AN APPLICATION OF QUEUING THEORY TO ORGANIZATION GROWTH

Thesis for the Degree of Ph. D.

MICHIGAN STATE UNIVERSITY

Lysle I. Benjamen

1966

This is to certify that the

thesis entitled

AN APPLICATION OF QUEUING THEORY
TO ORGANIZATION GROWTH

presented by

Lysle I. Benjamen

has been accepted towards fulfillment
of the requirements for

__________ degree in __________

DOCTOR OF PHILOSOPHY

Rollin H. Simonds
Major professor

Date Feb. 25, 1966

O-169

ABSTRACT

AN APPLICATION OF QUEUING THEORY
TO ORGANIZATION GROWTH

by Lysle I. Benjamen

The question of the proper time to add or subtract employees, and the question of the types of skills that these employees should have, are fundamental to problems of organization growth. The purpose of this study is to examine a use of queuing theory as a guide to understanding this growth process. The use of queuing theory formulae is examined to determine whether queuing theory analysis is a valid predictive tool when applied to organization growth problems, or whether it instead may be a theoretical explanation of the growth process, or both or neither. The analytical formulae of queuing theory are used in the thesis to find the "size" of organization at which employees for various functions are typically added to an organization in specific, defined situations.

Seventeen samples of eight firms of the American pleasure boat industry were taken to obtain data for evaluation of five hypotheses. These hypotheses were:

1. That there are regular and consequently predictable patterns in which personnel are added to various functional areas in

a marine organization as it grows in size as measured by certain stated parameters.

2. That these patterns are based on the principle of adding personnel when the queue of demands for service in a functional area reaches a given length.
3. That demands for service in some, at least, of the functional areas arrive in a random manner making queuing theory a suitable tool for analysis.
4. That queuing theory provides a good theoretical explanation of the consistency in the historical data as to when personnel are added in certain functional areas.
5. That queuing theory is a practical tool for predicting at what point in a marine organization's growth, as measured by stated parameters additional personnel will be hired in various functional areas.

Personnel changes for the below listed three functions were studied in the eight firms to find typical industry adjustments of number of employees to average work waiting line length of the function. A <u>full</u> personnel history of the three functions was obtained for one of the eight firms; the history of the (a) production, (b) purchasing, and (c) selling functions for this firm is compared with personnel growth patterns developed by solution of queuing theory models based on typical industry personnel adjustments determined in the 17 firm samples. This comparison of <u>actual</u> personnel changes for the three functions with the function <u>model solutions</u> is used to evaluate the hypotheses.

Propositions 1, 2, 3 and 4 were consistently supported by the data. This data was limited in two ways beyond the necessary sampling limitations.

(a) Samples were taken from eight firms in the marine industry only. Therefore, the results will not necessarily apply to other industries, but no reason is seen to indicate this industry is peculiar in this respect.

(b) Only one and two channel servicing agencies were included in the functional areas investigated. The results may not be applicable to function areas arranged with a larger number of channels.

Proposition 5 was not supported. The data showed queuing theory could, indeed, be used to predict when personnel would be added, but for this purpose the queuing theory proved to be only an added step in the analysis which contributed no prediction that was not inherent in the data without the queuing theory analysis.

The queuing theory analysis affords an explanation as to _why_, but contributed nothing as to _what_ in the prediction of personnel additions in one and two channel functional operations. To illustrate, the historical data shows that when the rate of engine production increases a given amount, if no new personnel have been hired for purchasing, orders awaiting servicing will reach a given mean length. At this point an additional person will be hired for the purchasing department. This will result in shortening the mean queue length back to what apparently is acceptable in the industry. Queuing theory affords an explanation of why the mean queue length elongates as it does and why the added personnel reduces its length in the observed manner.

AN APPLICATION OF QUEUING THEORY TO ORGANIZATION GROWTH

By

Lysle I. Benjamen

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Personnel and Production Administration

1966

ACKNOWLEDGMENTS

To Dr. Rollin Simonds the writer would like to offer his sincere thanks and appreciation for providing the critical encouragement and guidance so necessary to an understanding in depth of the vagaries of the American business system in general, and of business organization and management in particular.

From Dr. David G. Moore the author obtained a comprehensive understanding of the place that behavioralistic techniques and knowledge have within planning and controlling organizations.

The late Dr. Karl Boedecker provided the writer with a disciplined understanding of the relationship theory has to empirical knowledge in the science of management.

An expression of gratitude and thanks is due the entire graduate school faculty and the writer's fellow students for their patience and their capacity as intellectual whetstones.

Finally, to his ex-colleagues at Dearborn Marine Engines, Inc., the writer expresses thanks for their aid and interest.

VITA

The writer of this thesis was born on July 20, 1927, in Detroit, Michigan. In 1944, he was graduated from Redford High School, Detroit, and spent an academic year as a student in the College of Liberal Arts of Wayne University.

In 1945 he enlisted in the United States Coast Guard and was assigned to a year at the United States Coast Guard Academy Preparatory School at Groton, Connecticut. He was tendered an appointment as Cadet at the United States Coast Guard Academy in 1946, and was graduated in 1950 with a Bachelor of Science degree in Mechanical (Marine option) Engineering.

Upon release from active military duty in 1954, the writer entered Rensselaer Polytechnic Institute, Troy, New York; and was graduated in 1955 with the degree of Master of Science in Management Engineering.

Between 1955 and 1957 he was employed by the Eaton Manufacturing Company, Valve Division, Battle Creek, Michigan as Engineer of its Lawton Plant; and by the Prex Corporation, subsidiary of Wyman-Gordon Company, in Franklin Park, Illinois, as Chief Engineer. In September 1957, the writer was granted an educational leave from the Wyman-Gordon Company and was accepted as a candidate for the degree of Doctor of Philosophy by the Graduate School of Business Administration at Michigan State University, where he completed his residence in August 1958.

In September 1958, the writer joined the faculty of Ferris Institute, Big Rapids, Michigan, as Assistant Professor of Commerce and Finance.

He joined Dearborn Marine Engines, Inc., Madison Heights, Michigan, in June 1959, as Chief Engineer where he continued in capacity until May 1962. Concurrently, in September 1960, the writer joined the faculty of the University of Detroit as part-time lecturer in Industrial Management for the academic year 1960 to 1961.

He has resided in Birmingham and Bloomfield Hills, Michigan for the past five years where the research and writing of the thesis were based. He is presently employed as Executive Vice President of Midwest Machine Company of Marysville, Michigan.

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CHAPTER I

INTRODUCTION

The question of the time at which employees are added to or subtracted from a business organization and the question of the types of skills that these employees have, are fundamental to problems of organization growth. The purpose of this study is to examine a use of queuing theory as a guide to understanding this growth process. The use of queuing theory formulae is examined to determine whether queuing theory analysis is a valid predictive tool when applied to organization growth problems, or whether it instead may be a theoretical explanation of the growth process, or both or neither. The analytical formulae of queuing theory are used in the thesis to find the "size" of organization at which employees for various functions are typically added to an organization in specific, defined situations.

To find this size, the thesis defines an organization as being composed of a multiple combination of job functions. It establishes three parametric names to identify the activity of three job functions that are examined in the thesis. Demands for service are made on the function from within or without the firm, a queue of these service demands develops, and the demands are serviced. The greater the number of employees in a given function and the more efficient their organization, the more rapid will be the servicing and the "better" the performance of this function. This desirable condition must be compared with employee cost considerations. This employee performance cost is non-determinate in this study since no attempt is made to determine the optimum cost of employee activity versus quality of service of the function. Instead, patterns of functional activity typical of successful firms in the American pleasure boat industry will be found, and there is the presumption that such patterns of successful firms likely represent reasonable adjustments of employee cost to function performance.

Queuing theory seems possibly well suited to analysis of organizations, if we conceive of (1) an organization's customer, (2) a member of the organization, (3) a function of the organization, or (4) one of the organization's mechanical tools as a unit requiring "service"; and of (1) some other member of the organization, (2) another function of the organization, (3) another useful tool, or (4) a person or group external to the organization as the unit that renders the service. A waiting-line of demands for service may then develop.

> A waiting-time problem arises when either units requiring service or the facilities that are available for providing service stand idle, i.e., wait. Problems involving waiting-time fall into two different types depending on their structure.
>
> The first type of problem involves arrivals which are randomly spaced and/or service time of random duration. This class of problems includes situations requiring either determination of the optimal number of service facilities or the minimum arrival rate (or times of arrival), or both. The class of models applicable to the solution of these facility and scheduling problems is called <u>waiting-line</u> theory or (by the British) queuing theory.[1]

A second type of waiting-time problem is concerned with the sequence (or order) in which a series of "servicing centers" provide service to units demanding it, and is called the <u>sequencing</u> problem. This problem is of no concern for thesis purposes.

Through use of the systematic tools provided by queuing theory, the study will examine organization growth in both theory and practice.

Hypotheses

Five hypotheses provide the framework for the investigations. These hypotheses are:

1. That there are regular and consequently predictable patterns in which personnel are added to various functional areas in a marine

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[1]Charles W. Churchman, Robert L. Ackoff, and Edward L. Arnoff, <u>Introduction to Operations Research</u> (New York: John Wiley and Sons, 1957), pp. 389-390.

organization as it grows in size as measured by certain stated parameters.

2. That these patterns are based on the principle of adding personnel when the queue of demands for service in a functional area reaches a given length.

3. That demands for service in some, at least, of the functional areas arrive in a random manner making queuing theory a suitable tool for analysis.

4. That queuing theory provides a good theoretical explanation of the consistency in the historical data as to when personnel are added in certain functional areas.

5. That queuing theory is a practical tool for predicting at what point in a marine organization's growth, as measured by stated parameters, additional personnel will be hired in various functional areas.

Framework of the Hypotheses

It seems logical to believe that the delay encountered in the performance of a work-task service by an organization function is a measure of functional and organizational effectiveness. That is, the more speed with which a demand for service is satisfied within a business organization the more effective that organization is. The longer the delay before service begins, the more ineffective is the organization. Balanced with costs, there logically exists an optimum level of service for business organizations. A supermarket shopper does not wish to wait excessive time before checking out with his groceries, but neither does he necessarily wish to pay the higher prices for his groceries required to employ sufficient checkout clerks to insure him that he would never have any delay. This condition exists with regard to all functional activities of business organizations. An organization's employee is a servicing center analogous to the checkout counter of the supermarket. Demands are made on him for job performance and these demands are serviced by him. If these demands arrive at random intervals queuing theory may be used to measure this job performance. Through application of queuing theory to this problem we are seeking an understanding of the time at which personnel are added to an organization.

Conceptual Definitions

Throughout the thesis certain words and expressions will be used. It is necessary that their meaning be clear to the reader. Accordingly, the following definitions are given to aid clarity and preciseness of the presentation.

Ratio-Delay Study

This expression describes a technique in use by industrial engineers which employs random sampling techniques of statistical methods to develop the work task "elements" of a total job, and the average time required for certain work elements. The technique is generally applicable to a work task that is not regular and time regulated in its functioning. It is used to develop constant and variable job factors.

Constant Job Factor

This expression denotes the fraction of a total specific work task that results from factors independent of demands caused by the amount of organization activity. It is defined as that fraction of a specific job that must be performed whether the level of activity of the organization is high, low, or none. It is analogous to accounting fixed costs.

Variable Job Factor

This expression denotes the fraction of a specific work task that results from factors dependent on the amount of activity of an organization. It is defined as the fraction of the job task that varies directly with the level of organizational activity. It is analogous to accounting variable costs.

Evolution

This word indicates a process of development for a specific purpose or toward a specific goal.

Model

A model is a symbolic description or representation (in this case a mathematical formula or equation) of a work task about which decisions are to be made. A model describes the relationship between variables in a process such as a job.[2] We may have (1) work task models, (2) function models, and (3) organization models. With regard to the organization, work task models are the elemental model form. Models of organization functions are compounded of function models and/or work task models.

Organic Function

The thesis will make use of the concept of the organic function. This is necessary to develop parameters for investigation of organization changes. Organic functions are defined as activities within an area of organization endeavor that are so necessary that the activity of the organization will be brought to a stop by a failure to perform them, somehow, somewhere, at

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[2]Robert W. Crawford, "Operations Research and Its Role in Business Decisions," *Planning for Efficient Production* (New York: American Management Association, 1953), p. 5.

some time, by someone, in the minimum degree required for the satisfactory achievement of primary service needs.

Symbolic Definitions

This paragraph presents symbols, and their applicable definitions, that will be used in succeeding sections of the thesis. They are given here to aid in the clarity of the presentation of the analytical formulae of queuing theory.

D = mean rate of service of demands-for-service by an organic function.

A = mean rate of arriving demands-for-service from an organic function.

n = number of service demands in a functional queue at a specific time (including the demands being serviced).

P(n) = probability of "n" items in a functional queue at a specific time.

E(n) = expected mean queue length of "n" size in a functional queue.

E(w) = expected time of wait in a functional queue.

M = number of functional service channels.

N = number of total service demands in the demand for service universe.

m = new state of a functional queue as it changes from "n".

P_n = probability of an occurrence at functional queue.

CHAPTER II

HISTORICAL BACKGROUND AND QUEUING THEORY APPLICATION

History

The queuing theory has long been used to solve the problem of scheduling working times of telephone operators. It has made it possible to procure better service at a reduced cost by appropriately staggering employee working times in the manner indicated by the theory. As a matter of fact, queuing theory had its beginnings in its application to operational problems of telephone systems by the Danish engineer Erlang and others. For many years it remained largely restricted to the problems of telephone systems. In these cases the theory was highly successful in optimizing service with frequent reduction in the cost of the service supplied.

Since the end of World War II, the activity in many areas of management theory has been focused on increasing application of all facets of operations research. One of the leading exponents of queuing theory is professor of physics, Philip Morse, of Massachusetts Institute of Technology. In January of 1954 Professor

Morse delivered a speech before the Society for the Advancement of Management.[1] In this speech he described the application of operations research techniques to management problems and he also had much to say regarding queuing theory that is of interest to this study. As he shows, the effort in operations research activity is toward creation of a mathematical (quantitative) "model" of the problem, the mathematical model is a "unifying" influence. A model ties together operational variables and is, therefore, widely used in the physical sciences. Queuing theory is a case in point. A mathematical model based on the theory can aid the problem of understanding any problem where "units" arrive at an irregular rate at some point for service. The units are serviced and dispatched from this point at a <u>different</u> rate. Morse points out in his speech:[2]

> Unless the mean service rate is greater than the mean arrival rate, a waiting-line of units to be serviced will be formed and will increase in length continually. But even if the mean service rate is larger than the mean arrival rate, the waiting-line is not abolished unless both arrival and service operations are regularized, not random. A central problem of waiting-line theory is to calculate the relationship between the mean length of waiting-line and the degree of randomness of arrival and disposal. On it can be based

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[1] Philip Morse, "Operations Research, Past, Present, and Future," Advanced Management, November 1954, p. 10.

[2] Ibid., p. 10.

estimates of the optimum capacity of the servicing facilities when one balances the cost of letting the unit wait in line against the cost of increasing the service rate. These calculations are not very difficult if both arrivals and servicing take place in a purely random manner, as in the case of people coming into a store from the street. Having made the calculations we can proceed to apply them to a specific operational problem by first determining whether arrival and service are in fact random . . .

Next, one has to compare the cost of having end units waiting in line against the cost of increasing the service rate. If the ratio of arrival to service rates is small there is no great amount of time loss. But if the facility gets popular and arrival rate begins to approach service rate, the waiting-line increases rapidly in length and money must either be spent to increase service or effort must be spent to reduce or to schedule arrivals. Administrators not familiar with waiting-line theory can make wrong decisions with serious consequences in such cases.

In the case of aircraft stacking over airports in bad weather when landings take time, it was hoped that careful scheduling of aircraft arrivals would materially reduce the line. Computing the effect on the waiting-line of changes of randomness in arrivals and landings is a difficult mathematical problem. Preliminary analysis indicates that if arrivals are completely regular, each in equal time after the next previous, but if servicing is still purely random then the mean queue length is about half that predicted for the case of both arrivals and landings, or partially random in the cases where scheduling of flights and landings is attempted. No matter how hard they try to stick to schedules, some randomness creeps in.

To solve this problem, a procedure known as the Monte Carlo was evolved. By use of a table of random numbers and of empirically determined probability distributions for scheduled and non-scheduled arrivals and landings, a whole series of virtual arrivals and landings could be worked out on a high speed computing machine which would have the same statistical properties as actual arrivals and landings. . . . The results do not have the elegance of generality of an analytical solution, but they have the advantage of being numerical answers corresponding to the case of interest.

As Morse says, there are two possible ways to solve a particular queuing problem. The first is through use of analytical techniques and mathematical formulae solutions. The second is through use of the Monte Carlo simulation. Through one or a combination of these procedures the mathematical model may be built.

Application

Based on the idea that job function models can be developed from the analytical formulae of queuing theory, the application of the models to the problem of function growth is based on necessary rules of algebra. The steps in which these models will be brought to bear on the problem is accomplished in the following way:

1. A suitable measure of the quantity of activity of the function to be studied is to be determined. This measure is taken to be the average number of demands for service per unit time.
2. A suitable measure of the "size" of the organization to which the function belongs must be selected. This will be taken to be production of engines per unit time.
3. A quantitive relationship between these two parameters is to be found. That is, an algebraic relationship must be developed.
4. The statistical form in which servicing demands made upon the function distribute themselves,

in terms of queue length, must be determined (queuing theory requires expotential distributions).

5. The queue length mean at which function personnel additions are typically made is to be found through empirical investigation of eight similar successful organizations.
6. The mean rate of demands-for-service that a given function would handle will be found through ratio-delay study.
7. The queue discipline, the universe size and the number of service channels of the function are to be determined.
8. The applicable queuing model for the maximum allowable service demand arrivals at the function when personnel change typically occurs must be solved.
9. This measure of function activity will be related to a specific "size" of the organization at which function personnel changes normally occur. Thus, level of production per unit time will be compared with number of employees in the specific function.

Personnel changes for three functions will be studied in eight firms to find typical industry adjustments of number of employees to average work waiting-line length of the function. A full personnel history of the three functions will be evaluated from one of the eight firms; the history of the (a) production, (b) purchasing, and (c) selling functions for this firm is to be compared with personnel growth patterns developed by solution of queuing theory models based on typical industry personnel adjustments determined in 17 firm samples. This comparison of actual personnel changes for the three functions with the function model solutions will be used to evaluate the hypotheses.

CHAPTER III

APPLICATION OF QUEUING THEORY TECHNIQUES TO THE ORGANIC FUNCTIONS

Accomplishment of Organizational Purpose

This paper is concerned with organization _form_ and with a possible method for investigation of organization growth. This is to be accomplished empirically through:

(a) application of the "organic function" concept,

(b) application of queuing theory to the concept, and

(c) establishment of the scope of the organic function.

Let us then conceive of a job or job task which is organic in its make-up and its operation. It is absolutely vital to the continued operation of an organization. Let us further conceive of a person--a member of the organization--who is primarily responsible for the performance of this job task.

Accomplishment of this task may be considered to be a "service" rendered to the organization. There is a disciplinary demand made by the organization on the responsible organization member (or employee) for performance of the service. If the service is not rendered, or is unsatisfactorily rendered, the organization must procure a substitute source for this service. Otherwise the organization will--both by definition and in practice --fail. The "other source" may be achieved by replacement of the delinquent employee.

An economic decision problem occurs whenever there is a necessary demand for organic service. If arrival of service requirements is in any way irregular, the economic decision is further complicated, for the manager of the organization must make a decision concerning the <u>level</u> at which he is to provide the service. If he provides too little service capacity (e.g., not enough personnel), the job task will not be completed. This is one extreme. If he provides too much service, the cost to the organization of the service will be economically untenable; this is the opposite extreme. In short:

> As the organization grows larger, the problems of an organization for grouping, supervising, and <u>serving</u> operations become more complex.[1]

Despite the complexity of the problem, there logically exists a solution between the two extremes;

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[1] Laurence Bethel, Frank Atwater, <u>et al.</u>, <u>Essentials of Industrial Management</u> (New York: McGraw-Hill, 1959), p. 2.

if there were none, the organization would cease to exist. Empirically, we know there is a solution.

Solution to the problem of service level may be largely left up to experience and the "art". Techniques of Industrial Engineering have been unsuccessful at establishing predictability procedures for functions in which job services are not performed on a regular, repetitive basis. John Maynard Keynes discussed the "art" in the following way:

> . . . investment depended on a sufficient supply of individuals of . . . constructive impulses who embarked on business as a way of life, not really relying on a precise calculation of the prospective profit. The affair was partly a lottery, though, with the ultimate result largely governed by whether the abilities and character of the managers were above or below the average. Some would fail and some would succeed. . . . Businessmen play a mixed game of skill and chance, the average results of which to the players are not known by those who take a hand.[2]

Applicability of Queuing Theory

If queuing theory is applicable, it may help our understanding of actual cases. Let us examine the problem of an in-plant Resident Sales Representative whose (organic) function is to process sales orders arriving from the field, through to the production

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[2]John M. Keynes, General Theory of Employment, Interest and Money (New York: Harcourt, Brace and Co., 1935), pp. 150-151.

activity. These orders arrive by telephone. The in-plant salesman is thus supplying sales service to a group of customers who make random demands for service on him, such as order placing, product information, order follow-up, and so on.

