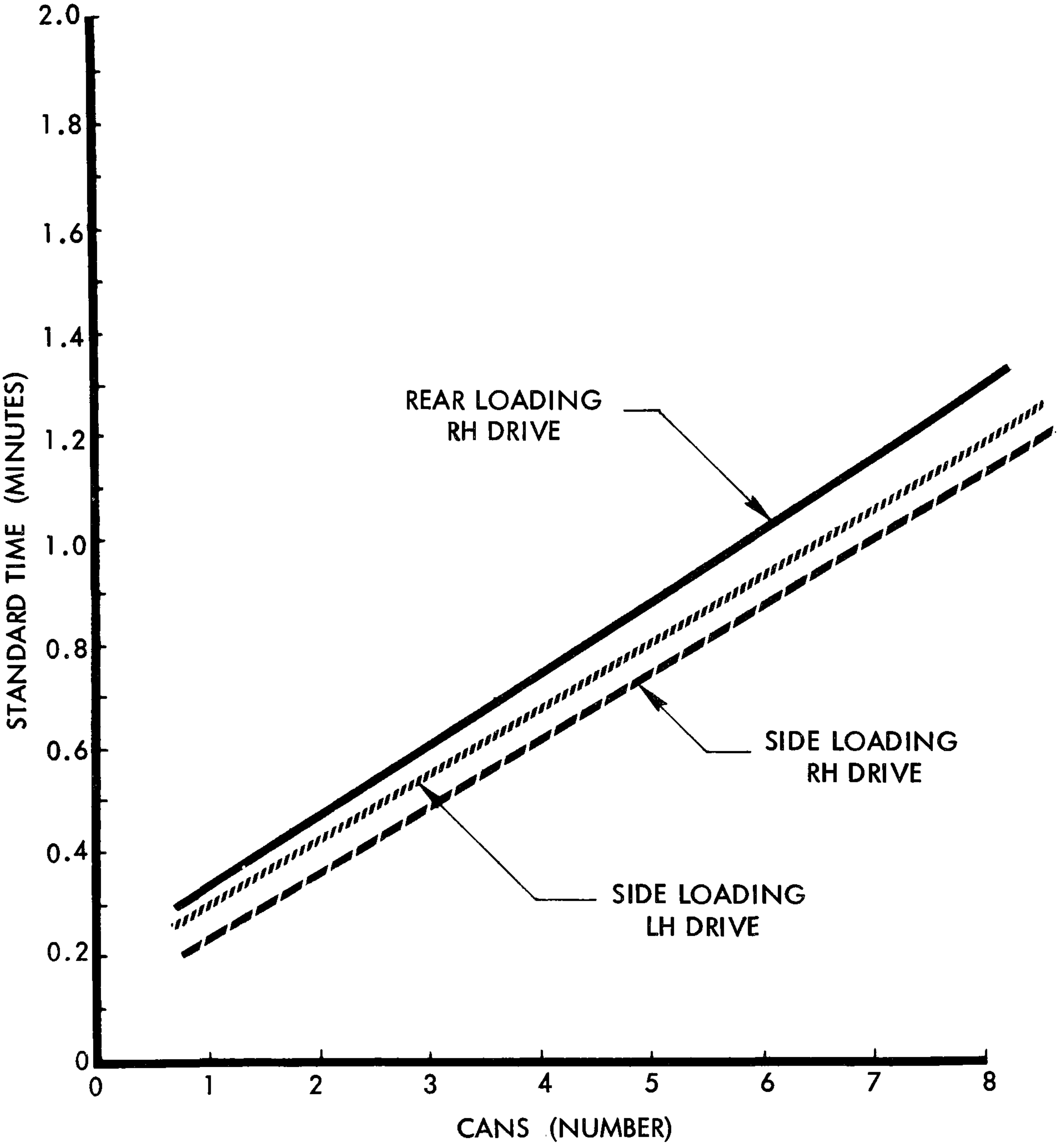


FIGURE 31
EQUIPMENT FACTORS-
STANDARD
COLLECTION TIME
CURBSIDE COLLECTION

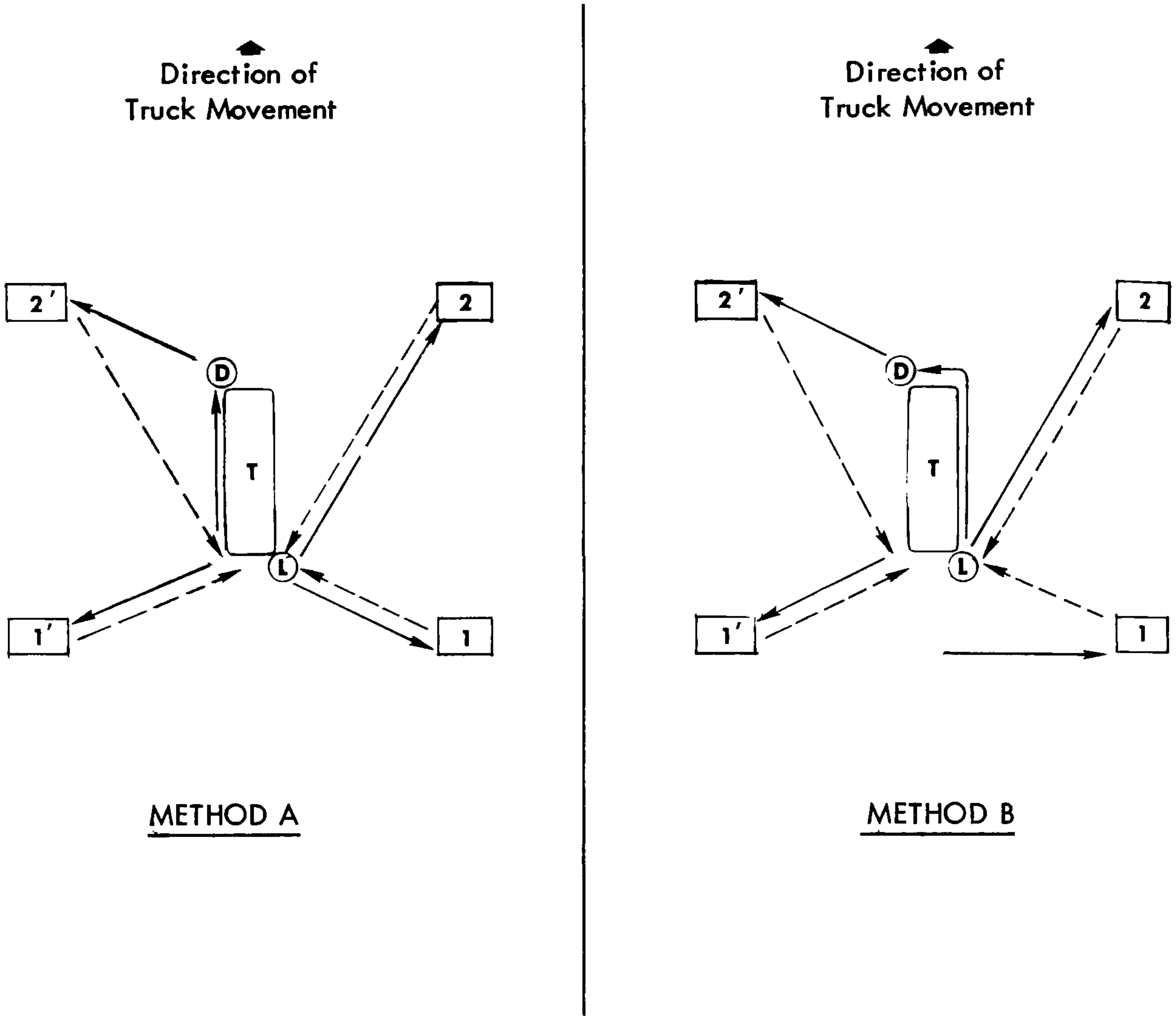
These evaluations have necessarily been limited due to the great variety of handling methodologies and operating conditions possible for backyard collections. In addition, the one-man collection system is less applicable to backyard collections, and major efforts in this area were therefore inappropriate under the scope of the contract. Future studies are needed to define the relative efficiency of backyard collections using alternative methodologies.

In using MTM to evaluate backyard collection with different sized crews, difficulty arises in defining the movements of each member of the crew. In general, both sides of the street are collected simultaneously, and usually, the truck does not stop in front of each service. Furthermore, crew members do not necessarily follow the same repetitive sequence as the collection operation proceeds. Certain rules were therefore established, and each crew member was assigned a sequence of houses to service. Additional variables were the number of containers at each service, the quantity of refuse to be collected from the rear of each house, and the distance to the storage location. Shoulder barrels used by crew members are normally capable of containing the total refuse behind each house. In some systems observed during field visits, crew members with large-capacity shoulder barrels served one or more houses on each trip from the truck. The standards developed, however, assume only one house may be served on each trip from the truck. Comparisons between the various sized crews on backyard collection were made on the basis of minutes per collection stop and man-minutes per service stop. Depending on the crew size, a collection stop could be composed of two, four, or six houses.

Figures 32 and 33 illustrate the methodology assumed for the two- and three-man backyard collection operations as defined in the motion studies. A description of each follows.

The first analysis involves the operation of a conventional rear-loading packer vehicle with a two-man crew: one driver and one loader (Figure 32). As the equipment proceeds down the street, the crew collects refuse from homes on both sides of the street. At each collection stop, four service stops are collected. The loader collects the two houses on the right side of the truck, and the driver collects from the two on the left. It is assumed that there is an average of 40 paces, or approximately 100 ft from the truck location to the backyard locations of the refuse containers. Two cans of refuse are located at the rear of each house. Both the loader and the driver use shoulder barrels of sufficient capacity to hold the total contents of the two cans.

In Method A, illustrated on the left of Figure 32, the driver must dismount from the cab of the vehicle and complete the same task as the loader. Under normal conditions, the loader would therefore complete his task shortly before the driver. Thus, the driver could control the rate of the system. In the other methods of backyard

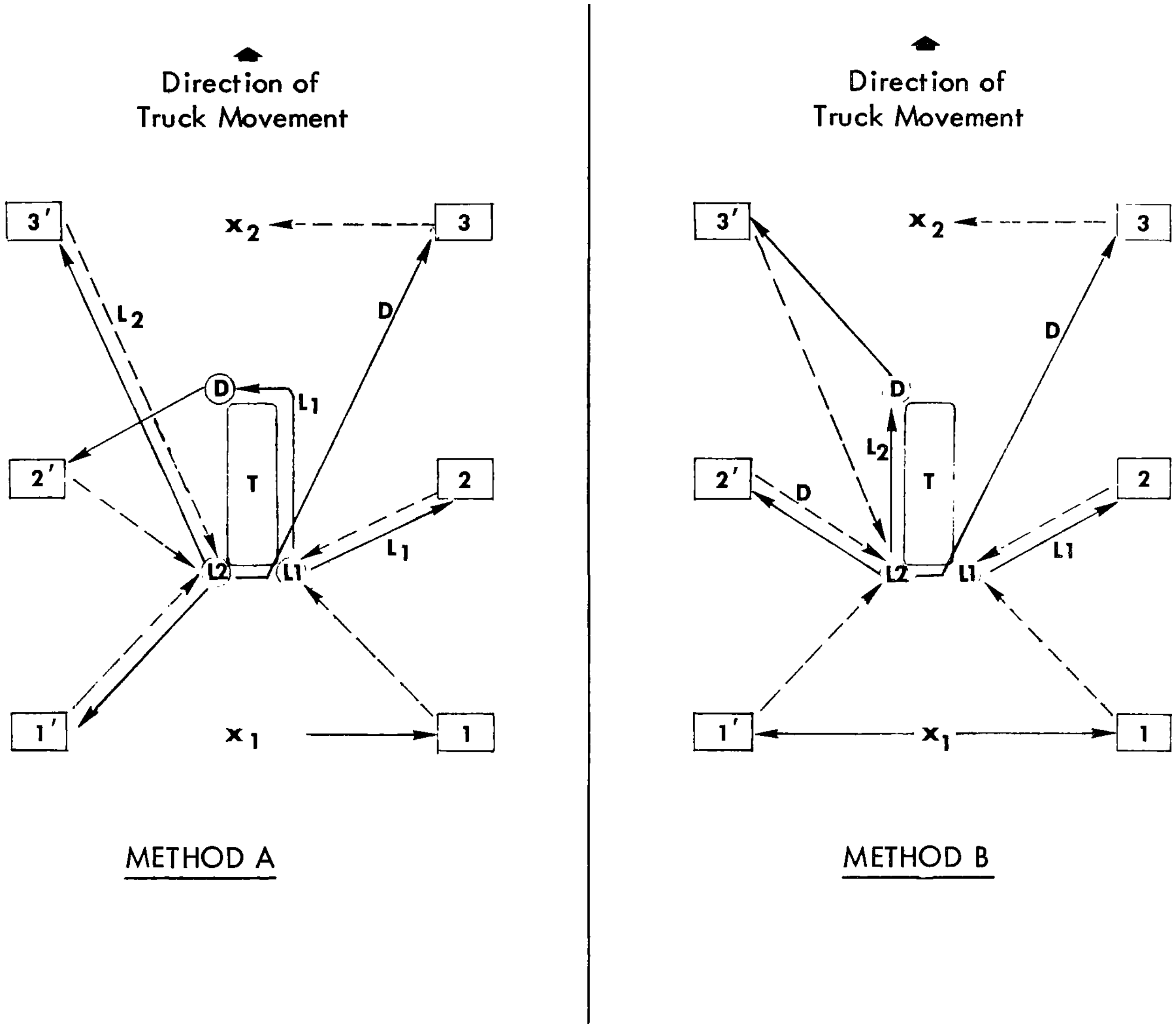


LEGEND

- (L) Loader
- (D) Driver
- [T] Refuse Truck
- [2'] Residence
- ——→ Path to Residence by Driver or Loader
- – – → Path to Truck by Driver or Loader

No Scale

FIGURE 32
SCHEMATIC
TWO - MAN BACKYARD
REFUSE COLLECTION



LEGEND

(L1)	Loader No. 1
(L2)	Loader No. 2
(D)	Driver
[2']	Residence
[T]	Refuse Truck
——→	Path to Residence by Loader or Driver
- - →	Path to Truck by Loader or Driver

No Scale

FIGURE 33
SCHEMATIC
THREE-MAN BACKYARD
REFUSE COLLECTION

collection subsequently discussed, one member of the crew usually controls the overall rate of the system. In actual practice, the members of the crew who arrive back at the truck first may begin walking to the next series of houses to be collected. In Method A, however, it is assumed that the loader will wait at the truck for the driver to return, and then ride on the truck to the next series of four houses to be collected.

In Method B, the loader and the driver alternate at each collection stop. At the first collection stop of four houses, the loader dismounts and collects the refuse from the two houses on the right; the driver dismounts from the cab of the vehicle and collects the refuse from the two houses on the left. As previously noted, the loader will normally return to the truck before the driver. In Method B, it is assumed that the loader then acts as the driver to the next stop of four houses. As the operation proceeds, the two crew members continue to alternate as driver and loader.

The hypothetical three-man backyard collection system consists of one driver and two loaders (see Figure 33). The following assumptions are made. Two members of the crew are qualified as drivers, and the first of these two men returning to the truck acts as the driver to the next collection stop. At each collection stop of the truck, refuse is collected from six houses (three on each side of the street), and each crew man collects two houses. The three men ride on the vehicle between collection stops. Two cans are collected from the backyard of each house, the location of the containers is 100 ft from the location of the truck, and shoulder barrels are used. Two different methods were studied for the three-man backyard collection operation based on the designation of homes to be served by each member of the crew.

In Method A, referring to the schematic on Figure 33, Loader 1 dismounts from the right rear of the truck at Point X_1, and walks to House No. 1. Loader 2 remains with the truck until it stops at its location between Houses 2 and 2'. Loader 2 then collects the refuse from Houses 3' and 3, and rejoins the vehicle at Point X_2. The driver collects Houses 2' and 1', and becomes Loader 1 when the truck proceeds on to the next collection stop. Loader 1, as indicated on the schematic, collects from Houses 1 and 2, and becomes the driver to the next stop. The truck pauses at Point X_2 for Loader 2 to load the refuse from House 3 into the truck. The system then repeats itself.

In Method B, again referring to Figure 33, Loader 2 and Loader 1 dismount from the truck at Location X_1. The driver stops the truck between Houses 2 and 2', collects the refuse from Houses 3' and 3, rejoins the truck at Point X_2, and becomes Loader 2 for the next collection stop. Loader 1 collects the refuse from Houses 1 and 2, and Loader 2 collects the refuse from Houses 1' and 2'. Loader 2 becomes the driver to the next stop. The sequence then repeats itself.

In the one-man backyard collection system, it is assumed that the driver collects from two houses on opposite sides of the street at each collection stop. All other factors are assumed the same as for the two-and three-man systems. Table XX summarizes the results of this phase of the time and motion studies. Although the time values shown in Table XX are not average times of actual experience because no allowance is made for fatigue and delays, they can be used to indicate the relative efficiency of the different methods investigated. Section D of the report will apply the data in Table XX to estimate system performance under simulated field conditions. Referring to the Table, it can be seen that Method B for both the two-man and three-man backyard collection operations has an advantage over Method A of about 0.1 man-minutes/house. Under Method B for backyard collection, both the two-man and three-man crews are more efficient than the one-man crew, in this simplified analysis. Although the man-minutes/house for each crew size are nearly equal, ranging from 1.352 min for the one-man crew to 1.326 for the three-man crew, the number of service stops completed in a given time period would be nearly three times greater for the three-man crew than for the one-man crew. Unlike curbside collection, in backyard collection the extra crew members can speed collections in approximate proportion to their number.

In Section D of the report, the above results have been incorporated into a mathematical model and projections made of system cost efficiency including the important effects of haul time, truck size, and other factors.

c. Refuse Set-Out Systems

In some refuse collection operations in the United States, a member of the crew sets out refuse from the backyard, and either the householder or a member of the collection crew returns the empty refuse containers to their backyard location. It has been determined that the one-man crew is the most efficient in collecting refuse under normal curbside collection procedures. It follows that the overall efficiency of the set-out and set-back, or simply the set-out method of refuse collection, would be improved when combined with curbside collection if the one-man crew were used. The number of men needed to set out refuse from the backyard location to the curb would depend on the quantity of refuse per service stop and the scheduling necessary to preclude the collection vehicle's overtaking them. Normally, the set-out operations would begin prior to the curbside collection operations. Table XX contains the standard time for collection by this method. Further discussion and projections appear in Section D.

d. Alley Collection

The use of various sized crews for alley collection has also been investigated using time and motion analysis methods. The following describes the basis for these studies. Table XX lists the respective minutes per collection stop and man-minutes per house for each method considered.

TABLE XX

TIME STANDARDS - ALLEY, BACKYARD, AND MODIFIED CURBSIDE REFUSE COLLECTION (2 CONTAINERS/SERVICE STOP)

Method	No. in Crew (Including Driver)	Can Location	Standard Time Min/Stop(1)	No. of Services/ Collection Stop	(2) Man-Min/ Service Stop
A(6)	2	Backyard(3)	2.507	4	1.402
B(6)	2	Backyard(3)	2.381	4	1.326
A(7)	3	Backyard(3)	2.558	6	1.437
B(7)	3	Backyard(3)	2.351	6	1.332
-	1	Backyard(3)	2.403	2	1.352
A(8)	1	Alley	0.911	2	0.606
B(8)	1	Alley	0.856	2	0.578
-(9)	2	Alley	0.490	2	0.790
-	3	Alley	0.347	2	0.972
B(7)	3	Modified Curbside(3)	1.434	6	0.867
B(6)	2	Modified Curbside(3)	1.340	4	0.820
-	1	Modified Curbside(3)	1.310	2	0.740
B(7)	3	Modified Curbside	2.060	6	1.180
B(6)	2	Modified Curbside	2.110	4	1.200
-	1	Modified Curbside	1.580	2	0.880
-	1 + 1	Backyard (4)	0.52	1	1.42(5)

Notes:

(1) Standard time per collection stop for both sides of street or alley with one pass of crew and equipment.
(2) - Includes travel time between collection stops on route.
(3) - Using shoulder barrels
(4) - One man sets refuse at the curb for curbside collection by a one-man crew.
(5) - Includes 0.90 min for set-out operation.
(6) - See text and Figure 32 for description.
(7) - See text and Figure 33 for description.
(8) - See text and Figure 34 for description.
(9) - See text and Figure 35 for description.

The use of one-man crews for alley refuse collection has been studied for two different types of equipment: the typical rear-loading packer, and side-loading equipment which can be loaded from either side. In each case, the collection of refuse from both sides of the alley with one pass of the truck is assumed. Figure 34 shows schematics of the necessary movements for one man using the two different types of equipment. A 25-ft alley was assumed in all cases studied. It will be noted on the schematic that the driver is located on the right side of the side-loading truck. In 100 percent alley collection, there would be no difference in the collection time whether the driver was located on the right or the left side. Most alley collection operations, however, are performed in conjunction with curbside collection, and there is a distinct advantage in having the driver located on the right side for curbside collection. Again, we have assumed for comparative purposes that there are two cans to be collected from each residence.

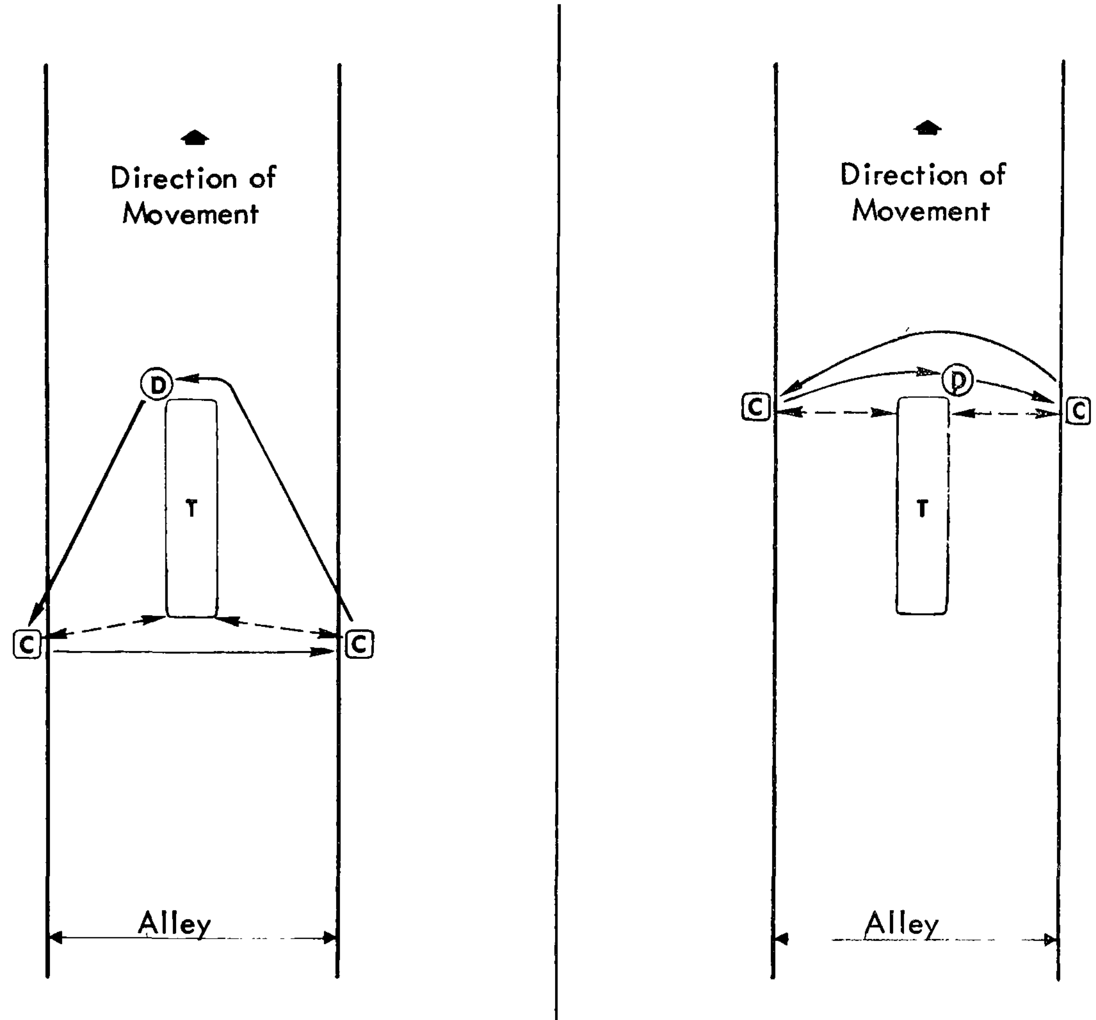
The collection of refuse from the alley location by a two-man crew on a rear-loading packer with the driver and loader alternating positions at each stop is illustrated schematically in Figure 35. All other considerations are the same as those in the previous example. Comparing the columns entitled standard times per collection stop and the man-minutes per service stop of Table XX indicates that the one-man crew using either Method A or B is more efficient than the two- or three-man crew on the basis of man-minutes per service stop. Although the two- and three-man crews complete each collection stop more rapidly than the one-man crew, the net man-minutes per service stop is still greater, a result similar to that found for curbside collections. Projections of system costs, including equipment and haul will be made for the alley collection method in Section D.

A final possibility is the use of three-man crews on a rear-loading packer truck where one man serves as a driver only and remains in the truck cab. This method has been considered but is not shown schematically.

e. Modified Curbside Collection of Refuse by One-, Two-, and Three-Man Crews

In some areas of the country where quiet, narrow residential streets exist, the curbside collection of both sides of the street may be possible with one pass of the equipment and crew. The efficiency of the system depends on street widths, number of containers per household, vehicular use of the street, and other factors. However, in the current study, modified curbside collection with alternative crew sizes and methodology was evaluated assuming two cans of refuse at each service stop, and a 30 ft street width.

Referring to Figures 32 and 33, observe Method B on the right of each Figure, but assume that the refuse container is located at the curb instead of the backyard. The motions of the respective crew members would be the same as those illustrated and discussed previously,



METHOD A

METHOD B

LEGEND

(D) Driver/Loader

[T] Refuse Truck

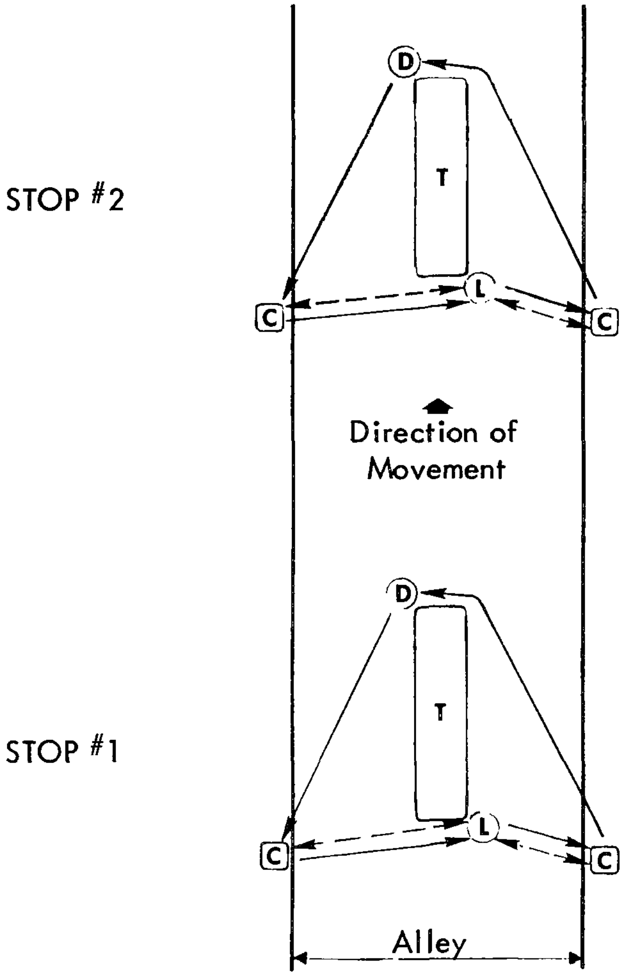
[C] Container Location

——► Path of Movement to Truck or Container

– – –► Path of Movement for Container Dumping

No Scale

FIGURE 34
SCHEMATIC
ONE-MAN ALLEY
REFUSE COLLECTION



LEGEND

- C — Container Location
- D — Driver
- L — Loader
- T — Refuse Truck
- ——► Path of Movement to Container Location
- - - ► Path of Movement for Container Dumping

No Scale

FIGURE 35
SCHEMATIC
TWO-MAN ALLEY
REFUSE COLLECTION

except for the curbside location of the refuse. The one-man modified curbside collection method is also identical to that assumed for the corresponding backyard collection except for the containers' curb location.

Two comparisons between the three alternative crew sizes under the modified curbside collection system were made, one involving the use of shoulder barrels, the other without shoulder barrels. Results are shown in Table XX. The slight saving indicated in the use of shoulder barrels is contingent upon two cans of refuse at each house and the crew member transporting only one of these cans on each trip to the truck without the use of the shoulder barrel. In visits to various cities, it has been observed that as many as four cans were carried by a collector at one time.

Although the three-man crew collects from 6 services at each collection stop compared with 2 services for the one-man crew, the man-minutes per service stop for the latter is about 25 percent less than the former when shoulder barrels are not used. A similar calculation indicates a 14 percent savings for the one-man crew when shoulder barrels are used. As with the backyard collection method, the two- and three-man crews complete a given collection route more quickly than the one-man crew and can therefore make additional service stops. As a result, equipment requirements are less; however, the collection labor cost per service stop will be lower for the one-man crew. Section D further investigates the cost factors involved.

4. Special Analysis

a. Fatigue

As previously observed, the difference between the "standards" and the field recorded time values are due to delays and fatigue. Fatigue occurs as the day progresses and also results from handling a large number of containers at a single collection stop. An attempt has been made to evaluate both types of fatigue in curbside collection with some degree of success. The approach for the first type was as follows: From the field survey data for Municipalities A, B, and C, the service stops completed early in the day were compared with similar stops during the later portion of the day. Approximately 150 stops at the beginning and a similar number near the end of the day for each day of the field surveys were used for the analysis. The final 50 service stops were omitted to reduce the effect of any tendency of the crew to work faster when the end of the collection day was near. The data is shown in Figures 36, 37, and 38 for Municipalities A, B, and C respectively, and is represented by a least squares line in each case.