The manager must decide the level of sales service i.e., number of in-plant sales representatives to hire, that will be "best" for the organization. Effects of the level chosen may not be felt <u>immediately</u> by the organization; rapid trial and error techniques may not operate. The manager must look elsewhere for planning help and ordinarily may fall back on ordinary, unsupported experience for his answer.

When the servicing capacity of this salesman is incapable of keeping up with the demand for sales service, a queue of unserviced customers will develop. A waiting customer is an <u>unfulfilled</u> customer whose experience with the company he is demanding service of is negative, related in some way to the length of the wait. Empirically we know that this adverse experience will adversely affect sales. On the other hand, if too many sales persons are hired the idle salesmen's time will be excessive.

The effectiveness of the level of sales service may depend on the manager's ability at predicting what portion of the total customer waiting time should be reduced. A manager, by increasing the number of sales persons or their effectiveness, can avoid loosing some business--but it costs excessively to increase the service level beyond some point.

If an organic function is definable and measureable we may draw an analogy between it and the kind of service problem that exists between machines and service for these machines. If the machines may make demands for various kinds of service, then the analogy is complete. Compare the sales order-taking problem just described, and a series of operator-tended automatic lathes. The customer requires various types of service; the lathe also does e.g., loading, unloading, setup, adjusting, etc. This service may be required at random intervals in both cases.

If an operator is required to service an increased number of lathes, he may not be able to keep abreast of the machine demands for service as they occur. "Down time" for some machines may then happen--the machines enter a waiting-line--with reduced productivity of the plant. If a Sales Department person is required to service an average number of calls per time period, and the number of calls, on average, increase, he may not be able to keep abreast of the calls as they occur. Customers that are waiting for service will become the rule. There will be lost sales and a resultant decrease in organizational effectiveness.

> This same problem exists when materials handling service must be provided in the face of some random demand, such as movement of in-process materials from department to department via fork-lift trucks or overhead cranes. Here the problem is one of determining the optimum number of pieces of equipment to provide. The number of machines to provide in a job shop production center presents a similar problem when the arrival of orders is essentially random.[3]

<u>Selling Service Problem</u>

The time required to satisfy service demands in such situations has two parts:

(a) the time that the unit or customer is waiting for service, and

(b) the time that the unit or customer is receiving the service that he requires.

The latter time period may be required and unavoidable, but not so the first. If it were possible to determine, on average, how many customers or units would be found in the line waiting for service it would be possible to predetermine the effects of an increase or decrease in service availability to the customer or unit demanding the service. This predictability depends on two factors:

(a) the probability that a salesman (or servicing unit) is occupied with an earlier demand.

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[3]Edward Bowman and Robert Fetter, <u>Analysis for Production Management</u> (Homewood, Illinois: R. D. Irwin, 1957), p. 259.

(b) the probability that a customer will make a call for, or demand, service.

In order to determine these probabilities, and thus be able to predict the results of organizational activities, there must be available information necessary to determine the following factors:

(a) What statistical form does the time required for servicing customer demands for service distribute itself in?

(b) What statistical form does the time at which customer demands for service distribute itself in?

(c) What the status of "queue discipline" is--that is, are customers serviced on a first-come-first-served basis, or on some other priority basis?

(d) The size of the customer population; is the number of customers finite or infinite in number?

(e) Does the servicing facility operate in parallel (i.e., multiple numbers of salesmen taking calls as they occur), in series (i.e., every call passes through each salesman as a stage in the total servicing process), or in a complex combination of the two?

If these facts are known, ordinarily we can develop waiting-line information from formulae solution; and barring this we can usually make use of simulation techniques of the Monte Carlo to determine the waiting-line information required.

> Imbalance between a facility and its need makes queuing situations in many places in a manufacturing company. . . . You can simulate queuing problems on paper either by formula or by Monte Carlo methods . . . And you can use actual or hypothetical data.[4]

Job Factors in Organization Functions

Thus it is possible to determine waiting-line data concerning the relationships existing between resident sales-order personnel and the customers of an organization. If the costs are available for the operation of this sales function, and the effects of the customer level of service activity (either real or assumed) are known, it must be possible to predetermine the optimum service level and so, by extension, predetermine the optimum form of the organization.

Let us assume a small business organization in which no product development activity is taking place, or is needed. This assumes away the existence of an Engineering Department or function. Accounting is

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[4]Franklin G. Moore, Manufacturing Management (Homewood, Illinois: R. D. Irwin, 1961), p. 552.

done on contract. The organic functions of the organization are specified as three:

(a) The "raw material" procurement function--purchasing.

(b) The production supervision function--production

(c) The resident selling function--sales

In addition, let us use the idea that the "service activity" of the organization's members to both those within and without the organization is composed of a fixed or constant component part of the servicing activity, and the complementary idea of a variable component of the job activity. The existence of analogous similarity between the constant and variable components of employee labor time, and the accounting concept of fixed and variable costs, highlights the meaning of this idea.

> The costs for which the plant--the fixed factor units--are responsible are known as fixed costs, while those arising from the use of the variable factors are known as variable costs. More precisely, fixed costs may be defined as those which are the same in total amount regardless of the volume of the output, even if the latter is zero. Even if a firm produces nothing at all, the fixed costs continue unchanged . . . Variable costs may be defined as those which are eliminated if production is not carried on, and which vary with the rate of output.[5]

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[5]John Due, Intermediate Economic Analysis (Homewood, Illinois: R. D. Irwin, 1956), pp. 152-154.

The constant job factor has been defined as that portion of a specific job that must be performed whether the level of activity of the organization is high or low or zero. The variable job factor has been defined as the portion of the job task that varies with the level of activity of the organization.

There is probably no such thing as an absolute instance of a constant or a variable job factor. The concept of a constant or variable job factor may be placed on a polar continuum. However, report writing, "meetings" with other members of the organization, personnel activity, etc., may be unrelated to organization size. In general, the variable job factor of an organic function is the organic portion of that function, and so is the factor of concern for model purposes.

The purchasing function has its function peculiarities.[6] Report writing is a constant factor and procurement of plant services and facilities may be constant. In the small organizations that were

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[6]"Organization and procedure are so closely related it is difficult to tell which determines the other. The procedures stipulate who is to do each of the steps involved. These assignments become a part of the job content which is considered in organization analysis." From William H. Newman and James P. Logan, Business Policies and Management (Cincinnati: Southwestern Publishing Co., 1959), p. 834.

investigated for this study, activity of purchasing generally varied directly with production activity.

The production supervision function also has its own constant factor in the form of plant maintenance activities and report making. The level of production supervisory activity seems mostly related to production demands.

In the sales service illustration, if pure in-plant sales planning rests with the manager, then resident sales activity may be a 100 per cent variable factor within the total selling function. Statistical job time study analysis as proposed by Professor Harold W. Martin of Rensselaer Polytechnic Institute allows a level of determination of constant and variable job factors adequate to the needs of waiting-line analysis. Professor Martin's technique, which he terms, Operations Analysis, is an effective extension and development of the techniques of ratio-delay analysis familiar to the field of Industrial Engineering. He employs the technique of randomly sampling the job activity of a person over time; and so developing a statistical explanation of the job itself.

Within the scope of our definition of organic function, it is apparent that managerial activity is vital to the life of the organization and so is "organic". Demands on a managerial activity for service may be made usually as demands for planning. Since planning activity within an organization is an activity whose primary characteristic is regularity, it will be assumed that the managerial activity is *wholly* composed of the *constant job factor*. The activity level of the constant job factor is definitionally determined by conditions independent of the level of organizational activity. In practice there must be a certain component of variable job factor in the managerial function.

There are other functions, that may or may not be organic, which have this characteristic also. *Product* (development) *Engineering* activities and Research activities--for example--may be organic. However, the level of activity of this function is determined by considerations largely independent of the organizational level of activity. The job activity is composed almost entirely of a *constant* job factor.

So, the production function provides service, in the organic sense, to the sales function by providing the product on demand that the sales function has required. The purchasing function provides service to the production function in the form of the raw materials necessary to production; this provision is made on demand of the production function. The organic description of the organization matches the definition:

> An organization basically is a group of individuals who are cooperating to a common end under the guidance of leadership.[7]

This, then, is the usual organization form.

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[7]Ralph C. Davis, Fundamentals of Top Management (New York: Harper and Bros., 1951), p. 787.

CHAPTER IV

RELATING SERVICING OF INDIVIDUAL FUNCTIONS TO A MEASURE OF ORGANIZATION SIZE

Adequate framework has been developed now to move into theoretical formulation. It will be useful first, though, to summarize the theoretical position that has been discussed in the first three chapters.

First, the formulation of hypotheses was accomplished, directed at using queuing theory for an examination of the growth processes of organization change.

Second, a concept of measuring function activity, was set forth. The measure is able to quantify the function activity within a reasonable confidence level.

This chapter is concerned with developing function models for a small company organization structure. The structure of this model may be applicable to organizations of any size, however. If the <u>line type of formal</u> organization structure is the fundamental form of organization structures, primary concern will be for this type.

Thesis discussion has been leading toward explanation of organization growth based on production level.

Such growth must be related to quality levels of function service as understood in queuing theory application.

Organizational Evolution

Steps must be taken toward examing the evolution of an organization as it grows from a single person operation. The reasoning that has been outlined will be used to develop an organization model for an evolving organization. The organization model is to be a quantitatively structured one.

> The method (the management consultants) introduced consisted of observing what was common in certain executive-type problems and analyzing proposed solutions. It was only natural that efforts should eventually be made to try to find a common structure ('model') in these solutions and the bases on which such structures could be tested. These efforts amounted to the use of science in the study of executive-type problems.[1]

Possible functions are shown in graphical form in Figure 1. The constant factor is defined as constant over changes in absolute organization size, and resolves quantitatively to a measurement of the number of demands for service per unit time. The specific quantity is shown by the vertical distance from the abscissa, measured on the ordinate, that the function begins. These functions are assumed to be concave downward due to the economic principle of "economies

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[1]Churchman, Ackoff and Arnoff, op. cit., p. 6.

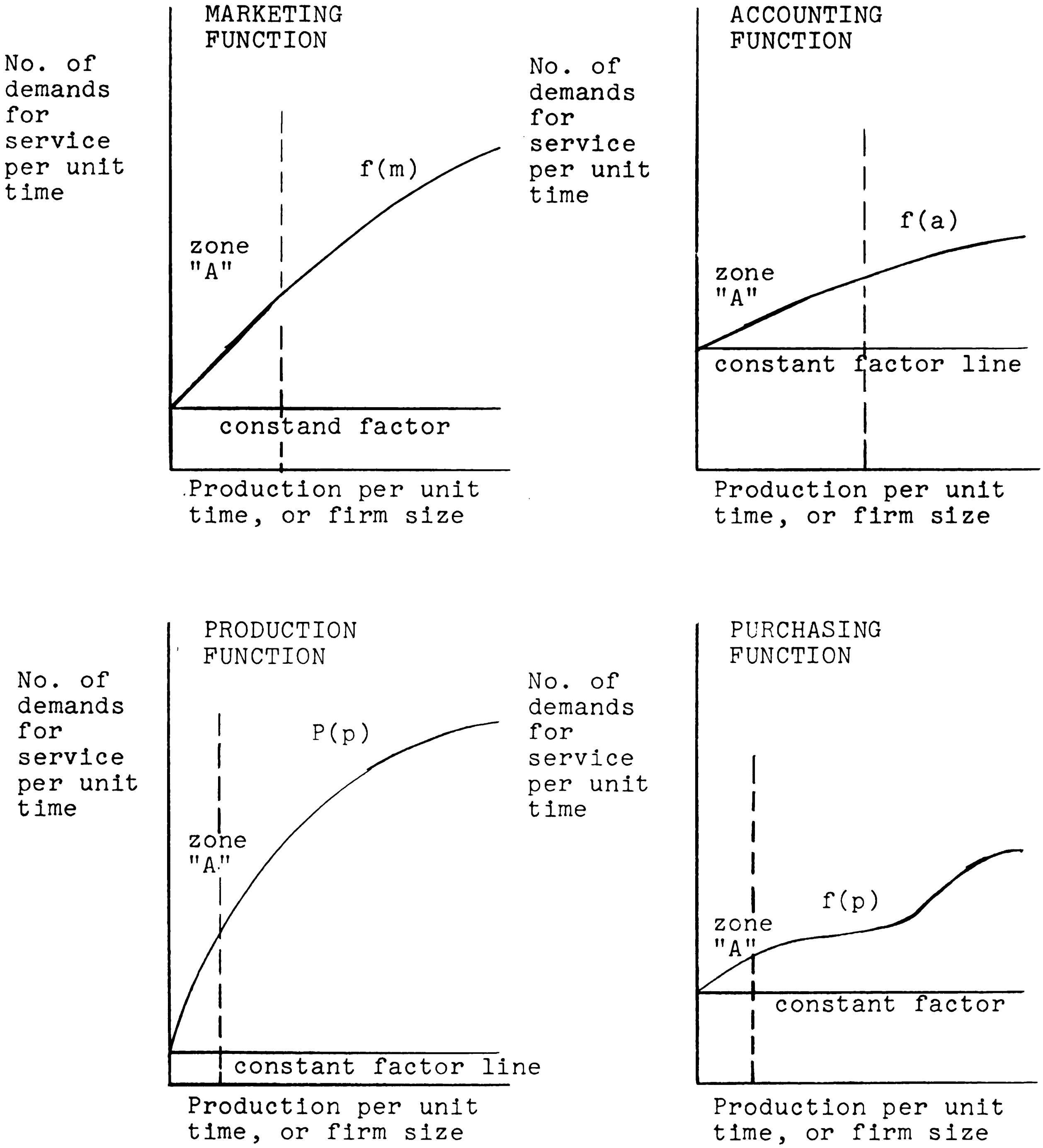

Figure 1--Hypothetical plots of four organic functions: functional service demands versus measure of firm size.

of scale" applied to the variable job factor concept, but this may not be necessarily so.

> At first glance it would appear that an increase in inputs of all factors by the same proportion would necessarily result in an increase in output by the same proportion. If the total quantities of all factors employed are doubled, it would appear that the output would double as well. Actually this result may not follow, and apparently does not, at least over portions of ranges of possible variation. The behavior regarded as typical is indicated by the Principle of Returns to Scale: as a firm increases the quantities of all factors employed, output is likely to rise initially at a more rapid rate than the rate of increase in inputs, but ultimately at a less rapid rate.[2]

Development of the Organization Model

Regardless of the quantity of production activity, and the size of each of the three organic functions, all constant and variable job factors within each of the four functions must be performed. If we know the following factors, we can build a waiting-line model for each of the organic functions under any particular set of conditions and so build a theoretical organization to be used for empirical comparisons. The factors are:

(a) the mean time required to render a completed service, and

(b) the mean number of demands for service, that may be expected in a functional service waiting-line.

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[2]Due, *op. cit.*, p. 140.

By knowing the statistical distribution of these two factors, the number of employees at any production level can be determined either by use of queuing formula or by use of simulation methods.

The only remaining variable concerns the job task efficiency of personnel performing these organic functions. It is obvious that work efficiency of the employees will vary. The <u>remuneration</u> of the employee might be taken as a measure of employee efficiency. If this were so then factor (b), above, could be modified to suit the index provided by the employee salary or wage. When employee efficiency differences within a function is of concern, a suitable index for modification of factor (a) must be found.

CHAPTER V

THE RESEARCH PLAN

Research Sampling Basis

The empirical research that was undertaken in an effort to evaluate the validity of the hypotheses of this thesis, was done in the American power boating industry. Due to the author's prior history of association with, and in, the industry, the opportunity for increasing the quality and completeness of data which otherwise would have been available was substantially enhanced. It was necessary to concentrate the research effort in one industry in order to negate the possibility that data would not be cross transferable from industry to industry.

The pleasure boating industry in the United States is composed of three essential specialty fields:

(a) the boat hull manufacturer,

(b) the engine or propulsive system manufacturer, and

(c) the "hardware" manufacturer, with products such as propellers, cleats, line, steering apparatus, etc.

The research was concentrated in firms of types (a) and (b). This was due to the fact that the third field of the industry has more of the operational characteristics of small volume retailers than do the first two. The first two possess, in general, the same organizational structure purpose. Thus, a degree of industry homogeneity was insured in the research.

In addition, the boating industry possesses a degree of growth potential that is matched by few industries at this time. This growth potential allows an evaluation of the organizational evolutions of firms in the industry over time periods that are not excessive. Uncontrolled variables may unknowingly get out of hand in a study made over a long period of time. Evidence of dynamic growth is given in the following authoritative evaluation.

> The pleasure boating market tripled in size over the decade ending in 1959. This explosive growth brought about far-reaching changes in the character of the market and the distribution structure of the industry, especially over the past few years.
>
> In particular, during the years 1959 and 1960, we witnessed an accelerated growth and a diffusion of outlets, many of which were under capitalized and under experienced in the field they were entering. The year 1960 was marked by low profits and disillusionment for many of the newer entrants, and for some of the longer established businesses affected by price competition.[1]

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[1]Dunn and Bradstreet 1962 Boating Directory (New York: Dunn and Bradstreet, Inc., 1962), p. iv.

The purpose of the thesis is, therefore, served by using organizational samples from an industry of this type.

Research Methodology[2]

Three research techniques were used to gather the data necessary to the investigation. The case study method in depth was used to provide detailed data not normally available to the researcher regarding the growth of an actual firm. The case study was made of a firm in the engine-propulsion system field of the industry. Material developed by the study that is pertinent to the thesis is brought together in the chapters that follow.

The personal survey technique was also used in the investigation to provide data regarding the queue length acceptable to organic functions of industry organizations. It was necessary to determine whether the concept of an acceptable queue length either explicitly or implicitly existed within those firms; and to find out what the queue length and charactertistics might be. To do this 12 departments in eight firms were surveyed.

Finally, the semi-directive interview technique was used to examine reasons and purposes, as they were understood by the functional managers, for organizational

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[2]Pauline Young, Scientific Social Surveys and Research (Englewood Cliffs, N. J.: Prentice-Hall, 1956).

techniques and devices in use that might affect functional evolution. Persons responsible for the type or timing of organizational changes were interviewed concerning those situations of interest to the study in order to seek out unknown variables and evaluate the known ones.

The Sample

Each of the persons responsible for the three functional activities of the company that was case studied (Dearborn Marine Engines, Inc.) was interviewed regarding his function. These functions are the same as the three functions described in the last chapter. A total of seven management level persons were contacted for this purpose. It was necessary to use this technique in conjunction with ratio-delay studies for determining values of D, the mean servicing rate for the organic activity of each organization department. In all three departments ratio-delay studies of one week were used to check any subjective opinions of department heads regarding the rate of service activity of their departments. Somewhat surprisingly the mean service rates found by ratio-delay techniques were within 10 per cent of the subjective values suggested by the department heads before the ratio-delay study.

Data for the case study, for the years 1955 to 1960, was provided by the records of Dearborn Marine. The following sources were the primary references for development of the data:

(a) Resident Sales function--Sales Department "Day Book" record.

(b) Production Supervision function--Monthly Production Control Summary.

(c) Purchasing function--Purchase Order Register.

From these sources, the data summarized in Appendix E was obtained which relates directly to that organization's growth.

To develop data regarding the mean length of the functional queue, 10 firms were approached by the author for the purpose of generating such information. Eight firms responded affirmatively, allowing a survey of 12 separate functions; in two firms, two departments were studied. In one firm, three functions were studied. The word "function" is used interchangeably here with "department" because those departments that were studied were carefully checked to insure that functions extraneous to the organic function concept of this thesis were eliminated from the data or were included as part of the constant job factor. Every attempt was made to insure that the expected mean queue length, E(n), met the definitional conditions of an organic function.

Publications Research

Research in the field of organization theory, and its application to management science practice; and research in the area of practical application of management science to the boating industry were undertaken in a library study and through investigation of publications available through boating industry trade organizations. The library research was done in the library of the Michigan State University at East Lansing, and in the library of the University of Michigan at Ann Arbor. Some reference use was made of the Detroit, Michigan, Public Library. The library research was primarily directed toward generating information of interest in the field of organization theory.

With regard to the boating industry, three industry trade organizations were helpful in avoiding pitfalls in the research, as well as providing aid through information which they possessed in published or unpublished form. These were the Outboard Boating Club of America located in Chicago, Illinois, the National Association of Engine and Boat Manufacturers of New York City, and the American Boat and Yacht Council of New York. All were helpful in directing the research toward cooperative firms; the Outboard Boating Club was most generous with industry-wide surveys which it had conducted.

CHAPTER VI

RESEARCH DATA

The empirical investigation had two phases, which were designed to provide the two types of data necessary for the evaluation of the hypotheses. The first type of data needed was data supporting or destroying the idea that implicit organic queues do exist in organization functions, that the queue length is determinate, and that the queue is of such form to be useable with queuing theory formulae. The second type of data was concerned with information pertinent to the queuing formulae and the growth of an actual organization. The entire investigation was accomplished in the spirit of Dr. L. J. Hendersen's expressions in Three Lectures on Concrete Sociology.

> In the complex business of living . . . both theory and practice are necessary conditions of understanding, and the method of Hippocrates is the only method that has ever succeeded widely and generally. The first element of that method is hard, persistent, intelligent, responsible, unremitting labor . . . The second element of that method is accurate observation of things and events, selection, guided by judgment born of familiarity and experience, of the salient and the recurrent phenomena, and their classification and methodical exploitation. The third element of that method is the judicious construction of a theory--not a philosophical theory, nor a grand effort of the imagination, nor a quasi-religious dogma, but a modest pedestrian

> affair or perhaps I had better say, a useful walking-stick to help on the way--and the use thereof. All this may be summed up in a word: (we) must have, first, intimate, habitual, intuitive familiarity with things; secondly, systematic knowledge of things; and thirdly, an effective way of thinking about things.[1]

Determination of Critical Queue Length and Queue Distribution

The first step in the investigation was to develop information regarding expected mean queue lengths of organic functions at the time of addition of personnel to the function. The data is summarized in Appendix A. With four exceptions, the data is not listed under the actual company name; some firms did not care to be identified. Four organic functions were investigated in this beginning phase of the investigation, but the accounting function investigation was dropped for lack of an adequate parameter.[2]

The hypotheses require parametric measures of organic functions; for example that the number of purchase orders issued per unit time is a valid measure of the job activity of the purchasing function. Optimum parametric measures in this investigation were developed

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[1]Fritz Jules Roethlisberger, Management and Morale (Cambridge, Massachusetts: Harvard University Press, 1959), p. 116

[2]Author's Note: Actual identification of the firms is, of course, available on a restricted basis to the interested reader.

by trial-and-error as an initial phase of the empirical investigation. "Number of Purchase Orders", and "Funds Spent" per unit time are two that were evaluated, with the elimination of the latter, in the case of the purchasing function. "Number of Productive Units Processed" was the only parameter considered for measuring the production function; but the in-plant sales function was also checked by two parameters: the "Number of Calls" made to the Sales Department and the "Gross Dollar Sales" per unit time. The latter was a measure of organic departmental activity, but was eliminated in favor of sales "calls".

Three functions were investigated at Dearborn Marine Engines for queue length, as part of the first phase of the study. There were two full-time, resident sales function employees, two full-time purchasing function employees at the time of the data gathering, and two production supervisors.

A three person in-plant sales function was investigated at the Francona Boat Company. The data from this company covered a three week period, which was adequate.

Two functional departments were investigated at the Willowby Boat Company--purchasing and production. The purchasing department had two employees, and the production department was checked at seven and eight supervisors.

Purchasing functions were sampled for data at the Renshaw and Graymarine Companies. Johnson and Raycraft Boat Companies provided added data on the in-plant sales function, and Crusader Marine on the production function. This investigation provided waiting-line data in these quantities:

(a) Purchasing function--four firms

(b) In-plant Sales function--five firms

(c) Production function--three firms

Data was gathered in the following way. The purchasing department queue length was taken to be the total number of purchase orders being processed, or waiting to be processed, at the end of days on which no overtime was worked. The in-plant sales function waiting-line data was developed by the company's switchboard operator and/or mail clerk. The switchboard operator, at a random time each day, recorded the number of "sales calls" in progress or waiting to be answered; the random times were supplied to the operator from a table of random numbers. The production function waiting-line was measured by the number of shop-order-cards in process or waiting to begin the manufacturing process at the end of the work day. The number of shop order cards in process was essentially constant in the firms sampled.

The waiting-line data at the time of personnel additions as shown in Appendix A, is summarized below.

(a) Purchase orders

Dearborn Marine	$\bar{n}$ = 4.2
Willowby Boat	$\bar{n}$ = 3.4
Graymarine	$\bar{n}$ = 5.4
Renshaw Boat	$\bar{n}$ = 4.3

(b) Sales calls

Dearborn Marine	$\bar{n}$ = 3.72 and 1.73
Crusader Marine	$\bar{n}$ = 1.57
Francona Boat	$\bar{n}$ = 2.19
Johnson Boat	$\bar{n}$ = 3.09
Raycraft	$\bar{n}$ = 2.08

(c) Production orders

Dearborn Marine	$\bar{n}$ = 5.12
Willowby Boat	$\bar{n}$ = 3.65 and 3.18
Crusader Marine	$\bar{n}$ = 3.90

Three function mean waiting-line lengths were checked immediately after personnel additions were made. One sample check was made for each of the three functions. The before-and-after data is as follows:

	$\bar{n}$ before	$\bar{n}$ after
(a) Purchase orders		
Graymarine	5.40	1.1
(b) Sales calls		
Crusader Marine	1.57	0.11
(c) Production orders		
Dearborn Marine	5.12	1.9

Based on the above mean waiting-line data, the following mean queue values were developed for use in the models for expected waiting-line lengths, E(n), and will be used in subsequent computations for solution of work task models. The mean of the $\bar{n}$ values for each function is taken to be the expected queue length, E(n).

(a) Purchase Orders E(n) = 4.3

(b) In-plant Sales "Calls" E(n) = 2.4

(c) Production Orders E(n) = 4.0

The next fundamental question is the statistical distribution types that the organic function queues fall into. In Figures 2 and 3 are shown the daily data of Appendix A, that resulted from the empirical investigation, arranged in a frequency distribution. In each case it is apparent that the data is distributed in an exponential manner. It is therefore accepted that the organic function queues investigated reasonably fill the Poisson-exponential distribution requirements for proper usage of analytical formulae.[3] Since they are

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[3]The derivation of the analytical formulae that will be presented in Chapter VIII requires that the arrivals for demands-for-service and that the time of servicing such a demand must be random in origin and the probability distributions of demand arrivals and functional servicing times be constant over time. The reader is referred to Churchman, Ackoff, and Arnoff, op. cit., for a discussion of this requirement. The requirement means that the demand arrivals will form an exponential distribution (generally based on the Poisson distribution in the case of natural phenomena). The servicing times will be governed by the binomial or Poisson distributions. Appendix H gives a short background to these statistical distributions.

```
DEARBORN MARINE ENGINES IN-PLANT SALES DEPARTMENT

Number of
Queued Calls
 20 |
 18 |
 16 |
 14 |x
 12 |xx
 10 |x
  8 |xx
  6 |x
  4 |xx
  2 |xxxxx
  0 |xxxxxxxxxxxxx
    +-------------------
```

```
DEARBORN MARINE ENGINES PRODUCTION DEPARTMENT

Number of
Queued
Prod.
Orders
 22 |
 20 | x
 18 |
 16 | x
 14 | x
 12 | x
 10 |
  8 |
  6 |
  4 | x
  2 | xxxx
  0 | xxxxxxxxxxxxxxx
    +-------------------
```

```
WILLOWBY BOAT COMPANY PRODUCTION DEPARTMENT

Number of
Queued
Production
Orders
 14 |
 12 |
 10 | xx
  8 | x
  6 | xx
  4 | xxx
  2 | xxxxx
  0 | xxxxxxx
    +-------------------
       Frequency
```

```
WILLOWBY BOAT COMPANY PURCHASING DEPARTMENT

Number of
Queued
Purchase
Orders
 14 |
 12 | x
 10 | x
  8 | x
  6 | xx
  4 | xx
  2 | xxxxx
  0 | xxxxxxxx
    +-------------------
       Frequency
```

Figure 2--Frequency plots of Appendix A data function queue data of Dearborn Marine Engines, Inc., and Willowby Boat Co.

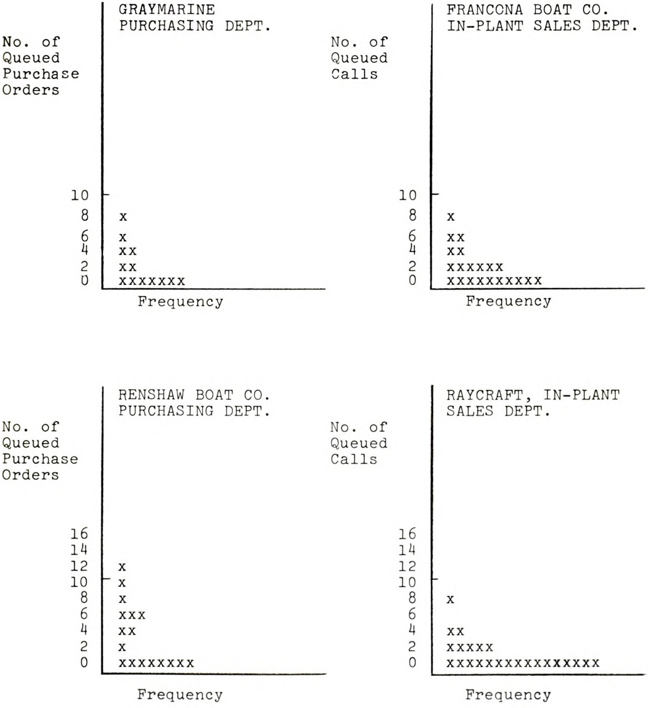

Figure 3--Frequency plots of Appendix A data: function queue data of Graymarine Co., Renshaw Boat Co., and Raycraft Co.

distributed in an exponential manner, they must be acceptable for queuing theory evaluation. It was pointed out earlier in the chapter that the parameters used were selected for quality of measurement of the functional activity. They also qualify for use with the analytical formulae of queuing theory.

Organizational Case: Dearborn Marine Engines, Inc.

The organizational evolution of Dearborn Marine Engines, Inc., was case studied. The firm was founded in late 1954 to design, manufacture, and market inboard marine engines and engine power trains. In August 1960, the firm was purchased by the Eaton Manufacturing Company, Cleveland, and made an operating division of the corporation. After this purchase according to corporate policy the organization lost much of its identity as a self-sustaining entity. Its interests were merged with, or over-ridden by, other operational considerations of the entire corporation. As a result, growth data of the firm from February 1955 through 1960 is considered to be homogeneous; but subsequent growth data, due to the above transitions, is not believed to be useable. The organization and the organization's objectives were changed due to the sale.

In Appendix E is summarized the growth data for the three organic functions we have been considering, for the actual case of Dearborn Marine Engines. This data reflects monthly averages of (1) daily engine production, of (2) purchase orders written daily, and of (3) sales calls handled per day. This data is presented graphically in Figures 4 through 7. The growth of the company is shown to best advantage in these plots. The effect of the 1957 economic recession is clearly shown in Figure 8, and the fact that production slowdown was preceded by a breakdown in the level of purchasing activity jibes well with recent work that uses purchasing activity as an economic indicator.[4] The purchasing function is shown graphically evolved in Figure 4.

Evaluation

The data summarized in the figures presented in this chapter and in Appendices A and E, is one base for evaluation of the hypotheses.

In Figure 7 is shown the evolution of the formal organization of Dearborn Marine Engines, Inc., during the time of the case study. This figure should aid in understanding the data of Appendix E, and also the work-task, the functional, and the organization model comparisons. The evolution will be briefly described by phases.

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[4]Selected Economic Indicators (New York: Federal Reserve Bank of New York, 1954), pp. 14-17.

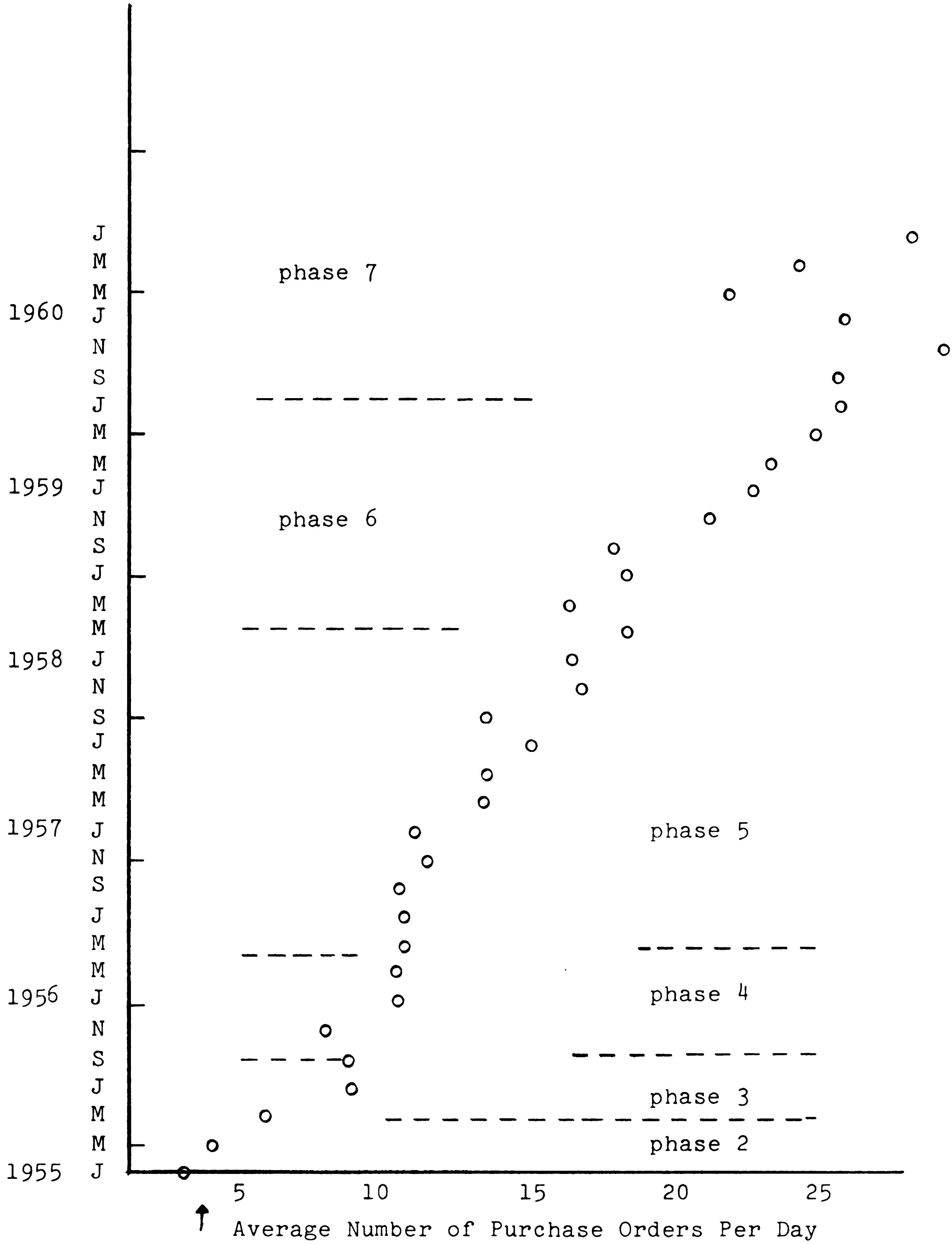


Figure 4--Functional growth of Dearborn Marine Engines, Inc.: purchasing function.

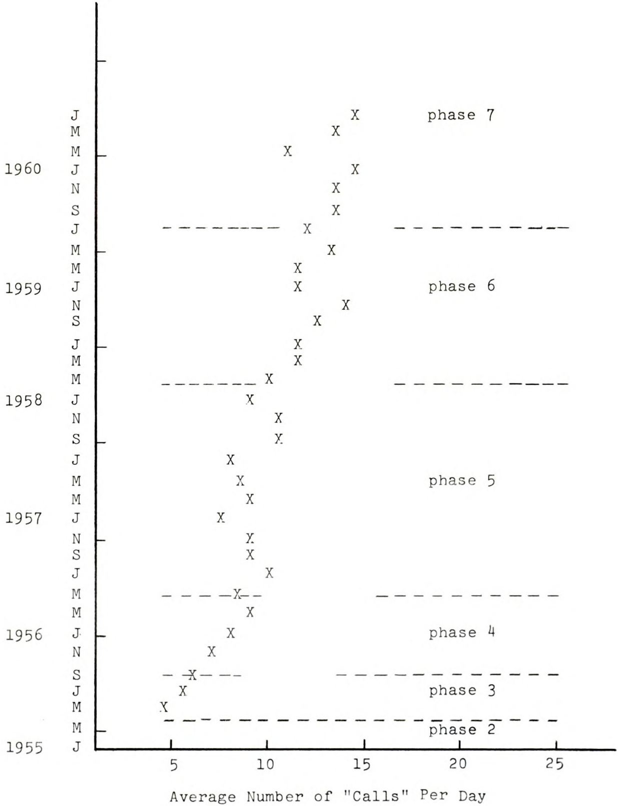


Figure 5--Functional growth of Dearborn Marine Engines, Inc.: in-plant sales function.

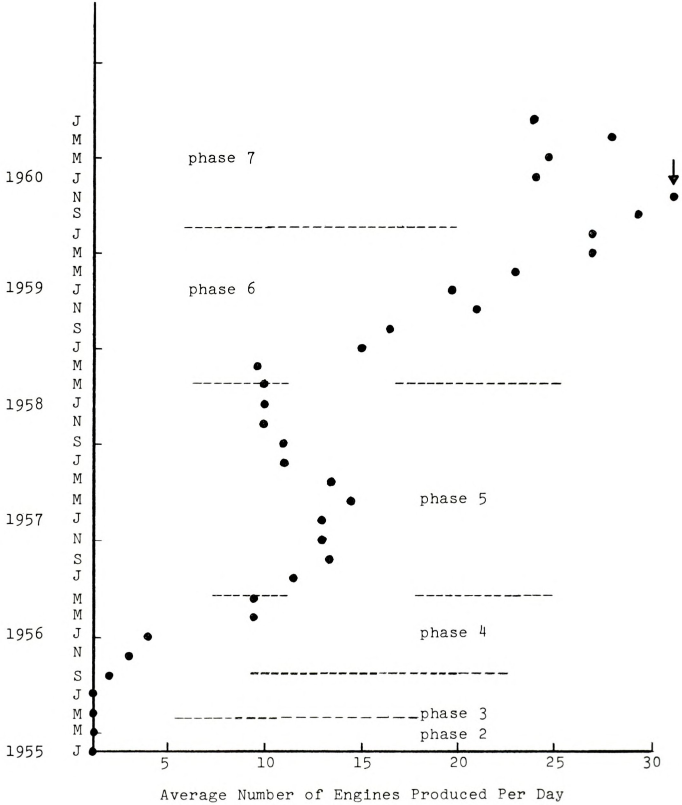


Figure 6--Functional growth of Dearborn Marine Engines, Inc.: production function.

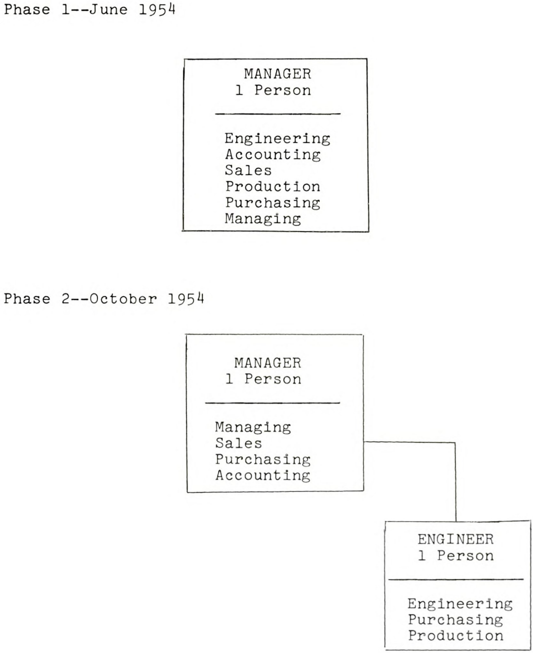
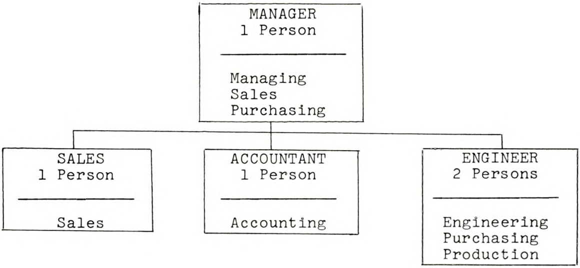


Figure 7--Organization evolution of Dearborn Marine Engines, Inc.