Figures 36 through 38 indicate that the one-man crew is not subject to more fatigue than either the two- or three-man crews. Factors such as motivation, interrelationships between members of the

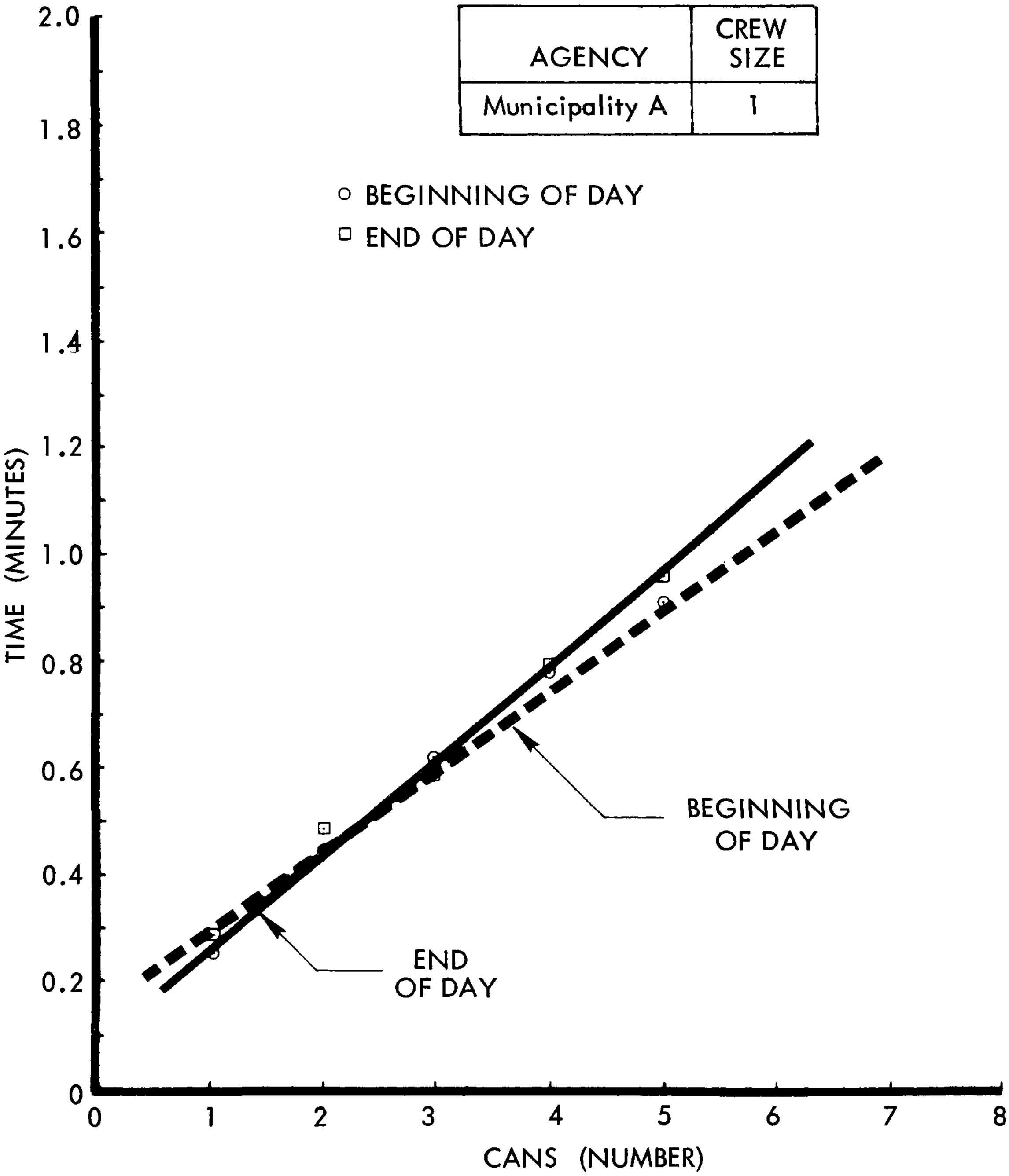


FIGURE 36
FATIGUE ANALYSIS
AVERAGE COLLECTION TIME
PER STOP

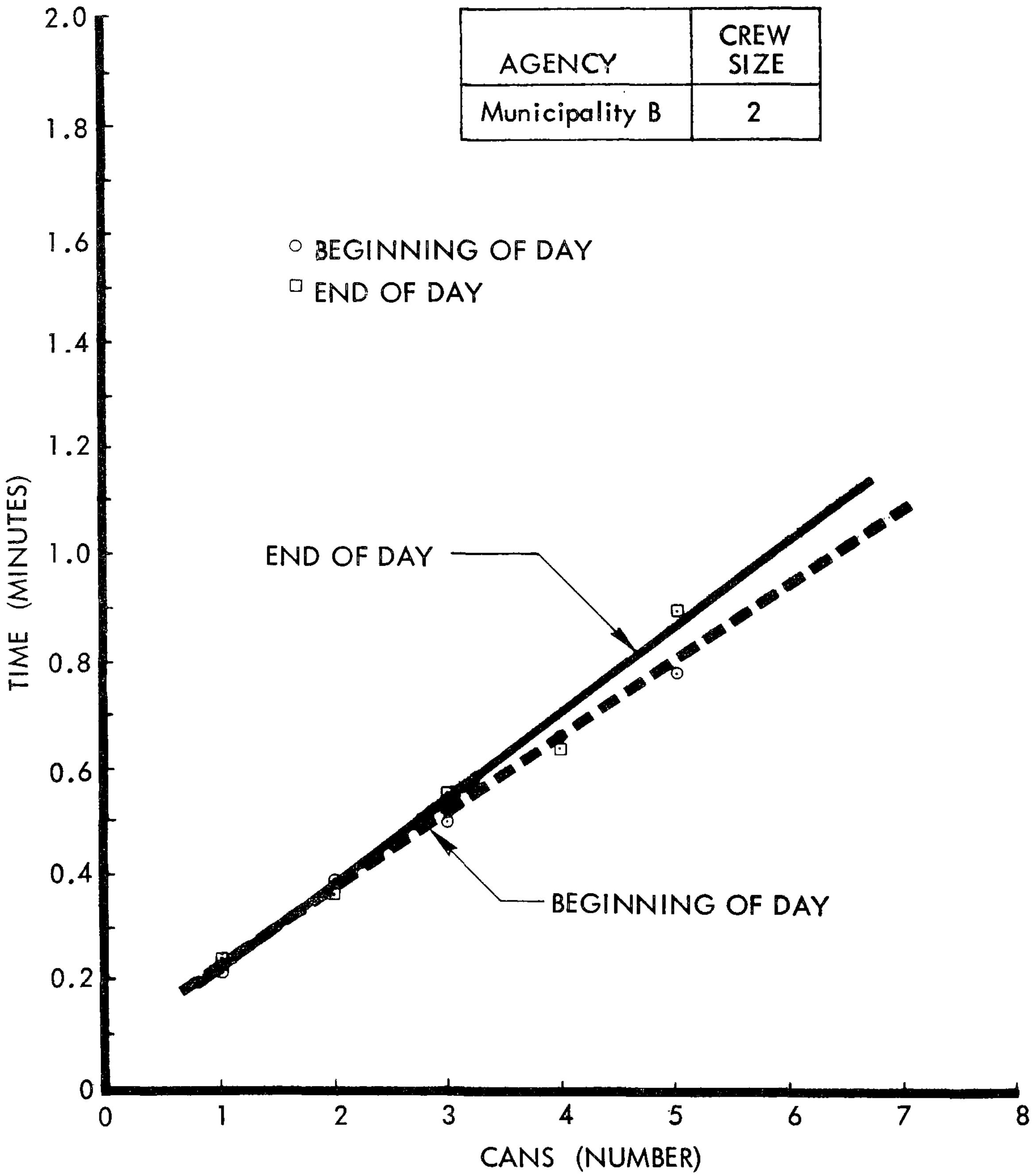


FIGURE 37
FATIGUE ANALYSIS
AVERAGE COLLECTION
TIME PER STOP

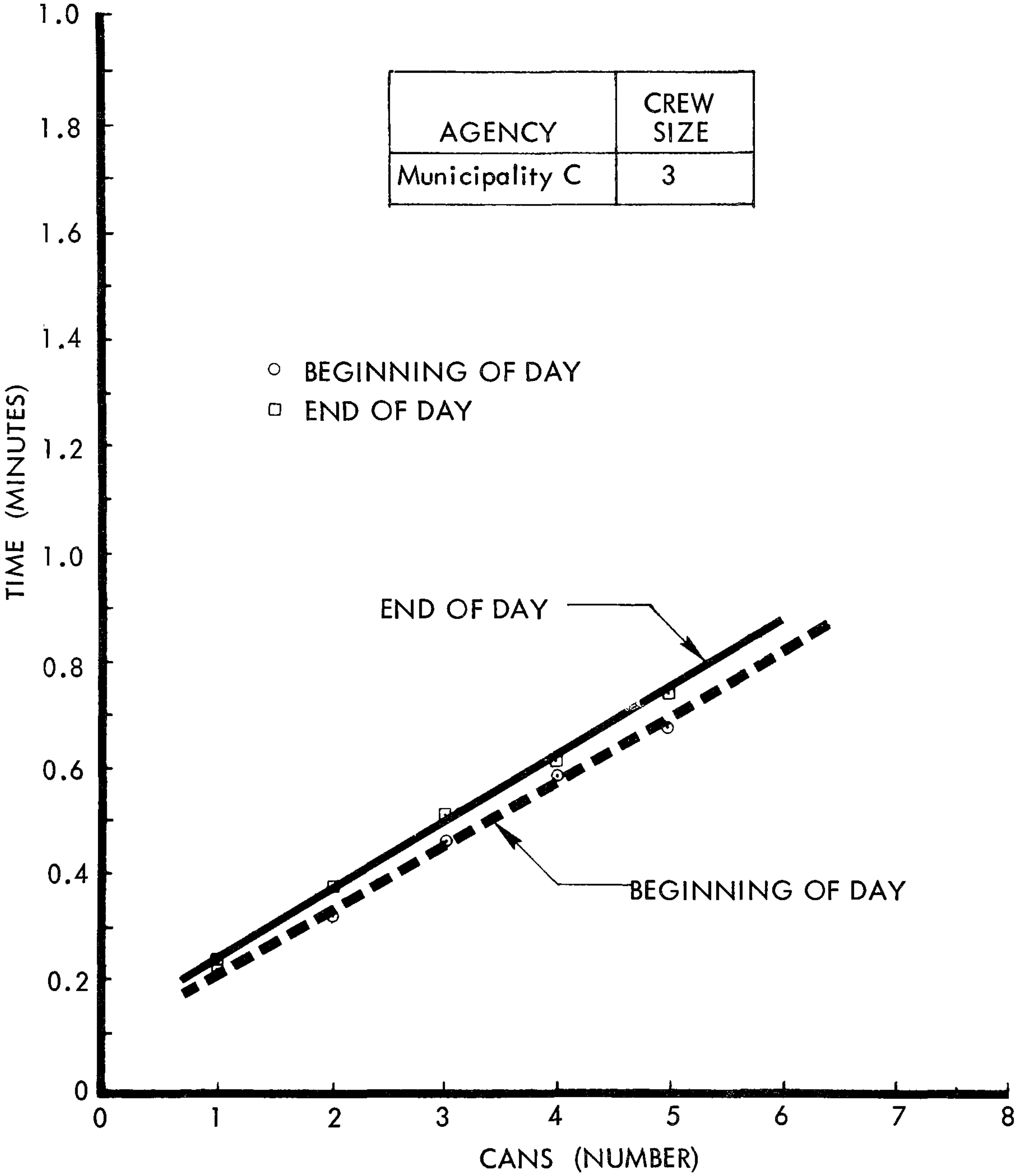


FIGURE 38
FATIGUE ANALYSIS
AVERAGE COLLECTION TIME
PER STOP

crew, climatic conditions, and others may have affected the results, but all Figures indicate that fatigue as measured by the above evaluation method has a relatively minor influence on the difference between the standard curves of Figure 29 and the field-recorded values of Figure 9.

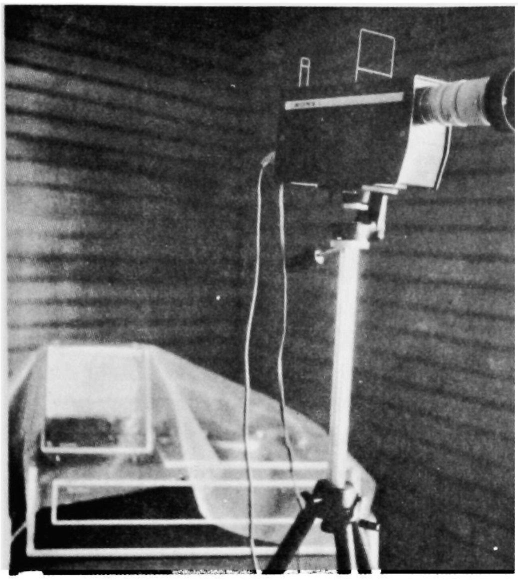
Fatigue of the second type was given preliminary evaluation under separate authorization by the Solid Waste Program. The physical work necessary to conduct refuse collection operations was studied, and experiments were conducted to assess the rate of performance degradation due to certain controllable factors. A literature search was also conducted and is included in the bibliography. These studies are preliminary in nature, and further full-scale human factors investigations of collection operations are required for a comprehensive definition of relationships.

The purpose of the human factors experiment was to evaluate the degradation in performance resulting from loading height and container (plus contents) weight. The loading heights used were 30 in., 42 in., and 48 in. Weights of containers plus contents were 45 lb, 60 lb, and 75 lb. Many municipalities limit allowable weights of containers plus contents to the 50 to 80 lb range. In practice, few containers actually contain the maximum weight, and the average weight per container is considerably less than the 45 lb minimum used in the experiment.

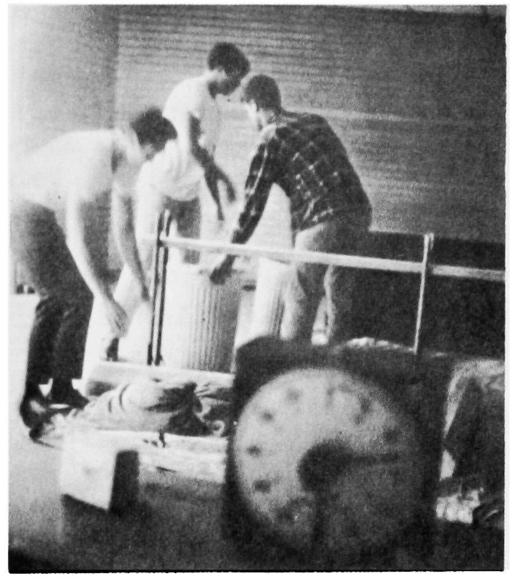
The experiment was conducted over a month and a half period at the company's laboratory. Photographs VIII, IX, X and XI illustrate the experimental monitoring equipment set-up, and the test subject during one test run. Continuous monitoring of the experiment for later review and study was made using the video unit shown. Burlap sacks were filled to the proper weight with discarded golf balls from a nearby driving range. A metal stand was fabricated to adjust the loading height. At least two refuse containers (conventional 32 gal galvanized) were used in each experimental test run. While one can was being lifted and emptied, the other was reloaded for the next lift motion. Two men were stationed adjacent to the adjustable loading height bar to replace the emptied contents into the empty can set down by the subject. A fourth man recorded the number of containers loaded and the elapsed time for selected groups of containers. A copy of the data form is included in Appendix E.

Initially, four subjects volunteered to participate in the study. Each was a student at a nearby university, between the ages of 20 and 22. The height, weight, and age of each subject is recorded in Table XXI. Subjects 1 and 2 were forced to drop out of the study due to illness and work requirements. The remaining subjects completed the experiment.

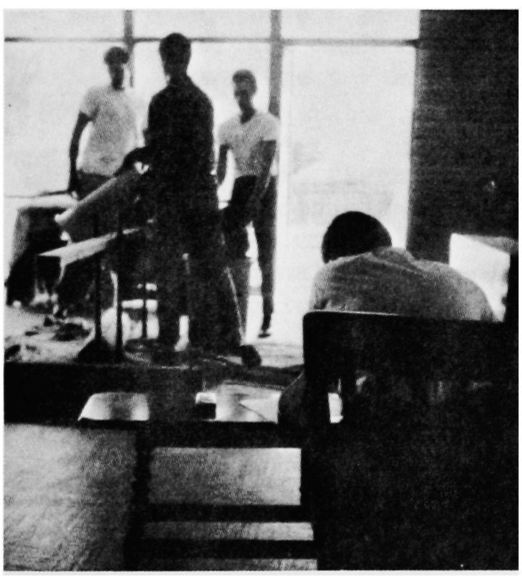
During the initial stages of the experiment, pilot studies were made to establish suitable experimental procedures for handling refuse containers, contents, and timing procedures, and to



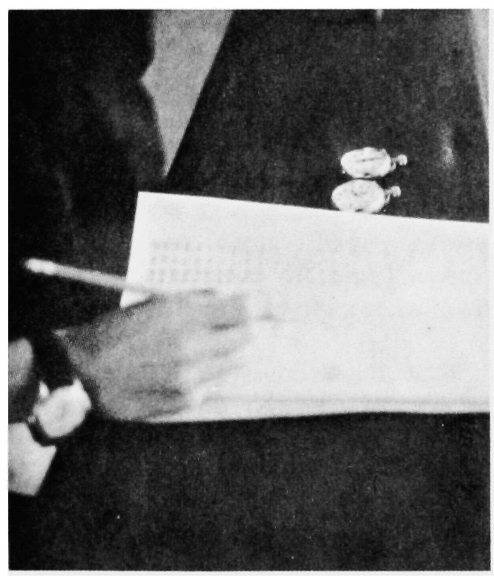
PHOTOGRAPH VIII.
VIDEO TAPE MONITORING EQUIPMENT



PHOTOGRAPH IX.
VIEW FROM VIDEO MONITOR



PHOTOGRAPH X.
EXPERIMENT IN PROGRESS



PHOTOGRAPH XI.
DATA RECORDING

TABLE XXI

HUMAN FACTORS EXPERIMENT
PHYSICAL DATA - SUBJECTS

Subject	Age	Height	Weight (Lb)
1	22	6'2"	180
2	21	6'0"	160
3	21	6'1"	170
4	20	5'9"	200

establish three simulated loading heights and weights for use throughout the study. Initially, subjects were instructed to start loading the cans' contents and to continue until the incremental time per can increased significantly over the initial loading rate. This method was found unsatisfactory because the subject would soon establish a pace for himself and continue the simulated loading operation for extended periods.

In order to use heights and weights reasonably close to those experienced in practice and concurrently obtain significant amounts of performance degradation, it was necessary to vary the procedure. The subjects were therefore instructed to load as rapidly as possible and to load until unable to continue or the data indicated rapid degradation. The results of these tests are presented in Table XXII. All subjects were of about average stature, ranging from 160 to 200 lb in weight and had no previous experience with loading refuse. Subject 1 performed at an average rate of 0.04 HP, Subject 2 at a rate of 0.02 HP, Subject 3 at an average rate of 0.05 HP, and Subject 4 at an average rate of 0.04 HP, during these pilot studies. Since the literature indicates that man may perform over extended periods at a 0.05 HP rate, the subjects were well within the accepted work rate level.

Opposition to the use of fewer men on collection vehicles is frequently based on the assumption that there is too much work for one man. The test subjects, however, were capable of simulating the loading of more tonnage in a period of one to two hours than most collection crews, regardless of the number in the crew, load during the entire time on the route. Route time normally totals some four hours in an efficient collection system.

Furthermore, one-man crews observed in Municipality A consistently loaded eight or more tons per day from the curbside location, and many one-man crews loaded from 10 to 12 tons per day. These crews experienced minimal amounts of overtime, usually because of the necessity to return to collect a partial load during heavy refuse generation periods.

The use of the video TV tape recording equipment was very helpful. Appendix F discusses the advantages and disadvantages of using video TV during human factor studies.

Each combination of loading height and container weight was repeated three times for each subject during the experiment. A random number table was used to assign a loading height and container weight for each subject for each day of the experiment.

Statistical methods were used to analyze the experimental test results. From the data, the average time to load the next container was calculated following the cumulative loading of 1000, 3000, and 5000 lb of refuse. The average was made up of six readings in each case. The data was placed in a 3 x 3 matrix for convenient analysis. Each matrix is illustrated below. The values within each matrix represent the average time in seconds to load the container with the indicated height and weight, following the cumulative loading of 1000, 3000, or 5000 lb respectively.

1000 Lb

Container Weight (Lb)	Loading Height (In.) 48	42	30
75	5.6	4.9	4.7
60	4.3	4.4	4.6
45	2.7	3.4	2.9

3000 Lb

Container Weight (Lb)	Loading Height (In.) 48	42	30
75	6.2	5.4	5.2
60	4.7	5.2	4.9
45	3.1	4.4	3.2

5000 Lb

Container Weight (Lb)	Loading Height (In.) 48	42	30
75	7.1	6.1	5.8
60	5.2	6.4	5.2
45	3.5	5.4	3.6

The data is illustrated graphically in Figure 39.

TABLE XXII

HUMAN FACTORS EXPERIMENT
SUMMARY OF RESULTS - PILOT STUDY

Subject	1	2	2	2	3	3	4	4
Can + Contents Weight (Lb)	30	75	45	75	60	45	60	75
Loading Height (In.)	24	48	30	30	42	42	30	48
Total Elapsed Time (Min)	110	30	53	50	30	29	31	28
Average Loading Time/Can (Sec)								
Beginning	3.75	7.00	4.37	6.00	4.00	4.50	6.00	10.10
End	6.00	20.00	7.60	10.00	13.00	8.80	12.00	12.00
Total Cans Loaded	1020	155	600	320	240	280	210	170
Total Weight Loaded (Tons)	15.3	5.8	13.5	12.0	7.2	6.3	6.3	6.4

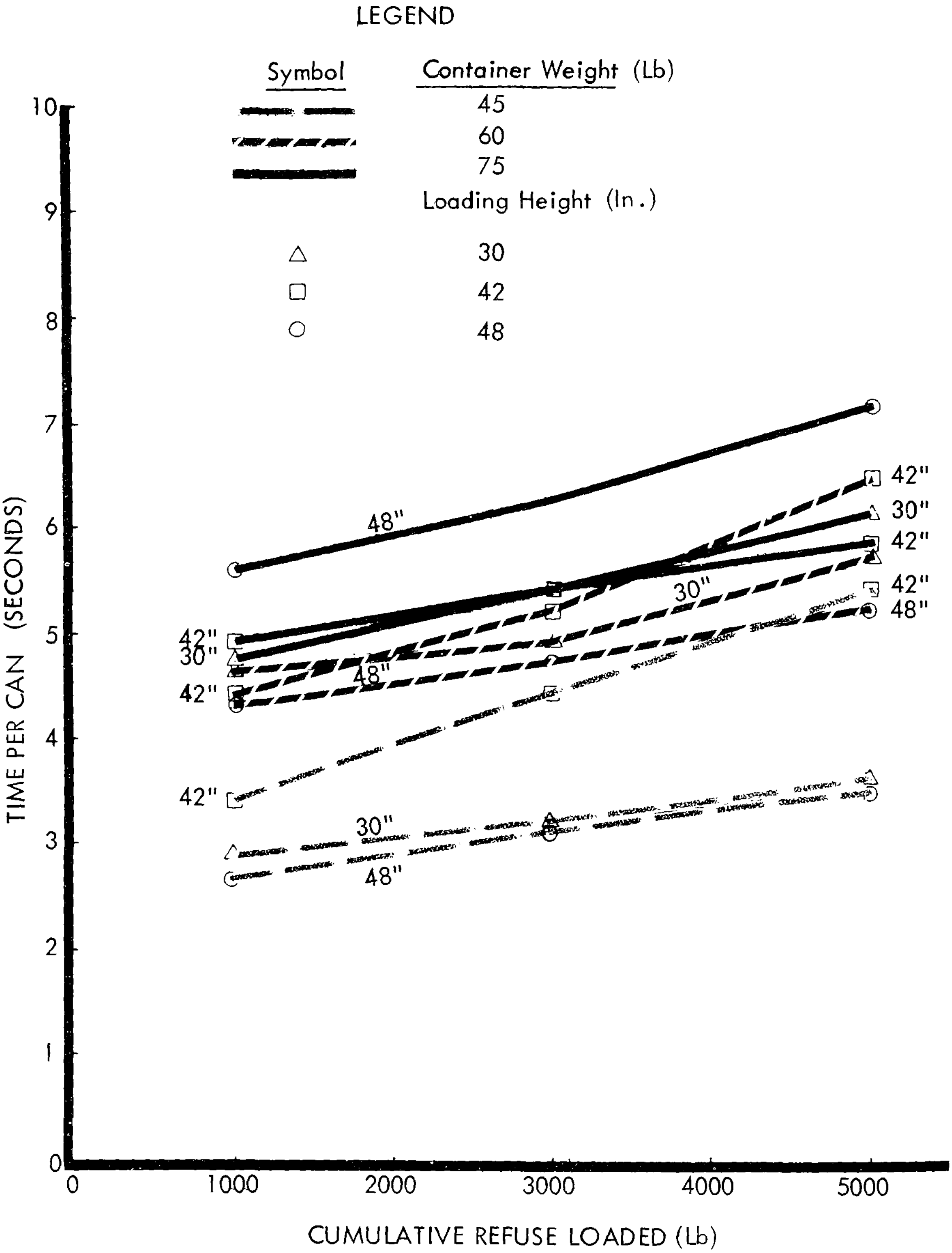


FIGURE 39
HUMAN FACTORS
EXPERIMENTAL DATA

The analysis of variance method permits us to determine whether the performance degradation is due to the height of the bar or to the container weight.

Using the above data, statistical tests at the 5 percent level of significance indicate that the total weight of the filled container and contents was a positive factor in the degradation of performance, and that the addition of each 10 lb increment to the container weight between 45 and 75 lb resulted in an additional 0.7 sec loading time per can. This increase was reasonably constant whether the cumulative quantity previously loaded was 1000 lb, 3000 lb, or 5000 lb.

Although the differences in performance between 45-lb and 60-lb containers, and between 45-lb and 75-lb containers, were significant at the 5 percent level, those between 60 and 75-lb containers were not. The effect of loading height on performance degradation was not significant.

Although the results are preliminary, they indicate that fatigue had little effect on the relative effiiciency of either the one-, two-, or three-man crew; the work load associated with use of the one-man crew was not excessive; and the combined weight of the refuse container and its contents was a more important factor in performance degradation than the loading height of the vehicle.

b. Delays

Video TV films of field collection operations in Municipalities A, B, and C were obtained and given detailed study. Using slow motion, instances of personal and unavoidable delays were extracted, and respective times for each type of delay were recorded along with the number of containers at the stop. The video tape equipment was valuable for this analysis as the tapes could be rerun, stopped, and operated in slow motion as required.

The video tapes revealed several different types of delays: the most common unavoidable delays resulted from removal of lids from refuse containers prior to loading and the operation of the truck's packer mechanism at a collection stop. The three municipalities used packer vehicles equipped with auxiliary engines so that the packing operation could normally be conducted while the vehicle was traveling between collection stops. However, at stops with large quantities of refuse or when the load was nearly full, it was often necessary to operate the packer while at the collection stop. Other delays were caused by cars parked adjacent to the container location, and the spilling of refuse from the hopper during packing or from the container while loading. Personal delays involved lighting a cigarette, conversation, interferences between members of the two- or three-man crew, and other incidents. Table XXIII lists the types of delays experienced in each of the municipalities along with the average lost time per occurrence and per service stop.

TABLE XXIII

DELAYS
MUNICIPALITY A

No.	Type of Delay	Number of Occurrences	Total Lost Time (Min)	Average Lost Time/ Occurrence (Min)	Average Lost Time/ Stop (Min)
1	Packer	150	15.51	0.103	0.120
2	Parked cars	22	2.48	0.113	0.019
3	Pick up spill	13	0.58	0.045	0.004
4	Lids	159	2.74	0.018	0.021
5	Difficulty in emptying cans	5	0.35	0.07	0.003
6	Scavenging	-	-	-	-
7	Talk	2	0.21	0.105	0.002
8	Wait, adjust gloves, etc.	8	2.06	0.257	0.016

Total Number Service Stops Studied: 129

TABLE XXIII
(Continued)

DELAYS
MUNICIPALITY B

No.	Type of Delay	Number of Occurrences	Total Lost Time (Min)	Average Lost Time/ Occurrence (Min)	Average Lost Time/ Stop (Min)
1	Packer	63	7.94	0.132	0.066
2	Parked cars	20	2.24	0.112	0.019
3	Pick up spill	16	2.33	0.146	0.019
4	Lids	46	0.79	0.017	0.007
5	Difficulty in emptying cans	47	3.65	0.078	0.030
6	Scavenging	1	0.53	0.53	0.004
7	Talk	9	3.49	0.388	0.029
8	Wait, adjust gloves, etc.	8	8.40	1.05	0.070

Total Number Service Stops Studied: 120

TABLE XXIII
(Continued)

DELAYS
MUNICIPALITY C

No.	Type of Delay	Number of Occurrences	Total Lost Time (Min)	Average Lost Time/ Occurrence (Min)	Average Lost Time/ Stop (Min)
1	Packer	60	4.59	0.076	0.043
2	Parked cars	13	1.45	0.112	0.014
3	Pick up spill	17	0.94	0.055	0.009
4	Lids	8	0.12	0.015	0.001
5	Difficulty in emptying cans	30	2.44	0.081	0.023
6	Scavenging	31	4.10	0.132	0.039
7	Talk	9	0.91	0.101	0.009
8	Wait, adjust gloves, etc.	20	2.34	0.117	0.022

Total Number Service Stops Studied: 106

The analysis of personal and unavoidable delays is illustrated in Figures 40, 41, and 42 for Municipalities A, B, and C, respectively. These figures indicate the mean collection time for service stops composed of from one through five cans based on the detailed field surveys, and the adjusted standard times for collecting similar stops based on the MTM values plus the personal and unavoidable delays just described. The close correlation between the two sets of data for each municipality is apparent.

Because the mean collection time for the field survey data was calculated on the basis of all field collection time values, it does include a fatigue factor. However, the previously described fatigue studies indicate that it probably plays a relatively minor role in the differences between MTM-developed collection times and those actually recorded during the field surveys.

The close agreement between the field-measured collection times and the MTM standard times adjusted for unavoidable and personal delays indicates the MTM values are applicable to refuse collection analysis and provide a convenient means for estimating efficiency of one-, two-, and three-man collection crews. In addition, it indicates that the municipalities and crews chosen for the detailed field surveys were closely comparable and that conclusions derived from the field studies are substantially valid.

D. Mathematical Model

1. General

A mathematical model may be defined as a mathematical formula which describes the interrelationships between variables affecting a given system. If a model can be formulated to describe a system, computers can be used to simulate system operation and performance when variables are assigned numerical values.

A limited model was developed describing the time required for the collection of refuse. The purpose of the model was to enable projections of refuse collection system performance for alternative crew sizes, collection methodologies, truck sizes, haul distances, and labor and equipment costs. The following factors which affect the efficiency of collection were included in the model:

a. Mean quantity of refuse per collection stop.

b. Driving time between the route and the disposal site.

c. Mean collection time at each collection stop and travel time to the next stop.