Figure 7--Continued

Phase 3--April 1955



Phase 4--September 1955

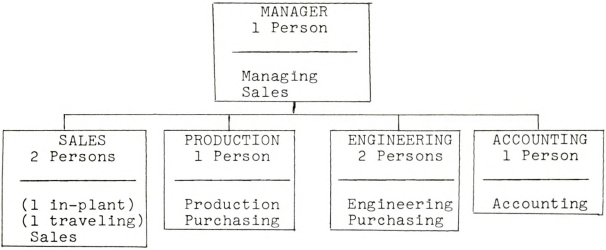
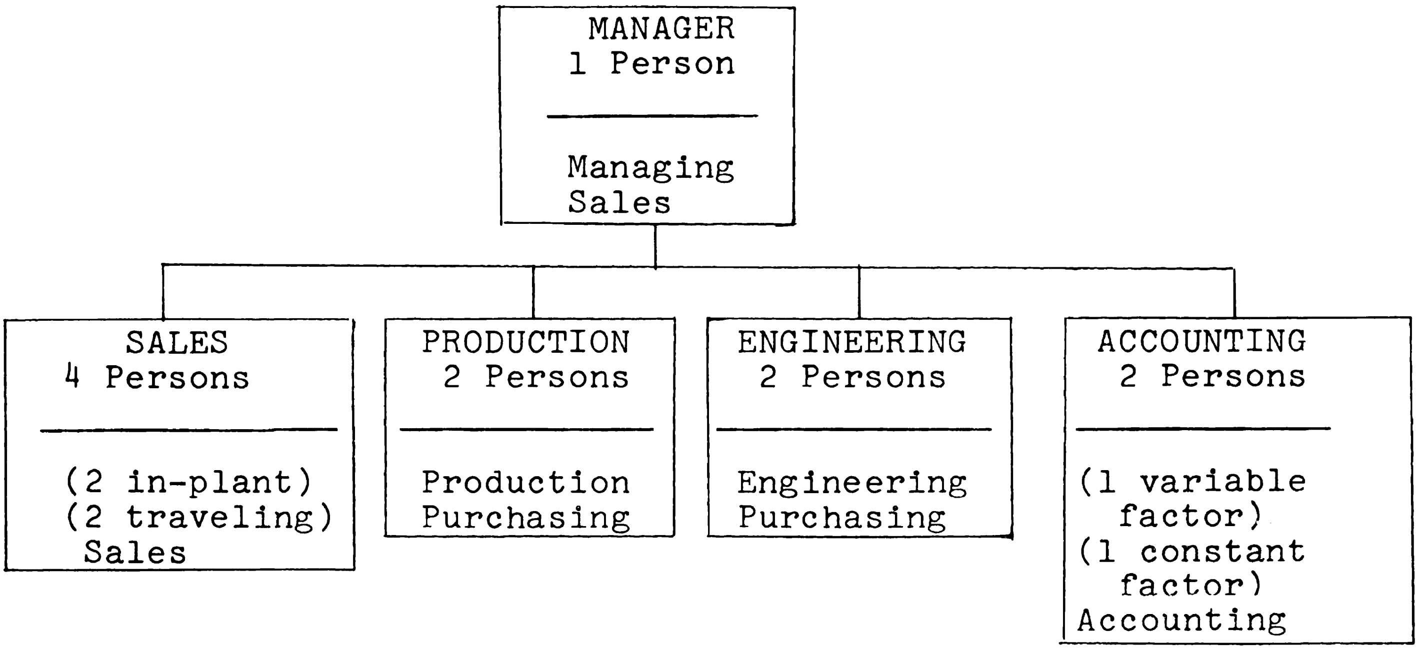


Figure 7--Continued

Phase 5--May 1956



Phase 6--March 1958

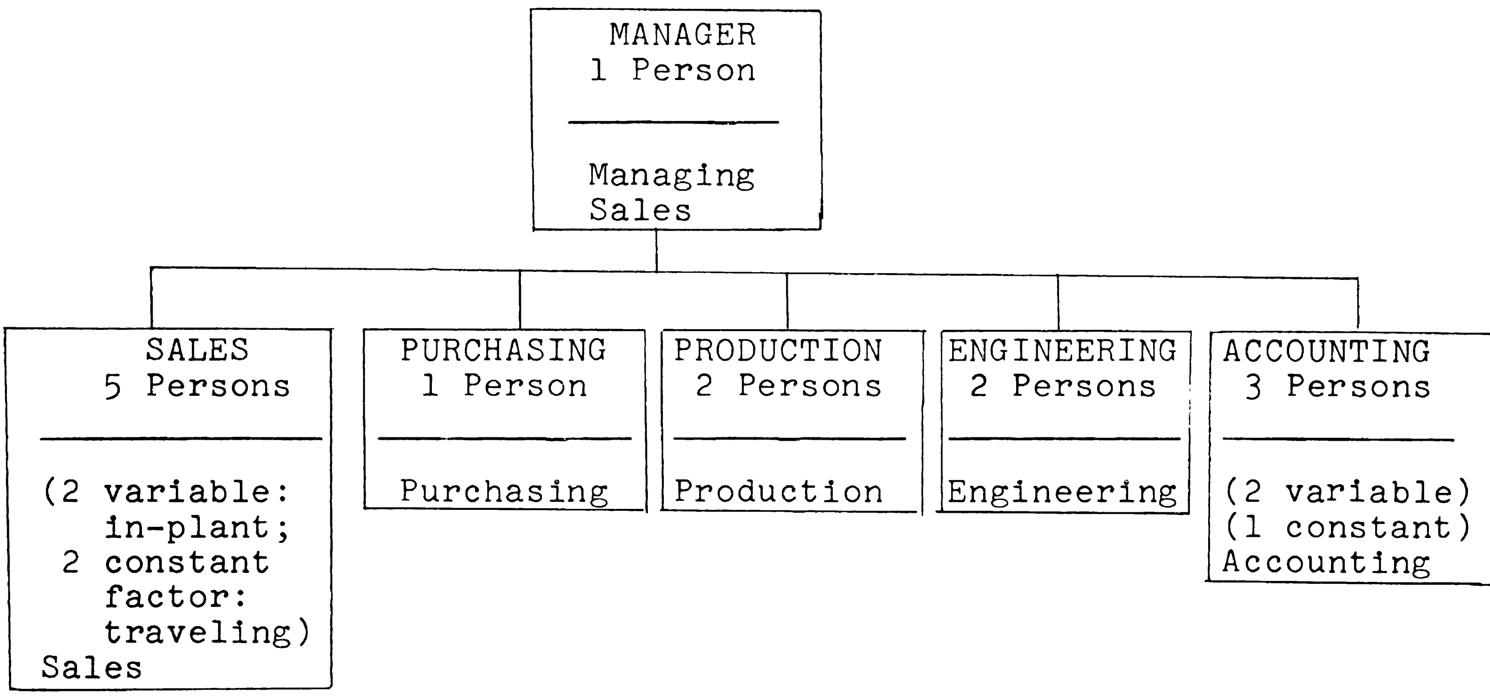
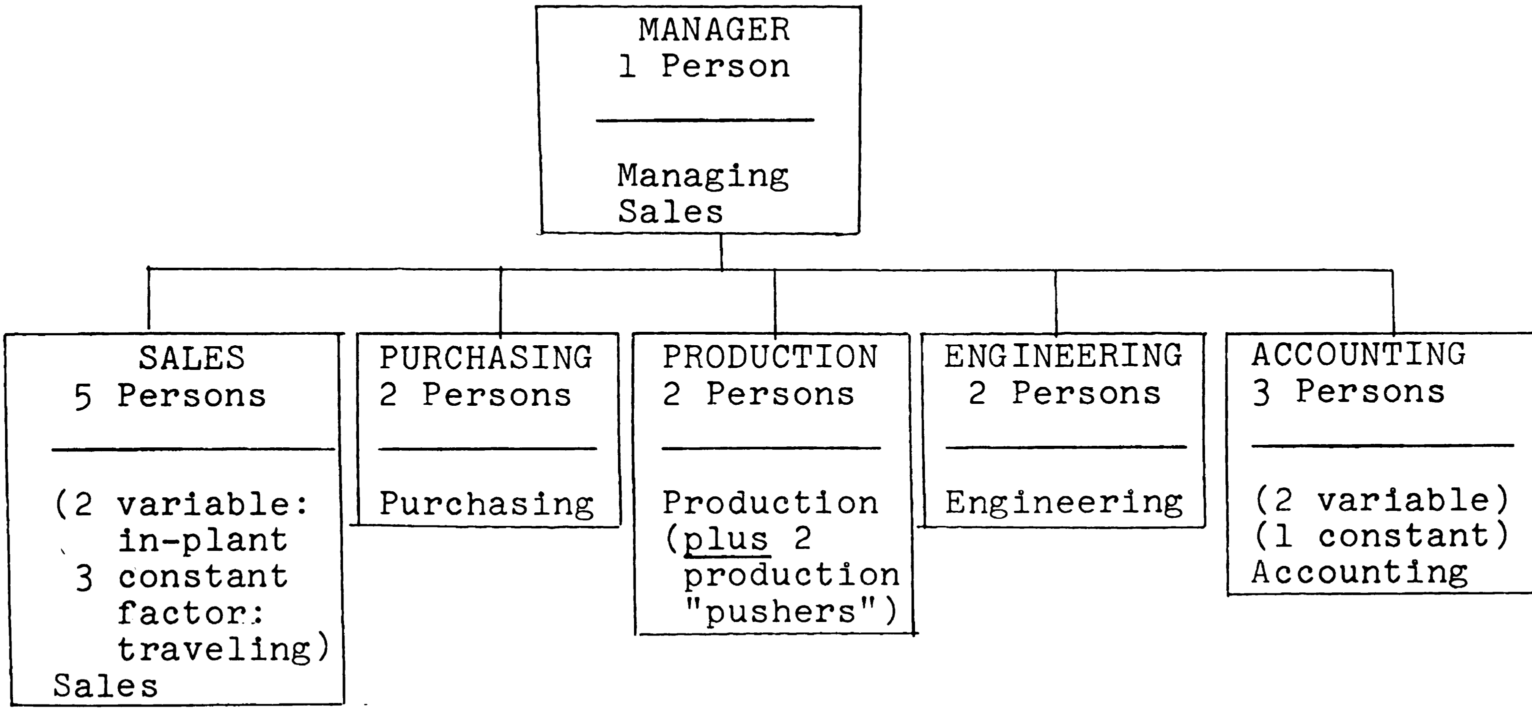


Figure 7--Continued

Phase 7--June 1959



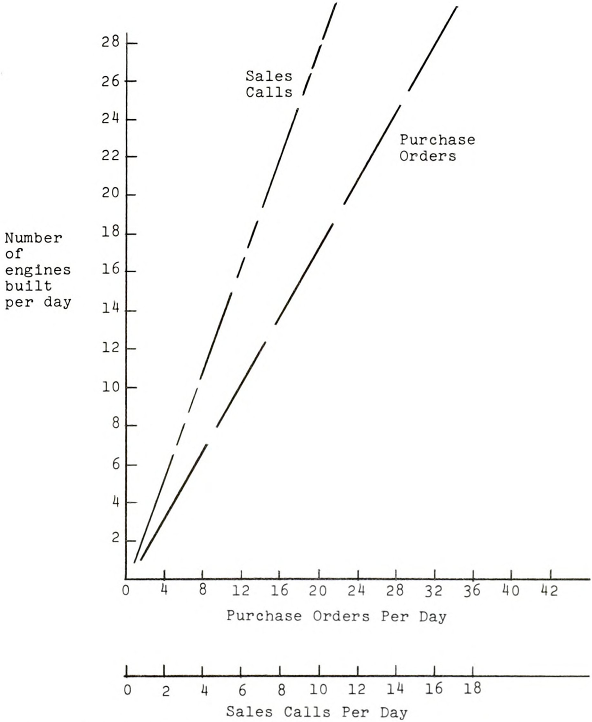


Figure 8--Plot of organic functional activity versus production activity.

Phase 1: Corporation Formation[5] beginning in June 1954 and ending in October 1954. This phase is of minor concern here due to lack of information.

Phase 2: Product and Product Engineering development beginning with the hiring of the first engineering person. The engineer accepted functional responsibility for the organic functions of engineering, production and part of purchasing (that portion pertaining to the execution of the engineering function. From October 1954 to April 1955.

Phase 3: Fundamental Organization developed in April 1955, by the addition of a sales person and a full-time accountant. Also a second engineer was added due to the press of getting engine facilities and

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[5]Author's Note: The corporation is shown as possessing six organic functions: those of management, engineering, sales (marketing), purchasing, accounting, and production. The managing and engineering functions are considered to be controlled by queuing service demands generally external to the production organizational demands, i.e., the functions of planning (in a top managerial sphere), and product research and engineering, have demands for service made on them primarily by groups such as boards of directors--and usually not by the customer except quite indirectly. Therefore, only the functions of sales, purchasing, accounting, and production are considered in the model.

designs ready for production. This lasted until September 1955.

Phase 4: In September 1955, production became serious and a manager of production was employed who assumed the purchasing duties that the firm's manager had exercised until this point. Another sales department person was added "on the road".

Phase 5: Early in 1956, due to high level of product demand, production requirements increased greatly. In May 1956, a second production supervisor was employed, shortly after another in-plant sales person had been hired. So the in-plant sales organization was increased to two persons and production supervision was increased to two persons.

Phase 6: In March 1958, a second accountant was hired, and the first purchasing agent was hired in February 1958. Engineering and production purchasing activity was surrendered to a full-time purchasing employee.

Phase 7: Largely due to the press of repeat business (spare parts, accessories, etc.)

> the second person was hired for the purchasing function in June 1959.

As described, this organization seems to have performed well through its rapid growth history. There is little doubt that "espit de corps" was fundamental to its success.[6]

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[6]From Henry David Thoreau: "The aim of the laborer should be, not to get his living, to get a 'good job', but to perform well a certain work . . . Do not hire a man who does your work for money, but him who does it for love of it." Henry Thoreau, Walden and Other Writings (New York: Modern Library, 1950), p. 711.

CHAPTER VII

QUEUING THEORY FORMULAE AS FUNCTION MODELS

Purpose of the Theory

Queuing theory is based on the concept of average waiting time (see Appendix F). The theory formulae establish quantitative relationships between equipment or personnel required and the level of service an organization is capable of supplying. Queuing theory is applicable to cases where its requirements are met.

Precise relationships can be found between production and level of function service if the model is coupled with norms of queue length of the function. Based on these solutions and their application to actual situations, organization management may then balance service levels.

The Organization Model

The organization model is based on work-task models and their solution. The model or models build the hypothetical standard against which actual occurrences may be compared. Service levels of actual organizations are compared with a model solution, or with the standard generated by solution of several models. From the model, the position of each function within an organization can be understood.

Usually a model can be constructed that will describe the function behavior if the general information of the five part program described in Chapter III, page 23 is available. The two fundamental types of analytical models in queuing theory are:

(a) the infinite statistical population model, and

(b) the finite statistical population model.

Morse describes the conditions for simple linear formulae.

> We mentioned earlier that only exponential facilities (and Poisson arrivals) give rise to simple linear equations for detailed balance of transitions between states, independent of time.[1]

Other conditions may give rise to quadratic, cubic, and other exponential forms of model formulae. As a practical matter the linear and quadratic formulae are the usual limits of our ability to work with simple methods. Resort is then made usually to a method of simulation.

This is not to say that it is impossible to solve analytically many of the problems that are solved through simulation. However, the task of working with the formulae may become overwhelming.

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[1]Philip Morse, Queues, Inventories and Maintenance (New York: John Wiley and Sons, 1958), p. 39.

> The construction of waiting-line processes usually involves relatively complex mathematics . . . However, many waiting-line problems can be solved more simply by use of Monte Carlo procedures.[2]

It is not the purpose of this thesis to examine the mathematics of queuing theory beyond simple description and justification. Formulae and descriptive assumptions that are pertinent to work with organization theory will be presented. Appendix G contains summary material concerning the Poisson and Exponential Distributions of underlying importance to queuing theory application. The background development of the formulae and the rational development of assumptions must be obtained from reference material such as that contained in the Bibliography.

The Infinite Universe

Since we will be speaking of an infinite universe, it is important to define the requirements of the infinite universe at this point. A universe (or population), for purposes of this study, is the group which is making demands for the service with which the organic function must be concerned. Refer to the formulation of Appendix I. An infinite universe may be constituted by a population of 100 or more, based on Appendix I analysis. We thus assume that each organizational

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[2]Churchman, Ackoff, and Arnoff, op. cit., p. 390.

function "faces" more than 100 possible situations that will (or may) generate demands for service from that function. From this we may logically operate with the queuing theory analytical formulae on the basis that an organization's functional queues are from an infinite universe.

Analytical Tools--Single Channel, Infinite Universe

The case of the single service center, servicing demands that arise from a population of infinite size is the most basic and simplest of the queuing situations.[3] The queue "discipline" requires that demands for service are satisfied on a first-come-first-served basis with no interruption. With "A" defined as the average rate of demand arrivals (per unit time), and "D" as the average rate of service demand satisfactions, this study will rationally assume that "A" is less than "D". This assumption is necessary to avoid an infinitely long queue possibility which is mathematically indeterminate.

It can be shown that:[4]

$$P(n) = \left(\frac{A}{D}\right)^n \left(1 - \frac{A}{D}\right)$$

From this it can be determined that the expected number of

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[3]For the mathematical development of this and the succeeding section, see Morse, Queues, Inventories and Maintenance, op. cit.

[4]Churchman, Ackoff and Arnoff, op. cit., p. 393.

demands-for-service in the functional queue--including the demand being serviced--will be:

$$E(n) = \frac{A/D}{1 - A/D}$$

It can be further shown that the expected time of wait in the functional queue will be given by the formula:

$$E(w) = \left(\frac{A}{D}\right)\left(\frac{A/D}{1 - A/D}\right)$$

From these analytical formulae[5] the majority of the questions about this queuing situation can be answered. They cover requirements for this type queue function.

Analytical Tools--Multiple Channels, Infinite Universe

With this case, the analytical problem begins to loose its simplicity. If the case of multiple service channels alone is considered, there exists two possibilities:

(a) service facilities arranged in parallel, in which each facility provides the complete service required by the demand, and

(b) service facilities arranged in series in

[5]The ratio A/D is frequently referred to as "traffic intensity". Say Churchman, *et al*.: "It is interesting to note that, for increasing values of the traffic intensity ratio . . . the expected length of the queue increases rapidly and as A/D approaches unity E(n) becomes infinitely large."

which each facility provides only a portion of the total service.

Parallel service facilities are properly analyzed as multiple channel cases. Series arrangements most usually may be classified as single channel cases or as some more complex form.

Morse has derived the formula for the expected number units in the queue system for the parallel, two-channel, infinite universe case. The Morse formula is:[6]

$$E(n) = \frac{2\ A/D}{1 - (A/D)^2}$$

This is a solution of the Morse general formula in which (as before) we are concerned with demand-for-service arrivals distributing themselves in the Poisson distribution form. The general formula is:

$$E(n) = \frac{AM}{D} \sum_{M = 1}^{\infty} (m_{pn})$$

The solution of the Morse general equation for the expected time of wait in a functional queue has such a difficult solution that it is of little use to this study. Its general form is:

$$E(w) = \sum_{n = M + 1}^{\infty} (n - m)\ P_n$$

[6]Morse, Queues, Inventories and Maintenance, op. cit., p. 109.

Analytical Tools--The Finite Universe Model

An average value of service-demand arrivals from a finite universe may not be used in a functional queue problem solution. Instead it is necessary to specify service demands as a unit of the population (in decimal form for the analytical solution). The solution to this model is simple in conception but complex to accomplish. The solution gives no general expressions for expected waiting time, E(w), or the mean expected queue length, E(n). For this model each situation has a separate solution.

Due to difficulties inherent to the finite case, it is fortunate that some tables exist for solution to this type problem--more are being presently generated at California Institute of Technology and at Massachusetts Institute of Technology. In addition there are some plotted graph solutions available.[7] With such tools of analysis there is developing adequate analytical strength to search into organization evolution.

Conclusion

Beyond these considerations, however, it is interesting to note some points regarding single versus

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[7]For example see T. A. Mangelsdorf, Waiting Line Theory Applied to Manufacturing Problems (Unpublished Master's Thesis, Massachusetts Institute of Technology, 1955).

multiple channel service facilities in organizations. While the average delays in the queue are reduced by adding parallel channels, the mean delays in service time are not helped. The primary advantage of multiple channels is to the servicing facility, and the major disadvantages are to the "customer" demanding the service. As Morse says:

> If the cost of service per channel is proportional to its rate of service, increasing the rate of service of a single channel by a factor of M will cost the same amount as increasing the number of channels to M, keeping the rate of each unchanged; and different facilities, for different values of M, will have the same cost of operation if they have the same (traffic intensity ratio)--assuming arrival rates . . . are the same. For a given value of (the traffic intensity ratio) increasing (the number of channels . . . increases) the (expected number of units in the queue thus being serviced). Therefore, if operating costs are proportional to rate of service, so that two slow channels cost as much as one twice as fast, whenever the most important requirement is to keep queue length (alone) down it is best to have many channels, even if each is slow; but whenever it is more important to keep total delay time to a minimum it is better to have a single high speed channel.[8]

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[8]Morse, Queues, Inventories and Maintenance, op. cit., p. 103.

CHAPTER VIII

SOLUTION OF FUNCTION MODELS

Assumptions and Procedures

As shown, the work-task investigation was concerned with three organic functions. Two of these functions were related directly to the third. That is resident sales activity, and purchasing activity were related proportionally to production activity. Production is the "size" measure of the organization. Reference to Figure 8 (representative of the functions developed empirically) will be made during the model solving. Mathematically expressed the graphed relationships are:

(a)	Number of sales calls per unit time	=	S x number of productive units per unit time
(b)	Number of purchase orders per unit time	=	P x number of productive units per unit time

Figure 8, therefore, assumes that the organic functions are linear and directly proportional. Justification for this assumption is found in Figures 4 through 7. Inspection of these empirical plots shows shape similarity supporting an assumption of linearity.

Also discussed were the parameters used as direct measures of the activity level for the three organic functions. The investigation developed these as the best parameters available for the Dearborn Marine case study.