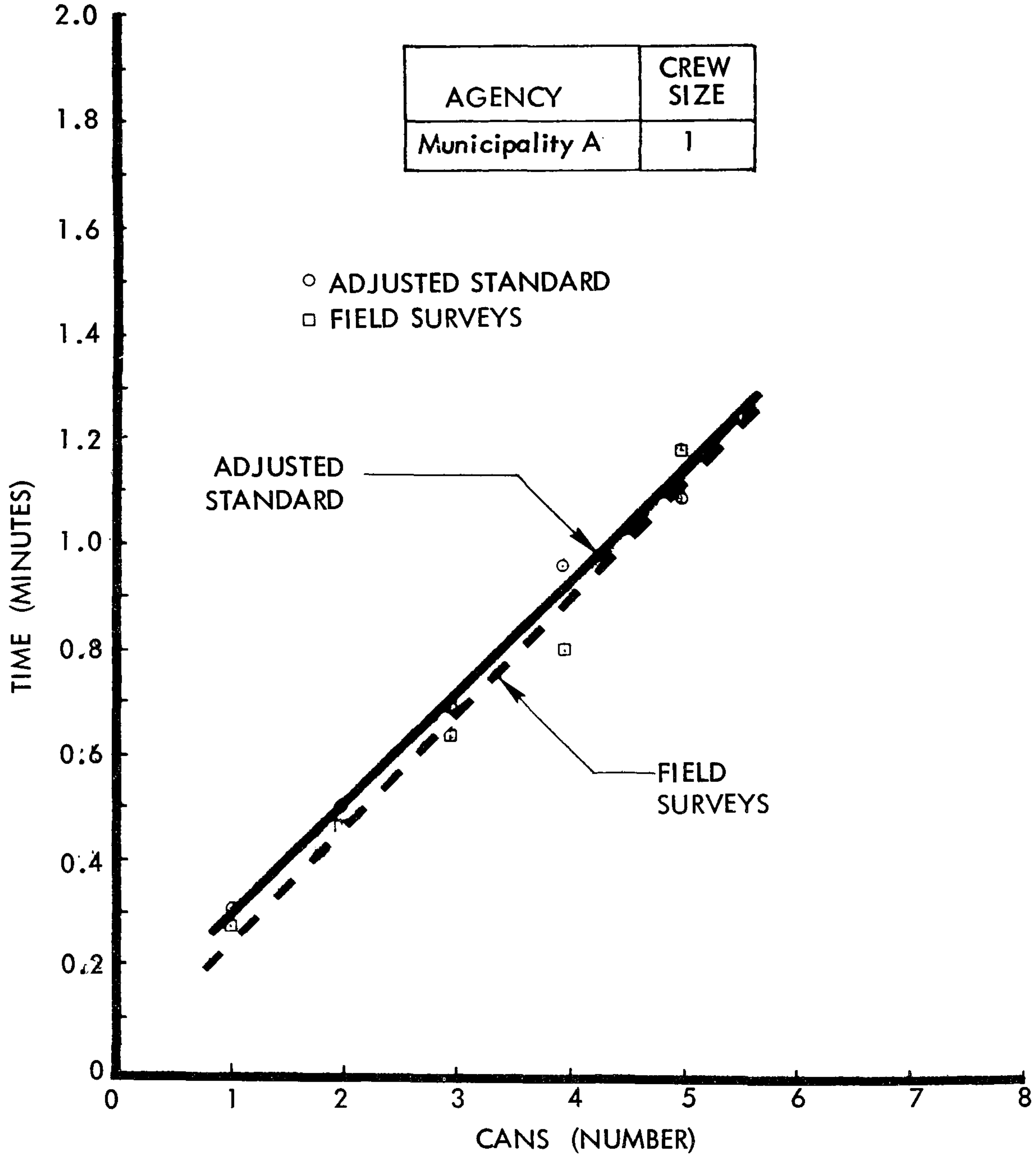


FIGURE 40
COMPARISON
AVERAGE COLLECTION TIME
FIELD - ADJUSTED STANDARD

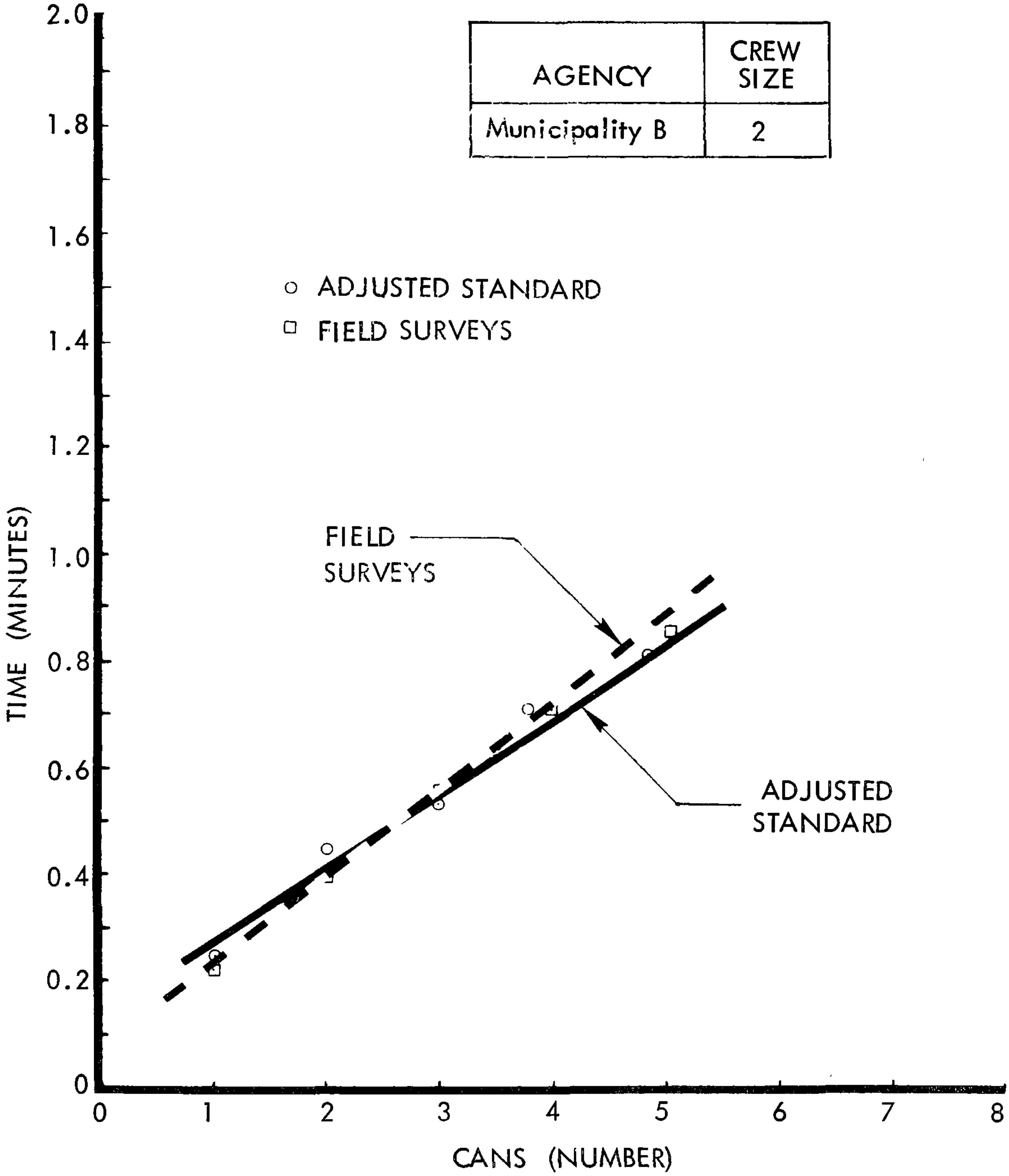


FIGURE 41
COMPARISON
AVERAGE COLLECTION TIME
FIELD-ADJUSTED STANDARD

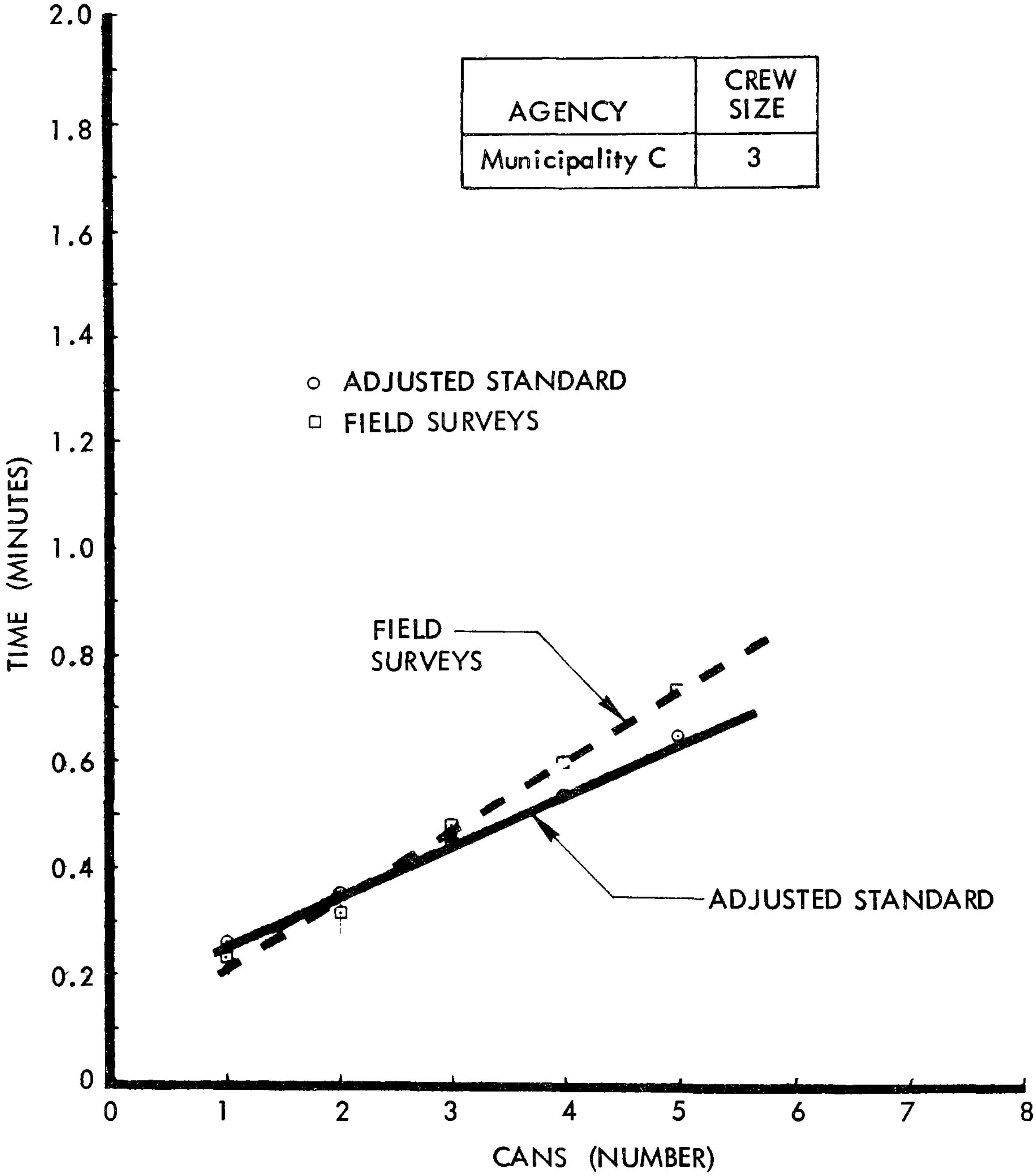


FIGURE 42
COMPARISON
AVERAGE COLLECTION TIME
FIELD-ADJUSTED STANDARD

d. Total non-productive time including: travel time between the yard and the route and between the disposal site and the yard; relief, lunch, and dispatch time; and incidential time losses resulting from road conditions, equipment breakdown, etc.

e. Mean disposal time per load at the disposal site.

To optimize a refuse collection system, it is necessary to minimize the total collection cost per unit of refuse collected. The combination of truck volume and crew size which satisfies the above criterion is the optimum for any given set of conditions.

In the study of field factors described subsequently in greater detail, the factors vary greatly. Ideally, the actual statistical distributions of each should be determined. However, this would complicate calculation of the model and the simulation could not be readily completed by the small desk-type electronic computer used in this study. The contract scope of work did not include large-scale simulation on a wide-range large-capacity electronic computer. A stochastic program with all the field factors considered can give much better and more accurate results, but it would require more data preparation and a larger computer for analysis.

Some assumptions were necessary in the model. Where possible, these assumptions were based on field experience and survey data. Discrete values were used in the model; however, a range of those considered most important was used. The model calculations thus are approximations of the true field conditions.

2. Basic Assumptions

a. The average number of cans per service stop is three, and the corresponding times required per collection stop for curbside collection are:

(1) One-man crew: 0.60 minutes

(2) Two-man crew: 0.54 minutes

(3) Three-man crew: 0.46 minutes

These values were based on field data from Municipalities A, B, and C, as verified by the MTM values. Because much of the simulation work was completed prior to the final field surveys in Municipalities A, B, and C, the above time values were based on only the summer and winter survey data. There are only minor differences, however, between these values and those compiled following the inclusion of data from the field surveys.

Table XX lists collection stop time values used for simulation of backyard, alley, and modified curbside collections.

b. The average time of travel between stops is 0.17 minutes based on field data. Correspondingly higher values were used for collection stops composed of four and six services.

c. The minimum partial load to be collected is one-eighth the volumetric capacity of the truck.

d. There is no limit to the allowable number of trips within the working day, and any total amount of refuse may be collected by the crew.

e. The normal work day is 480 minutes, with a maximum allowable overtime of 30 minutes.

f. The crew is paid for a minimum of eight hours; if they finish the assignment earlier, they are relieved.

g. The labor rate for overtime is 1.5 times the normal rate.

h. The truck operating cost is linearly proportioned to the capacity of the truck. The cost of the truck time during relief time taken by the crew is assumed to be half that during haul time. The assumed costs of various truck sizes are shown in Table XXIV.

i. Labor is available at 8 cents per man-minute, or $4.80 per hour (including fringe benefits). There is no cost differential between driver and loader.

j. Mean time per load at the disposal site is 10 minutes.

k. The mean density of the refuse following compaction in the vehicle is 550 lb per cu yd.

3. Symbols

a: The ratio of weight of refuse collected to the weight capacity of the collection vehicle.

B: One-way average driving time between the route and the disposal site (min).

C: Total cost per ton for labor and equipment ($/ton).

CS: Crew size (including driver).

TABLE XXIV

COSTS OF VEHICLE TIME
EQUIPMENT COST ONLY

Truck Size	12 Cu Yd	16 Cu Yd	20 Cu Yd	25 Cu Yd	32 Cu Yd	40 Cu Yd
Collection Time	$3.75/Hr 6.25¢/Min	$3.90/Hr 6.50¢/Min	$4.12/Hr 6.85¢/Min	$4.20/Hr 7.00¢/Min	$4.73/Hr 7.90¢/Min	$5.10/Hr 8.50¢/Min
Haul Time	$4.00/Hr 6.67¢/Min	$4.35/Hr 7.25¢/Min	$4.60/Hr 7.67¢/Min	$5.10/Hr 8.50¢/Min	$5.74/Hr 9.57¢/Min	$6.20/Hr 10.33¢/Min
Relief Time	$2.00/Hr 3.33¢/Min	$2.18/Hr 3.63¢/Min	$2.30/Hr 3.83¢/Min	$2.55/Hr 4.25¢/Min	$2.87/Hr 4.78¢/Min	$3.10/Hr 5.17¢/Min

CV: Total vehicle cost (\$/day).

D: Mean disposal time (min/load).

d: Mean density of refuse in the vehicle (lb/cu yd).

E: Total on-route collection time (min).

e: Vehicle cost during collection (\$/min).

H: Total haul time; includes driving between stops on route, to and from disposal site, yard to route, and disposal site to yard (min).

h: Vehicle cost during haul (\$/min).

K: Total non-productive time (min); includes dispatch, lunch and relief, yard to route time, and disposal site to yard time.

L_c: Labor cost (\$/ton).

L_R: Labor rate on straight time (\$/min).

L_T: Total labor time at straight time (min).

M_H: Paid man-minutes per ton (min/ton).

Q: Mean quantity of refuse per collection stop (lb).

R: Total relief time (min).

r: Vehicle cost while not in operation (\$/min).

S: Service stops per load (number/load).

SC: Service stops completed (number/day).

t: Mean time per collection stop plus travel time to the next stop (min).

T: Total refuse collection (tons).

V: Vehicle volumetric capacity (cu yd).

V_H: Vehicle time per ton (min/ton).

V_C: Vehicle cost (\$/ton).

X: Total time to make n trips, or to collect and dispose of N loads (min).

4. Formulation

The various values to be tabulated were calculated as follows:

Total time to complete one trip (collect one full load):

$$X_1 = \frac{Vtd}{Q} + B + K + D$$

At the disposal site, the following apply:

if $X_1 \geq 480$, there may be only one trip for the day.

if $X_1 + 2B + D \geq 510$, there may be only one trip for the day.

if $X_1 > 510$, the following calculation is made:

$510 = a \frac{Vtd}{Q} + B + K + D$; solving for a gives us

the fraction of the truck capacity filled or the partial load size.

if $X_1 + 2B + D < 510$ and $X_1 < 480$, the truck may be

sent for a second or more loads as the time permits.

The truck goes for a total of n trips, where:

$$X_n + (n + a - 1) \frac{Vtd}{Q} + (2n - 1) B + K + nD$$

if $X_n \leq 510 < X_{n+1}$ for $a \geq 1/8$

if $a < 1/8$, only $(n - 1)$ trips are made.

Now:

$$N = (n + a - 1)$$

$$T = \frac{NVd}{2000}$$

$$SC = \frac{NVd}{Q}$$

$L_T = 480$ (CS) if $X_n \leq 480$, or

$= CS \{1.5 (X_n - 480) + 480)\}$ if $X_n > 480$

$$M_H = \frac{L_T}{T}$$

$$V_H = \frac{X_n}{T}$$

$$L_c = M_H (L_R)$$

$$CV = H (h) + E (e) + R (r)$$

$$V_c = \frac{CV}{T}$$

$$C = V_c + L_c$$

5. Results - Mathematical Model

The model has been used to simulate the refuse collection operation with chosen values for the model variables. The results of the many simulations are shown in Figures 43 through 73. Most of the simulation work was conducted to compare one-, two-, and three-man collection crews for curbside collection. However, a few simulations were completed for backyard, alley, and modified curbside collection methods.

On each figure, the abscissa represents the volumetric capacity of the refuse collection vehicle. Figures 43, 44, and 45 compare the unit cost per ton for collection and haul of the three crew sizes for a range of representative values of K, B, and Q, where:

> K = total non-productive time (min); includes dispatch, lunch and relief, yard to route time, and disposal site to yard time.
>
> B = one-way average driving time between the route and the disposal site (min).
>
> Q = mean quantity of refuse per service stop (lb).

Referring to Figures 43, 44, and 45, the following observations can be made. The one-man operation is less costly than either the two- or three-man crew, regardless of truck size and over the full range chosen for K, B, and Q. As K and B become smaller, the cost differential between crews and the effect of truck size on cost also become less. Unit costs generally decrease as equipment volumetric capacity is increased; partial loads, however, cause instances of increased cost with larger equipment.

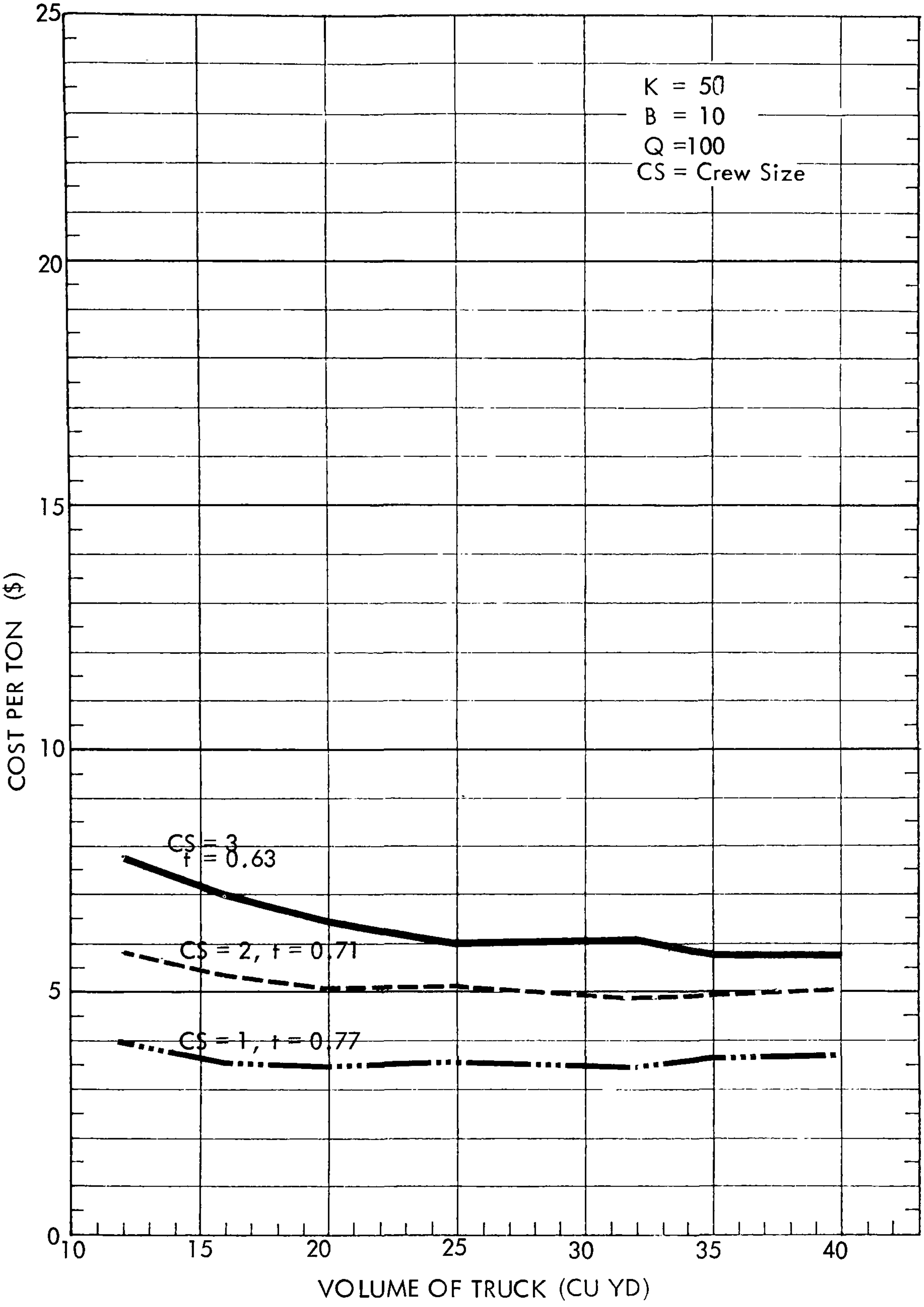


FIGURE 43
TOTAL COST CURVES
CREW COMPARISON

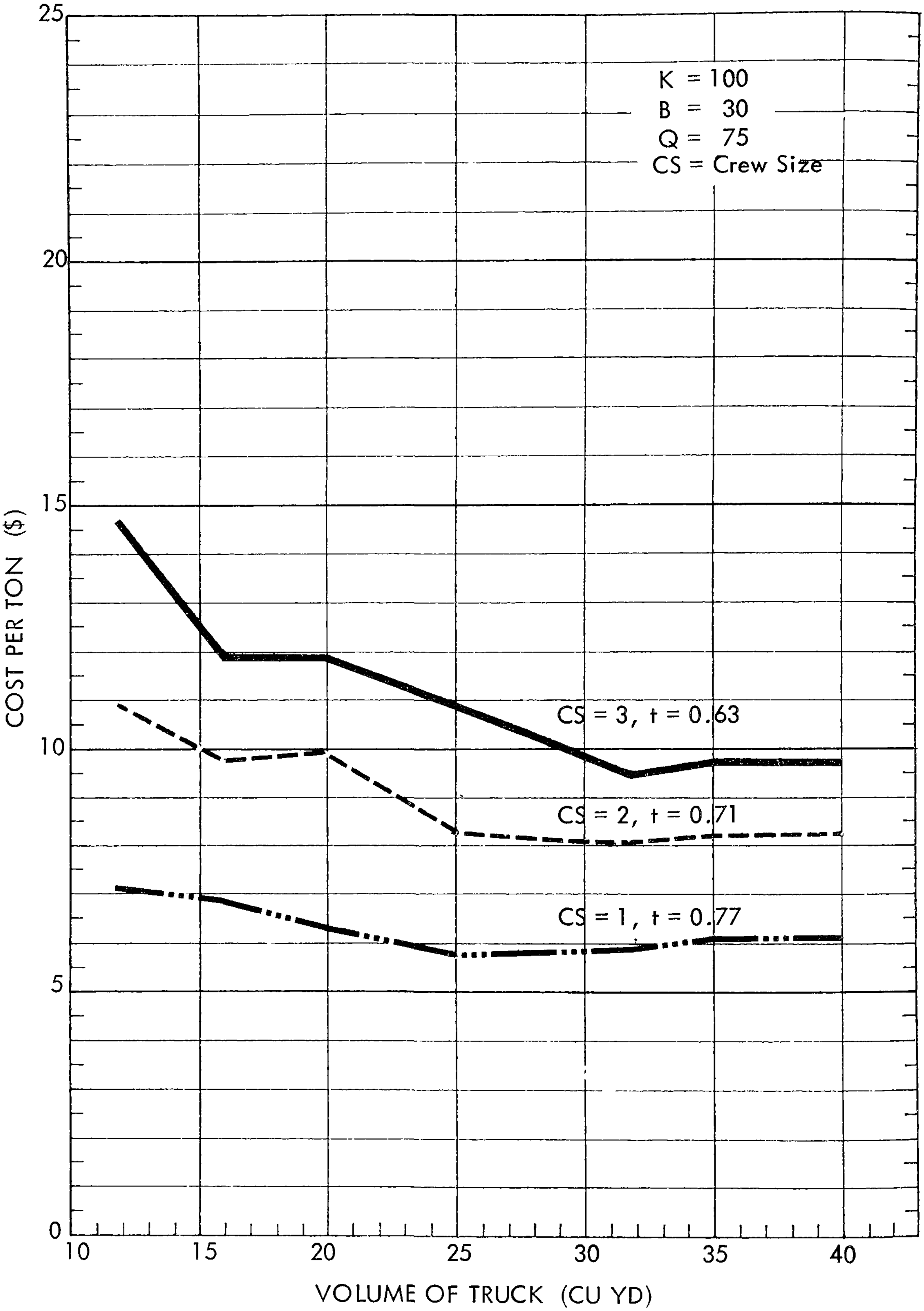


FIGURE 44
TOTAL COST CURVES
CREW COMPARISON

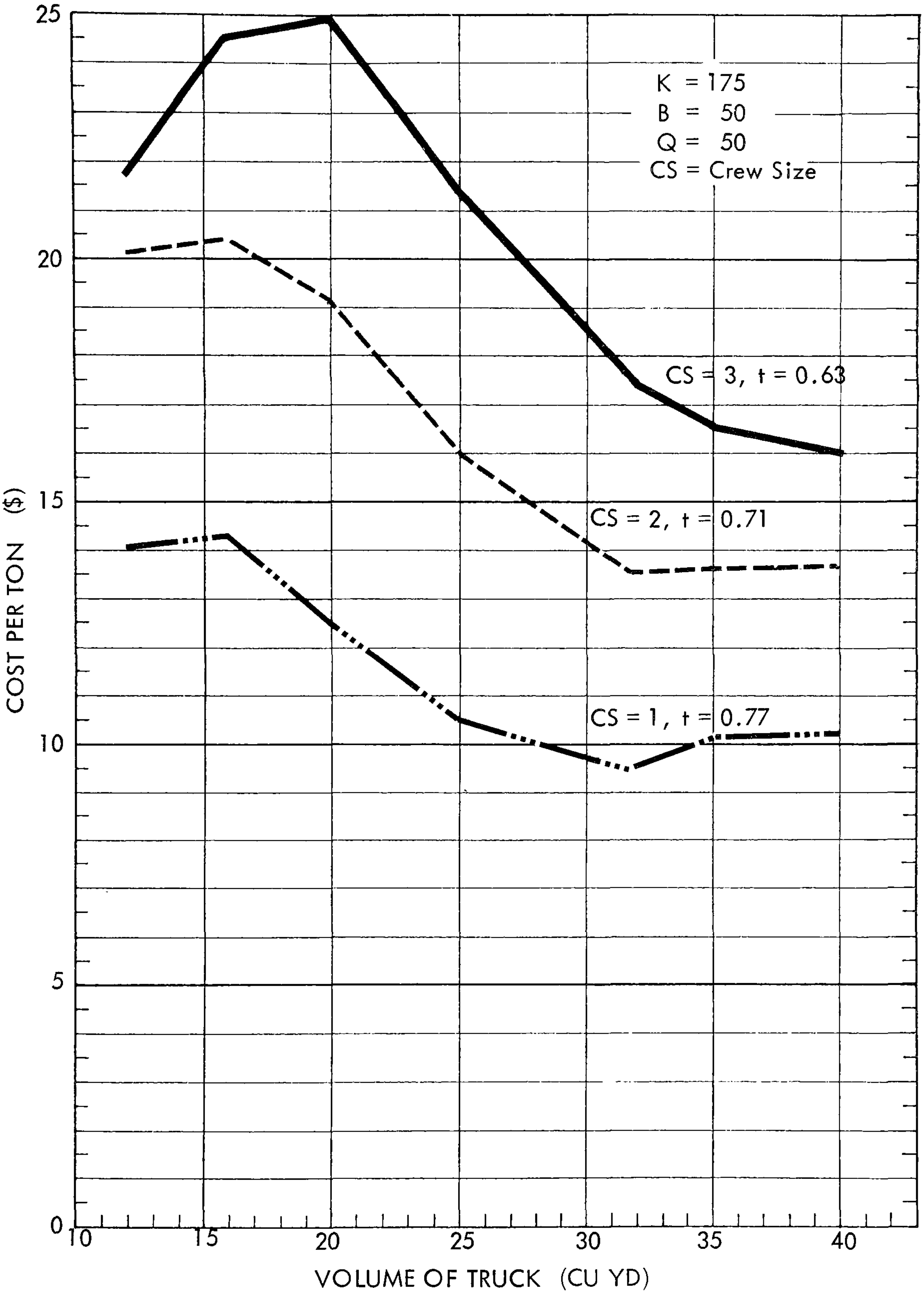


FIGURE 45
TOTAL COST CURVES
CREW COMPARISON

Figures 46, 47, and 48 were constructed from Figures 43, 44, and 45, and illustrate the range in unit cost per ton for each crew size. The chosen values for K, B, and Q represent probable extremes in any curbside collection operation in the United States. These results serve as an estimate of the reduced collection costs possible through the use of the one-man crew for curbside refuse collection under the field conditions assumed in the model. The differences in unit costs become increasingly important as haul time (B) and non-productive time (K) increase.

Figures 49, 50, and 51 compare the number of services collected by each of the three crew sizes. Generally, the use of larger vehicles enables the collection of more services by each crew because with fewer trips to the disposal site a greater portion of the collection day is spent on the route. The ability of the two- and three-man crews to collect a greater number of services per day reduces the total equipment requirements for the refuse collection operation, thereby reducing total equipment costs. However, in the above described cost calculations, reduced equipment costs are more than offset by the increased labor costs of the multi-man crews. In many collection operations, particularly those of municipalities, crews are required to collect a fixed number of services each day. Figures 49, 50, and 51 can be used to estimate the number of crews required for operations using different equipment capacities.

Figures 52, 53, and 54 illustrate for each crew size the range in services collected based on the chosen variations in (K), (B), and (Q).

The average cost per service for refuse collection is important to the operations manager and to the resident. Figures 55, 56, and 57 compare the average cost per service for the three crew sizes and demonstrate the potential value of the one-man crew in reducing collection costs.

Figures 58, 59, and 60 illustrate the effect of varying the value of (Q) on the number of services collected. As the mean quantity of refuse per service increases, the crew must use a larger truck to collect the same number of services per day. Although (Q) was varied from 50 to 100 lb, the model simulation assumed that in each instance three containers were placed for collection; thus (t) did not vary with (Q). In practice, an increase in (Q) would probably result in an increase in the average number of containers per service, and consequently, the (t) value. This would cause the curves on each figure to spread further apart. The curves developed, however, indicate the general relationship between the quantity of refuse per stop, haul and non-productive time, truck volume required to complete a given number of service stops, crew size, and costs.

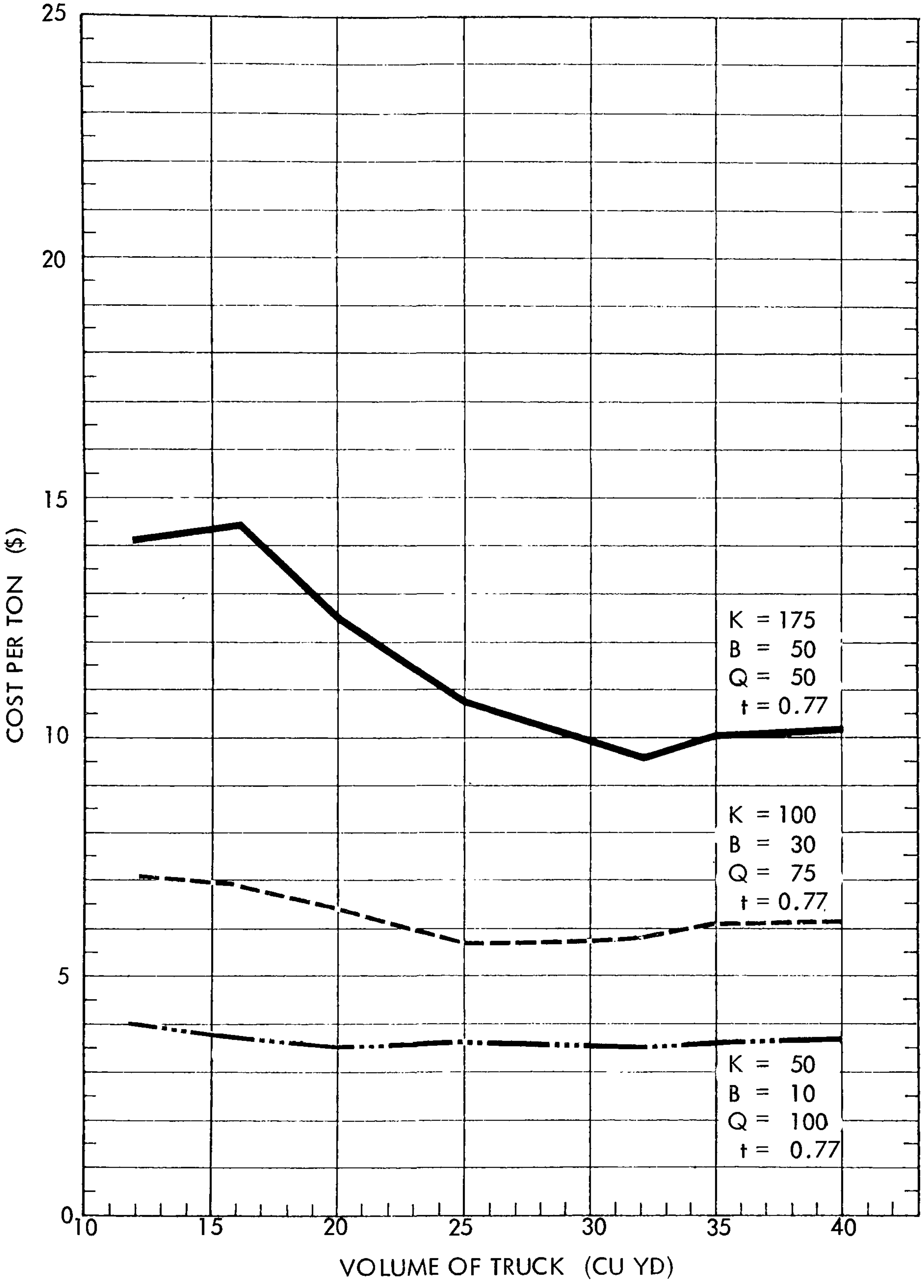


FIGURE 46
TOTAL COST CURVES
RANGE, ONE-MAN CREW

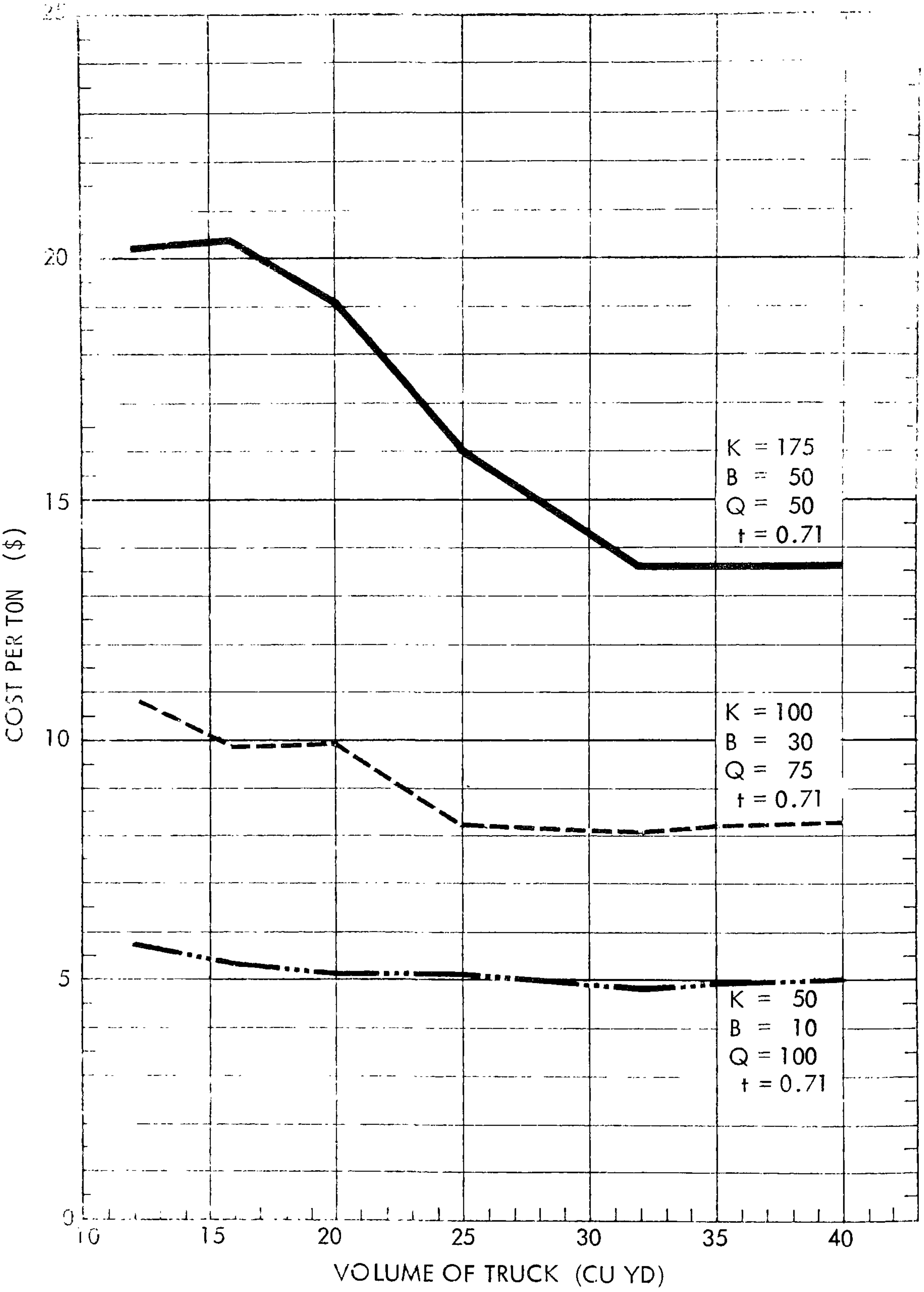


FIGURE 47
TOTAL COST CURVES
RANGE, TWO-MAN CREW

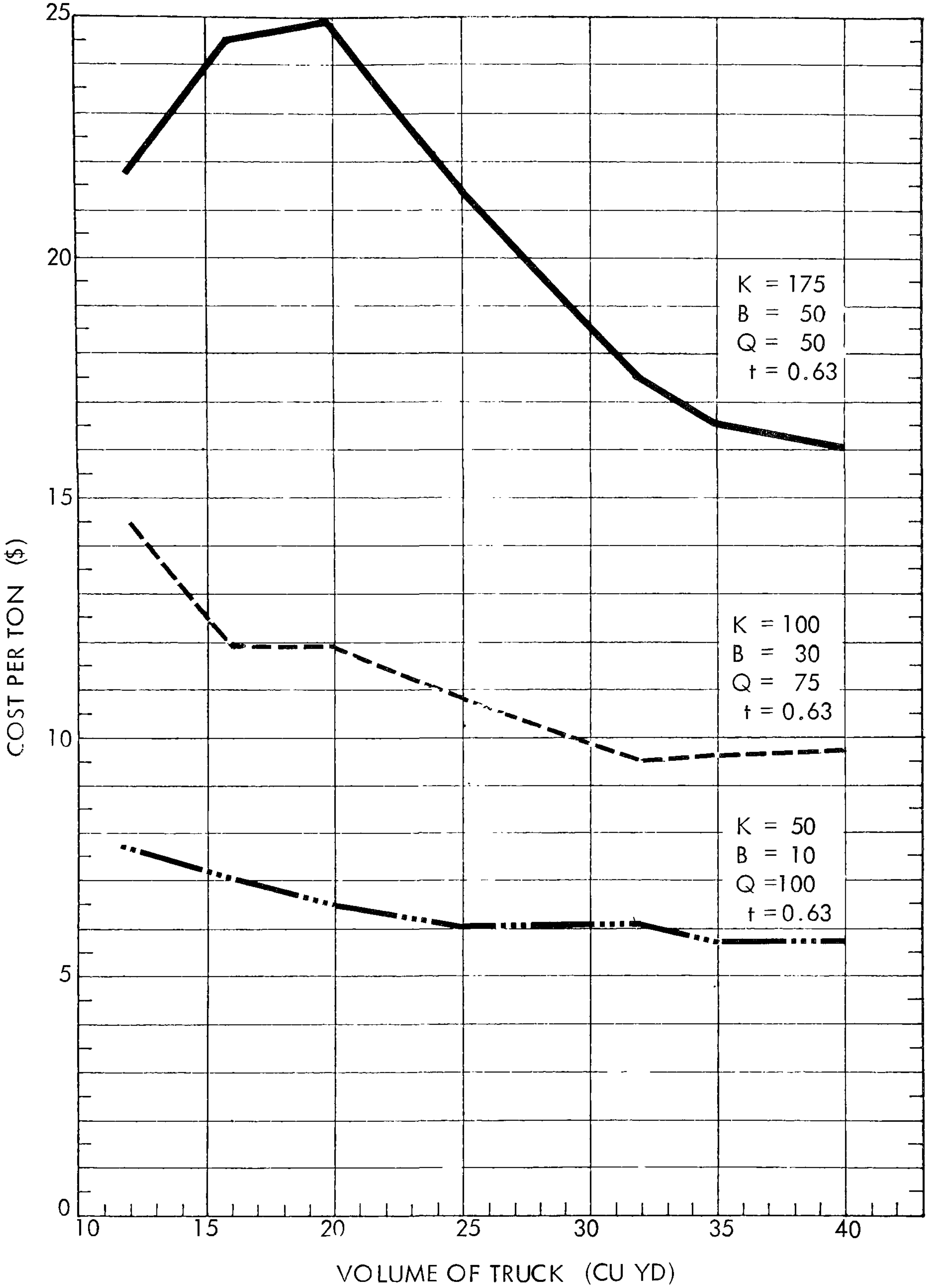


FIGURE 48
TOTAL COST CURVES
RANGE, THREE-MAN CREW

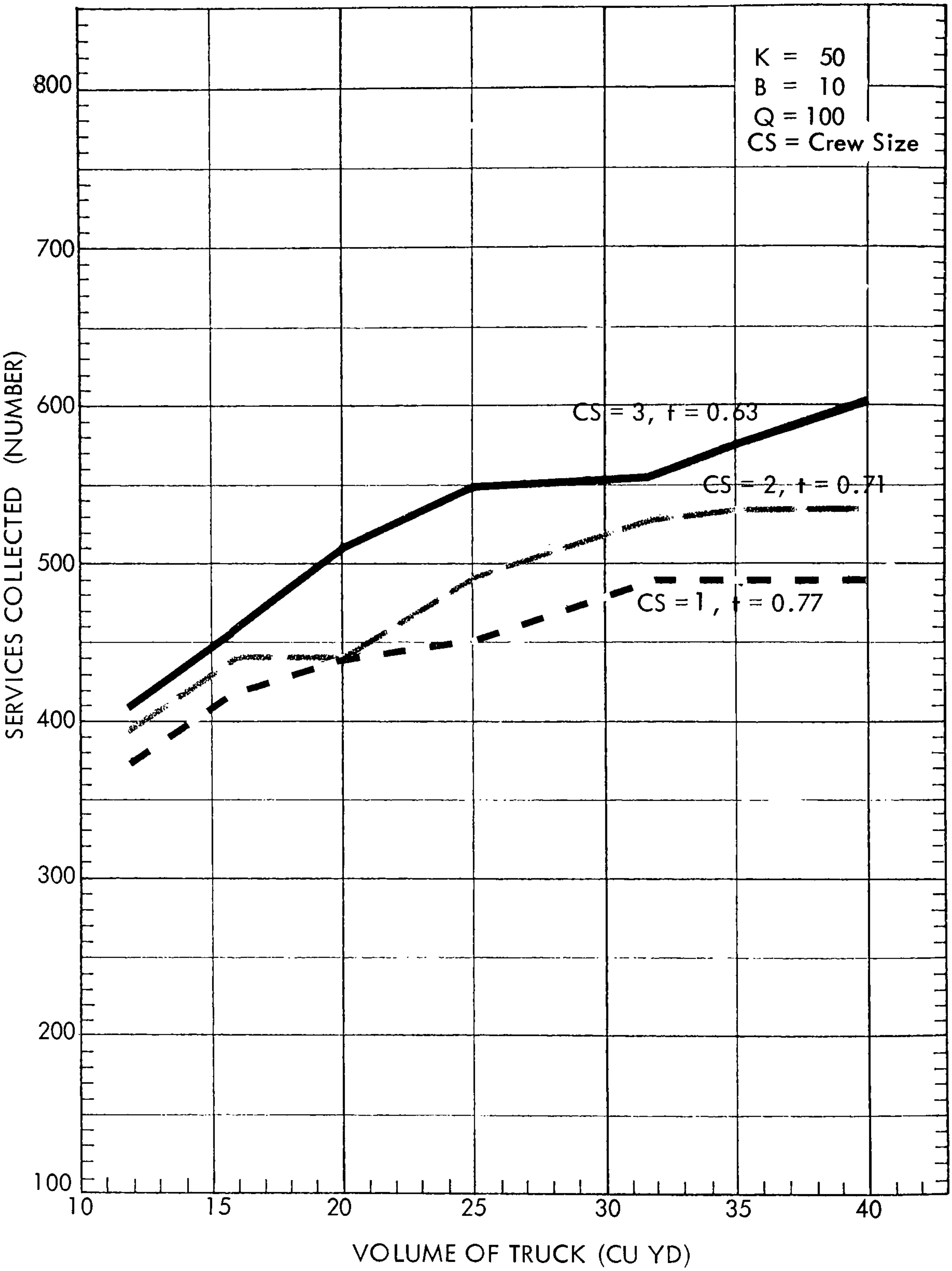


FIGURE 49
AVERAGE SERVICES COLLECTED PER CREW
CREW COMPARISON

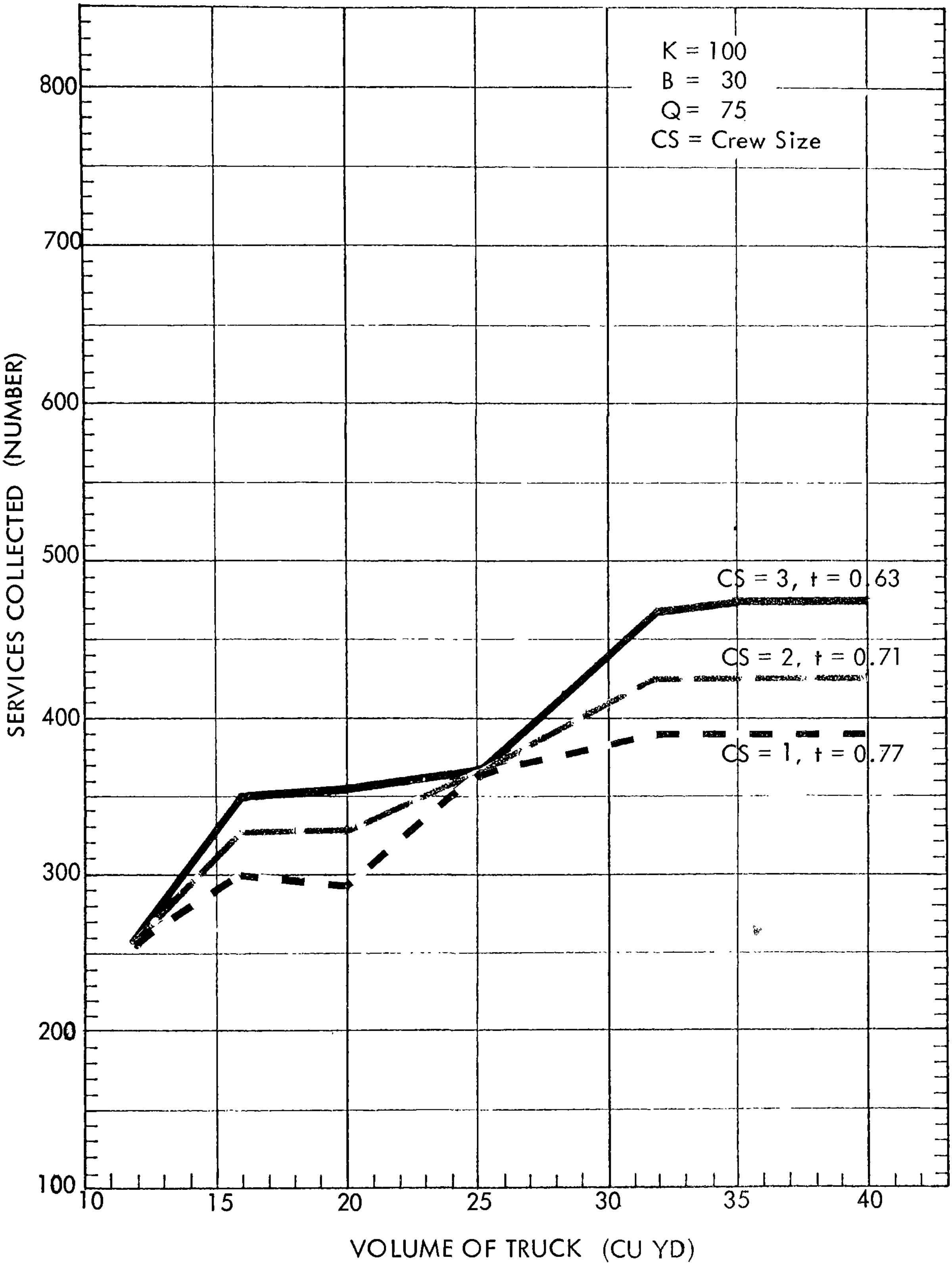


FIGURE 50
AVERAGE SERVICES COLLECTED PER CREW
CREW COMPARISON

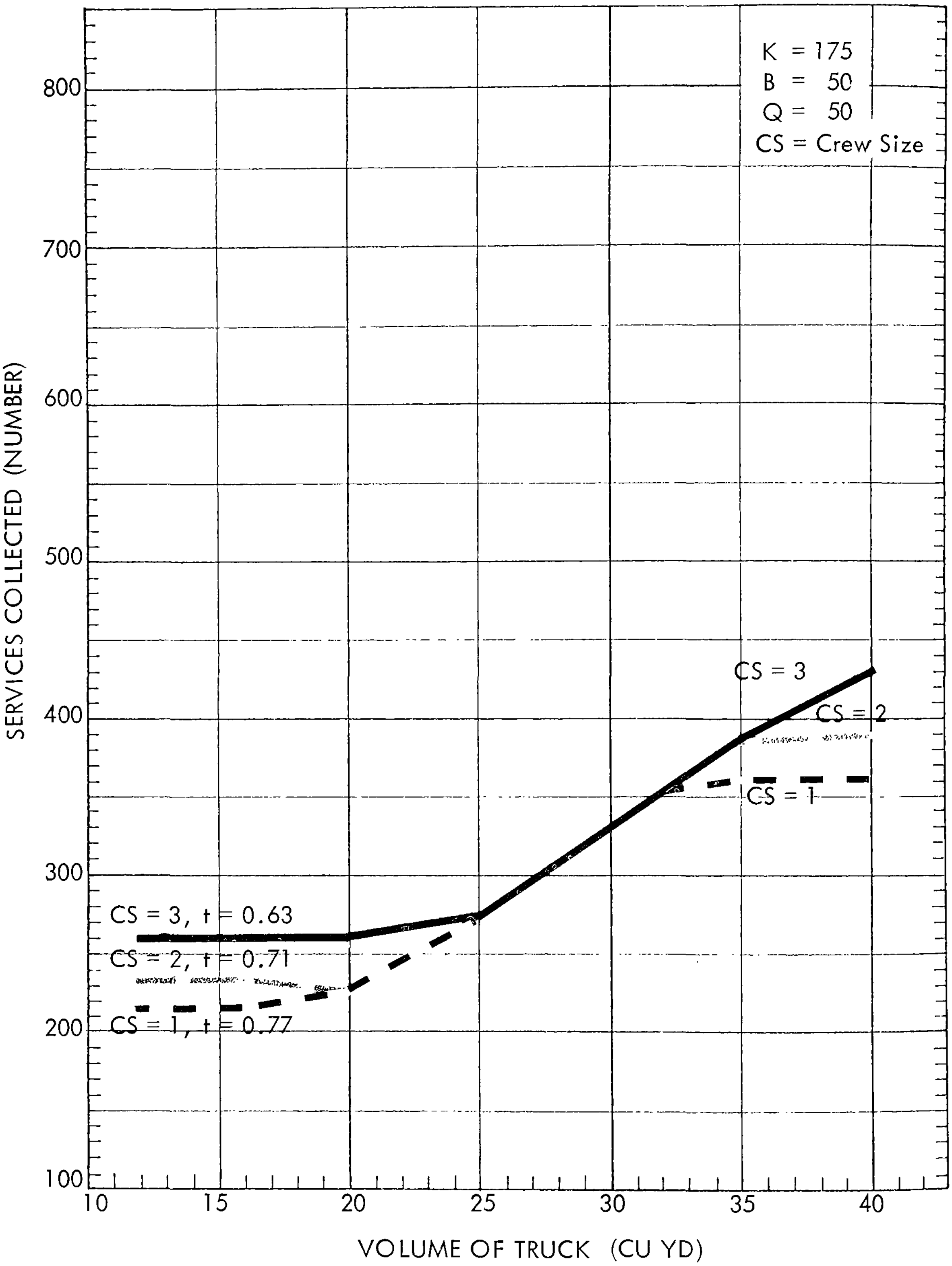


FIGURE 51
AVERAGE SERVICES COLLECTED PER CREW
CREW COMPARISON

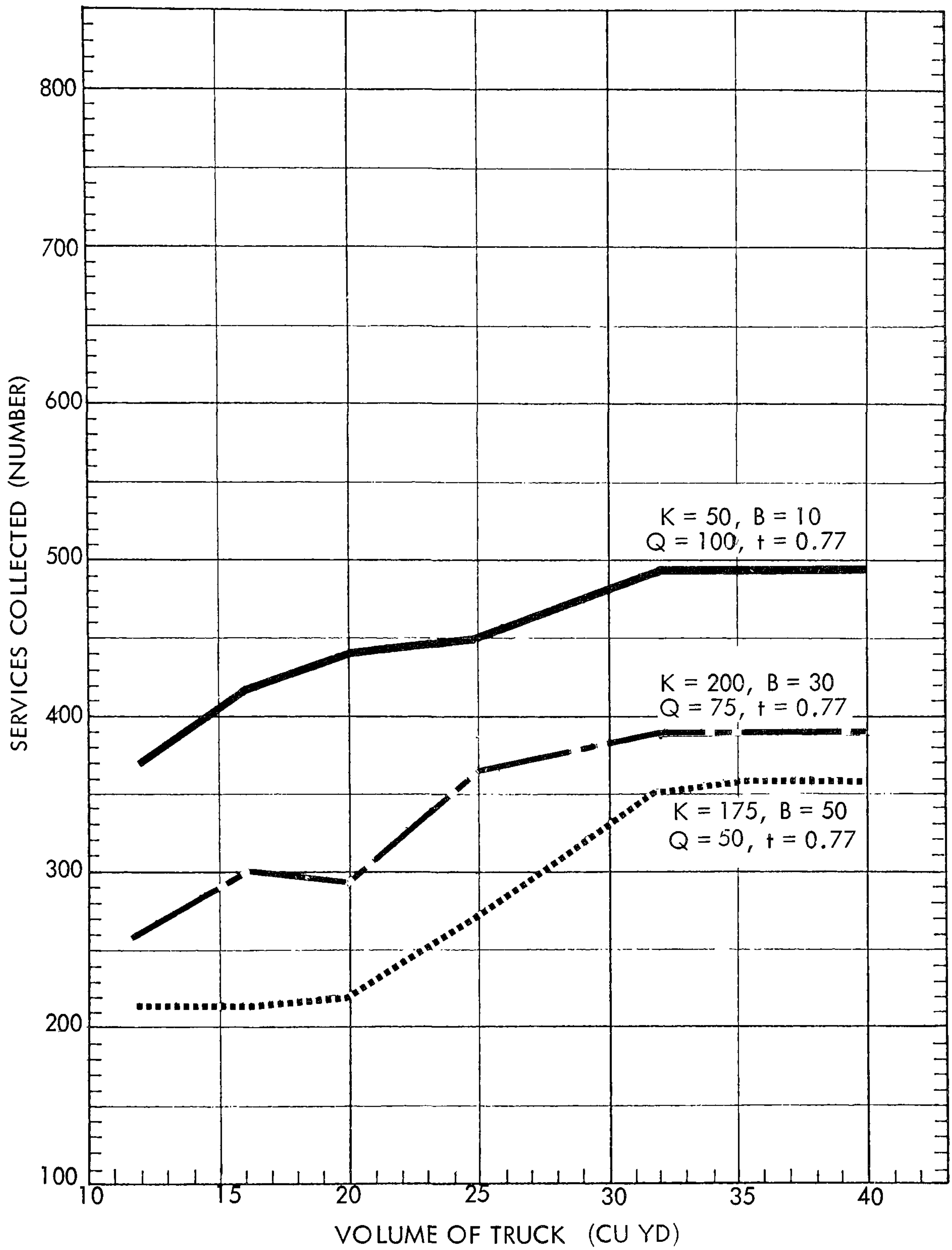


FIGURE 52
RANGE IN SERVICES
COLLECTED PER CREW
ONE-MAN CREW

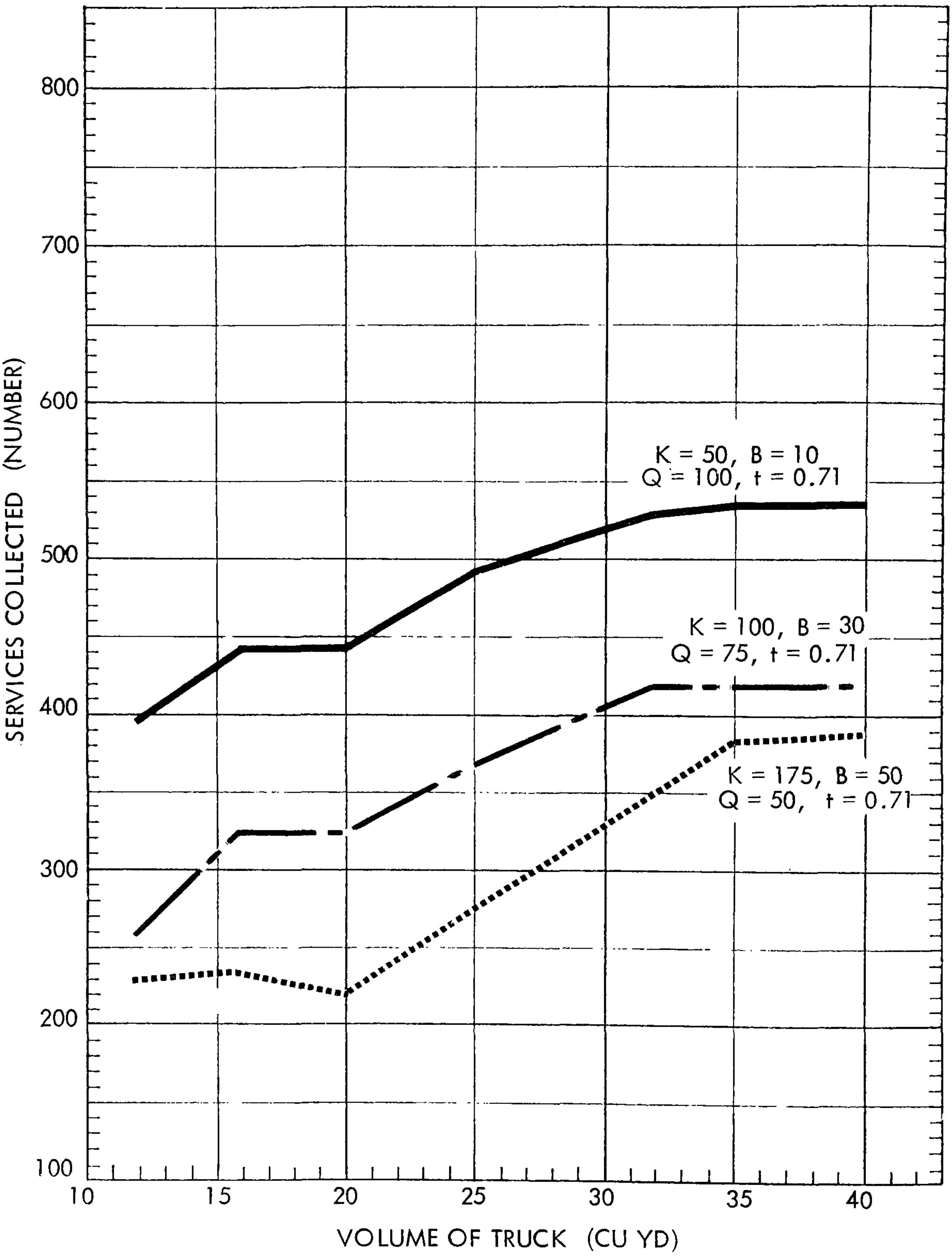


FIGURE 53
RANGE IN SERVICES
COLLECTED PER CREW
TWO-MAN CREW

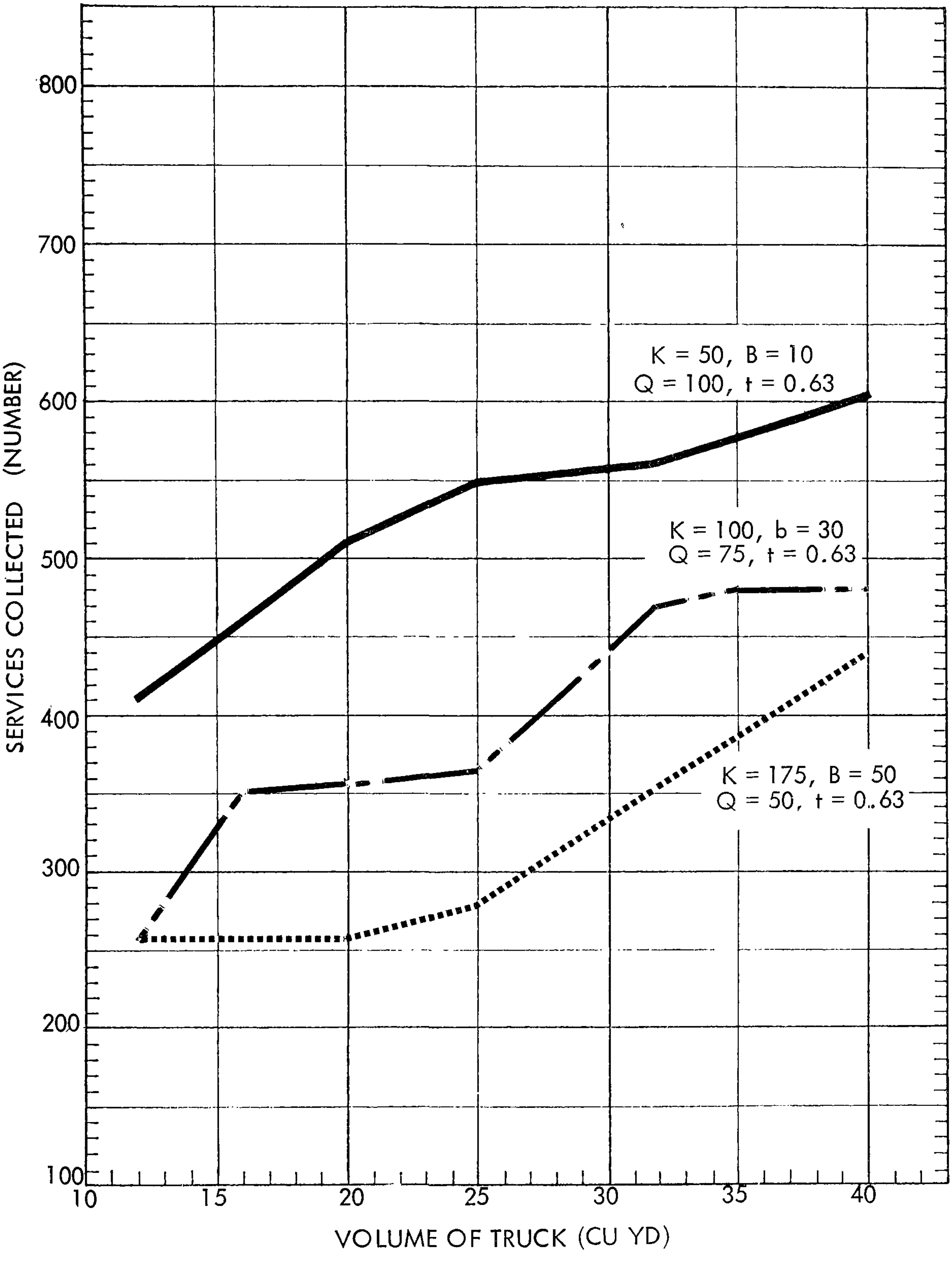


FIGURE 54
RANGE IN SERVICES
COLLECTED PER CREW
THREE-MAN CREW

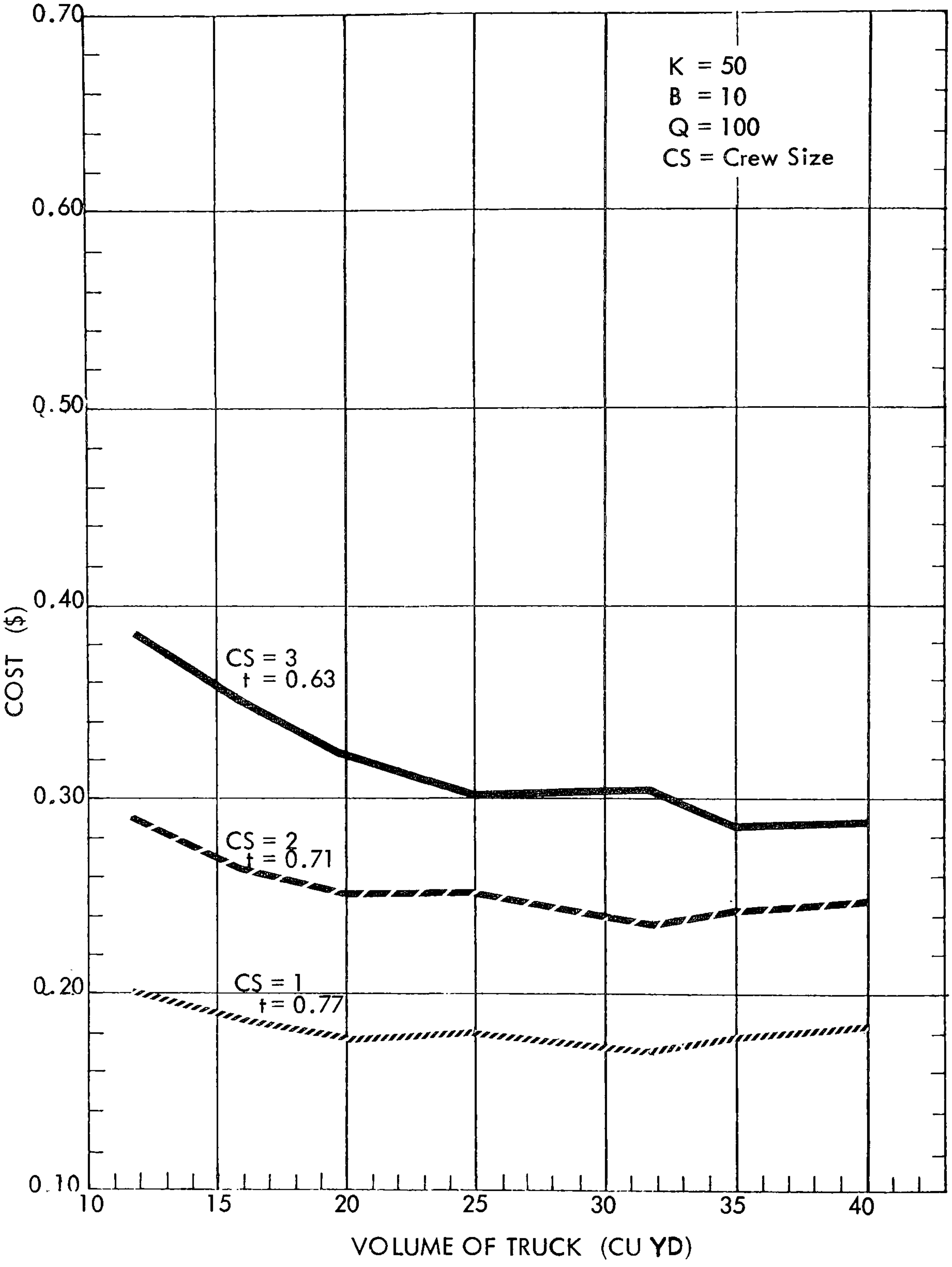


FIGURE 55
COST PER SERVICE
CREW COMPARISON

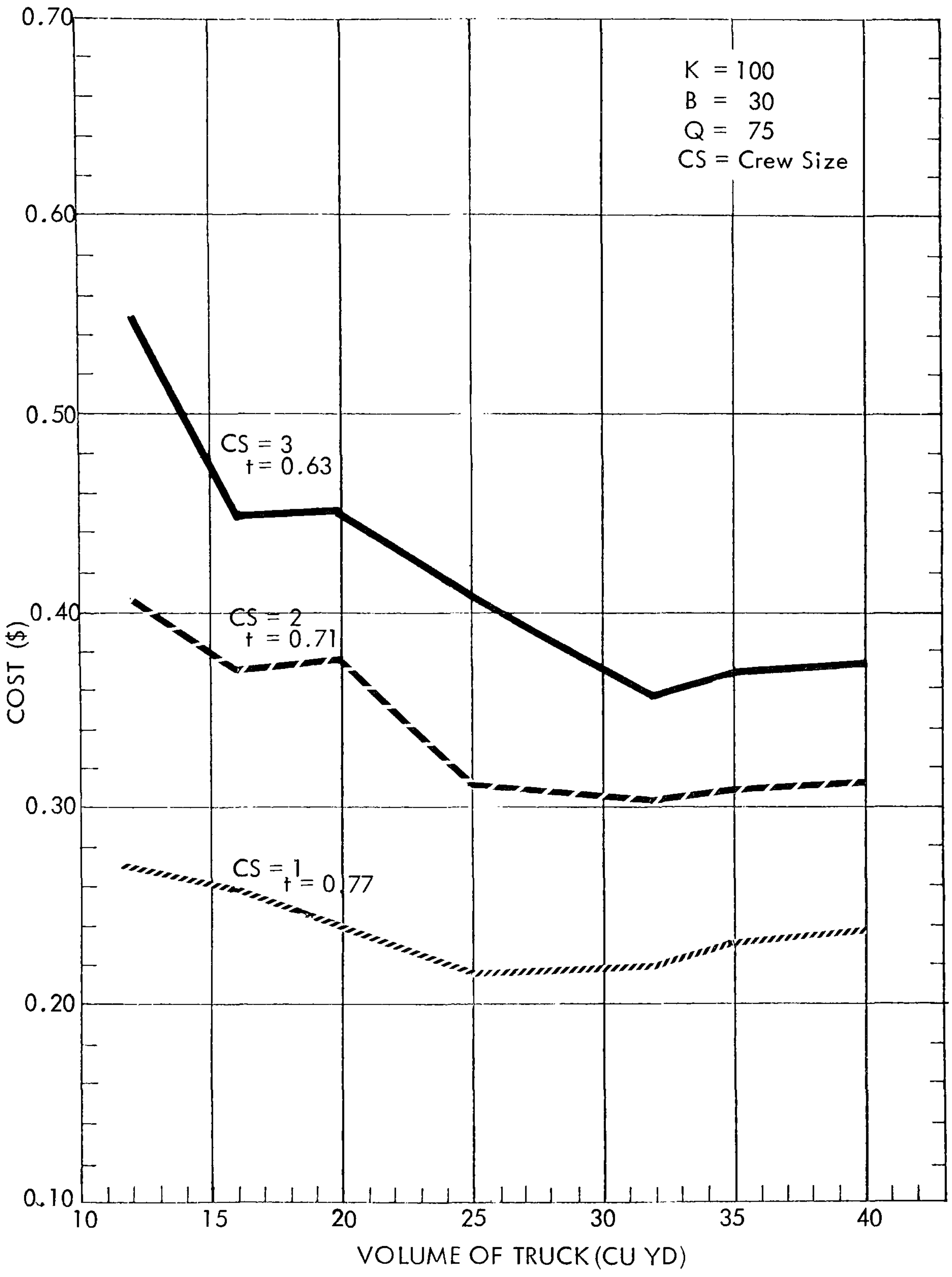


FIGURE 56
COST PER SERVICE
CREW COMPARISON

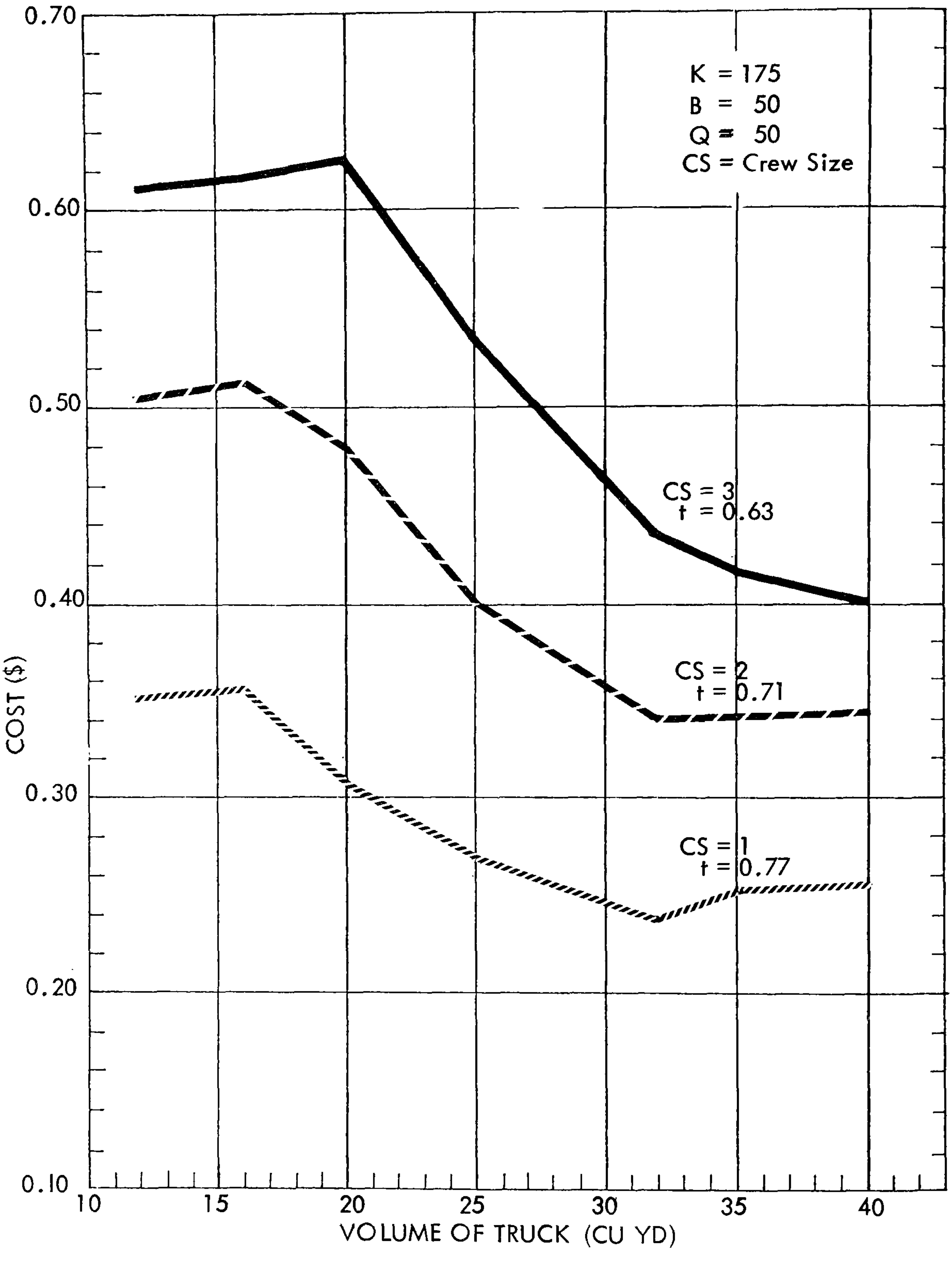


FIGURE 57
COST PER SERVICE
CREW COMPARISON

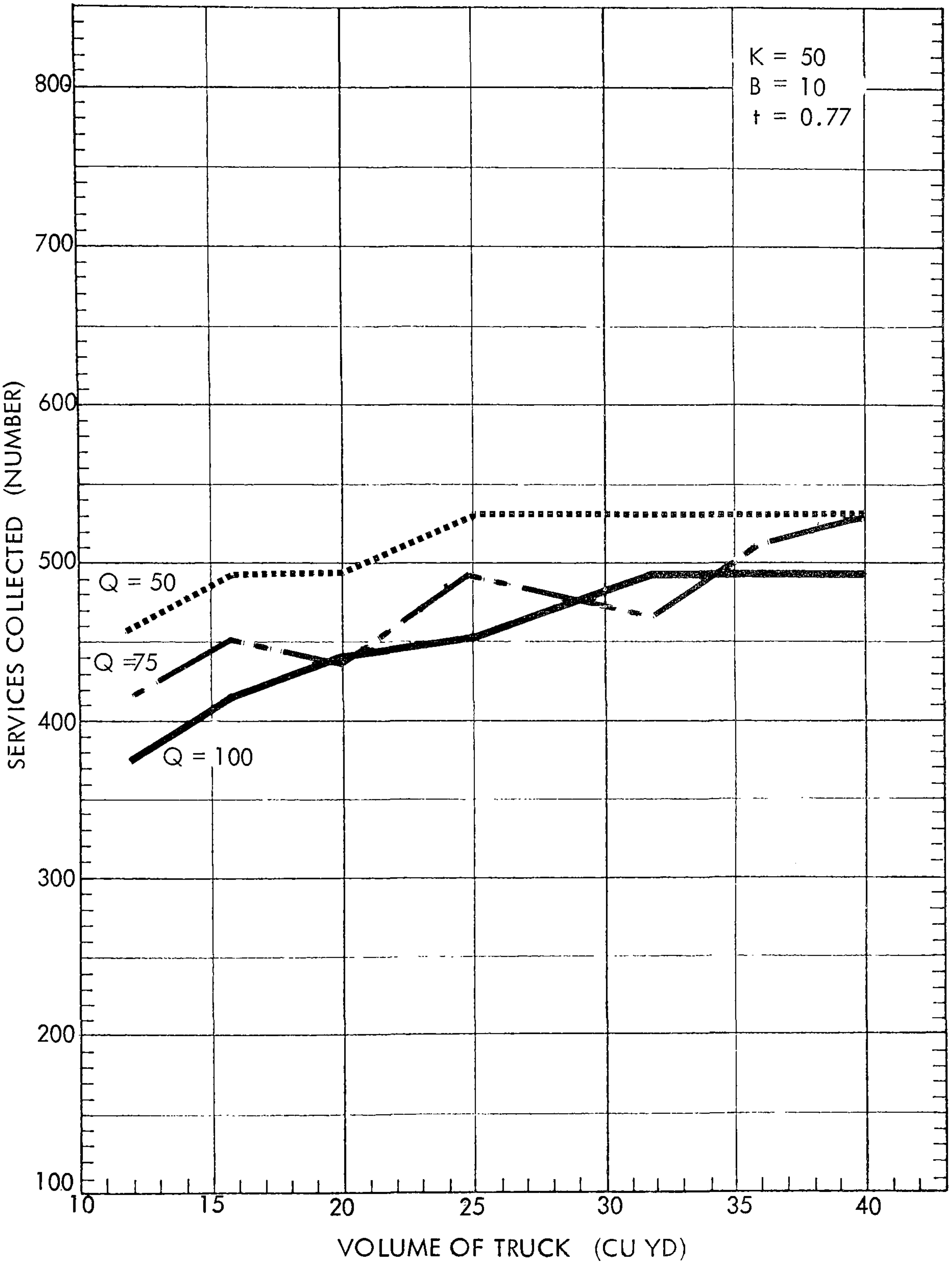


FIGURE 58
AVERAGE SERVICES COLLECTED PER CREW
ONE-MAN CREW

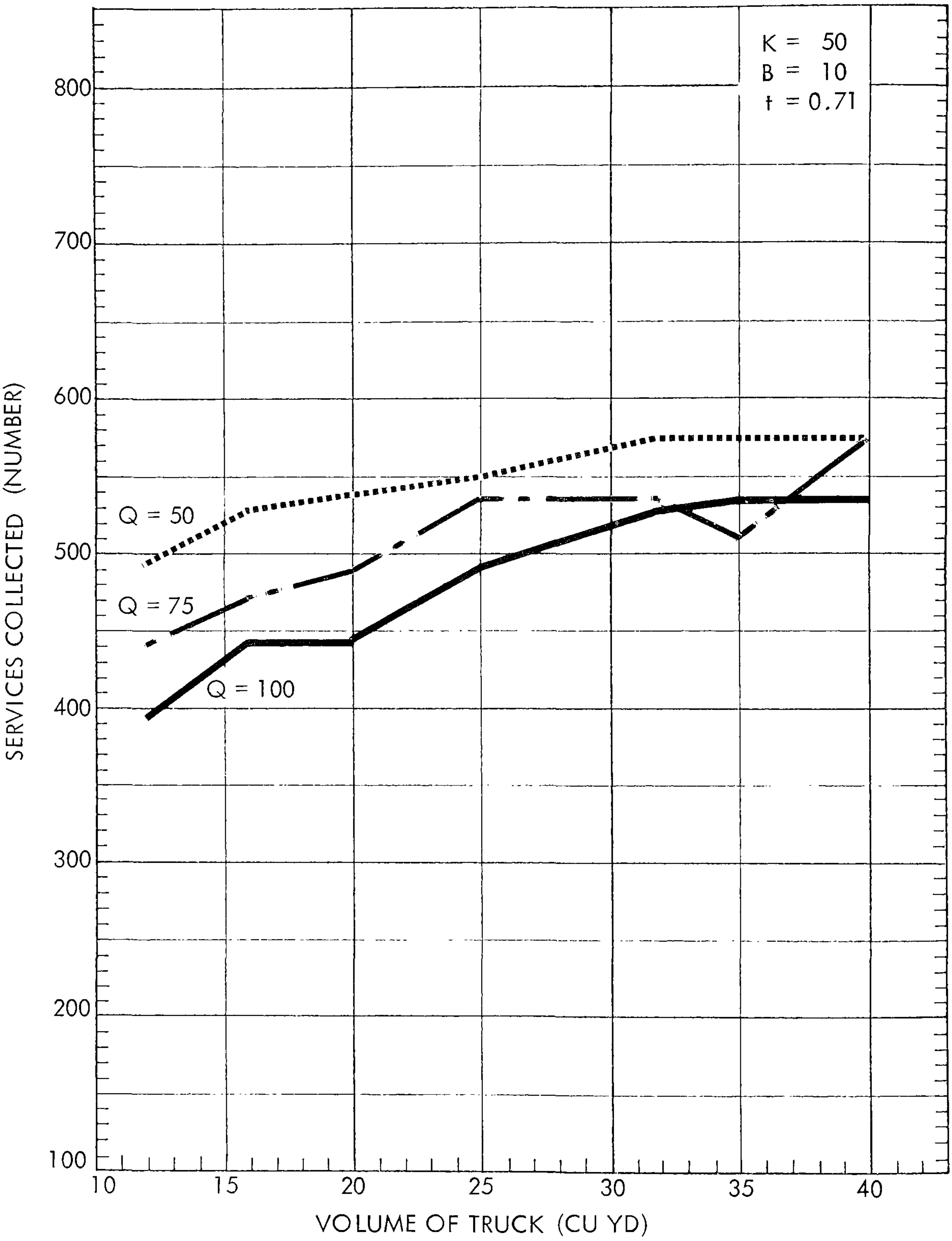


FIGURE 59
AVERAGE SERVICES COLLECTED PER CREW
TWO-MAN CREW

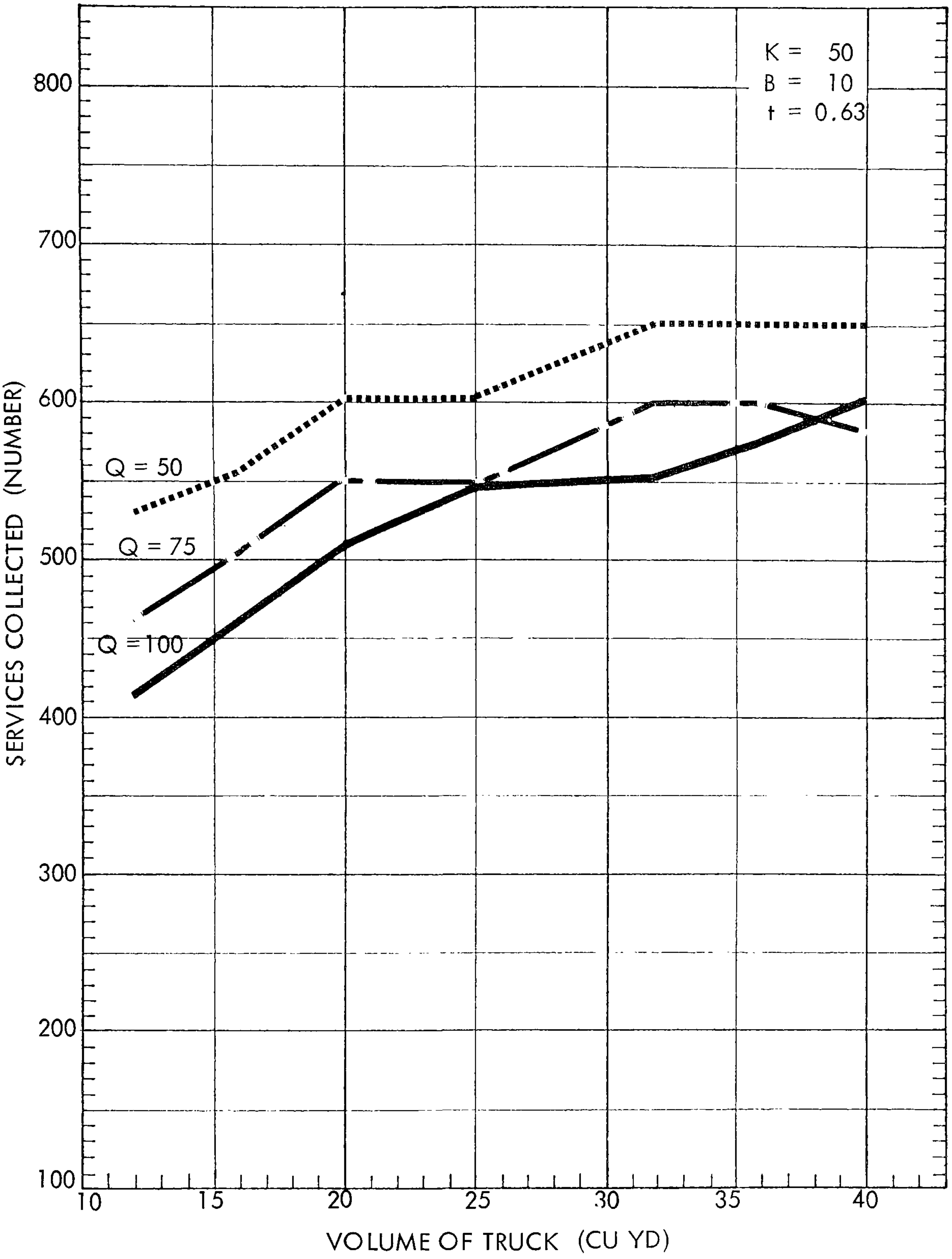


FIGURE 60
AVERAGE SERVICES COLLECTED PER CREW
THREE-MAN CREW

The assumption that the crews collect refuse as long as time permits, regardless of the number of services collected, is an ideal situation. Most refuse collection operations have a fixed number of services which must be collected each day or within a given period, and several calculations were made in which the total number of services to be collected was assumed to be fixed. The number of crews necessary for collection of these services was calculated for different truck sizes. In small systems involving less than 5000 service stops, the average cost per ton for all crews varied less than 10 percent from the values presented on the figures. As the number of service stops increased to 100,000, the difference dropped to less than 3 percent.