The following constants for use in the formulae (above) were developed empirically. The constants were found by fitting the monthly mean of the parameter (e.g., purchase orders) per day to the monthly mean of engines produced per day, using the method of least-squares. The least-square computation involved 54 consecutive months. The constants so computed are:

$S = 0.36$

$P = 1.14$

Finally, the empirical work discussed in Chapter VI, provided two other types of information: the mean value of expected queue length, $E(n)$ or $\bar{n}$; and mean values of functional service rates, D. The values for $E(n)$ or $\bar{n}$ were developed in Chapter VI, and will be used in model computations. A computed $E(n)$ value that exceeds the empirical $E(n)$ value will signal the addition of an additional employee. The service rate or D values that resulted from Dearborn Marine ratio-delay studies are as follows:

(a) Resident Sales Function:

One Employee = 1.0 "calls" per hour service.

Two Non-equal Employees = 1.8 "calls" per hour service.

Two Equal Employees = 2.0 "calls" per hour service.

Three Non-equal Employees = 2.6 "calls" per hour service.

Three Equal Employees = 3.0 "calls" per hour service.

(b) Purchasing Function:

One Employee = 3.1 purchase orders per hour service.

One Employee (increased efficiency due to office machinery) = 3.5 purchase orders per hour service.

Two Non-Equal Employees = 6.3 purchase orders per hour service.

Three Non-Equal Employees = 9.1 purchase orders per hour service.

(c) Production Supervision Function:

One Employee = 1.88 engines per hour.

Two Equal Employees = 3.76 engines per hour.

Three Equal Employees = 5.64 engines per hour.

Four Equal Employees = 7.52 engines per hour.

Resident Sales Function

Referring to page 45, Chapter VI, the E(n) value for sales function is 2.4, and the value for D at Dearborn Marine Engines was found to be 1.0 call per hour in the case of the first employee (page 70, Chapter VIII). Based on the single channel, infinite queue model the following is the computation for A:

$$E(n) = \frac{A/D}{1 - A/D}$$

$$2.4 = \frac{A}{1 - A}$$

$$A = 2.4 - 2.4A$$

$$3.4A = 2.4$$

$A = 0.71$ calls per hour = 5.65 calls per day

Referring to Figure 8 we find that this mean number of calls per day corresponds to a mean production level of 15.7 engines per day.

Beyond the level of 15.7 engines per day our model signals addition of personnel. If the personnel level is not increased, the queue of calls to the resident sales function will increase beyond the level of 2.4 and the quality level of service will deteriorate to an unacceptable level.

At the point that the second employee is hired the organization was faced with the problem of the type of new queuing situation that would be established for the function in question. The second employee became part of a speeded-up, single channel, infinite demand universe service function: all calls passed through both employees. The dual channel situation also will be computed, however.

There must be concern for the effect of job competence or effectiveness on the analytical model also. Is the second employee as effective on the job as the first?

The case of equal competence and unequal competence of employees will be shown. Work-task competence factor may also be arrived at through ratio-delay studies. In the case of unequal competence for the resident sales function with two employees D equals 1.8 calls per hour and 2.0 calls per hour for equal job competence. That is, the second employee worked 8/10 as rapidly as the first. The unequal competence model is:

$$2.4 = \frac{A/1.8}{1 - A/1.8}$$

$$3.4A = 4.32$$

$$A = 1.3 \text{ calls per hour} = 10.2 \text{ calls per day}$$

In the case of two employees of unequal competence (for the situation of a series single channel) the transition point (by reference to Figure 8) to three employees lies at 28.4 engines per day mean production level.

In the case of equal competence in the same situation, the analytical model is:

$$2.4 = \frac{A/2}{1 - A/2}$$

$$A = 1.41 \text{ calls per hour, or } 11.3 \text{ calls per day.}$$

This number of calls per day corresponds to a mean production level of 31.4 engines per day. Therefore the model solution requires that the third employee be hired when an average production level above 31.4 engines per day is attained.

It is interesting to contrast these single channel evolution points with those of the dual channel. By use of the formula

$$E(n) = \frac{2A/D}{1 - (A/D)^2}$$

the transition points are only slightly changed. The single channel 1.3 calls per hour compare with a computed 1.2 calls per hour for the dual channel situation of unequal employee competence, and 1.41 calls per hour compare with 1.37 calls for equal employee competence. These solutions indicate that the queue difference between the single and dual channel in a small organization may be of small significance.

If a third person were added to this sales function, there would be three organizational possibilities:

(a) a single channel, three person function;

(b) a triple channel function;

(c) a dual channel function in which the senior member of the department has calls from the other two persons channeled through him (in a series).

Situation (b), above, is not soluble with analytical formulae that have been presented. The simplest method of solution is through use of simulation methods; since it is of no immediate concern, the reader may refer to simulation Appendices B, C, and D that will be explained in detail. We are concerned with possibilities (a) and (c).

Situation (a) has an unequal-competence analytical solution represented by

$$E(n) = 2.4 = \frac{A/2.6}{1 - A/2.6}$$

$A = 1.84$ calls per hour or 14.7 calls per day

This number of calls per day corresponds to a production level of 40.9 engines per day, which is the point at which the organization function should evolve to four persons. The corresponding <u>equal</u> competence situation (with D equal to 3) is

$A = 2.12$ calls per hour or 17.0 calls per day

This situation would mean a production level of 47.0 engines per day could be reached before the fourth person should presumably be added to the function.

Possibility (c) has an unequal competence solution whose model is

$$2.4 = \frac{2A/2.6}{1 - (A/2.6)^2}$$

and, in the case of equal competence

$$2.4 = \frac{2A/3}{1 - (A/3)}$$

The unequal competence solution is A equals 1.69 calls per hour or 13.6 calls per day. This corresponds to a production level of 37.8 engines per day in Figure 8.

The equal-competence solution is that A equals 1.95 calls per hour or 15.6 calls per day; this corresponds to a production level of 43.3 engines per day.

These solutions point up the fact discussed in the last chapter, that a single channel made more rapid through the addition of personnel, is preferable to multiple servicing channels, and continues to become more so as the number of employees grows. For a given level the service to the customer will be better. Since this is now obvious from the above model solutions, the triple channel, three person department may be inferred to be (and indeed shown to be) the least efficient of the examined situations. For a three person sales department, then, the most effective way of organizing the department, in order of decreasing preference, is:

(a) Single channel, speedy organization

(b) Dual channel organization[1]

(c) Triple channel organization

The above listing presumes the same values of E(n) and D for each possibility.

Table I summarizes the sales function theoretical model just developed.

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[1]Author's note: The analytical formula for dual channel activity assumes no channel impediment. In this case, if the second person, in each channel line, requires but a small time period for his functional service the no impediment channel assumption is valid.

TABLE I.--In-plant Sales Function Model Solutions.

Number of Employees	Production in Engines Per Day For:							
	Single Channel Equal Competence		Single Channel Unequal Competence		Dual Channel Equal Competence		Dual Channel Unequal Competence	
	From	To	From	To	From	To	From	To
1	0	15.7						
2	15.7	31.4	15.7	28.4	15.7	31.4	15.7	29.0
3	31.4	47.0	28.4	40.9	31.4	43.3	29.0	37.8

Purchasing Function

The solution to the purchasing function model is accomplished in the same manner as was done for the sales function model just described. Mathematical development will be made without the redundancy of descriptive material.

(a) Single Employee

Empirical Values:

$$4.3 = \frac{A/3.1}{1 - A/3.1}$$

$E(n) = 4.3$

$D = 3.1$ purchase orders per hour

$A = 2.5$ purchase orders per hour

$A = 19.7$ purchase orders per day

*Single employee until 17.3 engines per day production level.

(b) Single Employee, Increased efficiency (due to installation of office machinery)

$$4.3 = \frac{A/3.5}{1 - A/3.5}$$

$E(n) = 4.3$

$D = 3.5$ purchase orders per hour

$A = 2.8$ purchase orders per hour

$A = 21.4$ purchase orders per day

*Single employee until 18.8 engines per day.

(c) Two Employees, single channel, not equal competence

$$4.3 = \frac{A/6.3}{1 - A/6.3}$$

E(n) = 4.3

D = 6.3 purchase orders per hour

A = 5.1 purchase orders per hour

A = 40.0 purchase orders per day

*Two employees until 35.2 engines per day

(d) Three Employees, dual channel, not equal competence

$$4.3 = \frac{2A/9.1}{1 - (A/9.1)^2}$$

E(n) = 4.3

D = 9.1 purchase orders per hour

A = 4.3 purchase orders per hour

A = 90.4 purchase orders per day

*Three employees until 79.3 engines per day

Table II provides the summary of the purchasing function analytical model.

Production Supervision Function

In the case of the production function a constant job factor of 2.4 hours per day was found in the survey. This resulted from a variable job factor of 5.6 hours per day, for the first employee. The value of D was established at 1.88 through the ratio-delay development that 15.1 engines per eight hour day was the mean number

TABLE II.--Purchasing function model solutions.

Number of Employees	Production In Engines Per Day For: Single Channel Equal Competence		Single Channel Unequal Competence		Dual Channel Unequal Competence	
	From	To	From	To	From	To
1	0	18.8				
2			18.8	35.2		
3					35.2	79.3

of engines a supervisor could effectively oversee for this type of manufacturing.

Following are the computations of the function model.

(a) Single Employee

A = 1.51 engines per hour

A = 1.51 x 5.6

= 8.1 engines per day

*One employee (supervisory) until production level of 8.1 engines per day is reached.

Empirical Values:

E(n) = 4.0

D = 1.88 engines per hour

(b) Two Employees, single channel, equal competence

A = 2.95 engines per hour

A = 19.8 engines per day

*Two employees until production of 19.8 engines per day.

E(n) = 4.0

D = 3.76 engines per hour

(c) Two Employees, dual channel, equal competence

$E(n) = 4.0$

$D = 3.76$ engines per hour

$A = 2.84$ engines per hour

$A = 18.5$ engines per day

*Two employees until production of 18.5 engines per day.

(d) Three Employees, single channel, equal competence

$E(n) = 4.0$

$D = 5.64$ engines per hour

$A = 4.4$ engines per hour

$A = 31.6$ engines per day

*Three employees, until production of 31.6 engines per day.

(e) Three Employees, dual channel, equal competence

$E(n) = 4.0$

$D = 5.64$ engines per hour

$A = 4.25$ engines per hour

$A = 30.5$ engines per day

*Three employees until production of 30.5 engines per day.

(f) Four Employees, single channel, equal competence

$E(n) = 4.0$

$D = 7.52$ engines per hour

$A = 5.85$ engines per hour

$A = 43.1$ engines per day

*Four employees until production of 43.1 engines per day.

(g) Four Employees, dual channel, equal competence

$E(n) = 4.0$

$D = 7.52$ engines per hour

$A = 5.6$ engines per hour

$A = 41.5$ engines per day

*Four employees until 41.5 engines per day production.

The difference is again illustrated between the dual channel and the single channel function organization. The difference is not large and probably is of no signfi-cance in a small organization. Other things remaining equal though, it can readily be seen from the computations that the higher the degree of organizational special-ization, the greater the efficiency of the organization.

The employees in the production function model were of equal competence. Table III summarizes the production function model.

TABLE III.--Production supervision function model solutions.

Number of Employees	Production in Engines Per Day For: Single Channel Equal Competence From	To	Dual Channel Equal Competence From	To
1	0	8.1		
2	8.1	19.8	8.1	18.5
3	19.8	31.6	18.5	30.5
4	31.6	43.1	30.5	41.5

Monte Carlo Development[2]

Brief description of the use of the Monte Carlo method of model solving is important. Simulation appli-cation is more universal than analytical techniques such

[2]See Appendix H.

as those just described. The formulae are limited to the specific model for which they were developed. Analytical methods are adequate for use with small, relatively uncomplicated organizations; if the organization becomes complex in the arrangement of its servicing facilities the model formulae may become so complex that they are impractical. At such a point a simulation method may substitute. Fortunately the solution of Monte Carlo models is a rapid, uncomplicated process if a digital computer is at hand.

In development of Monte Carlo organizational models it is vital that the random experience data generated be large enough in quantity to reflect the mean waiting-line value, E(n), in sufficient quality so as not to introduce unacceptable statistical errors. Between 1000 and 3000 is taken to be the minimum number of "experiences" that must be artificially developed, in order to be assured of reliable data.

The following illustration has been chosen to show the problem of a Monte Carlo model with too few "experiences" to adequately simulate the universe characteristics. In Appendices B, C, and D, the computations leading to the model solution are shown. The model so represented has 263 "experiences", and as such is inadequate. How inadequate this is may be seen by reference to Appendix C. On the Queue Summary Sheet of Appendix C, it may be seen that the E(n) value of the two-person Monte Carlo model of the sales function is 1.35 calls. The model as developed used a dual channel situation in which A equals 1.5 calls per hour, and D equals 2.0 calls per hour. From our analytical model:

$$E(n) = \frac{2A/D}{1 - (A/D)^2}$$

so,

$$E(n) = \frac{(2 \times 1.5)/2}{1 - (1.5/2)^2}$$

$$= 3.41 \text{ calls}$$

Obviously something is amiss; the Monte Carlo queue of 1.35 calls should be near the analytical queue computed as 3.41 calls.

If, however, attention is redirected to Appendix C it is interesting to note what the actual A and D values are that the model produced. The mean arrival rate may be developed by showing that the 263 calls in 26 days means an A value of 10.1 calls per day or 1.27 calls per hour. By computing the mean service rate, D, from Appendix B for the 26 day period, D may be shown to be 3.34 quarter hours per call or 2.4 calls per hour, as developed in the model.

The E(n) value may then be recomputed:

$$E(n) = \frac{(2 \times 1.27)/2.4}{1 - (1.27/2.4)^2}$$

$$= 1.47 \text{ calls}$$

The 1.47 calls is closely comparable to the 1.35 call "experience" data value generated by the Monte Carlo.

An enlarged model, although not reproduced here, was continued to 1448 experiences in 120 days. At this point, the E(n) value of the model was 3.52 calls--which compares very favorably with the computed expected queue length of 3.41 calls. The necessity for an adequate quantity of "experience" is strongly pointed up; the sample size error so apparent here was caused by the short range bias of the random number generator.

Since the analytical formulae of queuing theory become unwieldy if the service facility, queue discipline, or distribution of demands for service become at all complex, practical results from application of queuing theory requires use of tables which provide solutions to the Monte Carlo.

The Monte Carlo model shown in the appendices was developed as follows, based on the parameters shown in Appendix B. In this model we are supposing that the resident sales function of a firm is to be analyzed. We know from empirical investigation that resident sales activity is distributed in a random way. The cumulative probability from the Poisson distribution in tabular form, is:

P (c' - 12)			.00	.00	.00	.00	.01	.02
Number of Sales Calls			0	1	2	3	4	5
.05	.09	.16	.24	.35	.46	.58	.68	.77
6	7	8	9	10	11	12	13	14
.84	.90	.94	.96	.98	.99	.99	1.00	
15	16	17	18	19	20	21	22	

Using a table of random numbers--or other random number generator[3]--the sales call characteristics may be developed from the above table in the following manner.

Day				1	2	3	4	5	6
Random Number				.69	.33	.52	.13	.16	.19
Sales Calls Per 8 Hour Day				13	10	12	8	8	8
7	8	9	10	11	12	13	14	15	16
.04	.14	.06	.30	.25	.38	.00	.92	.82	.20
6	8	6	10	9	11	3	16	15	9
17	18	19	20	21	22	23	24	25	26
.40	.44	.25	.35	.88	.27	.48	.18	.86	.59
10	11	9	10	16	9	11	8	15	12

[3]Author's Note: Many digital computers have random number generators built into them.

In this way, then sequences of numbers that have the same statistical characteristics as actual experience are generated by a set of random numbers.

Since the servicing time per call has been determined to be randomly distributed in the Poisson manner, through use of the random number generator and the following Poisson distribution table, simulated experience data may be generated regarding servicing time.

P (c' - 4)	.018	.092	.238	.433	.629	.785	.889
Clock time, qtr. hrs.	0	1	2	3	4	5	6
.949	.979	.992	.997	.999	1.00		
7	8	9	10	11	12		

Finally, if the time between calls is also randomly distributed in a Poisson distribution, these times will be developed in the same manner as described above.

In Appendix B, the (1) number of calls per day, (2) the servicing time per call, and (3) the length of time between calls has been established in the form of an "experience model" for a 26 day period. Based on this model, the waiting-line summary of the resident sales function, for two employees of equal competence, has been presented in Appendix C; and for three employees of equal competence, in Appendix D. The three person model was carried to 1,448 "experiences" and the expanded model produced an E(n) of 1.53 calls.

Conclusion

This chapter completes explanation of the thesis mechanics. Concern now is with how well the model solutions compare with the results of the empirical investigation. Function organization has been noted with model solutions.

One of the more interesting results of model solving is the realization that a single channel functional organization form is the most efficient if personnel work-task performance efficiency is constant. The single channel organization form is the most highly specialized of the organization possibilities, which probably accounts for the efficiency, according to our solutions. We may question either the correctness or the completeness of the Terry statement regarding centralization as a result.

> Organization structures with a strong leaning toward centralization are in common evidence, and despite all interest and discussion in management circles about decentralization, many chief executives continue to make most or all major decisions and see that they are enforced. This results from quite natural causes. Delegation of authority may imply to the executive a loss of power and prestige. He doesn't want to be dependent upon others, nor does he wish to suffer a loss in status.[4]

Probably the experienced executive intuitively knows and so favors the increased efficiency of the centralized organization.

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[4]George Terry, Principles of Management (Homewood, Illinois: R. D. Irwin, 1956), p. 275.

CHAPTER IX

COMPARISON: ACTUAL ORGANIZATION AND THE MODEL SOLUTIONS

The solutions of function models will be compared with the actual evolution of Dearborn Marine Engines, Inc., in this chapter. The solutions are based on the premise that certain functions--the organic functions--are vital to the success of any organization.

> Balanced organization structure does not necessarily mean that there are equal numbers of employees in each of the departments and sections under consideration. Instead it should be more concerned with the crucial factors in success of the enterprise. For every company there are certain activities which are particularly important to its success.[1]

The function models were solved in Chapter VIII for the case under consideration. Each actual function history will now be compared with its model solution counterpart.

The Resident Sales Function

In Chapter VIII, Table I, the model solution data corresponding to the function history of Dearborn Marine

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[1]Newman and Logan, <u>op. cit</u>., p. 516.

Engines resident sales function is obtained. Comparing the organization growth charts shown in Figure 7 with Table I, it is seen that the first full-time in-plant sales employee was hired in April 1955, and that the second in-plant sales person was hired in May 1956. By reference to Production Department Summary Sheet of Appendix E, we see that the first resident sales employee was hired at an organization production level of approximately one engine per day (3.2 calls per day). The second employee was hired at a production level of about 10.0 engines per day. No third resident sales person was brought into the organization until after July 1960.

Table I shows that, according to the model solution the second sales employee "should" have been added at a production level of 15.7 engines per day. Since the second employee was hired at a production level of 10 engines per day, the model solution indicates that the second sales person was hired too soon by 36 per cent. When asked about the growth of this department, the firm's manager offered that the second person "didn't add too much" for a couple of years, but "at the time, it looked as if another man was necessary". This was due to sudden increase in demand for the product (shown in organization phase 4).

The two sales employees were organized as a dual channel, unequal competence service function. The next function addition should have been, according to the model, at a production level of 29.0 engines per day. During the months of January through July of 1960, the firm's production level was near this point. No third employee was hired. A third employee was placed on the job in November of 1960, when the production was still at approximately 30 engines per day. The model solution indicates that the fourth person should be hired for this function at a level of 42.5 engines per day, but there is no historical data for comparison.

Purchasing Function

The model solutions of the purchasing function, summarized in Table II, indicate that one person "should" be servicing the function until a production level of 18.8 engines per day is attained--then the second employee should be added to maintain an acceptable queue length. Figure 7 shows that the first full-time purchasing employee was hired at a production level of 10.8 engines per day. Prior to this, the production and engineering functions had maintained responsibility for purchasing. The second employee was hired at a production level of about 25 engines per day. According to the model solution of 18.8 engines per day the employment of the second purchasing employee was late. Reference to the Production Summary of Appendix E will indicate, however, that the five months prior to June 1959, were ones of rapidly rising production. The function expansion was tardy, but not excessively so, perhaps.

The third employee is due to be hired at a production level, according to model solution of 35.2 engines per day. The addition was made in September 1960, when the production level was running at a three month average of 32.3 engines per day. The next expansion of function service is due to occur at a level of 79.3 engines per day; this level has not yet been reached.

Production Supervision Function

The production supervision function also had its constant job factor. This constant factor of 2.5 hours per day was included in the model solutions of this function.

The model solutions shown in Table III indicate that the second employee should be hired at the production level of 8.1 engines per day. Actually, the first production supervisor did not join the organization until the production level had reached 2.0 engines per day; the engineering function serviced production demands prior to that. The second production supervisor was employed at organizational

phase 3 at a production level of 9.3 engines per day. This transition point compares favorably with the model solution of 8.1 engines per day.