Irregularities in the total cost curves are mainly due to the collection of partial loads and the occurrence of overtime. The return to collect a small partial load, particularly where the haul time, B, is large, may be quite expensive on a unit cost basis. The model restricted partial loads to those greater than one-eighth of a full load in an attempt to reduce their effect on costs. Refuse collected on overtime costs more per unit of refuse than that collected on regular time. However, once a truck and crew are on the route collecting refuse, if the truck has remaining capacity to collect an additional quantity, it is more economical to let that crew continue to collect overtime than to schedule an additional truck and crew for a full day's operations, unless the additional refuse is sufficient to keep the crew active for most of the day.

Referring again to Figures 49, 50, and 51, it can be seen that the number of services collected varies both with crew size and truck volume. The number of services collected may remain constant, increase, or decrease with increasing truck volume. The services collected remain constant when two different sized trucks each complete a 510 minute day with one full load and a partial second load. Although the final partial load is larger in the smaller truck, since each truck has spent an equal time collecting, the number of services collected is the same. The number of services may decrease with a larger truck because after collectin one or more full loads, there may not be sufficient time to collect the minimum one-eighth partial load of the larger truck, whereas the smaller truck may be able to collect refuse for the full 510 minute day.

As previously noted, the model was used to simulate backyard, alley, modified curbside, and set-out systems of collection using the time standards presented in Table XX. The simulations were based on one set of input data, and the results are only an indication of the existing relationships. Figures 61 through 66 illustrate the unit costs and services collected by one-, two-, and three-man crews for backyard, alley, and modified curbside collections. Figures 61 and 62 indicate the inefficiency of the one-man crew for use in backyard collections. The three-man crew has an advantage over both the one- and two-man crews for backyard collection. Figures 63 and 64 indicate that the one-man crew is more efficient for alley collections. The trend of the total cost curves of Figure 63 indicates, however, that the advantage may disappear when larger trucks are used in conjunction with short haul distances.

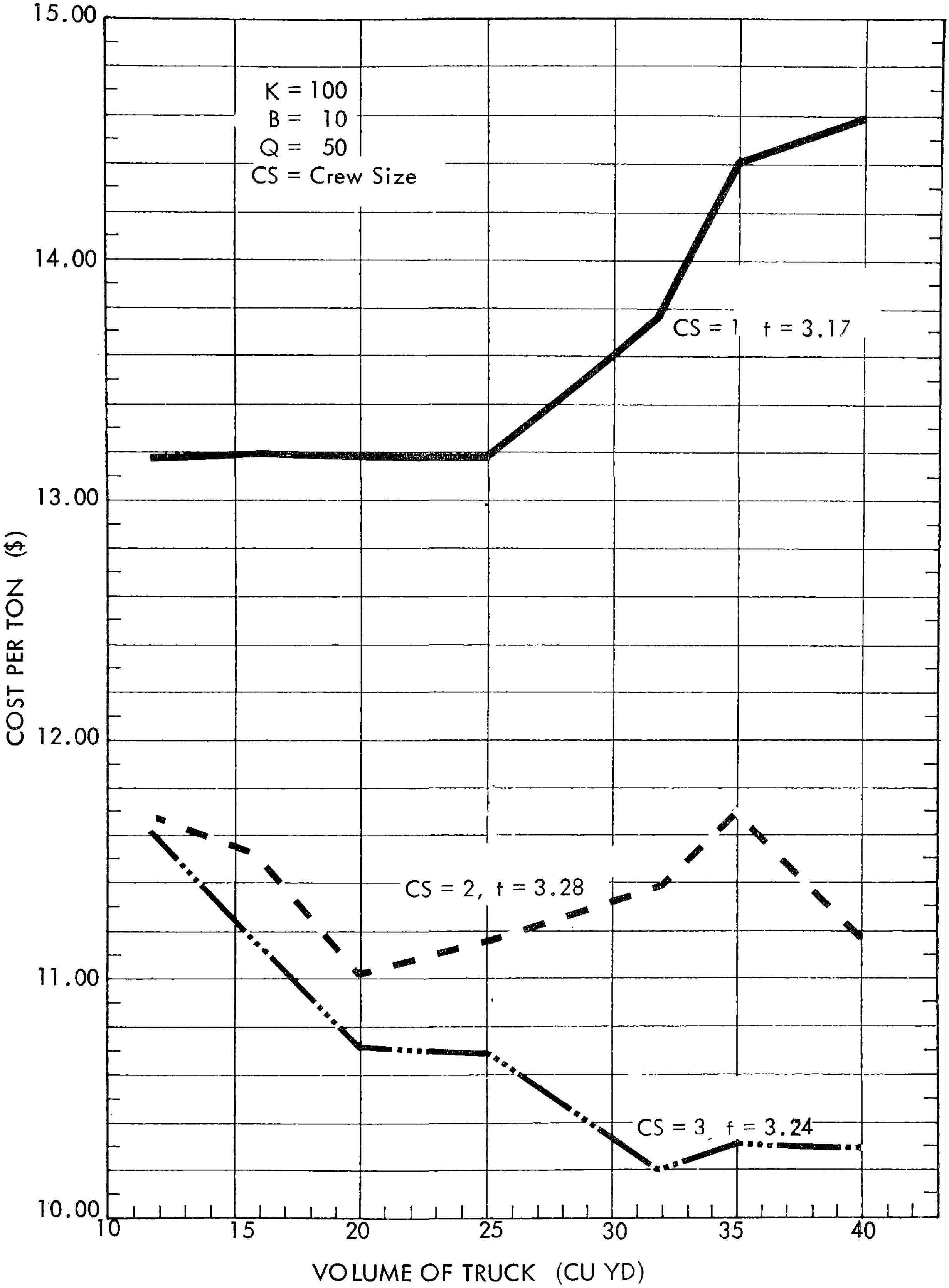


FIGURE 61
TOTAL COST PER TON
BACKYARD COLLECTION

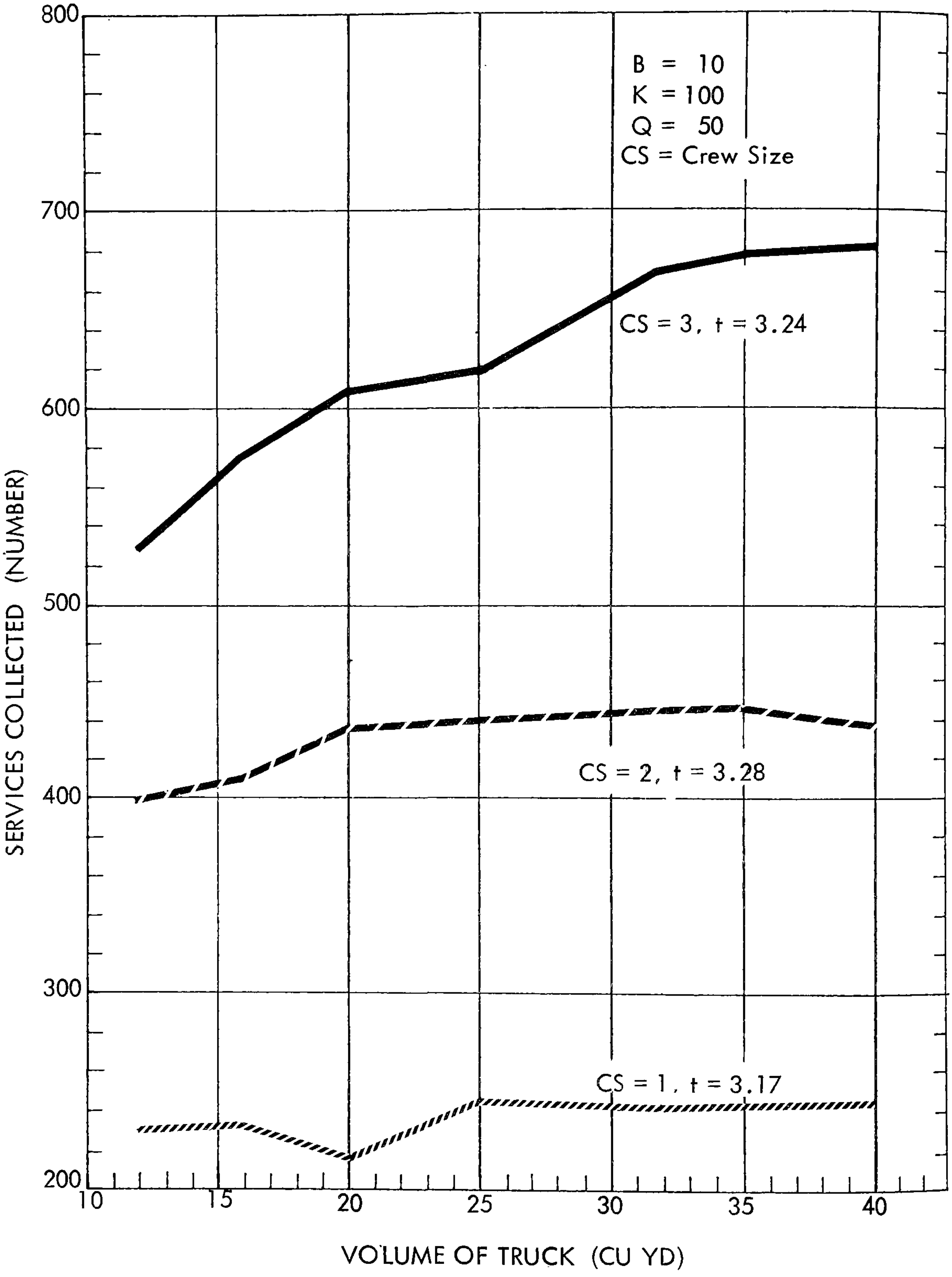


FIGURE 62
SERVICES COLLECTED
BACKYARD COLLECTION

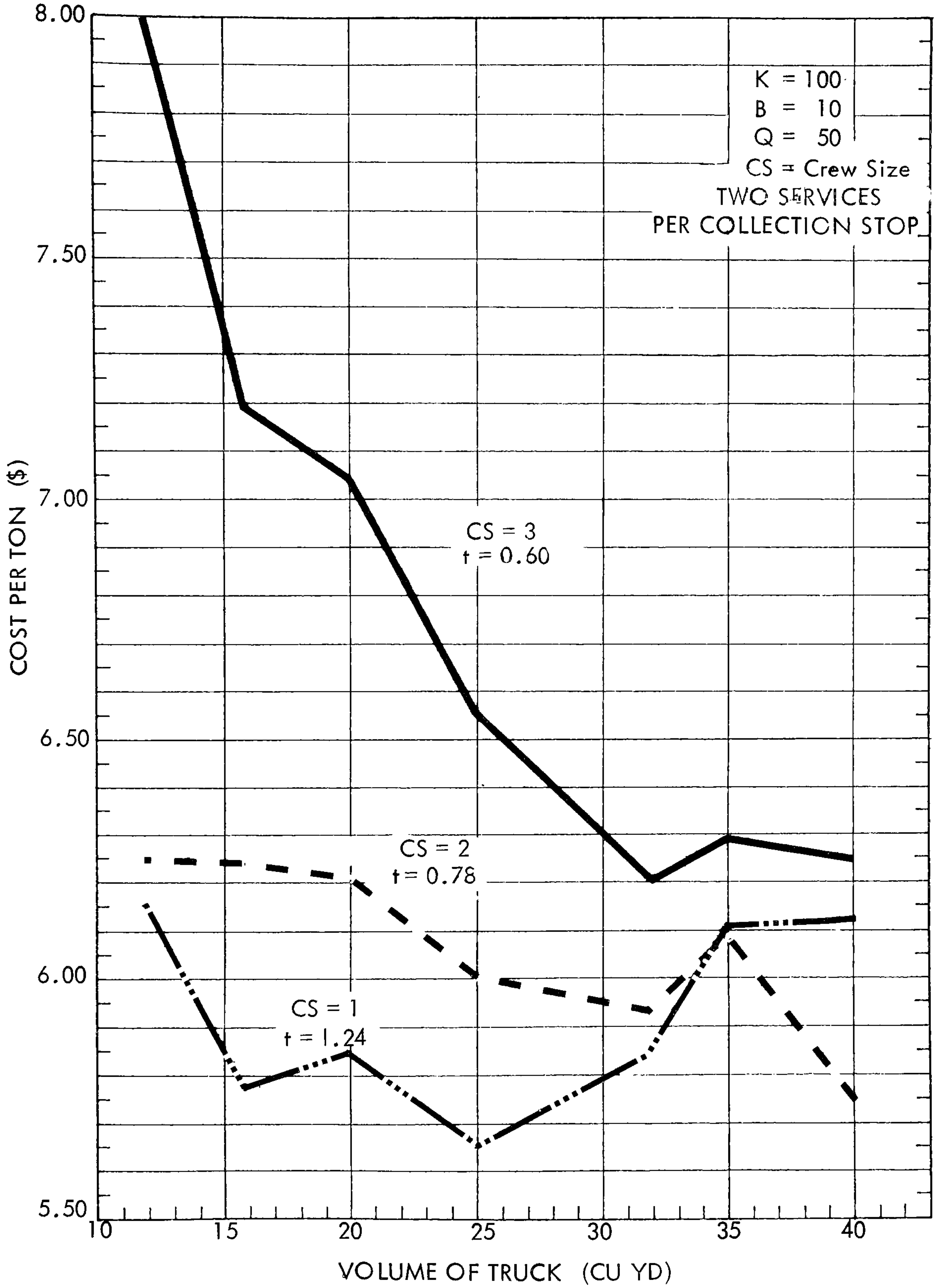


FIGURE 63
TOTAL COST PER TON
ALLEY COLLECTION

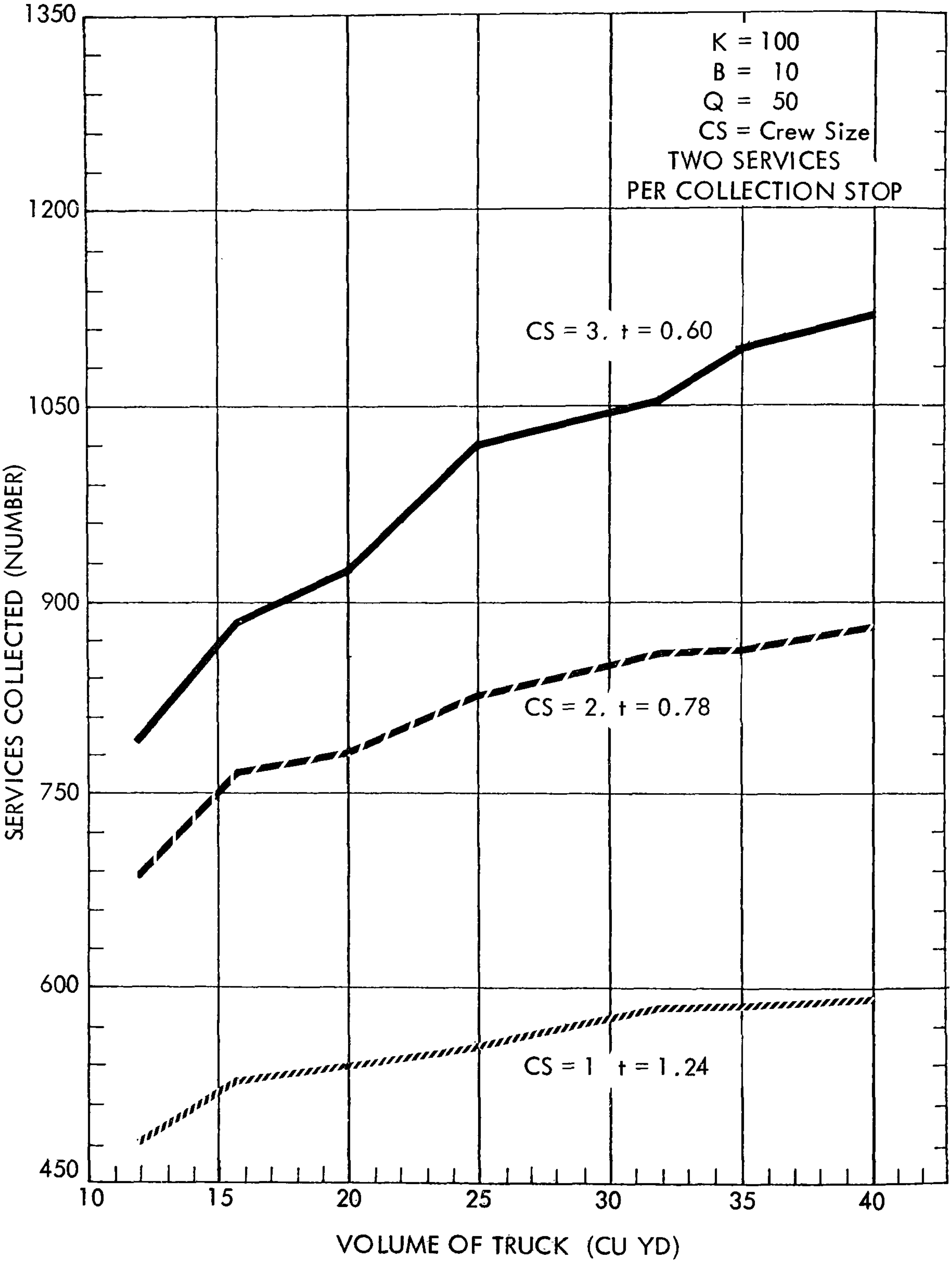


FIGURE 64
SERVICES COLLECTED
ALLEY COLLECTION

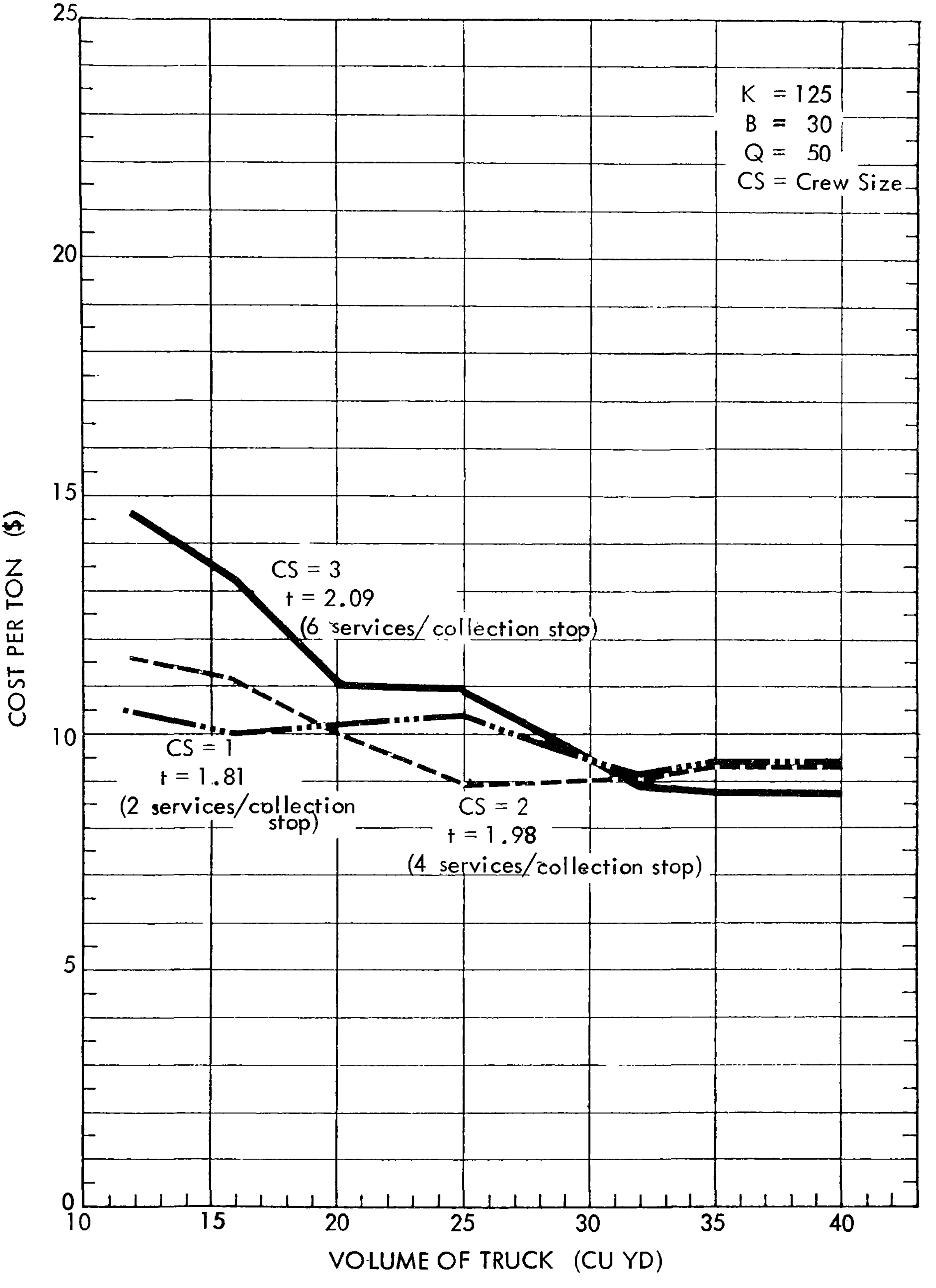


FIGURE 65
TOTAL COST PER TON
MODIFIED CURBSIDE COLLECTION
SHOULDER BARREL - METHOD A

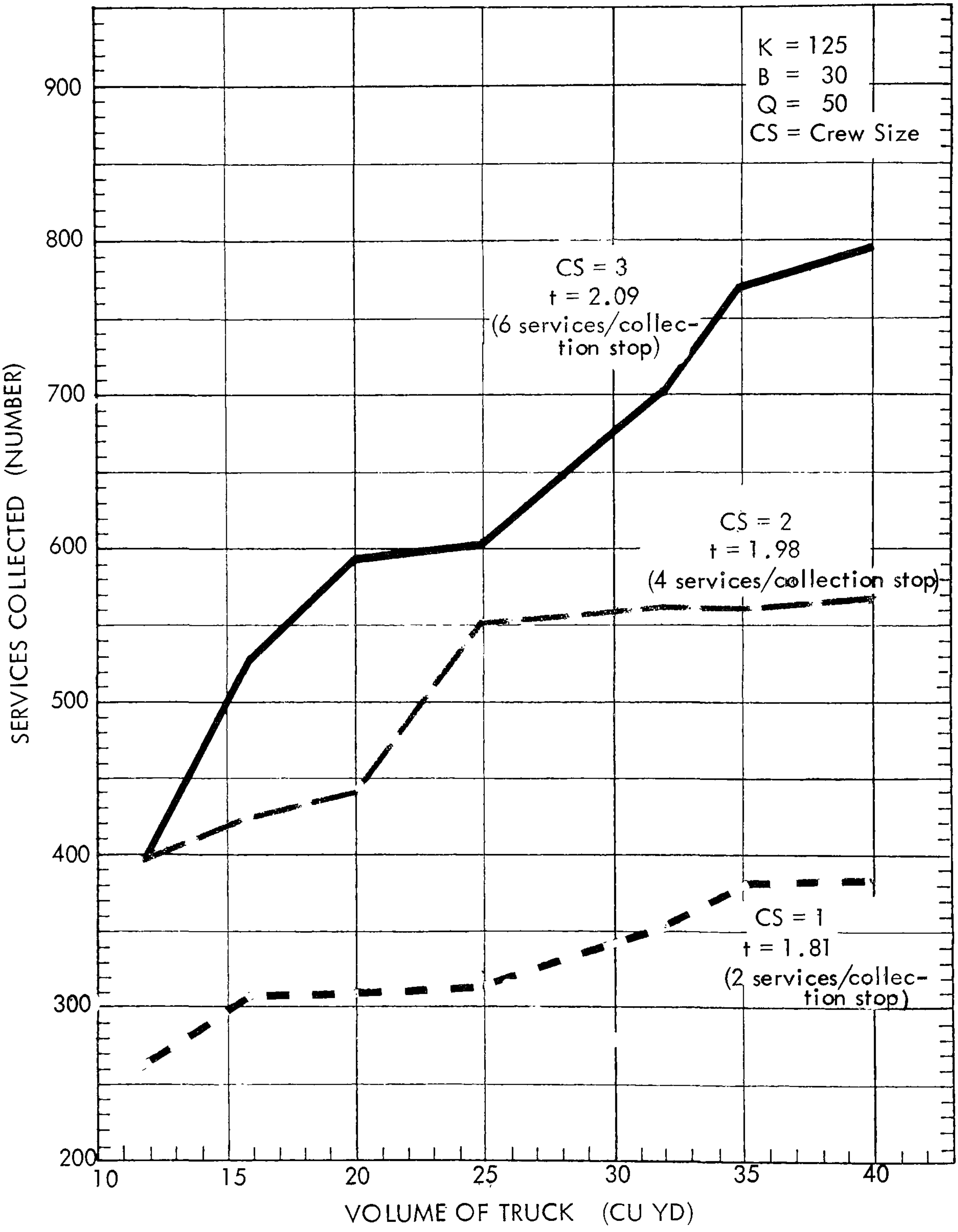


FIGURE 66
AVERAGE SERVICES COLLECTED PER CREW
MODIFIED
CURBSIDE COLLECTION
SHOULDER BARREL - METHOD A

For modified curbside collection under the conditions assumed, the one-man crew loses its economic advantage as a result of the multiple collections by each crew member. Figure 65 indicates that the three systems are almost equal in terms of cost per ton of refuse collected. As haul distances and the total value of non-productive time increase, the one-man crew could be expected to become more efficient for modified curbside collection than either the two- or three-man crew, but the advantage would be less than with curbside or alley collection. Figure 67 illustrates the cost per ton for an assumed backyard set out system.

The curves on Figures 68 to 73 were developed using the previously described mathematical model with the identical rules and cost relationships; however, the time per service stop for curbside collection has been assumed to conform to commonly used system design data. These values for the time per stop assume that the two-man and three-man crews are respectively one-third and two-thirds faster per service stop than the one-man crew.

The general form and relative position of the one-, two-, and three-man curves on these figures have little similarity to the curves for curbside collection based on the report data. As the time per stop values developed in this report are based on significant amounts of detailed field study and were verified by industrial engineering time and motion analyses, the above-mentioned system design values appear erroneous, and their further use does not seem warranted.

6. Nomographs

A series of nomographs have been devised to give the refuse collection operation manager tools for the study of the internal workings of his operation and insight into possible changes and their effects upon his system.

Figures 74 and 75 are two nomographs developed to solve the formula of the mathematical model previously presented. Using the nomographs, various values of the parameters which affect the refuse collection operation can be determined. The following examples use the nomograph in Figure 74. It will be noted on the nomograph chart that:

(Q) = Mean quantity of refuse per service stop (lb).

(d) = Mean density of refuse in the refuse collection vehicle (lb/cu yd).

(t) = Mean time for the crew to collect the stop and drive to the next collection stop (min).

(T) = Total tons of refuse collected by the crew during the day.