According to the model solution, the third production supervisor "should" have been hired at a production level of 30.5 engines per day. Actually, the third and fourth supervisors were never employed. In December of 1958, at a production level of approximately 20 engines per day, two production "pushers" were appointed from the blue-collar work force. They were retained on hourly wage, but the wage itself--and fringe benefits--were increased for these two. The production function retained this exact form throughout the period investigated.

Although not shown in Figure 7, the employment of "pushers" in the production function coincided with model solutions for the third and fourth production supervisors. The production function model solutions and actual function growth compare well.

Summary of Comparison

In the preceding paragraphs, comparisons are made of a growing organization with solved model solutions. Generally the model solutions compared favorably with the empirical data. It is obvious that a change in the mean length of the waiting-line, E(n), or a change in the departure rate value, D, will immediately change the model formulation through a change in arrival rate, A. For this reason the E(n) values used <u>throughout</u> were generated mean values from many firms. Likewise, values of D were used that were the objective results of specific ratio-delay studies.

CHAPTER X

CONCLUSION

Evaluation of Hypotheses

The thesis set out to accomplish two related objectives. The first was to bring together formulae and techniques necessary to an evaluation of the hypotheses, and the second was to gather empirical data for testing five hypotheses. This has been done.

Four of the hypotheses are supported by the empirical data. Reference to Figure 9 provides a graphic look at production levels at which personnel were added in the actual case versus the levels that queuing model solutions indicate the additions would be made. The history of personnel changes at Dearborn Marine Engines follows rather closely changes that queuing model solutions would indicate. The model solutions have a 0.82 coefficient of correlation with the Dearborn Marine history of personnel changes based on functional work demands. The coefficient of determination of 0.672 means that 67.2 per cent of the personnel changes are explained by queuing model solutions.

In summary, the thesis investigation and analysis shows that propositions 1, 2, 3, and 4 were consistently supported by the data. This data was limited in two ways beyond the necessary sampling limitations.

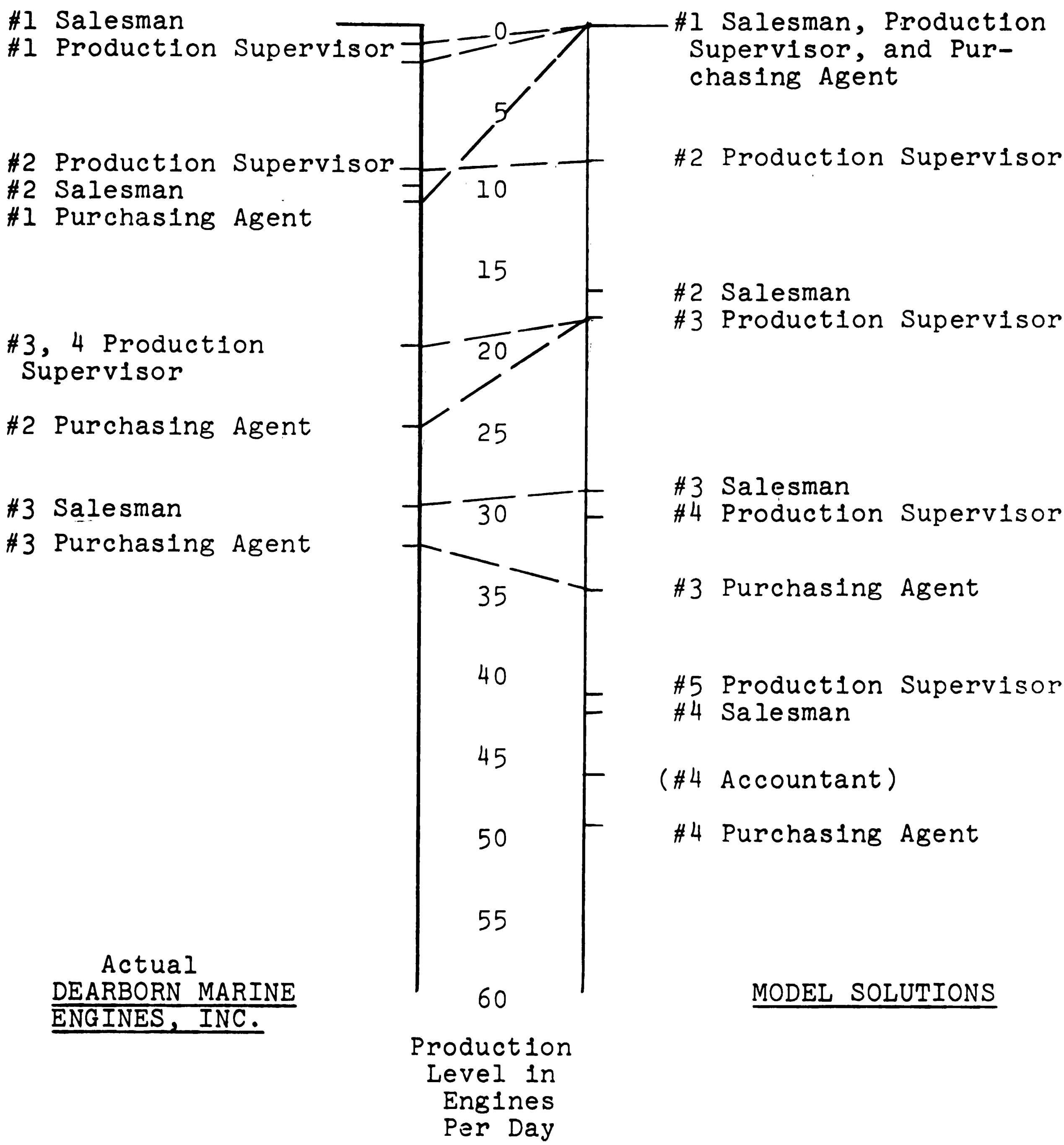

Figure 9--Comparative growth chart: queuing theory model solutions versus comparable organizational growth.

(a) Samples were taken from eight firms in the marine industry only. Therefore, the results will not necessarily apply to other industries, but no reason is seen to indicate this industry is peculiar in this respect.

(b) Only one and two channel servicing agencies were included in the functional areas investigated. The results may not be applicable to function areas arranged with a larger number of channels.

Hypothesis number one proposed that there are regular and consequently predictable patterns in which personnel are added to various functional areas in a marine organization, as it grows in size, as measured by certain stated parameters. The parameters of size and function activity level developed in the empirical investigation showed that personnel were added in a regular and predictable pattern in the marine organizations studied.

The second hypothesis that these patterns are based on the principle of adding personnel when the queue of demands for service in a functional area reaches a given length was also supported. The empirical data developed in the 17 samples showed an undeniable grouping of mean queue lengths from firm to firm in a given function area.

Proposition 3 that demands for service in some, at least, of the functional areas arrive in a random manner making queuing theory a suitable analytical tool was also fully supported by the data. In the three functions investigated--purchasing, in-plant sales, and production--this was found. A limited analysis of the accounting function, based on checks written, proved unsatisfactory and was abandoned. It may be either that service needs do not arrive in a random manner in this function or that a suitable service unit was not found. Figures 2 and 3 show parameter queue length distributions for the three investigated functions. Statistically they are Poisson distributions, which result from random arrivals of service demands. The Monte Carlo model based on random arrivals correlated with empirical queue data. Finally, inspection of Appendix A shows the randomness of the functional queue raw data.

The fourth hypothesis that queuing theory provides a good theoretical explanation of the consistency in the historical data as to when personnel are added in certain functional areas was supported by the data and the analysis. The correlation coefficient of 0.82 provides substantial support for this conclusion.

Proposition 5 was not supported. This was the hypothesis that queuing theory is a practical tool for predicting at what point in a marine organization's growth, as measured by stated parameters, additional personnel will be hired in various functional areas. The data showed queuing theory could, indeed, be used to predict when personnel would be added, but for this purpose the queuing theory proved to be only an added step in the analysis which contributed no prediction that was not inherent in the data without the queuing theory analysis. The queuing theory analysis affords an explanation as to <u>why</u>, but contributed nothing as to <u>what</u> in the prediction of personnel additions in one and two channel functional operations. To illustrate, the historical data shows that when the rate of engine production increases a given amount, if no new personnel have been hired for purchasing, orders awaiting servicing will reach a given mean length. At this point an additional person will be hired for the purchasing department. This will result in shortening the mean queue length back to what apparently is acceptable in the industry. Queuing theory affords an explanation of <u>why</u> the mean queue length elongates as it does and why the added personnel reduces its length in the observed manner.

Since there was a direct pattern of relationship between growth as indicated by the parameters chosen on the one hand and the time at which personnel would be added in the functional area, there was no need to go through the queuing theory analysis to predict when the personnel additions would be made.

Put in another way, if an increase in parameter Y of size causes mean queue length to reach X, a mean queue length of X results in addition of personnel which reduces mean queue length below X. Thus, we can predict that a certain increase in parameter Y of size will result in addition of personnel. Queuing theory only explains why an increase of parameter Y of size results in lengthening the mean queue length to X, and the added personnel reduced mean queue length below X.

Some other investigation gathering data on functions carried out with a higher number of channels, or with varying numbers of channels, may show an irregular relationship between increase in the growth parameter Y and the mean queue length at which personnel additions will be made, such that queuing theory analysis may be a necessary step in the calculation to estimate how much increase in parameter Y will occur in order to increase the mean queue length to X. It is believed that such an investigation employing the type of analysis used in this thesis would be a very desirable further step.

APPENDIX A

PRIMARY DATA

Production Supervision Function

I. Dearborn Marine Engine Division, Eaton Manufacturing Company.

Production order queue situation immediately prior to increase from two to three production supervisory employees.

Day	Date	Total Number Units Produced	Total Number Unit Orders Waiting
	November 1963		
1	5	18	4
2	6	23	2
3	7	21	1
4	8	22	6
5	11	20	4
6	12	20	13
7	13	19	15
8	14	21	1
9	15	23	4
10	18	19	10
11	19	20	8
12	20	26	0
13	25	20	1
14	26	19	6
15	27	22	1
		313	77

Average number of units produced per day was 20.1
Average number of unit orders waiting per day was 5.12 (mean queue length).

II. Dearborn Marine Engine Division, Eaton Manufacturing Company.

Production order queue situation immediately <u>after</u> increase from two to three production supervisory employees.

Day	Date	Total Number Units Produced	Total Number Unit Orders Waiting
	December 1963		
1	2	21	5
2	3	23	1
3	4	21	2
4	5	20	0
5	6	23	4
6	9	20	0
7	10	19	0
8	11	19	3
		166	15

Average number of units produced per day was 20.8
Average number of unit orders waiting per day was <u>1.9</u> (mean queue length).

Note: Addition was made at this time to the production facility.

III. Willowby Boat Company

Production order queue situation immediately prior to increase from seven to eight production supervisory employees.

Day	Date	Total Number Units Produced	Total Number Unit Orders Waiting
	June 1962		
1	4	23	6
2	5	18	1
3	6	17	3
4	7	18	2
5	8	18	1
6	11	17	11
7	12	19	7
8	13	19	0
9	14	20	1
10	15	19	3
11	18	18	4
12	19	20	1
13	20	19	2
14	21	18	8
15	22	18	4
16	25	18	5
17	26	22	1
18	27	23	2
19	28	22	11
20	29	23	0
		389	73

Average number of units produced per day was 19.5
Average number of unit orders waiting per day was 3.65 (mean queue length).

IV. Willowby Boat Company

Production order queue situation immediately prior to increase from eight to nine production supervisory employees.

Day	Date	Total Number Units Produced	Total Number Unit Orders Waiting
	February 1964		
1	18	22	3
2	19	22	5
3	20	18	1
4	21	22	0
5	24	20	2
6	25	21	4
7	26	19	6
8	27	22	4
9	28	22	1
	March 1964		
10	2	16	3
11	3	20	6
		224	35

Average number of units produced per day was 20.4
Average number of unit orders waiting per day was 3.18 (mean queue length).

V. Crusader Marine Engine Company

Production order queue situation immediately prior to increase from three to four production supervisory employees.

Day	Date	Total Number Units Produced	Total Number Unit Orders Waiting
	May 1963		
1	23	23	10
2	24	25	1
3	25	21	0
4	27	24	6
5	28	24	6
6	29	18	0
	June 1963		
7	3	22	4
8	4	27	6
9	5	22	3
10	6	22	0
11	7	26	1
12	8	21	2
13	10	22	0
14	11	22	8
15	12	24	3
16	13	25	5
17	14	24	6
		401	61

Average number of units produced per day was 23.5
Average number of unit orders waiting per day was 3.59 (mean queue length).

Purchasing Function

I. Dearborn Marine Engine Division, Eaton Manufacturing Company

Purchase order/production release queue situation immediately prior to increase from two to three purchasing agent/buyers.

Day	Date	Total Number Purchase Orders Issued	Purchase Orders Waiting Issue At End of Day
	July 1964		
1	27	21	8
2	28	32	4
3	29	37	7
4	30	21	0
5	31	22	5
	August 1964		
6	3	13	0
7	4	28	6
8	5	30	3
9	6	15	0
10	7	20	0
11	10	31	12
12	11	30	11
13	12	27	7
14	13	31	0
15	14	28	0
16	17	34	4
		420	67

Average number of purchase orders issued per day was 26.2

Average number of purchase orders waiting issue was 4.2 (mean queue length).

II. Willowby Boat Company

Purchase order/production release queue situation immediately prior to increase from two to three purchasing agent/buyers.

Day	Date	Total Number Purchase Orders Issued	Purchase Orders Waiting Issue At End of Day
	June 1962		
1	4	22	7
2	5	31	10
3	6	40	0
4	7	32	2
5	8	18	3
6	11	37	6
7	12	35	13
8	13	46	0
9	14	39	2
10	15	26	0
11	18	30	4
12	19	33	0
13	20	27	1
14	21	37	0
15	22	21	0
16	25	32	9
17	26	36	3
18	27	38	0
19	28	29	3
20	29	28	4
		637	67

Average number of purchase orders issued per day was 31.8

Average number of purchase orders waiting issue was 3.4 (mean queue length).

III. Renshaw Boat Company

Purchase order/production release situation immediately prior to increase from two to three purchasing agent/buyers.

Day	Date	Total Number Purchase Orders Issued	Purchase Orders Waiting Issue At End of Day
	July 1962		
1	23	40	7
2	24	31	6
3	25	38	0
4	26	36	1
5	27	44	12
6	28	27	2
7	30	32	0
8	31	31	1
	August 1962		
9	1	42	9
10	2	38	4
11	3	36	0
12	6	44	0
13	7	35	11
14	8	39	5
15	9	34	0
16	10	41	13
17	13	29	7
18	14	37	0
		654	78

Average number of purchase orders issued per day was 36.8

Average number of purchase orders waiting issue was 4.3 (mean queue length).

IV. Graymarine Engine Company, Division of Continental Motors

Purchase order/production release situation immediately prior to increase from three to four buyers.

Day	Date	Total Number Purchase Orders Issued	Purchase Orders Waiting Issue At End of Day
	April 1964		
1	13	30	4
2	14	39	10
3	15	26	6
4	16	31	2
5	20	29	9
6	21	37	0
7	22	39	0
8	23	32	0
9	24	31	6
10	27	24	12
11	28	35	3
12	29	34	7
13	30	38	11
		425	70

Average number of purchase orders issued per day was 32.7

Average number of purchase orders waiting issue was 5.4 (mean queue length).

V. Graymarine Engine Company, Division of Continental Motors

Purchase order/production release situation immediately <u>after</u> increase from three to four buyers.

Day	Date	Total Number Purchase Orders Issued	Purchase Orders Waiting Issue At End of Day
	May 1964		
1	12	41	0
2	13	33	0
3	14	38	0
4	15	24	4
5	18	36	0
6	19	40	0
7	20	31	3
8	21	29	2
9	22	26	1
10	26	34	2
11	27	33	0
		365	12

Average number of purchase orders issued per day was 33.2

Average number of purchase orders waiting issue was <u>1.1</u> (mean queue length).

Inside Sales Function

I. Dearborn Marine Engine Division, Eaton Manufacturing Company

"Call" queue situation immediately prior to increase from two to three in-plant contact sales employees.

Day	Date	Total Number Daily Calls	Total Number "Call Waits"
	June 1961		
1	5	16	12
2	6	10	2
3	7	11	0
4	8	19	14
5	9	11	7
6	12	16	9
7	13	10	1
8	14	12	0
9	15	9	0
10	16	15	3
11	19	9	0
12	20	15	10
13	21	13	3
14	22	13	0
15	23	9	1
16	26	6	1
17	27	7	0
18	28	12	5
19	29	14	0
20	30	11	4
	July 1961		
21	1	7	0
22	5	16	8
23	6	10	0
24	7	7	2
25	10	11	3
26	11	16	12
		304	97

Average number of "Calls" per day was 11.7
Average number of "Call Waits" per day was 3.72 (or the mean queue length).

II. Dearborn Marine Engine Division, Eaton Manufacturing Company

"Call" queue situation immediately prior to increase from three to four in-plant contact sales employees.

Day	Date	Total Number Daily Calls	Total Number "Call Waits"
	November 1963		
1	5	18	0
2	6	14	4
3	7	9	2
4	8	12	8
5	11	19	5
6	12	10	0
7	13	15	1
8	14	16	2
9	15	15	0
10	18	11	0
11	19	20	3
12	20	9	0
13	25	16	1
14	26	13	0
15	27	14	0
		211	26

Average number of "Calls" per day was 14.1
Average number of "Call Waits" per day was 1.73 (mean queue length).

III. Francona Boat Company

"Call" queue situation immediately prior to increase from three to four in-plant contact sales employees.

Day	Date	Total Number Daily Calls	Total Number "Call Waits"
	June 1962		
1	4	27	0
2	5	32	4
3	6	20	2
4	7	24	1
5	8	16	0
6	11	22	2
7	12	18	3
8	13	16	1
9	14	28	0
10	15	22	0
11	16	24	5
12	18	19	0
13	19	25	8
14	20	20	6
15	21	10	2
16	22	21	6
17	25	18	0
18	26	20	2
19	27	23	1
20	28	27	3
21	29	17	0
		459	46

Average number of "Calls" per day was 21.8
Average number of "Call Waits" per day was 2.19 (mean queue length).

IV. Johnson Boat Company

"Call queue situation immediately prior to increase from four to five in-plant contact sales employees.

Day	Date	Total Number Daily Calls	Total Number "Call Waits"
	July 1962		
1	20	37	7
2	21	20	0
3	23	49	2
4	24	58	1
5	25	38	0
6	26	43	2
7	27	31	3
8	30	56	5
9	31	43	16
	August 1962		
10	1	48	0
11	2	37	2
12	3	42	0
13	6	50	3
14	7	48	1
15	8	55	8
16	9	51	0
17	10	46	1
18	13	49	0
19	14	52	0
20	15	54	3
21	16	50	4
22	17	46	0
		1003	68

Average number of "Calls" per day was 45.6
Average number of "Call Waits" per day way 3.09
(mean queue length).

V. Raycraft Boat Company

"Call" queue situation immediately prior to increase from three to four in-plant contact sales employees.

Day	Date	Total Number Daily Calls	Total Number "Call Waits"
	January 1964		
1	15	16	1
2	16	23	2
3	17	10	3
4	20	21	0
5	21	17	0
6	22	13	2
7	23	20	5
8	24	16	2
9	27	21	1
10	28	18	4
11	29	17	5
12	30	19	0
13	31	15	2
		226	27

Average number of "Calls" per day was 17.4
Average number of "Call Waits" per day was 2.08 (mean queue length).

VI. Crusader Marine Engine Company

"Call" queue situation immediately prior to increase from two to three in-plant contact sales employees.

Day	Date	Total Number Daily Calls	Total Number "Call Waits"
	May 1964		
1	4	6	0
2	5	10	0
3	6	8	1
4	7	15	4
5	8	17	1
6	12	10	1
7	13	16	5
8	14	8	0
9	15	11	2
10	18	15	4
11	19	12	0
12	20	13	1
13	21	19	3
14	22	11	0
		171	22

Average number of "Calls" per day was 12.2
Average number of "Call Waits" per day was 1.57
(mean queue length).

VII. Crusader Marine Engine Company

"Call queue situation immediately after increase from two to three in-plant contact sales employees.

Day	Date	Total Number Daily Calls	Total Number "Call Waits"
	May 1964		
1	25	11	0
2	26	16	0
3	27	2	0
	June 1964		
4	2	10	0
5	3	18	1
6	4	13	0
7	5	18	0
8	8	11	0
9	9	7	0
		106	1

Average number of "Calls" per day was 11.8
Average number of "Call Waits" per day was 0.11.

APPENDIX B

QUEUING THEORY MODEL OF "IN-PLANT" SALES DEPARTMENT BASED ON THE MONTE CARLO

Dearborn Marine Engine Division, Eaton Manufacturing Company

Assumptions:

1. Number of sales "calls" per day is randomly distributed according to the Poisson (c' - 12).
2. Service (sale) time per call is randomly distributed according to the Poisson (c' - 4).
3. Times at which sales calls occur are randomly distributed according to the Poisson (c' varies with the number of calls per day).

Data:

1. Time is measured in quarter hours; there are 32 quarter hours per day.
2. There are an average of 12 sales calls per day.
3. Average service (sale) time per call is one per hour.

Day	Call No.	R.N.	Service Time (qtr. hrs.)	R.N.	Time Between Calls (qtr. hrs.)	Calling Time
1	1	.33	2	.87	3	3
	2	.46	3	.28	1	4
	3	.33	2	.21	0	4
	4	.85	6	.97	5	9
	5	.22	2	.37	1	10
	6	.05	0	.34	1	11
	7	.87	6	.39	1	12
	8	.28	2	.86	3	15
	9	.04	0	.64	2	17
	10	.68	4	.69	2	19
	11	.38	3	.17	0	19
	12	.25	2	.17	0	19
	13	.64	4	.97	5	24
2	14	.62	4	.88	5	5
	15	.95	7	.77	4	9
	16	.29	2	.58	3	12
	17	.73	5	.99	8	20
	18	.27	2	.45	2	22
	19	.90	6	.24	1	23
	20	.18	2	.05	0	23
	21	.94	7	.62	3	26
	22	.35	3	.20	1	27
	23	.33	2	.75	4	31

Day	Call No.	R.N.	Service Time (qtr. hrs.)	R.N.	Time Between Calls (qtr. hrs.)	Calling Time
3	24	.88	6	.90	4	4
	25	.39	3	.00	0	4
	26	.36	3	.06	2	6
	27	.40	3	.10	2	8
	28	.83	5	.02	1	9
	29	.33	2	.01	0	9
	30	.31	2	.21	3	12
	31	.93	7	.03	1	13
	32	.20	2	.19	3	16
	33	.02	0	.01	0	16
	34	.85	6	.09	2	18
	35	.97	8	.22	3	21
4	36	.61	4	.51	3	3
	37	.16	1	.94	7	10
	38	.42	3	.72	5	15
	39	.69	4	.81	5	20
	40	.07	1	.88	6	26
	41	.10	1	.76	5	31
	42	.53	4	.27	2	33
	43	.33	2	.37	3	36
5	44	.03	0	.89	6	6
	45	.92	6	.78	5	11
	46	.85	6	.59	4	15
	47	.08	1	.68	4	19
	48	.51	3	.04	0	19
	49	.60	4	.86	6	25
	50	.94	7	.98	8	33
	51	.58	4	.46	3	36
6	52	.09	1	.03	0	0
	53	.14	1	.00	0	0
	54	.74	5	.08	1	1
	55	.24	2	.51	3	4
	56	.87	6	.23	2	6
	57	.07	1	.32	2	8
	58	.96	7	.32	2	10
	59	.26	2	.22	2	12

Day	Call No.	R.N.	Service Time (qtr. hrs.)	R.N.	Time Between Calls (qtr. hrs.)	Calling Time
7	60	.26	2	.41	4	4
	61	.94	7	.70	6	10
	62	.77	5	.93	9	19
	63	.56	4	.04	1	20
	64	.55	4	.08	2	22
	65	.88	6	.34	4	26
8	66	.12	1	.27	2	2
	67	.30	2	.18	2	4
	68	.49	3	.71	5	9
	69	.49	3	.63	4	13
	70	.78	5	.70	4	17
	71	.81	5	.65	4	21
	72	.64	4	.73	5	26
	73	.82	5	.45	3	29
9	74	.46	3	.91	6	6
	75	.67	4	.92	6	12
	76	.07	1	.26	2	14
	77	.29	2	.88	5	19
	78	.31	2	.65	4	23
	79	.25	2	.91	6	29
10	80	.38	3	.95	6	6
	81	.81	5	.93	6	12
	82	.30	2	.56	3	15
	83	.76	5	.21	1	16
	84	.07	1	.56	3	19
	85	.06	1	.72	4	23
	86	.27	2	.76	4	27
	87	.98	8	.53	3	30
	88	.18	2	.60	3	33
	89	.17	2	.97	7	40
11	90	.53	3	.26	1	1
	91	.70	4	.74	4	5
	92	.49	3	.37	2	7
	93	.88	6	.33	2	9
	94	.48	3	.52	3	12
	95	.77	5	.68	3	15
	96	.77	5	.73	4	19
	97	.89	6	.16	1	20
	98	.31	2	.98	7	27

Day	Call No.	R.N.	Service Time (qtr. hrs.)	R.N.	Time Between Calls (qtr. hrs.)	Calling Time
12	99	.42	3	.70	3	3
	100	.09	1	.63	3	6
	101	.47	3	.31	1	7
	102	.13	1	.31	1	8
	103	.58	4	.78	4	12
	104	.19	2	.01	0	12
	105	.24	2	.73	3	15
	106	.46	3	.07	0	15
	107	.84	6	.66	3	18
	108	.44	3	.06	0	18
	109	.26	2	.24	1	19
13	110	.42	3	.88	14	14
	111	.86	6	.17	7	21
	112	.18	2	.83	13	34
14	113	.67	4	.24	0	0
	114	.30	2	.44	1	1
	115	.04	1	.04	0	1
	116	.20	2	.10	0	1
	117	.02	0	.67	2	3
	118	.84	6	.38	1	4
	119	.39	3	.76	2	6
	120	.01	0	.19	0	6
	121	.34	3	.50	1	7
	122	.23	2	.45	1	8
	123	.68	4	.31	1	9
	124	.58	4	.83	3	12
	125	.65	4	.42	1	13
	126	.14	1	.92	4	17
	127	.61	4	.32	1	18
	128	.10	1	.46	1	19
15	129	.91	6	.16	0	0
	130	.53	3	.22	0	0
	131	.31	2	.03	0	0
	132	.20	2	.33	1	1
	133	.18	2	.36	1	2
	134	.59	4	.45	1	3
	135	.79	5	.88	4	7
	136	.69	4	.67	2	9
	137	.33	2	.16	0	9
	138	.52	3	.08	0	9
	139	.13	1	.85	3	12

Day	Call No.	R.N.	Service Time (qtr. hrs.)	R.N.	Time Between Calls (qtr. hrs.)	Calling Time
15	140	.16	1	.46	1	13
	141	.19	2	.13	0	13
	142	.04	1	.91	4	17
	143	.14	1	.68	2	19
16	144	.06	1	.06	0	0
	145	.30	2	.05	0	0
	146	.25	2	.56	3	3
	147	.38	3	.20	1	4
	148	.00	0	.51	3	7
	149	.92	7	.49	3	10
	150	.82	5	.27	2	12
	151	.20	2	.48	3	15
	152	.40	3	.40	2	17
17	153	.44	3	.26	1	1
	154	.25	2	.72	4	5
	155	.35	3	.54	3	8
	156	.88	6	.08	0	8
	157	.27	2	.17	1	9
	158	.48	3	.85	5	14
	159	.18	2	.31	2	16
	160	.86	6	.38	2	18
	161	.59	4	.34	2	20
	162	.51	3	.58	3	23
18	163	.47	3	.32	2	2
	164	.92	7	.16	1	3
	165	.17	2	.48	2	5
	166	.53	3	.74	4	9
	167	.82	5	.57	3	12
	168	.25	2	.13	1	13
	169	.38	3	.72	3	16
	170	.24	2	.42	2	18
	171	.34	3	.99	8	26
	172	.04	0	.79	4	30
	173	.21	2	.82	4	34
19	174	.69	4	.79	5	5
	175	.27	2	.40	2	7
	176	.15	1	.68	4	11
	177	.39	3	.02	0	11
	178	.60	4	.94	6	17
	179	.18	2	.95	7	24

Day	Call No.	R.N.	Service Time (qtr. hrs.)	R.N.	Time Between Calls (qtr. hrs.)	Calling Time
19	180	.71	5	.40	2	26
	181	.94	7	.67	4	30
	182	.57	4	.65	4	34
20	183	.56	4	.20	1	1
	184	.18	2	.89	5	6
	185	.36	3	.64	3	9
	186	.67	4	.56	3	12
	187	.47	3	.22	1	13
	188	.60	4	.94	6	19
	189	.55	4	.49	2	21
	190	.18	2	.88	5	26
	191	.83	5	.29	2	28
	192	.76	5	.68	3	31
21	193	.90	6	.42	1	1
	194	.76	5	.34	1	2
	195	.94	7	.52	1	3
	196	.45	3	.66	2	5
	197	.60	4	.68	2	7
	198	.66	4	.32	1	8
	199	.89	6	.37	1	9
	200	.32	2	.72	2	11
	201	.37	3	.87	3	14
	202	.39	3	.22	0	14
	203	.74	5	.75	2	16
	204	.76	5	.12	0	16
	205	.26	2	.90	3	19
	206	.18	2	.80	3	22
	207	.28	2	.15	0	22
	208	.29	2	.55	2	24
22	209	.06	1	.22	2	2
	210	.20	2	.73	4	6
	211	.09	1	.69	4	10
	212	.56	4	.89	6	16
	213	.66	4	.70	4	20
	214	.87	6	.98	8	28
	215	.94	7	.87	5	33
	216	.11	1	.90	6	39
	217	.22	2	.44	3	42

Day	Call No.	R.N.	Service Time (qtr. hrs.)	R.N.	Time Between Calls (qtr. hrs.)	Calling Time
23	218	.59	4	.63	3	3
	219	.81	5	.16	1	4
	220	.76	5	.94	5	9
	221	.59	4	.02	0	9
	222	.14	1	.30	1	10
	223	.53	3	.37	2	12
	224	.24	2	.05	0	12
	225	.53	3	.59	3	15
	226	.81	5	.38	2	17
	227	.70	4	.69	3	20
	228	.18	2	.78	4	24
24	229	.84	6	.59	4	4
	230	.62	4	.95	7	11
	231	.05	0	.17	2	13
	232	.72	5	.94	7	20
	233	.17	2	.56	4	24
	234	.93	7	.44	3	27
	235	.81	5	.19	2	29
	236	.92	6	.52	3	32
25	237	.29	2	.02	0	0
	238	.98	8	.34	1	1
	239	.13	1	.84	3	4
	240	.04	0	.28	1	5
	241	.26	2	.98	5	10
	242	.28	2	.80	3	13
	243	.15	1	.78	3	16
	244	.61	4	.36	1	17
	245	.14	1	.62	2	19
	246	.81	5	.04	0	19
	247	.61	4	.09	0	19
	248	.63	4	.47	1	20
	249	.22	2	.86	3	23
	250	.99	9	.25	1	24
	251	.36	3	.71	2	26

Day	Call No.	R.N.	Service Time (qtr. hrs.)	R.N.	Time Between Calls (qtr. hrs.)	Calling Time
26	252	.82	5	.30	1	1
	253	.35	3	.42	2	3
	254	.99	9	.27	1	4
	255	.20	2	.17	0	4
	256	.58	4	.07	0	4
	257	.25	2	.20	1	5
	258	.56	4	.36	1	6
	259	.98	8	.32	1	7
	260	.40	3	.78	3	10
	261	.25	2	.59	2	12
	262	.42	3	.65	3	15
	263	.80	5	.51	2	17

APPENDIX C

MONTE CARLO SALES MODEL

WAITING-LINE SUMMARY: TWO EMPLOYEES

Dearborn Marine Engine Division, Eaton Manufacturing Company

Day	Call No.	Calling Time	Calls Sales Manager Begin	Calls Sales Manager End	Calls Salesclerk Begin	Calls Salesclerk End
1	1	3			3	5
	2	4	4	7		
	3	4			5	7
	4	9			9	15
	5	10	10	12		
	6	11	12	12		
	7	12	12	18		
	8	15			15	17
	9	17			17	17
	10	19			19	23
	11	19	19	22		
	12	19	22	24		
	13	24			24	28
2	14	5			5	9
	15	9			9	16
	16	12	14			
	17	20			20	25
	18	22	22	24		
	19	23	24	30		
	20	23			25	27
	21	26			27	34
	22	27	30	33		
	23	31	33	35		
3	24	4			4	10
	25	4	4	7		
	26	6	7	10		
	27	8			10	13
	28	9	10	15		
	29	9			13	15
	30	12			15	17
	31	13	15	22		
	32	16			17	19
	33	16			19	19
	34	13			19	25
	35	21	22	30		
4	36	3			3	7
	37	10			10	11
	38	15			15	18
	39	20			20	24

Day	Call No.	Calling Time	Calls Sales Manager Begin	Calls Sales Manager End	Calls Salesclerk Begin	Calls Salesclerk End
4	40	26			26	27
	41	31			31	32
	42	33	33	37		
	43	36	37	39		
5	44	6			6	6
	45	11			11	17
	46	15	15	21		
	47	19			19	20
	48	19			20	23
	49	25			25	29
	50	33	33	40		
	51	36	40	44		
6	52	0			0	1
	53	0	0	1		
	54	1			1	6
	55	4	4	6		
	56	6			6	12
	57	8	8	9		
	58	10	10	17		
	59	12			12	14
7	60	4			4	6
	61	10			10	17
	62	19			19	24
	63	20	20	24		
	64	22			24	28
	65	26	26	32		
8	66	2			2	3
	67	4			4	6
	68	9			9	12
	69	13			13	16
	70	17			17	22
	71	21	21	26		
	72	26			26	30
	73	29	29	34		
9	74	6			6	9
	75	12			12	16
	76	14	14	15		
	77	19			19	21
	78	23			23	25
	79	29			29	31

Day	Call No.	Calling Time	Calls Sales Manager Begin	Calls Sales Manager End	Calls Salesclerk Begin	Calls Salesclerk End
10	80	6			6	9
	81	12			12	17
	82	15	15	17		
	83	16			17	22
	84	19	19	20		
	85	23			23	24
	86	27			27	29
	87	30			30	38
	88	33	33	35		
	89	40	40	42		
11	90	1			1	4
	91	5			5	9
	92	7	7	10		
	93	9			9	15
	94	12	12	15		
	95	15			15	20
	96	19	19	24		
	97	20			20	26
	98	27			27	29
12	99	3			3	6
	100	6			6	7
	101	7			7	10
	102	8	8	9		
	103	12			12	16
	104	12	12	14		
	105	15	15	17		
	106	15			16	19
	107	18	18	24		
	108	18			19	22
	109	19			22	24
13	110	14			14	17
	111	21			21	27
	112	34	34	36		
14	113	0			0	4
	114	1	1	3		
	115	1	3	4		
	116	1			4	6
	117	3	4	4		
	118	4	4	10		
	119	6			6	9
	120	6			9	9

Day	Call No.	Calling Time	Calls Sales Manager Begin	Calls Sales Manager End	Calls Salesclerk Begin	Calls Salesclerk End
14	121	7			9	12
	122	8	10	12		
	123	9			12	16
	124	12	12	16		
	125	13			16	20
	126	17	17	18		
	127	18	18	22		
	128	19			20	21
15	129	0			0	6
	130	0	0	3		
	131	0	3	5		
	132	1	5	7		
	133	2			6	8
	134	3	7	11		
	135	7			8	13
	136	9	11	15		
	137	9			13	15
	138	9			15	18
	139	12	15	16		
	140	13	16	17		
	141	13	17	19		
	142	17			18	19
	143	19			19	20
16	144	0			0	1
	145	0	0	2		
	146	3			3	5
	147	4	4	7		
	148	7			7	7
	149	10			10	17
	150	12	12	17		
	151	15			17	19
	152	17	17	20		
17	153	1			1	4
	154	5			5	7
	155	8			8	11
	156	8	8	14		
	157	9			11	13
	158	14			14	17
	159	16	16	18		
	160	18			18	24
	161	20	20	24		
	162	23			24	27

Day	Call No.	Calling Time	Calls Sales Manager Begin	End	Calls Salesclerk Begin	End
18	163	2			2	5
	164	3	3	10		
	165	5			5	7
	166	9			9	12
	167	12			12	17
	168	13	13	15		
	169	16	16	19		
	170	18			18	20
	171	26			26	29
	172	30			30	30
	173	34	34	36		
19	174	5			5	9
	175	7	7	9		
	176	11			11	12
	177	11	11	14		
	178	17			17	21
	179	24			24	26
	180	26			26	31
	181	30	30	37		
	182	34			34	38
20	183	1			1	5
	184	6			6	8
	185	9			9	12
	186	12			12	16
	187	13	13	16		
	188	19			19	23
	189	21	21	25		
	190	26			26	28
	191	28			28	33
	192	31	31	36		
21	193	1			1	7
	194	2	2	7		
	195	3			7	14
	196	5	7	10		
	197	7	10	14		
	198	8			14	18
	199	9	14	20		
	200	11			18	20
	201	14			20	23
	202	14	20	23		
	203	16			23	28
	204	16	23	28		

Day	Call No.	Calling Time	Calls Sales Manager Begin	Calls Sales Manager End	Calls Salesclerk Begin	Calls Salesclerk End
21	205	19			28	30
	206	22	28	30		
	207	22			30	32
	208	24	30	32		
22	209	2			2	3
	210	6			6	8
	211	10			10	11
	212	16			16	20
	213	20			20	24
	214	28			28	34
	215	33	33	40		
	216	39			39	40
	217	42	42	44		
23	218	3			3	7
	219	4	4	9		
	220	9			9	14
	221	9	9	13		
	222	10	13	14		
	223	12			14	17
	224	12	14	16		
	225	15	16	19		
	226	17			17	22
	227	20	20	24		
	228	24			24	26
24	229	4			4	10
	230	11			11	15
	231	13	13	13		
	232	20			20	25
	233	24	24	26		
	234	27			27	34
	235	29	29	34		
	236	32	34	40		
25	237	0			0	2
	238	1	1	9		
	239	4			4	5
	240	5			5	5
	241	10			10	12
	242	13			13	15
	243	16			16	17
	244	17			17	21
	245	19	19	20		

Day	Call No.	Calling Time	Calls Sales Manager		Calls Salesclerk	
			Begin	End	Begin	End
25	246	19	20	25		
	247	19			21	25
	248	20			25	29
	249	23	25	27		
	250	24	27	36		
	251	26			29	32
26	252	1			1	6
	253	3	3	6		
	254	4			6	15
	255	4	6	8		
	256	4	8	12		
	257	5	12	14		
	258	6	14	18		
	259	7			15	23
	260	10	18	21		
	261	12	21	23		
	262	15			23	26
	263	17	23	28		

QUEUE SUMMARY SHEET

Day	Time of Day 4	8	12	16	20	24	28	32
1	3	0	3	2	3	1	0	0
2	0	1	2	0	1	2	2	3
3	2	3	4	4	2	2	1	0
4	1	0	0	0	1	0	0	2
5	0	0	1	2	2	0	0	2
6	2	2	2	1	0	0	0	0
7	1	0	1	1	2	1	1	0
8	1	0	0	0	1	1	1	1
9	0	1	1	0	1	1	0	0
10	0	1	1	3	1	0	1	3
11	0	2	2	1	2	0	1	0
12	1	2	2	2	3	0	0	0
13	0	0	0	1	0	1	0	1
14	2	5	2	1	2	0	0	0
15	5	2	5	3	0	0	0	0
16	2	0	2	3	0	0	0	0
17	0	2	2	2	2	1	0	0
18	2	1	1	2	0	0	1	1
19	0	2	1	0	1	1	1	2
20	1	0	1	0	1	1	1	1
21	3	4	5	7	5	6	4	0
22	0	0	0	1	1	0	1	4
23	2	1	5	2	2	1	0	0
24	1	2	0	0	1	2	1	3
25	2	1	0	1	4	5	3	1
26	5	5	6	5	5	2	0	0
	35	36	46	42	43	28	18	27

$$E(n) = \frac{282}{208} = 1.35$$

APPENDIX D

MONTE CARLO SALES MODEL

WAITING-LINE SUMMARY: THREE EMPLOYEES

Dearborn Marine Engine Division, Eaton Manufacturing Company

Day	Call No.	Calling Time	Calls Sales Mgr. Begin	Calls Sales Mgr. End	Calls Salesclerk Begin	Calls Salesclerk End	Calls Salesclerk Begin	Calls Salesclerk End
1	1	3					3	5
	2	4			4	7		
	3	4	4	6				
	4	9					9	15
	5	10			10	12		
	6	11	11	11				
	7	12			12	18		
	8	15					15	17
	9	17					17	17
	10	19					19	23
	11	19			19	22		
	12	19	19	21				
	13	24					24	28
2	14	5					5	9
	15	9					9	16
	16	12			12	14		
	17	20					20	25
	18	22			22	24		
	19	23	23	29				
	20	23			24	26		
	21	26					26	33
	22	27			27	30		
	23	31			31	33		
3	24	4					4	10
	25	4			4	7		
	26	6	6	7				
	27	8			8	11		
	28	9	9	14				
	29	9					10	12
	30	12					12	14
	31	13			13	20		
	32	16					16	18
	33	16	16	16				
	34	18					18	24
	35	21			21	29		
4	36	3					3	7
	37	10					10	11
	38	15					15	18
	39	20					20	24