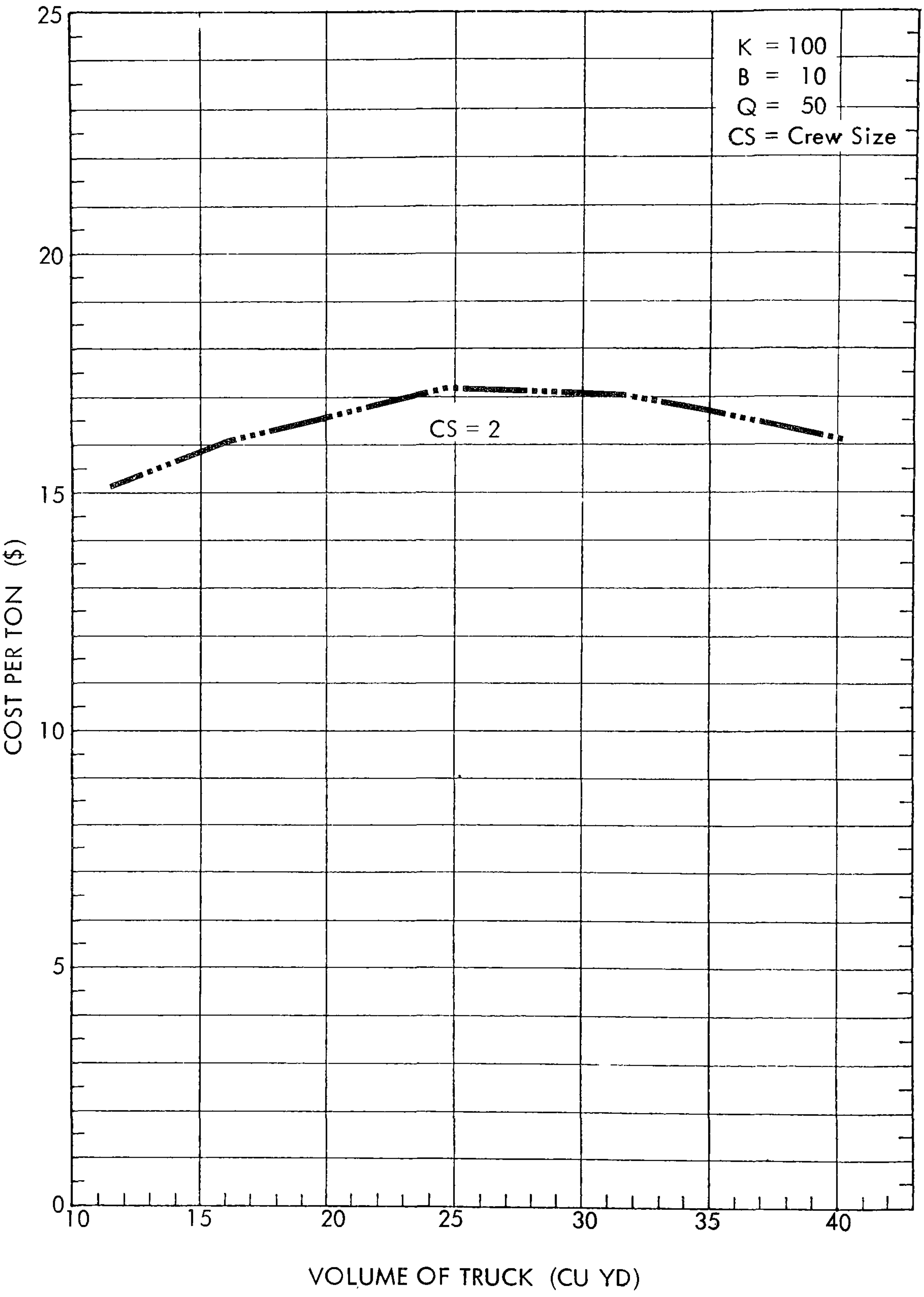


FIGURE 67
COST PER TON
BACKYARD SET-OUT WITH
CURBSIDE COLLECTION

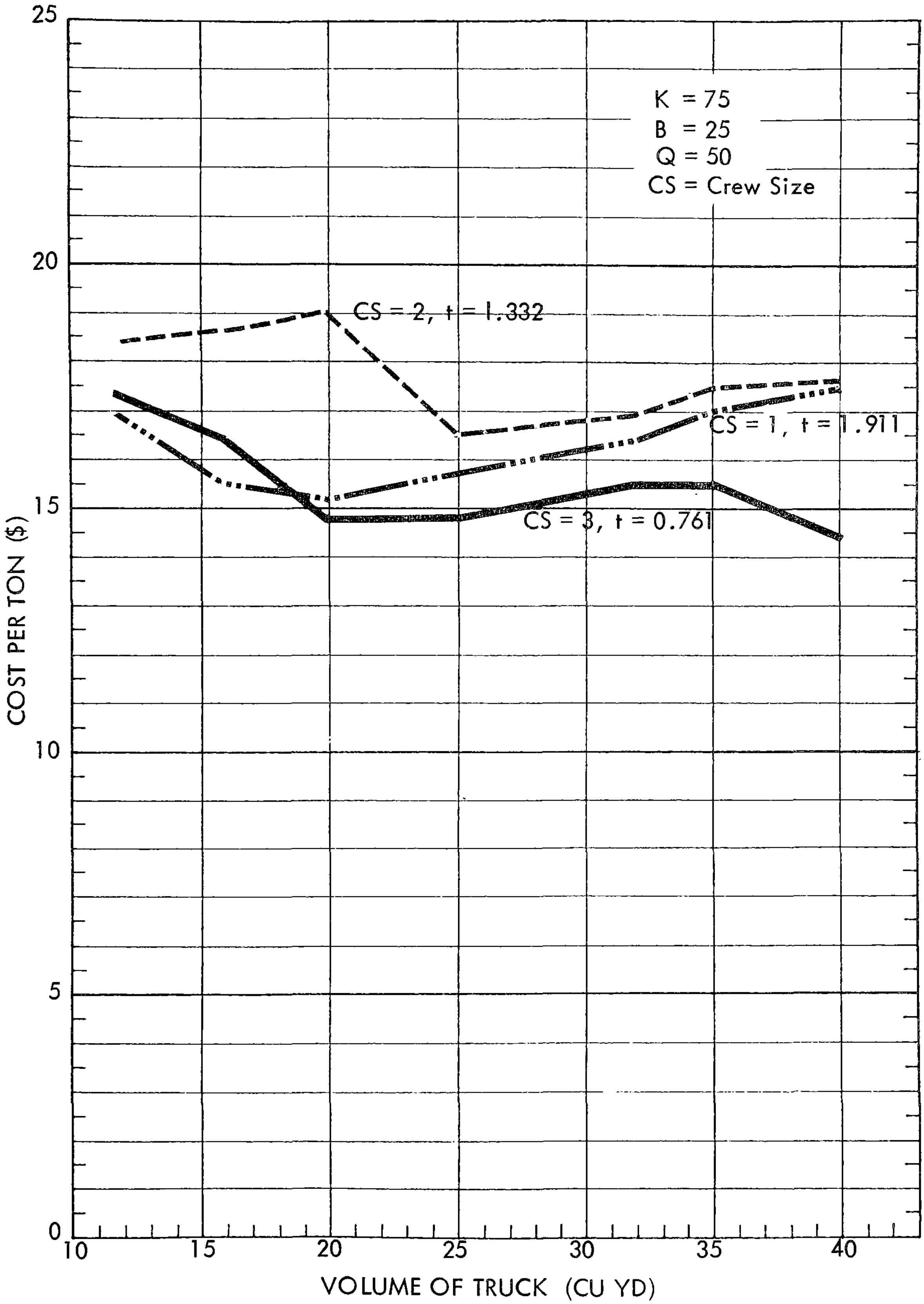


FIGURE 68
TOTAL COST CURVES
CREW COMPARISON

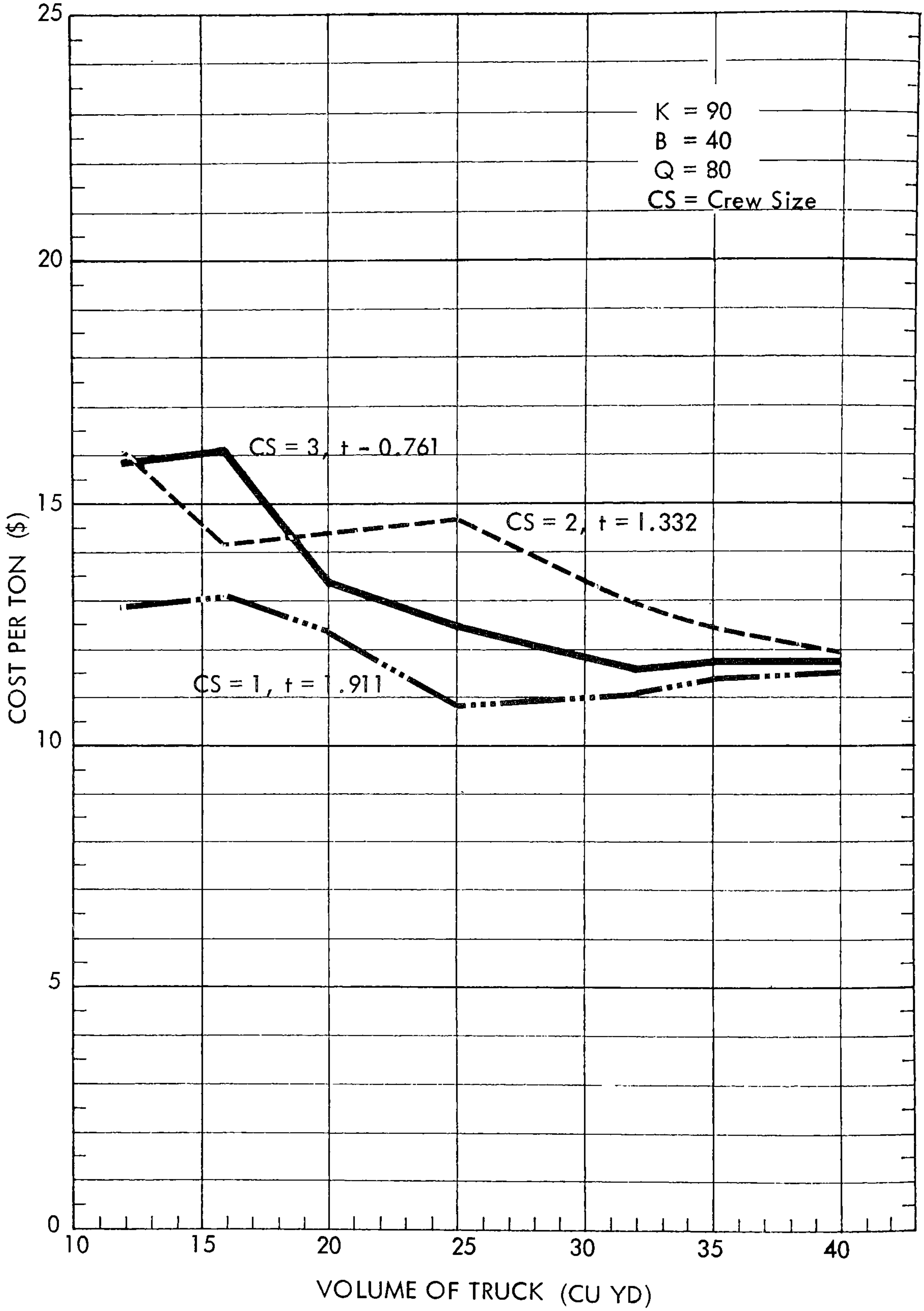


FIGURE 69
TOTAL COST CURVES
CREW COMPARISON

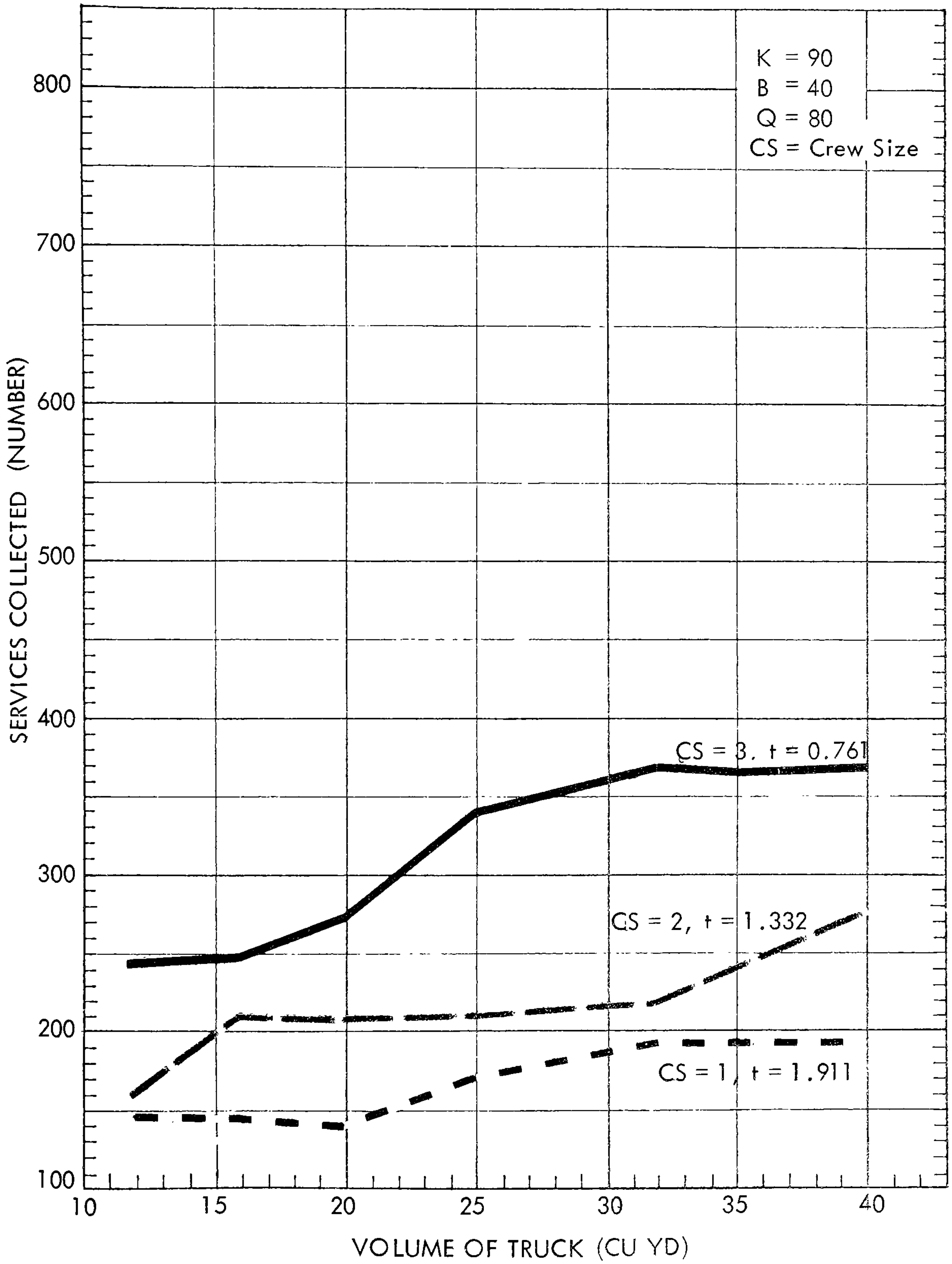


FIGURE 70
AVERAGE SERVICES COLLECTED PER CREW
CREW COMPARISON

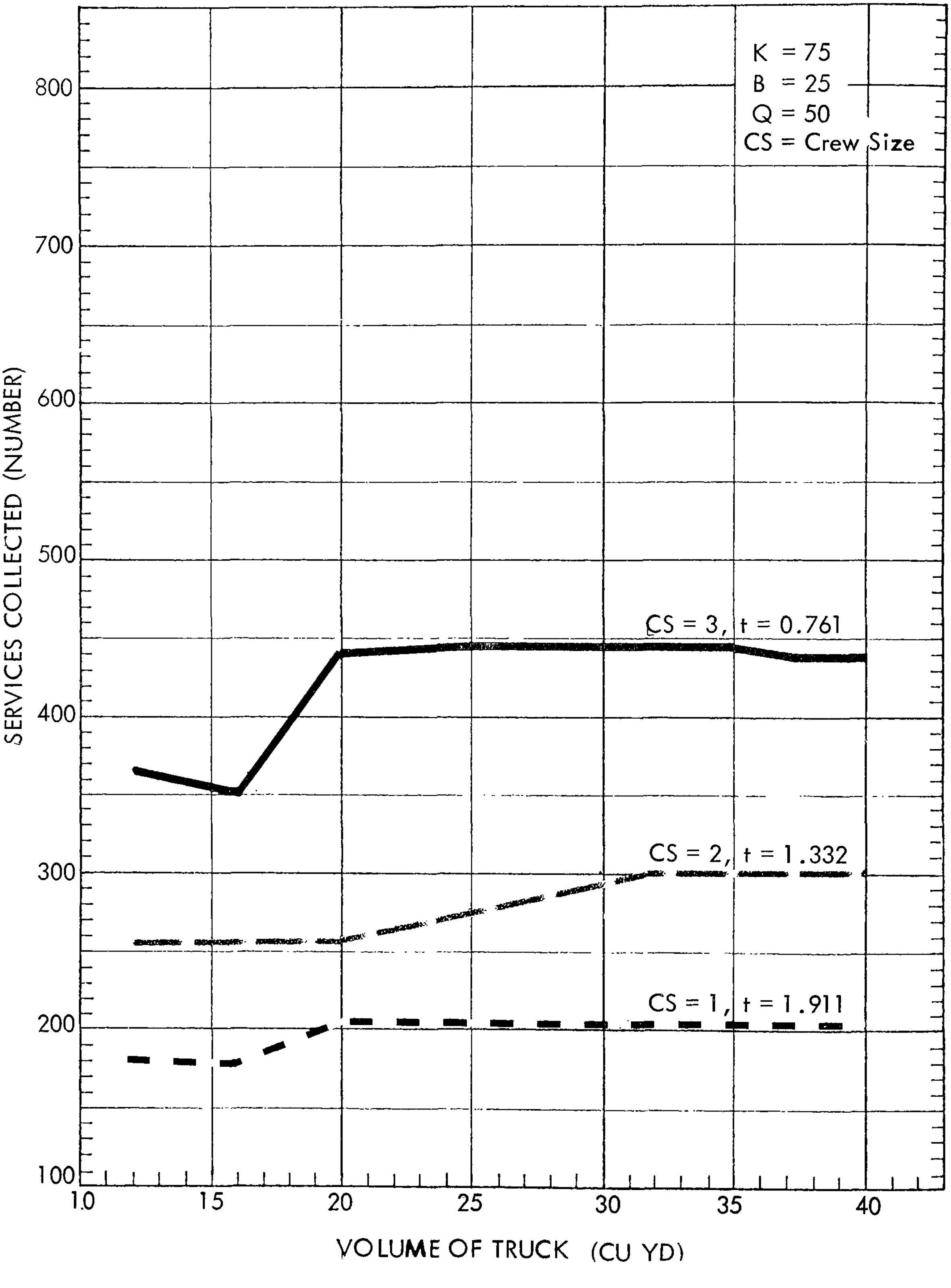


FIGURE 71
AVERAGE SERVICES COLLECTED PER CREW
CREW COMPARISON

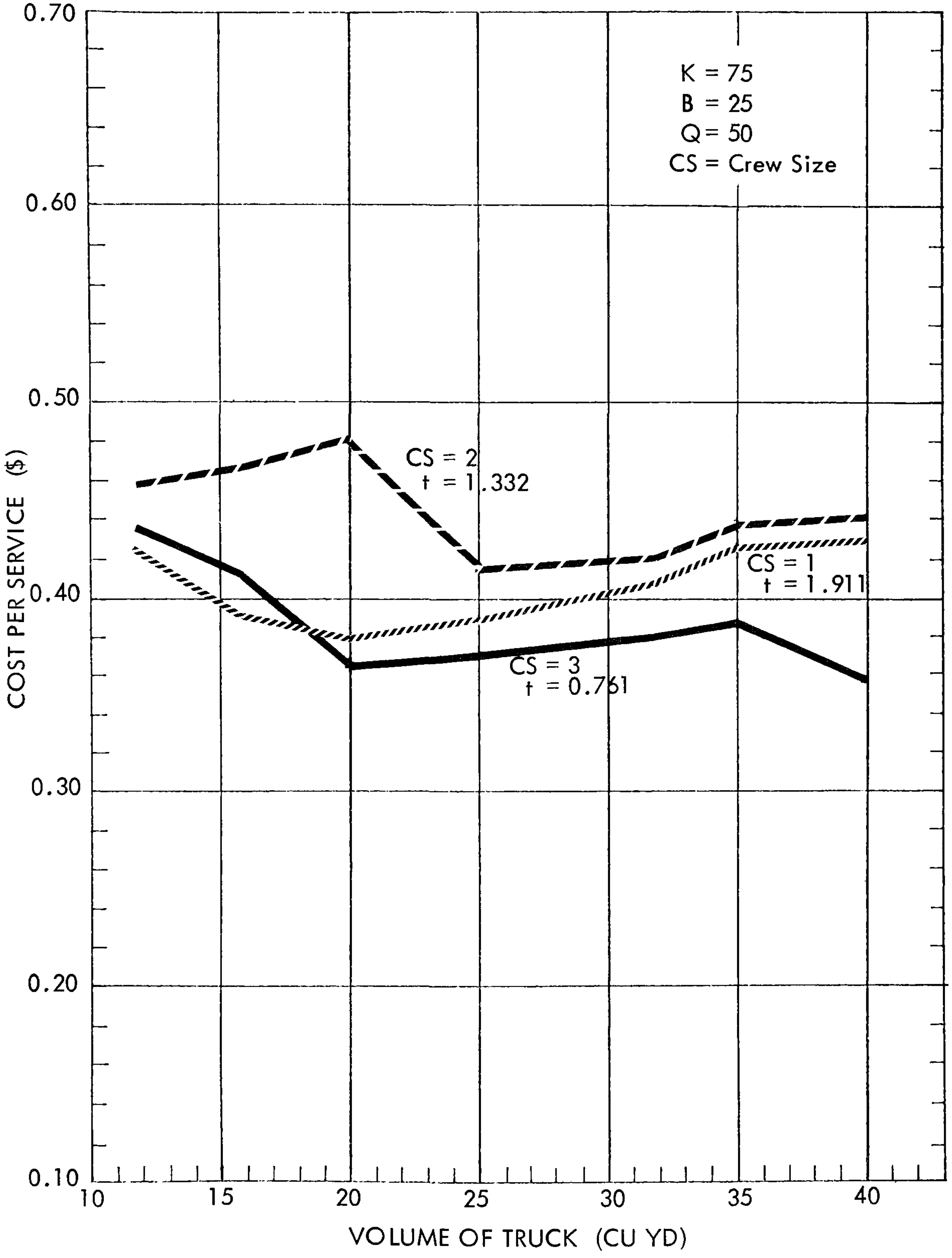


FIGURE 72
COST PER SERVICE
CREW COMPARISON

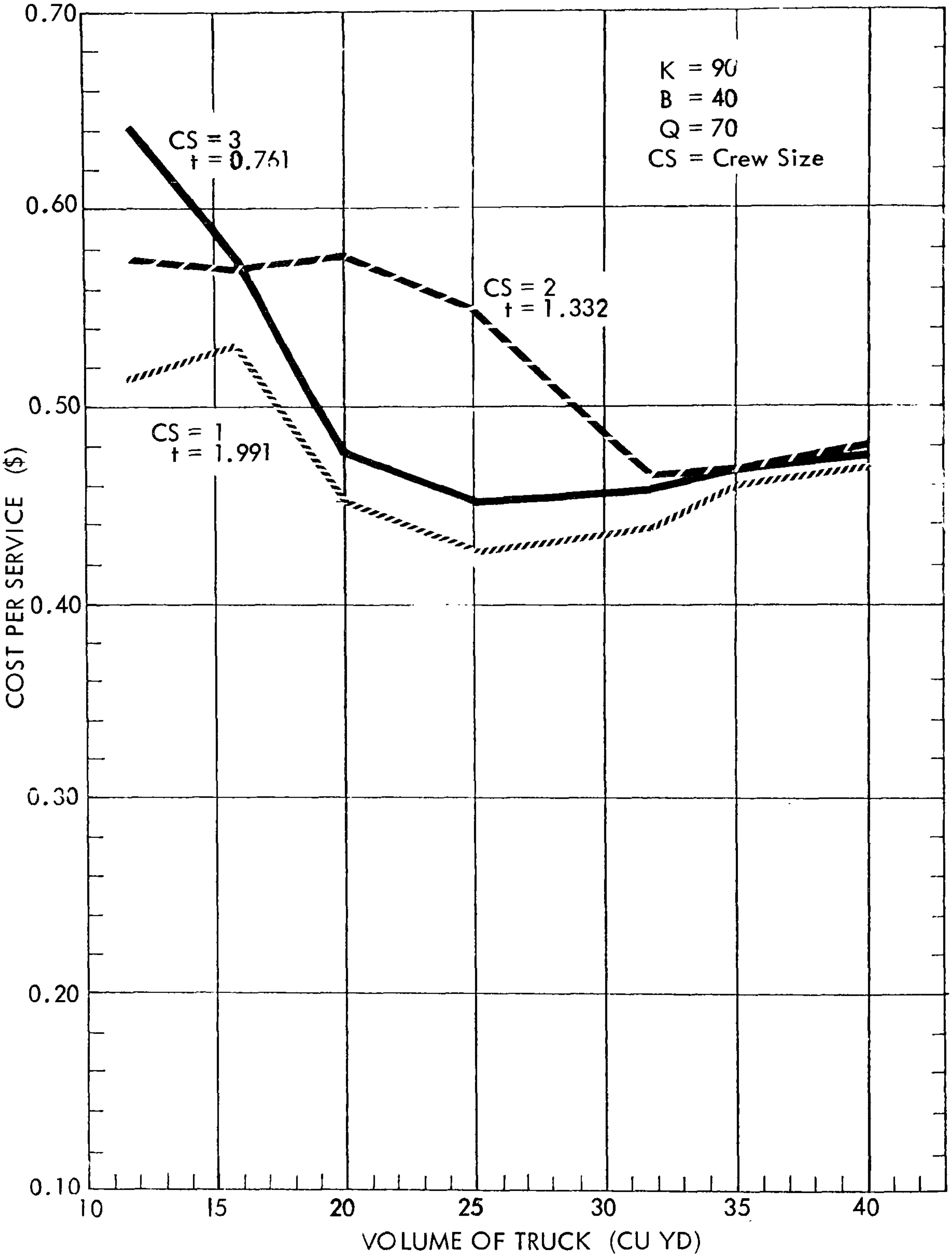


FIGURE 73
COST PER SERVICE
CREW COMPARISON

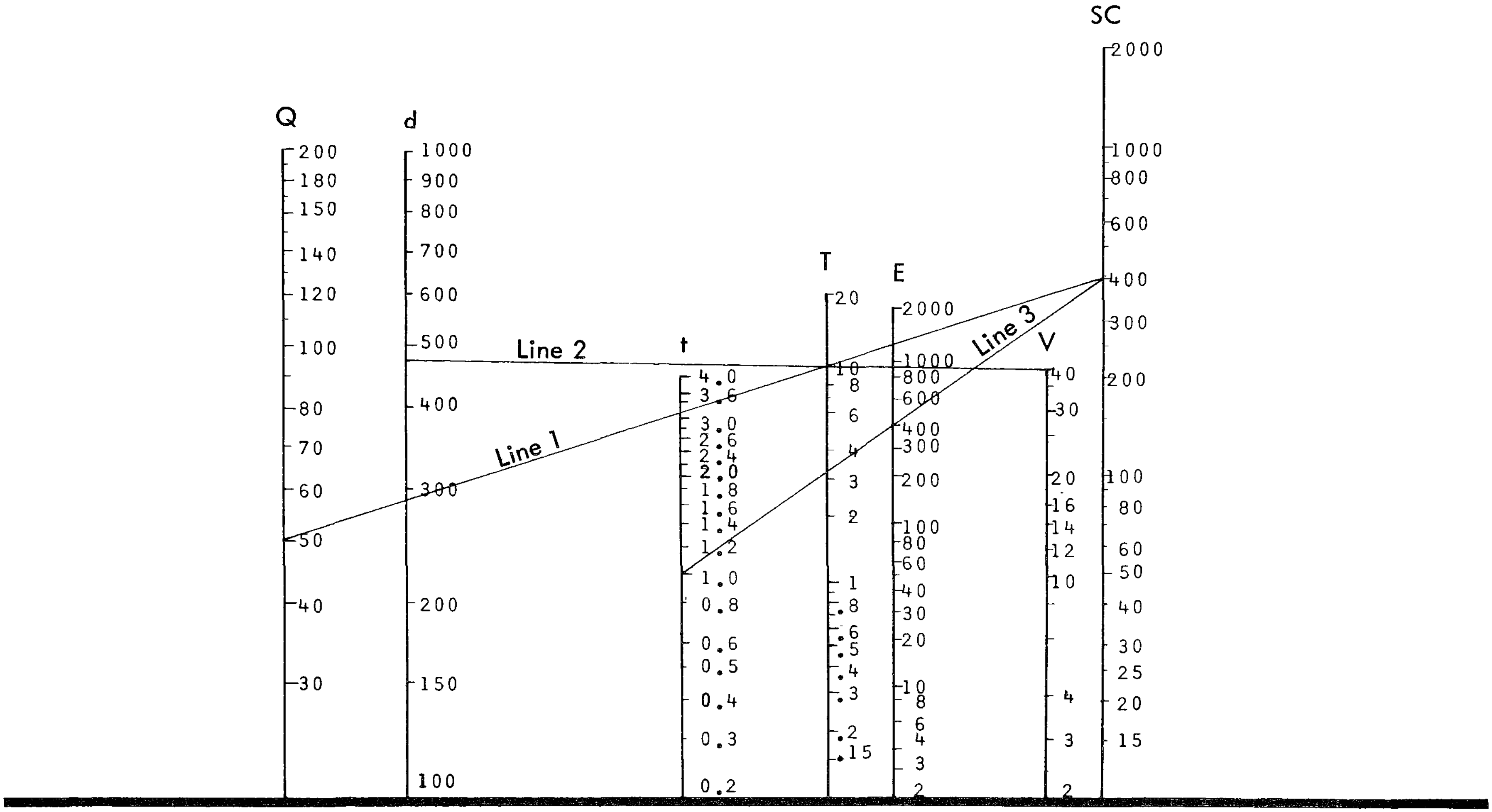


FIGURE 74
NOMOGRAPH NO. 1
SYSTEM DESIGN

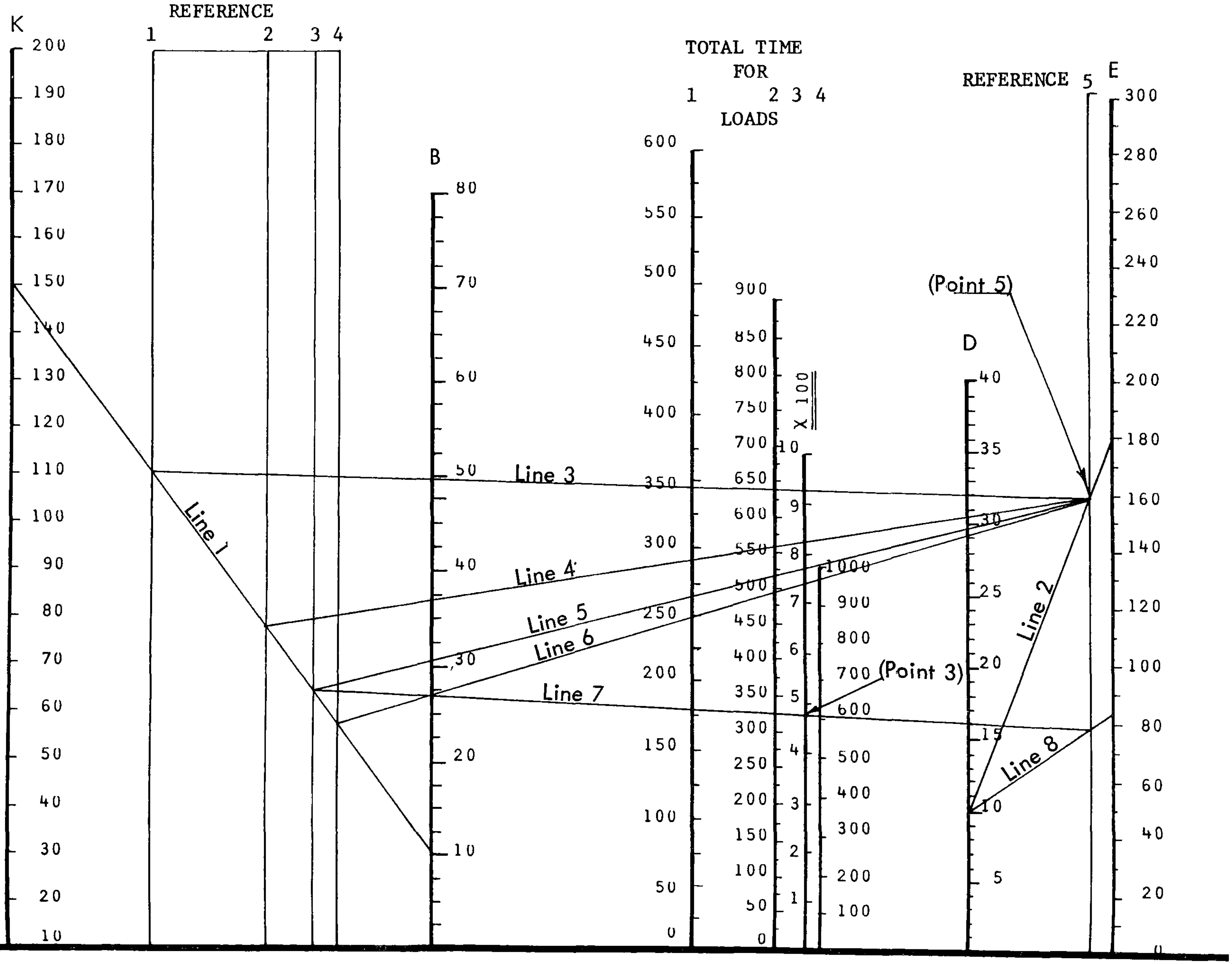


FIGURE 75
NOMOGRAPH NO. 2
SYSTEM DESIGN

(E) = Total time to collect the refuse (min). (E) does not include haul, disposal, or other non-productive times, but is simply the time on the collection route.

(SC) = Number of services completed (number/day).

(V) = Vehicle volumetric capacity (cu yd).

Example 1

Knowing the total quantity of refuse collected by a crew or crews and the total number of service stops served, the mean or average quantity of refuse per service stop can be calculated as follows:

Plot the total number of services on the scale marked (SC); plot the total weight of refuse on the scale marked (T). Connect these two points by a straight line (see Line 1 on Figure 74) and extend the line to the scale marked (Q). The point found on (Q) is the average quantity of refuse per service stop. The same procedure may be used to estimate the total weight of refuse given the number of services collected and the average quantity of refuse per service stop, as follows:

Plot the average quantity of refuse per service on the scale marked (Q) and the total number of services collected on (SC). The straight line (Line 1) connecting these two points will indicate the total quantity of refuse collected in tons where the line crosses the scale marked (T).

Example 2

To calculate the average density of the refuse in the truck, the following procedure can be used:

On the scale marked (T), plot the weight in tons of a full load of refuse. On the scale marked (V), plot the volumetric capacity of the truck. A line connecting these two points, shown as Example Line 2, extended to the scale marked (d), will indicate the average density in lb per cu yd of the refuse in the truck. As in Example 1, knowing any two of the values of (d), (T), and (V), the other value can be found by proper procedures.

Example 3

If any three of the following is known, (Q), (V), (d), and (SC), the fourth value can be calculated. For example, assume that (Q), (SC), and (V) are known. To find (d), the procedure is as follows:

Plot (Q) and (SC) on the appropriate scales and join with a straight line (see Line 1). Where this line intersects the scale for (T), connect that point with the value for (V), and extend to the value of (d) on scale (d) (see Line 2).

Example 4

To calculate the total collection time per load (E), the procedure would be as follows:

Knowing (V), (d), (Q), and (t), first plot the value for (V) and (d) and join these two points with a straight line (see Line 2). Where this line crosses the scale of (T), join that point with the value of (Q) and extend this line to the scale of (SC) (see Line 1). Join the point of intersection with (SC) with the proper (t) value on the (t) scale. The point where this line (Line 3) intersects the (E) line gives the total collection time for the load. The knowledge of actual values, or the use of assumed values, for any five of the scales on the nomograph can enable the user to determine the other two values. In addition, if (T), (E), (SC), and (V), are known, we can determine (Q), (d), and (t). The procedure would be as follows:

(Q) can be determined by extending a straight line through (T) and (SC) (Line 1); (d) can be found be extending a straight line through (T) and (V) (Line 2); and (t) can be found by extending a straight line through (SC) and (E) (Line 3).

The second series of examples given will deal with Nomograph 2 shown on Figure 75. This nomograph has been devised to aid in determining the total time required for the collection and disposal of 1, 2, 3, or 4 loads. In order to use the nomograph, four values must be known. These are (K), the total non-productive time as defined earlier in the report; (B), the one-way travel time from the route to the disposal site; (E), which is the on-route collection time for one full load; and (D), which is the dumping time per load. The procedure would be as follows:

Plot each of the values of (K), (B), (E), and (D) on their respective scales on the nomograph. Assume for this example that they are 150, 10, 180, and 10, respectively. Join the point (K) and the point (B) with a straight line (Line 1). This line intersects the Reference lines numbered 1, 2, 3, and 4 at four different points. Now, join the plotted points of (E) and (D) with a straight line (Line 2). Where this line intersects Reference Line 5, mark a point (Point 5). Join Point 5 with the respective points where the line drawn between (K) and (B) intersects Reference scales 1, 2, 3, and 4. Construct four separate lines (see Lines 3, 4, 5, and 6). Now, each of these four lines crosses the Total Time scales 1, 2, 3, and 4, at the total time required by the crew to collect, haul, and dispose of 1, 2, 3, or 4 full loads respectively. Note that in this example the crew could collect and dispose of one full load in 345 minutes but would require 560 minutes to collect and dispose of two full loads. One full load and partial second load would probably be planned, therefore.

The value of collection time (E) available for any number of loads can be determined by reversing the above process. For example: assume that the total collection time available for each of three loads is to be determined. On the Total Time scale, mark the scale designated 3 with a point at 480 minutes (Point 3), which is assumed to be the desired total day time for the crew. Assuming the same values for (K) and (B) as in the previous example, join a straight line from the 480 point on Total Time scale 3 to the point where the K-B line crosses Reference scale 3 (Line 7). Extend Line 7 to the right, to intersect Reference scale 5 between (E) and (D). Draw a straight line (Line 8) from (D) through this point on Reference scale 5 to intersect (E) at the available collection time in minutes for each of the three loads, 83 minutes in this example.

Nomograph 1 can also be used for a preliminary evaluation of the crew size and the truck volume to be used for a given route size. The procedure would require a preliminary study during representative periods of the year of the actual collection of refuse using various crew sizes. If collection time per stop values presented within this report are used, alternative crew sizes would not be required. The following items would be recorded during this field study:

(a) Haul time in minutes to the disposal site (B).

(b) Non-productive time (K).

(c) Full load weights of refuse.

(d) Disposal time per load.

(e) Number of services collected each load (SC).

(f) On-route collection time per full load (E).

It is not necessary to use a particular truck size for this preliminary study.

The desired length of day can be assumed as any value; however, we shall use 480 minutes, equal to 8 hours. From the field data for the number of services collected (SC) in time(E), the average time per collection stop (t) can be determined using the nomograph on Figure 74. The average quantity of refuse per stop (Q), can be determined from the same nomograph using field values of (T), the total weight collected in full loads, and (SC), the number of services collected. Similarly, the average density of refuse in the truck can be determined from the plotted values of (T) and (V). Knowing (t), (Q), and (d), the loading time (E) and services collected (SC) per full load can be estimated for various truck volumes and crew sizes. It is convenient to construct a table for the purpose of recording various values, and an example is shown as Table XXV.

TABLE XXV

EXAMPLE TABLE - NOMOGRAPHS

(V) Volume of Truck	(CS) Crew Size	(t) Time Per Stop	(E) Time Per Load	(S) Services Per Load	Truck Loads Required
12	1				
	2				
	3				
16	1				
	2				
	3				
20	1				
	2				
	3				

Column 6 on Table XXV, truck loads required, is calculated by dividing the total number of services on the route by the services per load, Column 5. The time per stop for the respective crew size can be based upon either the values shown on the figures included in this report or the values determined during the preliminary study. Column 4, the time per load, can be estimated from the use of the nomograph on Figure 74, based upon (t) and (SC). Column 5, the services per load, will be based upon the field data on the tonnage per load and the average quantity of refuse per service stop.

E. Equipment

1. General

The scope of work of the contract required the compilation of background information, specifications, and brochures on refuse collection equipment suitable for use by the one-man crew. Such a compilation has been completed and is included as Attachment C to this Final Report. Brochures have been obtained from American and European equipment manufacturers.

Although certain equipment is more efficient for one-man collection than others, many types of available refuse collection equipment may be operated by one man. We have therefore compiled a reasonably complete listing of existing refuse collection equipment suitable for one or more man operations.

Appendix G is a summary of pertinent specifications from manufacturers of American equipment. It provides the manufacturer's name and address and a brief description of the types and sizes of equipment available. Detailed specifications are available from the manufacturer.

2. Equipment Characteristics

Of existing American-made refuse collection equipment, the side-loading, packer type vehicle is probably best suited for one-man collection operations regardless of methodology. As brought out in Section C, this equipment enables the operator to complete the collection task with a minimum of lost-time effort. With curbside collections, the side-loading packer equipped with right-hand drive may prove more efficient. The costs involved in installing the right-hand drive equipment on the truck must be known in order to complete a cost-benefit study. Figure 31 indicates the potential savings in collection time per service stop possible with the use of a right-hand drive equipped vehicle in comparison with the conventional vehicle. Assuming a useful truck life of 5 to 8 years, if the crew completes 200 to 400 collection stops each day, even minor time savings can become significant over the life of the vehicle.

Rear-loading packers are satisfactory for one-man operation, although somewhat less efficient than side-loaders in terms of crew time. There is some disagreement within the industry on whether the rear-loading packer is more efficient for processing and compressing the refuse than the side-loading packer. During the field surveys, the side-loading packer was more susceptible to the wind blowing light refuse materials out of the hopper; in addition, the packing mechanism tended to become less efficient as the full load capacity of the truck was approached. However, the particular side-loading model studied was designed to permit continuous loading into the hopper. In most rear-loading packers, a cycle time is involved, and lost time results when loaders are required to wait for the packing mechanism to complete its cycle prior to loading additional refuse.

For one-man curbside collection of refuse, the ideal collection vehicle would locate the driver and the packing mechanism close together; it would also locate the driver close to the containers at the service stop. Ideally, the man should step directly from the cab to the container location, then pivot and load the containers directly into a hopper immediately adjacent to this position. The cover of this report illustrates such an idealized condition. The capacity of the hopper should be adequate so that quantities involved in one stop would not require the driver to operate the packer mechanism. Safety, of course, is of the utmost importance, and adequate safeguards should be standard equipment on any truck. Included should be a positive braking system; guards to prevent the operator from becoming entangled in the packing mechanism; and conveniently located controls on the packer mechanism such that in case of accidentally catching an arm or hand in the packer mechanism, the man can positively stop the mechanism at any point. Adequate mirrors should be installed on the truck to provide the driver with maximum visibility while driving. The wheel base on the truck should be as short as possible consistent with the necessary wheel base dimensions and axle capacities for efficient vehicle design. The figures in the mathematical analysis section of this report indicate that the larger sized vehicles will generally enable more efficient refuse collection regardless of crew size. There is, of course, a practical upper limit to this, depending upon the time required to drive between collection stops, other non-productive time, disposal time, and route factors such as street widths, alley widths, and the presence of obstructions to the passage of the vehicles. Ideally, the crew would travel to the route, collect one full load of refuse, and complete its trip to the disposal site and back to the yard, all within eight hours. Thus, the crew would spend the maximum amount of time on the route, collecting refuse.

3. European Equipment

A great deal of foreign equipment has been produced. However, to our knowledge none of this equipment is extensively purchased in the United States. Many systems in Europe use more sophisticated equipment than that used in the United States. Light alloy steels are used for truck bodies, and the systems for mechanically handling containers often maintain dustless conditions. Elaborate screw-conveyor compactors are also common. Although their maintenance costs may be higher, the screw-conveyor type vehicles have an advantage in that the partially disintegrated refuse is sometimes easier to dispose of at the incinerator or landfill site. In general, European systems use larger sized crews.