Day	Call No.	Calling Time	Calls Sales Mgr. Begin	Calls Sales Mgr. End	Calls Salesclerk Begin	Calls Salesclerk End	Calls Salesclerk Begin	Calls Salesclerk End
4	40	26					26	27
	41	31					31	32
	42	33					33	37
	43	36			36	38		
5	44	6					6	6
	45	11					11	17
	46	15			15	21		
	47	19					19	20
	48	19	19	22				
	49	25					25	29
	50	33					33	40
	51	36			36	40		
6	52	0					0	1
	53	0			0	1		
	54	1					1	6
	55	4			4	6		
	56	6					6	12
	57	8			8	9		
	58	10			10	17		
	59	12					12	14
7	60	4					4	6
	61	10					10	17
	62	19					19	24
	63	20			20	24		
	64	22	22	26				
	65	26					26	32
8	66	2					2	3
	67	4					4	6
	68	9					9	12
	69	13					13	16
	70	17					17	22
	71	21			21	26		
	72	26					26	30
	73	29			29	34		
9	74	6					6	9
	75	12					12	16
	76	14			14	15		
	77	19					19	21
	78	23					23	25
	79	29					29	31

Day	Call No.	Calling Time	Calls Sales Mgr. Begin	Calls Sales Mgr. End	Calls Salesclerk Begin	Calls Salesclerk End	Calls Salesclerk Begin	Calls Salesclerk End
10	80	6					6	9
	81	12					12	17
	82	15			15	17		
	83	16	16	21				
	84	19					19	20
	85	23					23	24
	86	27					27	29
	87	30					30	38
	88	33			33	35		
	89	40			40	42		
11	90	1					1	4
	91	5					5	9
	92	7			7	10		
	93	9					9	15
	94	12			12	15		
	95	15					15	20
	96	19			19	24		
	97	20					20	26
	98	27					27	29
12	99	3					3	6
	100	6					6	7
	101	7					7	10
	102	8			8	9		
	103	12					12	16
	104	12			12	14		
	105	15			15	17		
	106	15	15	18				
	107	18					18	24
	108	18			18	21		
	109	19	19	21				
13	110	14					14	17
	111	21					21	27
	112	34			34	36		
14	113	0					0	4
	114	1			1	3		
	115	1	1	2				
	116	1	2	4				
	117	3			3	3		
	118	4					4	10
	119	6			6	9		
	120	6	6	6				

Day	Call No.	Calling Time	Calls Sales Mgr.		Calls Salesclerk		Calls Salesclerk	
			Begin	End	Begin	End	Begin	End
14	121	7	7	10				
	122	8			9	11		
	123	9					10	14
	124	12			12	16		
	125	13	13	17				
	126	17					17	18
	127	18					18	22
	128	19			19	20		
15	129	0					0	6
	130	0			0	3		
	131	0	0	2				
	132	1	2	4				
	133	2			3	5		
	134	3	4	8				
	135	7					7	12
	136	9			9	13		
	137	9	9	11				
	138	9	11	14				
	139	12					12	13
	140	13					13	14
	141	13			13	15		
	142	17					17	18
	143	19					19	20
16	144	0					0	1
	145	0			0	2		
	146	3					3	5
	147	4			4	7		
	148	7					7	7
	149	10					10	17
	150	12			12	17		
	151	15	15	17				
	152	17					17	20
17	153	1					1	4
	154	5					5	7
	155	8					8	11
	156	8			8	14		
	157	9	9	11				
	158	14					14	17
	159	16			16	18		
	160	18					18	24
	161	20			20	24		
	162	23	23	26				

Day	Call No.	Calling Time	Calls Sales Mgr. Begin	Calls Sales Mgr. End	Calls Salesclerk Begin	Calls Salesclerk End	Calls Salesclerk Begin	Calls Salesclerk End
18	163	2					2	5
	164	3			3	10		
	165	5					5	7
	166	9					9	12
	167	12					12	17
	168	13			13	15		
	169	16			16	19		
	170	16					18	20
	171	26					26	29
	172	30					30	30
	173	34					34	36
19	174	5					5	9
	175	7			7	9		
	176	11					11	12
	177	11			11	14		
	178	17					17	21
	179	24					24	26
	180	26					26	31
	181	30			30	37		
	182	34					34	38
20	183	1					1	5
	184	6					6	8
	185	9					9	12
	186	12					12	16
	187	13			13	16		
	188	19					19	23
	189	21			21	25		
	190	26					26	28
	191	28					28	33
	192	31			31	36		
21	193	1					1	7
	194	2			2	7		
	195	3	3	10				
	196	5					5	8
	197	7			7	11		
	198	8					8	12
	199	9	10	16				
	200	11			11	13		
	201	14					14	17
	202	14			14	17		
	203	16	16	21				
	204	16					17	22

Day	Call No.	Calling Time	Calls Sales Mgr. Begin	Calls Sales Mgr. End	Calls Salesclerk Begin	Calls Salesclerk End	Calls Salesclerk Begin	Calls Salesclerk End
21	204	16					17	22
	205	19			19	21		
	206	22					22	24
	207	22			22	24		
	208	24					24	26
22	209	2					2	3
	210	6					6	8
	211	10					10	11
	212	16					16	20
	213	20					20	24
	214	28					28	34
	215	33			33	39		
	216	39			39	40		
	217	42			42	44		
23	218	3					3	7
	219	4			4	9		
	220	9					9	14
	221	9			9	13		
	222	10	10	11				
	223	12	12	15				
	224	12			13	15		
	225						15	18
	226	17			17	22		
	227	20					20	24
	228	24					24	26
24	229	4					4	10
	230	11					11	15
	231	13			13	13		
	232	20					20	25
	233	24			24	26		
	234	27					27	34
	235	29			29	34		
	236	32	32	38				
25	237	0					0	2
	238	1			1	9		
	239	4					4	5
	240	5					5	5
	241	10					10	12
	242	13					13	15
	243	16					16	17
	244	17					17	21

Day	Call No.	Calling Time	Calls Sales Mgr.		Calls Salesclerk		Calls Salesclerk	
			Begin	End	Begin	End	Begin	End
25	245	19			19	20		
	246	19	19	24				
	247	19			20	24		
	248	20					21	25
	249	23			24	26		
	250	24	24	33				
	251	26					26	29
26	252	1					1	6
	253	3			3	6		
	254	4	4	13				
	255	4					6	8
	256	4			6	10		
	257	5					8	10
	258	6					10	14
	259	7			10	18		
	260	10	13	16				
	261	12					14	16
	262	15					16	19
	263	17	22					

Queue Summary

Day	Time of Day 4	8	12	16	20	24	28	32
1	3	0	2	2	3	1	0	0
2	0	1	2	0	1	3	3	2
3	2	2	2	3	1	1	1	0
4	1	0	0	1	1	0	0	2
5	0	0	0	1	2	2	1	2
6	1	2	2	1	0	0	0	0
7	1	0	1	0	2	1	1	0
8	1	0	0	0	1	1	1	1
9	0	1	1	0	1	1	0	0
10	0	1	1	3	1	0	1	3
11	0	2	2	1	2	1	1	0
12	1	2	2	2	3	0	0	0
13	0	0	0	1	0	1	0	1
14	1	4	2	1	1	0	0	0
15	3	1	3	0	0	0	0	0
16	2	0	2	3	0	0	0	0
17	1	2	1	2	2	1	0	0
18	2	1	1	2	0	0	1	1
19	0	2	1	0	1	1	1	2
20	1	0	1	0	1	1	1	1
21	3	3	2	4	3	1	0	0
22	0	0	0	1	1	0	1	3
23	2	1	4	1	2	1	0	0
24	1	1	1	0	1	2	1	3
25	2	1	0	1	4	3	2	1
26	5	5	5	2	1	0	0	0
	33	32	39	33	35	20	16	22

$$E(n) = \frac{230}{26 \times 8} = \frac{230}{208} = 1.11 \text{ calls}$$

APPENDIX E

DATA SHEET: GROWTH OF

DEARBORN MARINE ENGINES, INC.

Production Function

Year	Month	Number of Engines	Number of Days	Engines Per Day
1955	January	-	20	-
	February	-	21	-
	March	16	23	0.7
	April	22	21	1.1
	May	19	21	0.9
	June	18	21	0.9
	July	22	20	1.1
	August	37	23	1.6
	September	43	21	2.0
	October	45	21	2.1
	November	58	21	2.8
	December	50	21	2.4
1956	January	79	21	3.8
	February	134	21	6.4
	March	208	22	9.4
	April	233	20	11.7
	May	204	22	9.3
	June	228	21	10.8
	July	241	21	11.5
	August	219	23	10.4
	September	263	19	13.8
	October	286	23	12.5
	November	272	21	12.9
	December	268	20	13.4
1957	January	280	22	12.7
	February	248	20	12.4
	March	287	20	14.4
	April	259	22	11.8
	May	268	20	13.4
	June	221	19	11.6
	July	253	23	11.0
	August	261	22	11.9
	September	230	21	10.9
	October	226	23	9.8
	November	202	20	10.1
	December	219	21	10.4

Year	Month	Number of Engines	Number of Days	Engines Per Day
1958	January	217	22	9.9
	February	215	20	10.8
	March	212	21	10.0
	April	187	22	8.5
	May	199	21	9.5
	June	248	21	11.8
	July	327	22	14.9
	August	390	21	18.5
	September	344	21	16.3
	October	361	23	15.7
	November	383	18	21.3
	December	360	21	17.1
1959	January	403	21	19.2
	February	512	20	25.6
	March	488	21	23.1
	April	496	22	22.5
	May	537	20	26.9
	June	573	23	25.0
	July	620	23	26.9
	August	591	21	28.1
	September	616	21	29.3
	October	502	22	22.9
	November	478	20	23.9
	December	513	21	24.4
1960	January	640	20	32.0
	February	682	21	32.4
	March	537	23	24.4
	April	618	20	30.9
	May	592	21	28.1
	June	526	22	23.9
	July	481	20	24.0

Purchasing Function

Year	Month	Number of Purchase Orders Mgr.	Engr.	No. Days	Average Number of Purchase Orders Mgr.	Engr.	Day Total
1955	January	-	-	20	-	-	-
	February	38	61	21	1.8	2.9	4.7
	March	56	55	23	2.4	2.4	4.8
	April	44	57	21	2.1	2.7	4.8
	May	69	51	21	3.3	2.4	5.7
	June	73	48	21	3.5	2.3	5.8
	July	121	46	20	6.0	2.3	8.3
	August	42	51	23	1.8	2.2	4.0
		Prod.			Prod.		
	September	130	52	21	6.2	2.5	8.7
	October	116	43	21	5.5	2.0	7.5
	November	123	45	21	5.8	2.1	7.9
	December	141	39	21	6.7	1.9	8.6
1956	January	168	61	21	8.0	2.9	10.9
	February	129	61	21	6.1	2.9	9.0
	March	146	83	22	6.6	3.8	10.4
	April	180	47	20	9.0	2.4	11.4
	May	189	51	22	8.6	2.3	10.9
	June	194	44	21	9.2	2.1	11.3
	July	161	68	21	7.7	3.2	10.9
	August	172	57	23	7.5	2.5	10.0
	September	141	55	19	7.4	2.9	10.3
	October	201	73	23	8.7	3.2	11.9
	November	195	48	21	9.3	2.3	11.6
	December	133	51	20	6.7	2.6	9.3
1957	January	188	52	22	8.5	2.4	10.9
	February	218	75	20	10.9	3.7	14.6
	March	204	60	20	10.2	3.0	13.2
	April	227	66	22	10.3	3.0	13.3
	May	280	51	20	14.0	2.5	16.5
	June	263	48	19	13.9	2.5	16.4
	July	288	63	23	12.5	2.7	15.2
	August	261	79	22	11.7	3.6	15.3
	September	212	74	21	10.1	3.5	13.6
	October	151	63	23	6.6	2.7	9.9
	November	272	66	20	13.6	3.3	16.9
	December	299	57	21	14.2	2.7	16.9

Year	Month	Number of Purchase Orders Mgr.	Number of Purchase Orders Engr.	No. Days	Average Number of Purchase Orders Mgr.	Average Number of Purchase Orders Engr.	Day Total
1958	January	276	84	22	12.6	3.8	16.4
	February	341	58	20	17.1	2.9	20.0
	March		387	21		18.4	
	April		362	22		16.5	
	May		366	21		17.4	
	June		390	21		18.6	
	July		412	22		18.7	
	August		367	21		17.5	
	September		379	21		18.0	
	October		510	23		22.2	
	November		417	18		23.2	
	December		415	21		19.7	
1959	January		476	21		22.6	
	February		454	20		22.6	
	March		493	21		23.5	
	April		511	22		23.2	
	May		502	20		25.1	
	June		508	23		22.1	
	July		569	23		24.7	
	August		532	21		25.3	
	September		519	21		24.7	
	October		500	22		22.8	
	November		588	20		29.4	
	December		476	21		22.7	
1960	January		525	20		26.3	
	February		593	21		28.2	
	March		509	23		22.1	
	April		616	20		30.8	
	May		513	21		24.5	
	June		538	22		24.5	
	July		576	20		28.8	

In-Plant Sales Function

Year	Month	Number of Calls	Number of Days	Average No. Calls Per Day
1955	January	-	20	-
	February	-	21	-
	March	-	23	-
	April	67	21	3.2
	May	93	21	4.4
	June	140	21	6.7
	July	111	20	5.5
	August	133	23	5.8
	September	126	21	6.0
	October	121	21	5.7
	November	147	21	7.0
	December	138	21	6.7
1956	January	166	21	7.9
	February	185	21	8.8
	March	192	22	9.1
	April	139	20	6.9
	May	183	22	8.3
	June	202	21	9.6
	July	213	21	10.1
	August	176	23	7.8
	September	166	19	8.7
	October	191	23	8.3
	November	187	21	8.9
	December	205	20	10.3
1957	January	162	22	7.4
	February	171	20	8.6
	March	184	20	9.2
	April	216	22	9.8
	May	166	20	8.3
	June	192	19	10.1
	July	188	23	8.2
	August	181	22	8.2
	September	219	21	10.4
	October	221	23	9.6
	November	201	20	10.5
	December	170	21	8.1

Year	Month	Number of Calls	Number of Days	Average No. Calls Per Day
1958	January	195	22	8.9
	February	179	20	9.0
	March	208	21	9.9
	April	229	22	10.4
	May	244	21	11.6
	June	251	21	12.0
	July	252	22	11.4
	August	241	21	11.5
	September	267	21	12.7
	October	284	23	12.3
	November	255	18	14.2
	December	271	21	12.9
1959	January	233	21	11.1
	February	270	20	13.5
	March	281	21	13.4
	April	293	22	13.3
	May	264	20	13.2
	June	278	23	12.1
	July	266	23	11.6
	August	291	21	13.9
	September	282	21	13.4
	October	257	22	11.7
	November	266	20	13.3
	December	247	21	11.8
1960	January	291	20	14.6
	February	266	21	12.7
	March	248	23	10.8
	April	259	20	12.9
	May	283	21	13.5
	June	302	22	13.7
	July	288	20	14.4

APPENDIX F

PREDICTION OF PERSONNEL NEEDS DIRECTLY FROM SIZE PARAMETERS VERSUS PREDICTION BASED ON QUEUING THEORY MODEL SOLUTIONS

This appendix departs from conventional organizational analysis. Conventional analysis is concerned with analysis of organizational operation by determining the time, on average, that will be required for a person to discharge a demand for service made on an organic function. It further determines the mean number of demands made on this organic function per unit time. The product of these two values is the number of persons required to perform the function. The evolution of the organization based on this is a straightforeward thing, based on changes in the above two variable factors.

This technique is fully applicable, however, in only one _special_ case--that in which the arrivals of demands for service occur at regular intervals. This regularity is vital to effective prediction and analysis of the organization needs if this method is to be used. The regularity can be assured by controls external to the system; or by establishing a storage facility ahead of the function, to "smooth out" the irregularities in the arrivals of service demands. Actually the work "storage" facility is nothing more or less than a waiting-line.

This technique tells nothing about the length of the queue, if one exists, or the effect on organizational efficiency of a queue. If arrival of demands for service

by a function is in any way irregular, or if the length of the service time is irregular, etc., it cannot. Only application of queuing theory is able to.

It is entirely possible through application of queuing theory to predict or develop data, for "irregular" functions, for the mean waiting time, the average length of the waiting-line, the probability of a waiting-line of a certain length, and so on. Since such waiting-line data is a measure of the quality of service which a particular organizational function is rendering, and since the quality of service is a measure of organizational efficiency, we are able to match efficiency of the organization against a cost level. Hence we are able to develop a mathematical optimum for an organization or at least to have substantial knowledge--and so managerial control--of the service level of the organization.

One of the things that the empirical investigation attendant to this thesis did was to determine the waiting-line situation acceptable to several selected business organizations for several organic functions. A hypothetical organization model is shown to have a waiting-line characteristic for each function that is partly governed by the function characteristics as indicated by Figure 2, and partly by the number and efficiency of the organizational members (employees) that are

engaged in providing the service of their function as it is demanded.

If three factors are known, (a) optimum or acceptable queue length of demands for service on a function, (b) mean servicing time, and (c) mean number of arrivals per unit time, then for a given level of productivity it is possible to determine the organizational size necessary to that production level, through the determination of the number of employees that should be engaged by the organization for that production level.

> Many of management's scale-of-operations decisions involve a choice of the amount of facilities required to provide service, either to customers or to other departments of the company. The number of salesclerks, the number of repairmen, and the number of machine operators assigned to automatic machines fall into this category. A characteristic of such problems is that units to be serviced (customers or machies) arrive at random and require a random length of time for service. When arrivals occur faster than departures, a waiting-line, or queue, forms, hence the name given to this class of problems.
>
> There is a determinable cost associated with maintenance of each unit of servicing facilities and another cost (not always so determinable) associated with requiring the unit to wait in the waiting-line. The management problem is to choose that level of servicing facilities which will minimize total cost.
>
> The reason that waiting cost is not always determinable is that one cannot always predict the behavior of the waiting unit. For example, if Mrs. Jones must wait at the check-out counter of a chain grocery store, she may (1) not let it bother her, (2) fail to purchase groceries at this market on this particular day, or (3) stop trading at the store altogether. There are still other actions, such as influencing

are still other actions, such as influencing the trade of others. It is clear that assignment of cost of waiting in such cases is somewhat arbitrary.[1]

[1]Edward C. Bryant, Statistical Analysis (New York: McGraw-Hill, 1960), p. 272.

APPENDIX G

STATISTICAL BACKGROUND

Poisson Distribution

Computations of probability distributions that derive from the binomial probability distribution are frequently laborious. Probability problems in which the probability of occurrence of an event may be assumed to be constant may be solved by use of the familiar but complex binomial formula of quadratic algebra. A simple approximation called Poisson's Exponential Binomial Limit may be used to obtain any term of the binomial distribution.[1] In this distribution the probability of an occurrence is constant, and the occurrence is not dependent on what has happened precedent to any specific occurrence.

Exponential Distribution

Adjunct to discussion of the Poisson distribution is discussion of the exponential distribution. If it is of interest to consider the waiting-time until the first occurrence of an event, this waiting period has its own distribution known as an exponential distribution.[2] The exponential distribution is a special

---

[1]Eugene L. Grant, Statistical Quality Control (New York: McGraw-Hill, 1952), p. 209.

[2]For justification see Harold Bierman, Jr., Lawrence E. Fouraker, and Robert K. Jaedicke, Quantitative Analysis for Business Decisions (Homewood, Illinois: R. D. Irwin, 1961), p. 188.

case of a distribution known as the Gamma distribution that is occasioned if a process can be described by the Poisson distribution and only the time until the first occurrence is of concern.

APPENDIX H

MONTE CARLO--A SIMULATION METHOD

In cases where the irregular activity distribution is so complex that analytical techniques are not practical, queuing problems may be solved by one of the techniques of system simulation. One such technique is called the Monte Carlo method.

The Monte Carlo is a method of artificially producing "experience data" through use of a random number generating process. Through use of computers a large quantity of such data can be produced in a very brief period of time. This data becomes the artificially produced "empirical" solution to any queuing situation under investigation.

There occur a large number of occasions in statistical investigation when the mathematical form of the probability distribution is so complex that it cannot be analytically represented, or it is not worth the time to do so. Construction of a model by Monte Carlo is an answer. The greater the quantity of simulation data generated, the closer the model will come to describing the actual empirical case.

For a general discussion of the construction of the Monte Carlo model the reader is referred to basic texts in operations research listed in the Bibliography. Chapter IX describes the method and builds a model, the results of which are included in Appendices B, C, and D.

APPENDIX I

THE FINITE UNIVERSE FACTOR

This study makes use of the following rule, called the finite universe factor, for establishing for the purpose of the thesis the size of an "infinite" statistical universe.

> In the formula . . . the factor
>
> $$\frac{N - n}{N - 1}$$
>
> is called the finite universe factor. It is unimportant when the sample size is small relative to the size of the universe (which generally is the case in practice). For example, suppose the universe contains 100,000 people and the sample 2,000. Then
>
> $$\frac{N - n}{N - 1} = \frac{98,000}{99,999} = .9899$$
>
> which is almost equal to 1. Inasmuch as the finite universe factor has no effect on (the standard error of the mean) if it equals 1, there would be little harm done if it were omitted when it was very close to one, as is the case here. As a working rule, the factor may be omitted whenever the sample contains 10 per cent or less of the universe.[1]

---

[1]Earl K. Bowen, <u>Statistics</u> (Homewood, Illinois: R. D. Irwin, 1960), p. 365.

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