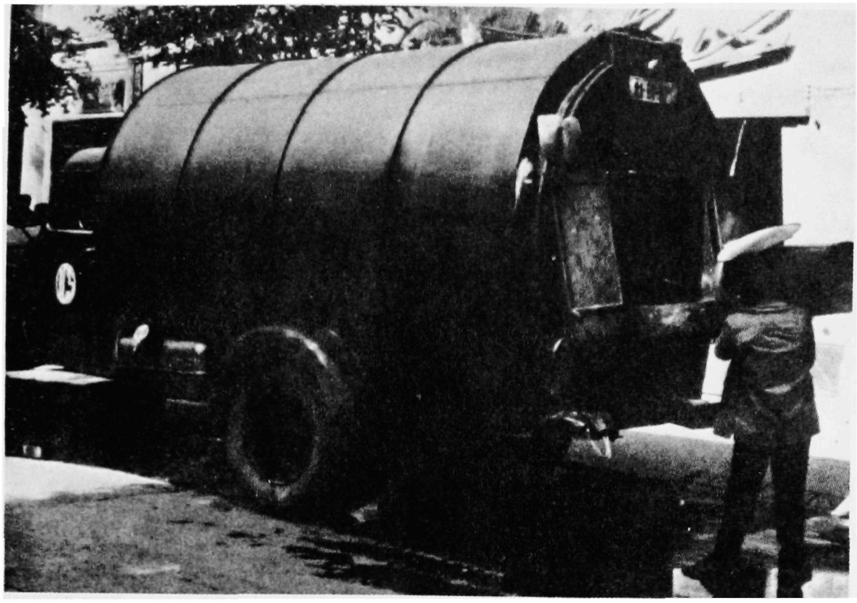
Photographs XII through XV illustrate typical European collection equipment.

PHOTOGRAPH XII.
DUSTLESS COLLECTION SYSTEM,
VIENNA, AUSTRIA

NOTE: AUTOMATIC LIFTING DEVICE.

PHOTOGRAPH XIII.
SCREW COMPACTOR
ATHENS, GREECE

PHOTOGRAPH XIV.
SCREW COMPACTOR
CENTRAL EUROPE
NOTE: SHOULDER
HEIGHT LOADING



PHOTOGRAPH XV.
COMPACTION
VEHICLE
NEVI, FRANCE

GLOSSARY

Adjusted Standard Time	Standard Time plus allowance for fatigue, personal and unavoidable delays.
Alley Collection	The collection of refuse placed adjacent to the alley by a crew collecting from both sides of the alley with each pass of the equipment.
Backyard Collection	The collection of refuse located at the rear of the service by a crew operating from the street fronting the property and collecting from both sides of the street with one pass of the equipment.
Box	Cardboard, paper, wood or other container for refuse normally intended for disposal along with its contents.
Bundle	Prepared garden trimmings, tied paper, or other similar material placed for collection.
Can	Conventional metallic, fiberboard or other reuseable refuse container fitted with handle and a lid.
Collection Methodology	Method and procedure followed by the refuse collection crew in completing their work assignments.
Collection Stop	Stop made by the collection vehicle and crew on the route to collect refuse from one or more service stops.
Collection Time	Elapsed or cumulative time spent by the refuse collection crew in collecting refuse from a collection stop. Does not include travel time between collection stops on the route.
Container	Can, box, or disposable container used for storage of refuse.
Cost per Service	Average cost per service stop including labor and equipment costs.
Cost per Ton	Average cost per ton of refuse collected including labor and equipment costs.

Crew Size	Number of persons assigned to each refuse collection vehicle, including the driver.
Curbside Collection	The collection of refuse placed at the curb location by a crew wherein collection is made at each service stop on one side of the street with each pass of the equipment.
Disposable Container	Plastic, paper, cardboard, or other container for refuse intended for disposal along with its contents.
Frequency	The number of times a given event occurs; expressed as a percentage of all recorded occurrences.
Haul Time	Elapsed or cumulative time spent hauling collected refuse from the route to the disposal point and return to the route.
Least Squares Line	A straight line representing a set of data such that the difference between the value on the straight line and the corresponding data points is minimized.
Level of Service	Extent of refuse collection service provided to the recipient, including collection frequency; material collected; storage location; pre-preparation; and other factors.
Load Mean Quantity	The total weight of one load from many service stops divided by the total number of those service stops.
Load Standard Deviation	Square root of the mean of the squares of the deviations of the Load Mean Quantity from the Mean Quantity of Refuse.
Man-Minutes per Ton	Total labor minutes expended per ton of refuse collected. Route man-minutes per ton refers to only the portion of total labor time expended while the crew is on the route.
Mean Quantity of Refuse	The cumulative total weight of all loads divided by the cumulative number of all service stops.
Median	Statistical point in a series at which the number of items with higher values is equal to the number of items with lower values.

Modified Curbside Collection	The collection of refuse placed at the curb location by a crew wherein each collection stop is made for two or more services and both sides of the street are collected with each pass of the equipment.
Service Stop	Residence, commercial establishment, or other living or business unit receiving periodic refuse collection service.
Standard Time	MTM time required for the completion of a work task. Does not include allowance for fatigue, personal, and unavoidable delays.
Total Items	Total number of containers and bundles at the service stop.
Travel Time	The elapsed or cumulative time of travel between collection stops on the route.
Truck Capacity	Volumetric capacity for refuse.

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APPENDIX A

UNITED STATES PUBLIC HEALTH SERVICE

RALPH STONE & CO., INC., ENGINEERS

REFUSE COLLECTION DATA SHEET

DATE ____________________ CLIMATE ____________________

COLLECTION AGENCY ____________________

CREW SIZE ____________________

EQUIPMENT DESCRIPTION

BODY MANUFACTURER ____________________

CAPACITY ____________________ (CUBIC YARDS)

TYPE ____________________

HOPPER SIZE ____________________ (CUBIC YARDS)

CHASSIS ____________________

DRIVER LOCATION ____________________ (RT. OR LEFT) ____________________

AXLES ____________________

MAX. LEGAL LOAD ____________________ (TONS)

COMMENTS ____________________

____

ROUTE INFORMATION	DATA WRISTWATCH TIME	ODOMETER MILEAGE	NET TONS
Leave yard	______	______	
Arrive route	______	______	
Leave Route (1st load)	______	______	______
Arrive @ Disposal Site	______	______	
Leave Disposal Site	______		
Arrive Route (2nd load)	______	______	
Leave Route	______	______	______
Arrive @ Disposal Site	______	______	
Leave Disposal Site	______		
Arrive @ yard	______	______	

Page 1 of ______

APPENDIX A - CONTINUED

CANS	BOXES	BUNDLES	#UNITS	COLLECTION	TRAVEL	LOST TIME	REASON FOR LOST TIME

PAGE ______ OF ______

APPENDIX B

UNITED STATES PUBLIC
HEALTH SERVICE

RALPH STONE AND COMPANY, INC.
ENGINEERS

CONTRACT PH 86-67-248

DATA SUMMARY FORM
REFUSE COLLECTION OPERATIONS

Agency____

Date____________________ Climate____________________

Crew Size____________________

Equipment Description:

Body Manufacturer:____________________

Capacity____________________ Cubic Yards

Type____________________

Hopper Size____________________ Cubic Yards

Chassis____________________

Driver Location____________________ (Rt. or Lt.)

Axles____________ Max. Legal Load____________Tons

I. TOTAL TIMES AND MILEAGE (Exclude Lunch and Break Time)

Item	Time	Miles
Yard to Route		
On Route (First Load)		
Route to Disposal Site		
Disposal Site to Route		
On Route (Second Load)		
Route to Disposal Site		

Item	Time	Miles
Disposal Site to Route		
On Route (Third Load)		
Route to Disposal Site		
Disposal Site to Yard		
Total For Day		
Route to Yard (Return with Partial Load Only)		
Lost Time and Mileage		

Lunch:____________Minutes. BREAK, __________ MINUTES.

Total Disposal Time:______________Minutes

II. INCREMENTAL TIMES

Time/Stop

Time Increment (Minutes)	Number Occurrences
0 - 0.20	
0.21 - 0.40	
0.41 - 0.60	
0.61 - 0.80	
0.81 - 1.00	
1.01 - 1.20	
1.21 - 1.40	
1.41 - 1.60	
1.61 - 1.80	
1.81 - 2.00	
Over 2.00	

Minimum Value:__________(Minutes)

Maximum Value:__________(Minutes)

Travel Time Between Stops

Time Increment (Minutes)	Number Occurrences
0 - 0.10	
0.11 - 0.20	
0.21 - 0.40 0.30 0.31	
0.41 - 0.50	
0.51 - 0.60	
0.61 - 0.70	
0.71 - 0.80	
0.81 - 0.90	
0.91 - 1.00	
Over 1.00	

Minimum Value:____________(Minutes)

Maximum Value:____________(Minutes)

III. DISPOSAL SUMMARY

	Net Tonnage	Total # Stops
First Load		
Second Load		
Third Load		
Fourth Load		
Partial Load		

IV. CONTAINER SUMMARY

Average Number of Cans/Stop:____________

Average Number of Boxes/Stop:____________

Average Number of Bundles/Stop:____________

APPENDIX C

POSSIBLE COLLECTION COST SAVINGS ATTRIBUTED TO THE USE OF DISPOSABLE CONTAINERS

The following estimate has been prepared based on information received from Municipality 'A' obtained during the conduct of comprehensive time studies of field collection operations.

I. Present average cost per ton for collection and disposal of solid wastes from residences:

Yearly Average:	$9.00/T
Less Disposal Cost:	1.25
Collection and Haul Cost:	$7.75/T

Assume 10% for City and Administrative Overhead:
10% (9.00) = $0.90/T

New Collection and Haul Cost (Crews & Equipment Only)

$7.75
-0.90
$6.85/Ton

II. Based on preliminary survey studies, a potential reduction in the incremental time for a collection stop consisting of three items will be about 40 percent assuming the replacement of conventional containers with disposable containers. Studies indicated that on the average three cans were used by householders each week.

This potential saving applies only to the portion of the collection day when the crew is actually collecting refuse, and not when traveling between collection stops, to and from the disposal site, etc.

A conservative estimate based on Field Studies indicates that the typical crew in Municipality 'A' collects from an average of 260 collection stops.

The average time of travel between stops is presently 0.17 minutes.

Therefore, if each collection stop required 40 percent less time to collect, the additional time available for collection of refuse could be expressed as follows:

$$260(0.60)\beta + 260\ (0.17) + \chi\ (0.6\beta) + \chi(0.17) = 260(\beta) + 260(0.17)$$

Simplifying:

$$\chi = \frac{140\beta}{0.6\beta + 0.17}$$

Where β = Average collection time per stop (conventional containers).
χ = Number of additional services per day.

Based on values for collection time as determined during the One-Man Collection Study:

$$\beta = 0.63$$

Therefore,

$$\chi = 120$$

Each collection vehicle could be expected to collect about 120 additional stops; thus, for every four trucks presently used, one could be eliminated. This indicates an approximate saving of 25 percent in collection costs. The capacity of collection vehicles may have to be increased to accommodate the additional refuse; however, this factor has been omitted in this analysis.

Net savings per ton would be 25 percent ($6.85) or $1.71/T. If it is assumed that the average household produces 1-1/2 T of refuse per year, a savings per household of about $2.57/Year is indicated, or approximately $0.05 per household per week.

This conservative estimate of the possible savings in collection cost resulting from the use of disposable containers would pay about 15 to 20 percent of the estimated weekly cost of disposable bags.

In addition, the cost of purchasing and periodically replacing conventional containers would be eliminated.

The cost of conventional containers can be estimated as follows:

Assume 3 containers with an average 3-year life costing $5.00 each.

$$\text{Cost/Week} = \frac{\$5.00\ (3)}{52(3)} = 9.6¢\text{/Week}$$

Total Savings Possible:	5.0¢	(Collection)
	9.6¢	(Containers)
Total:	14.6¢/Week	

This total could represent nearly 50 percent of the weekly cost of both the disposable bags and holder. Potential collection savings may be considerably greater in multi-man crews due to the greater unit costs for collection per ton.

APPENDIX D

NATIONAL SURVEY DATA FORM

RALPH STONE AND COMPANY, INC.
ENGINEERS.

REFUSE COLLECTION INFORMATION

I. NAME OF CITY:____________________________________

II. COLLECTION INFORMATION (Residential or Residential/Commercial only; Please do not include street sweeping, snow removal, tree trimmings, etc.)

A. Materials Collected: Combined Refuse_____Combustible only_______Wet Garbage only_____Yard Refuse only_____Non-Combustible only_________
Comment:____________________________________

B. Collection Frequency: 1/week_____ 2/week______ Comment:_____________

C. Number of Residential Units Served:____________________

D. Number of Commercial Units Served:____________________

E. Refuse Tonnage(Items in IIA above only) Collected/Year:____________

F. Average Number of Lost Time Accidents(Industrial Only) per Year:___

III. REFUSE COLLECTION EQUIPMENT

Please list the equipment used for the collection of waste materials named in IIA above by type and cubic yard capacity and number of each normally utilized.(Type-rear loading packer, side loading packer, front bucket loader, open truck, other(please specify).____________________

IV. GENERAL

Total Annual Budget for Refuse Collection(please include equipment maintenance, but exclude disposal costs such as dump fees, incinerator operations, etc.)____________________________

V. COMMENTS

VI SPECIAL NOTE

Please provide a copy of the current refuse collection ordinance or regulations for your City.

PREPARED BY:

Name:_________________________________

Title:_________________________________ Date:_________________________

I. Name of City__________________________ Population______________
Residential Collection Provided By:______ Municipal______ Private

II. Collection Information (Residential or Residential/Commercial Service Only)

A. Normal Crew Size (One-Man)______ (Two-Man)______
Other (Please Specify)____
Comment____

B. Normal Collection Location: Curb or Alley______________________
Other (Please Specify)____
Comment____

C. Collection Information:

	Municipal	Private
1. Number of collection services	_________	_________
2. Number of commercial services	_________	_________
3. Average Number of Crews/Day	_________	_________
4. Average Tons/Day/Crew	_________	_________
5. Average Working Day (Hours)	_________	_________
6. Tonnage Collected/Year	_________	_________
7. Annual Budget for Collection	$_________	$_________

D. Equipment Utilized - Please indicate the type, model, and cu yd of collection utilized by the various crew sizes (rear loading packer, side loading packer, front bucket loader, open truck, other (please specify).

III. General

A. Total Tonnage Collected/Year_____________________________Tons

B. Annual Budget for Collection $______________________________

IV. Comments____

____

____

____

NOTE: Please provide copy of 1967-68 solid waste ordinance and Annual Report.

Prepared By:
NAME__________________________
TITLE__________________________ DATE__________________

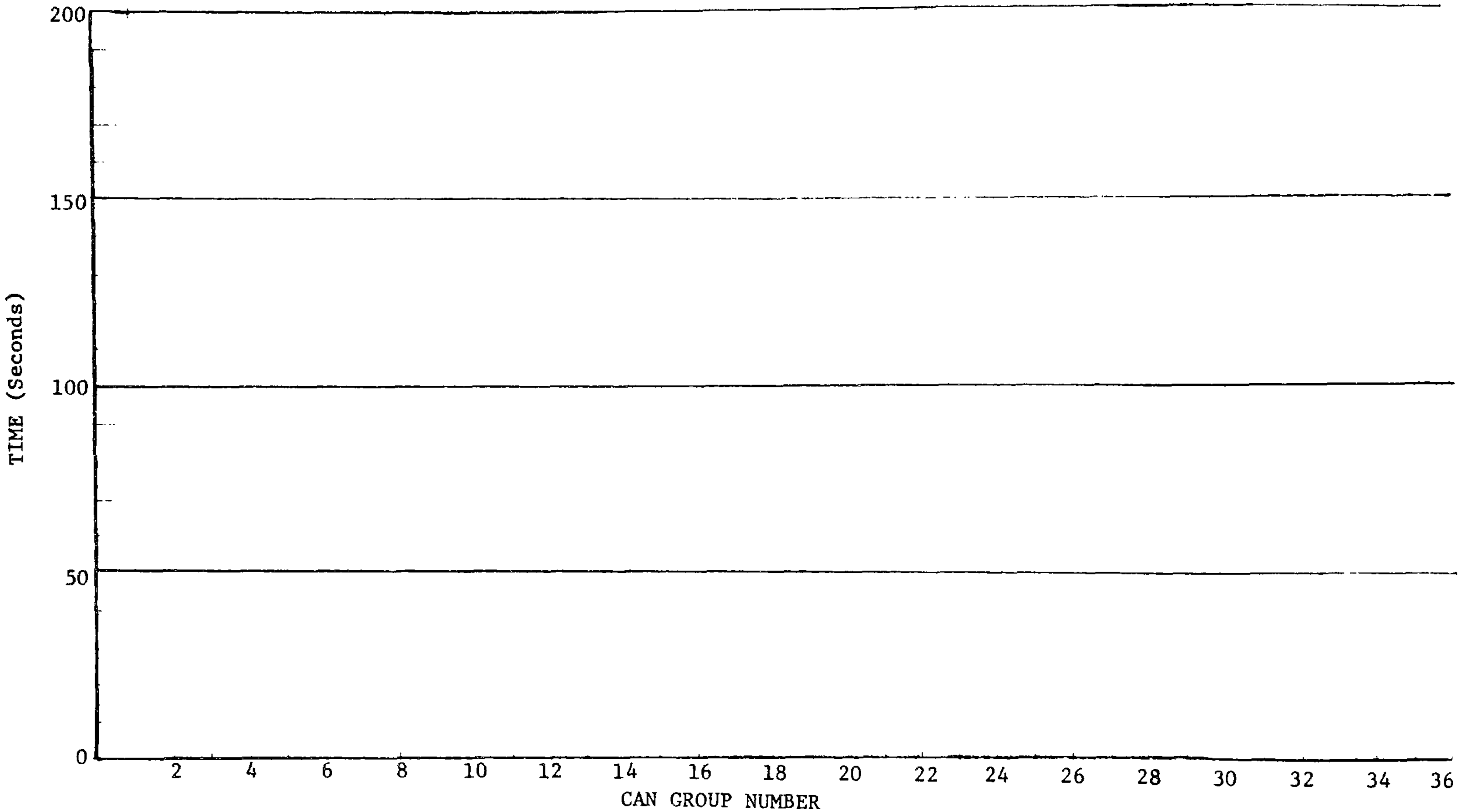
APPENDIX E

RALPH STONE AND COMPANY, INC., ENGINEERS
U.S.P.H.S. PH 86-67-248

SUBJECT______________ LOADING HEIGHT______________ TEMPERATURE______________

RECORDER______________ CAN WEIGHT______________ HUMIDITY______________

DATE______________ TIME______________ CANS IN GROUP______________



4/68

APPENDIX F

VIDEO TV USE FOR HUMAN FACTORS STUDIES

Advantages of the unit include the following:

(1) Allows a continuous record which can be consulted to verify data for any portion of the experiment. If the information is not needed, the tape can be reused for a subsequent experiment. This is the main advantage of video tape recording equipment over a movie camera.

(2) Use of the unit allows spot checking of observer recorded data by reobserving and recording sample data from the video tape.

(3) In human factors experiments involving physical labor, the possible legal liability involved in the experiment may be lessened by having a permanent record of work activity conducted during the experiment.

(4) A new variable previously not thought important may become important during the experiment, and this factor may be evaluated based upon the video tape record.

(5) Allows management or clients to view the conduct of the experiment at a time more convenient to individual schedules.

(6) It allows retrieval of experimental data which might otherwise be lost due to misplacement, observer error, or other problems.

(7) It allows the possibility for subjective evaluations of the subject's physical or even mental state at some point in the experiment.

(8) Depending on the experimental design, the use of the TV video system along with special timing or electronic apparatus can be made to periodically or randomly sample the experimental data without the presence of a continuous observer for data recording.

(9) The presence of a continuously monitoring system can prevent data falsification by a subject.

(10) The amount of data desired may be excessive for one or two observers to record during the conduct of the experiment. The video tape system can preserve all the information and allow detailed data recording at a more convenient time.

There are, of course, certain disadvantages which may preclude the use of the TV video system in certain experimental designs. Some of these could be the following:

(1) The presence of a monitoring device that continuously records personnel characteristics may tend to inhibit the performance of the subject.

(2) The recording device should be present during all experimental trials; otherwise, the subject's performance may vary as a function of its presence.

(3) For the TV video system to be useful to its fullest extent, a qualified technician or other observer must spend time reviewing the video tape recordings.

(4) The cost of the unit.

(5) The experiment must be conducted in a location where power is available to operate the video TV system. A portable unit may be used in short-term experiments where power is not available. The battery life on typical systems is on the order of 20 minutes.

APPENDIX G

EQUIPMENT SPECIFICATIONS

MANUFACTURER		OUTSIDE DIMENSIONS			BODY		LOADING LOCATION			LOADING DIMENSIONS		LOADING HEIGHT	PACKING SYSTEM			EQUIPMENT TYPE	
Name and Address	Model Description	Height (in.)	Width (in.)	Length (in.)	Weight (lb.)	Volume (cu yd)	Front	Side	Rear	Height (in.)	Width (in.)	(in.)	Aux. Eng.	Oper. Press.	Dead Time	Open Body	Compactor
Bynal Products, Inc.	6 Yd. Hussler	76	82	114	2000	5.9		& Top		57		7½ over				•	
11990 Franklin Ave.												Frame					
Franklin Park, Illinois	8 Yd. Hussler	76	82	138	2300	7.3		& Top		57		7½ over				•	
60131												Frame					
Cobey Perfection -		I.D.	I.D.	I.D.						(30)	(34)						
Cobey Company	Cobey Paktainer PT 1224	74	84	204		24	•	(•)		84	96			(78000)			•
Division of Harsco Corp.	PT 1230	74	84	246		30	•	(•)		84	96			(78000)			•
Galion, Ohio	Cobey Train-Tainer)	53-5/8	59-3/8	93		4	Top					53-5/8				•	
	Containers)	55	59-3/8	93		5	Top					46-5/8				•	
Cushman Motors	Cushman Refuse	70	45-1/2	129	1282	1-1/4	Top									•	
Division, Outboard	Collection Vehicle																
Marine Corp.																	
Lincoln, Nebraska																	
Dempster Bros., Inc.	Dempster Dumpmaster							•									
Knoxville 17, Tenn.	Container Train															•	
	Dempster Front End																
	Loader DP-3B-20-DB						•					36		(68000)			•
										(30)	(30)						
E-Z Pack Co.	FL 45-20	103-1/2	96	293	13750	20	•	(•)		13-3/4	L.88			1150			•
Division of Hercules											80						
Galion Products, Inc.	FL 45-25	103-1/2	96	328 Inch Arms	14560	25	•	(•)		13-3/4	L.88			1150			•
Galion, Ohio											80						
	FL 45-30	103-1/2	96	394	15620	30	•	(•)		13-3/4	L.88			1150			•
											80						
	Econo Train		I.D.														
	Container CT-4	50	72	108	1100	4	•					50				•	
	Unit CT-5	56-1/2	72	112	1200	5	•					56-1/2				•	
	SL 16	81	95-1/2	181	7108	16-3/4		•& Top			36			(76600)			•
	SL 20	81	95-1/2	205	7808	20		•& Top			36			(76600)			•
	SL 24	81	95-1/2	239	8758	24		•& Top			48			(76600)			•
	A 16	81	95-1/2	181	7108	16-3/4		•& Top			36	(23 in above frame)		(76600)			•
	A 20	81	95-1/2	205	7808	20		•& Top			36			(76600)			•
	A 24	81	95-1/2	239	8758	24		•& Top			48			(76600)			•
Garwood Industries, Inc.	LP 716	94	95-1/2	232	8800	16			•					1050	10		•
Wayne, Michigan	LP 718	94	95-1/2	250	9080	18			•					1050	10		•
	LP 720	94	95-1/2	265	9300	20			•					1050	10		•
	LP 725	94	95-1/2	299	9780	25			•					1050	10		•
	T-130 L*	120		330	22900	40			•	38	80	35			20		•

Containers Available

(Self-contained unit-dimensions include cab and wheels)

*T-100 Series has 11 models, front and rear loaders, w/varying specs.

(---) = lb pressure when PSI not avail.

APPENDIX G (Continued)

EQUIPMENT SPECIFICATIONS

MANUFACTURER		OUTSIDE DIMENSIONS			BODY		LOADING					LOADING HEIGHT	PACKING SYSTEM			EQUIPMENT TYPE	
							LOCATION			DIMENSIONS							
Name and Address	Model Description	Height (in)	Width (in)	Length (in)	Weight (lb)	Volume (cu yd)	Front	Side	Rear	Height (in)	Width (in)	(in)	Aux. Eng.	Oper. Press.	Dead Time	Open Body	Compactor
The Heil Company	Colectomatic Mark III	83	95-3/4	172-1/4	8800	13			•	54	80	5 in below top of frame		(98000)	12		•
Milwaukee, Wisc. 53201		83	95-3/4	189-1/4	9200	16			•	54	80			(98000)	12		•
		83	95-3/4	219-1/4	9700	20			•	54	80			(98000)	12		•
		90	95-3/4	241-1/4	10500	25			•	54	80			(98000)	12		•
Hobbs Trailers	Hobbs Hyd-Pak Rear																
609 N. Main Street	Loader - HRL 18	89-3/4	95-1/2	208-3/4	9000	18			•	72	79-1/2	6 in below frame		2000	17		•
Fort Worth, Texas	HRL 20	89-3/4	95-1/2	221-3/4	9500	20			•	72	79-1/2			2000	17		•
	HRL 25	89-3/4	95-1/2	254-3/4	10000	25			•	72	79-1/2			2000	17		•
	Hyd-Pak 60 Series -																
	Containers Avail. 6013	72	96	174	6000	16		Sides of Front + Top						1500	28		•
	6016	84	96	174	6900	19								1500	28		•
	6020	84	96	198	7300	23								1500	28		•
	6024	84	96	234	8300	27								1500	28		•
	Hyd-Pak Trailer Units	108	96	379-1/2		32		•				40-42		1500			•
		131						(&top)		(L 96)	(96-)						
	(as transfer units)	(137-1/4)	96	375-1/2		42	Large Top as Transfer	•						1500			•
	"	132-1/2						(&top)		(L 96)	(96-)						
		(138-7/8)	96	444-5/8		50		•						1500			•
		150-1/2						(&top)		(L 96)	(96-)						
		(156-7/8)	96	444-5/8		60		•						2000			•
	Hyd-Pak M Series - M18	83-5/8	95	165	7085	18		•						1500			•
	M21	83-5/8	95	189	7750	21		•						1500			•
	M25	83-5/8	95	219	8635	25		•						1500			•
	Hyd-Pak Packing					20-35		(& Top)						1800			•
	Containers							•									
Leach Company	Leach 2R Packmaster	96	96	249	12600	20			•	56	80	31					•
222 West Adams St.		96	96	270	12900	25			•	56	80	31					•
Chicago, Ill. 60606						31			•	56	80	31					•
	Leach Pakmaster					13, 16, 17, 20			•	48	77	31					
Lodal, Inc.	EVO (Detachable Body)				11000							28		(30000)			•
P.O. Box 791	Load-A-Matic					21,25, 30		•						(76000)			•
Kingsford, Mich. 49802	Train Transfer System																
	Transfer Truck					20628								(60000)			•
	Lodal Trains					4 & 5										•	

APPENDIX (Continued)

EQUIPMENT SPECIFICATIONS

MANUFACTURER		OUTSIDE DIMENSIONS			BODY		LOADING					LOADING HEIGHT	PACKING SYSTEM			EQUIPMENT TYPE	
							LOCATION			DIMENSIONS							
Name and Address	Model Description	Height (in)	Width (in)	Length (in)	Weight (lb)	Volume (cu yd)	Front	Side	Rear	Height (in)	Width (in)	(in)	Aux. Eng.	Oper. Press.	Dead Time	Open Body	Compactor
Marion Metal Products Co., Marion, Ohio	20 S	74-1/2	96	186	8280	20	(also top)	•		54	36	50		1600			•
	Hydropaka Model Q	60	90	192	13500	28		•		44	34			1000	10-12		•
	Trash Tainer Body	35-1/2	26	56	320	1	top					43					
		44	39	56	480	2	top					52					
M - B Company New Holstein, Wisc.	M - B Pack King	90	Inside Width 88	156		14		•		51-1/2	36			2000			•
		90		170		16		•		51-1/2	36			2000			•
		90		198		20		•		51-1/2	36			2000			•
		90		226		24		•		51-1/2	36		(optional-avail.)	2000			•
Pack-Mor Mfg. Co. 1123 S.E. Military Dr. P.O. Box 14147 San Antonio, Texas 78214	RLA 1315	88	96	177	9490	13			•	48	76	5 in below frame					•
	RLA 1615	88	96	196	9840	16			•	48	76						•
	RLA 1815	88	96	213	10215	18			•	48	76						•
	RLA 2015	88	96	227	10590	20			•	48	76						•
	RLA 2515	88	96	262	10940	25			•	48	76						•
	RLA 3015	88	96	297	11290	30			•	48	76						•
	3 RL					20, 25, 30								1500			•
	Hydraulic Packer &Cylindrical Body)	87	87	165	7966	13		•			Unlimited			(78000)	10		•
		87	87	181	8051	16		•						(78000)	10		•
		87	87	210	8600	20		•						(78000)	10		•
		87	87	248	9400	24		•						(78000)	10		•
		95	95	248	9820	28		•						(78000)	10		•
	Stationary Packer & Side Loader Avail.					13 to 28									8 to 12		
	Transfer Trailers					45 - 75									18-20		•
	Lo-Boye Trailer (cylind)					28 - 38									10-12		•
	Front Loader					20 - 32											
Seal Press - Division of Tampo Mfg. Co., Inc. 1146 W. Lowell St. P.O. Box 7248 San Antonio, Texas 78207	Mark '16' Cylindrical Body	91	(Diam) 93	168	8400	16-1/2		(& top) •			37	22 above frame		1500			•
	Mark '20'	91	93	192	8900	20-1/2		•			37			1500			•
	Mark '24'	91	93	227	9500	24-1/2		•						1500			•
H. E. Smith, Inc. 1069 S. Jackson St. Defiance, Ohio	Smithpac 5	84-1/2	84	120 (204)*		5.08		•		39	28						•
	Smithpack 10	84-1/2	84	120 (204)		10.33		•		38	28						•

* (204) = LENGTH FROM BUMPER TO TAIL.

APPENDIX G (Continued)

EQUIPMENT SPECIFICATIONS

MANUFACTURER		OUTSIDE DIMENSIONS			BODY		LOADING LOCATION			LOADING DIMENSIONS		LOADING HEIGHT	PACKING SYSTEM			EQUIPMENT TYPE	
Name and Address	Model Description	Height (in)	Width (in)	Length (in)	Weight (lb)	Volume (cu yd)	Front	Side	Rear	Height (in)	Width (in)	(in)	Aux. Eng.	Oper. Press.	Dead Time	Open Body	Compactor
Sterling Mfg. Co. 241 N. Third St. Laurens, Iowa 50554	Hippo	78	90	132		10.44		•		54	36	56		1800			•
Vel-Jac Mfg. Co.,Inc. 5650 N. Broadway Wichita, Kansas 67219	Pak Rat	70	96	126	3800	10		•		42	36			1500	10		•
Wayne Engineering Co. Cedar Falls, Iowa	Mighty Pack (incl.chassis)	112		132	7400	10		• (& top)						2000			•
Toledo Industrial Fabricating Co., Inc. 1100 Bush Street Toledo, Ohio	Shu-Pak (to replace incinerators in hi-rise)													800 - 1000			•
	Stationary Packers	87-3/4	92	90	900	2											
		102-3/4	92	204		4-1/2											•
	Shu-Pak Side Loaders	78	96	168 to 216		25 to 38									8-10		•
Western Body & Houst Co. (Distributors) 8901 Juniper St. LosAngeles, Calif. 90002	Western Full Pak	I.D. 72	I.D. 81	I.D. 240		30	•										•

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