LAW ENFORCEMENT DISPATCH SYSTEMS OPERATIONS ANALYSIS

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1.0 INTRODUCTION

The purpose of this manual is to provide law enforcement agencies with simplified field proven techniques for the analysis and design of communications dispatching operations.

These analysis techniques, derived from queuing theory, have been successfully applied in over twenty law enforcement agencies throughout the United States. The techniques are presented through the use of look up graphs and tables so that the reader need not take time out to sharpen his mathematical skills beyond simple arithmetic, and may turn directly to the issues at hand.

The three fundamental dispatch system design issues treated are;

1. the number of incoming telephone lines (or number of trunk lines) required,
2. the number of telephone operators required, and,
3. the number of radio channels and/or dispatchers required.

These requirements are basically determined by communications traffic demands, personnel skill levels, and by desired system performance.

Determination of these basic requirements naturally provides for the further treatment of such important considerations as system response time measurement, utilization measurements, bottleneck identification, realistic performance standards, and round-the-clock and future staffing needs.

The manual is organized into six sections. Section 1 is the introduction. Section 2 defines the basic set of data required to carry out system performance analysis. Methodologies for acquiring this data are provided in Section 3. Section 4 then treats the actual system analysis procedures. Section 5 offers case sample problems utilizing techniques presented earlier. The last section, Section 6, discusses sources and limitations of the analytic approach.

2.0 DEFINITIONS OF REQUIRED DATA

This section defines basic data requirements to carry out the following analyses;

a. the number of telephone trunk lines required,

b. the number of Complaint Board Operators (CBOs) required,

c. the number of dispatchers required,

d. radio channel loading determination, and

e. a figure of merit for system response time.

The next section, Section 3, will discuss the actual measurement and data gathering techniques needed to acquire the data defined in this section.

To perform the above analyses, two classes of data are needed. The first class of data consists of direct measurements taken from present system operations. The second class of data consists of a set of performance goals that are specified as a matter of policy by agency management, (such as desired average citizen waiting time for telephone service, average channel waiting time, etc.). These data are determined basically by agency policy decisions and are hence referred to as Policy Data. Section 3.2 will discuss reasonable agency performance goals for this class of data.

2.1 MEASURED DATA DEFINITIONS

There are four types of data to be measured. They are;

a. the average and the peak number of incoming and outgoing telephone calls encountered at the dispatch center over a given period of time. The average call rate value shall be denoted as Nc (read as the Number of calls) and the peak call rate value denoted as Ncp (Number of calls, peak),

b. the average amount of time required to process a telephone call by a Complaint Board Operator (CBO) referred to as the mean or average CBO service time, and denoted by the abbreviation Tsc (read as Time for service, CBO),

c. the average number of radio transactions that take place over each radio channel over a given period of time. A radio transaction is defined as a complete functional interchange between the dispatcher and a field unit. Thus, a unit status transaction consists of at least two radio transmissions, e.g.,

"Adam 3, 10-8"

"Adam 3, 10-8, 10-4"

A dispatch transaction may typically involve four or five separate transmissions.(1) This

transaction rate value is denoted by Nt (read as Number dispatcher transactions).

d. the average amount of time required to process a radio transaction by a dispatcher, referred to as the mean dispatcher service time, and denoted by the abbreviation Tsd, (read as Time for service, dispatcher).

2.2 POLICY DATA DEFINITIONS

There are three types of data values related to desired agency performance goals that need to be determined by agency policy. These values impact both the number of trunk lines and personnel staffing required. The three are:

a. the probability that an incoming phone call may encounter a busy signal, such as 1 in 1000, or 1 in 10,000. This value shall be denoted as Pb, (Probability of busy). To clarify the meaning of Pb, suppose an agency had six incoming seven

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(1) The concept of the transaction is used in deriving average transaction service times and radio channel utilizations since a field officer will not normally break into an ongoing transaction as long as he can hear the ongoing transaction, and he does not consider his own need for channel access to be of a higher priority. This is typically the case, so that the analyses carried out in this manual considers that during a "transaction" the channel is "occupied". This approach leads to a more conservative but more realistic measure of channel utilization than the simple approach that measures transmitter "on-time".

digit emergency lines (or trunks). As long as the number of telephones in the community which the agency serves is greater then six, there exists a **distinct** possibility (or probability) that a caller may encounter a busy signal when calling in. Given that this probability exists, it is of course desirable to maintain it at some minimal level. Hence, to say, for example, that the probability of encountering a busy signal is 1 in 1000 (or Pb = 1/1000) means that if you were to pick up a phone in the community and randomly dial your agency 1,000 times, then 999 of the times you would not get a busy signal.

b. the average waiting time that an incoming caller is to wait before the phone is answered, that is, before call service begins, such as one ring, two rings, etc. This value is denoted as Twc (read as Time to wait for CBO).

c. the average utilization of each radio channel. Utilization is defined as the percentage of time that the radio channel is busy. A channel is considered busy throughout the entire period that a transaction (see footnote 1) is in progress. Over a given period of time, say one hour, (3600 seconds), the sum of transaction times in seconds

divided by 3600 gives the percentage of time the channel is busy, or the channel utilization for that single hour. Average channel utilization, U, is determined by multiplying the average number of radio transactions per second, Nt, by the average dispatcher service time in seconds, Tsd. By way of a simple example, suppose a radio channel had one transaction per hour and each transaction took 15 minutes on the average. Clearly, the average utilization would be .25. That is;

$$Nt = 1/3600 \text{ sec.} = .0002778 \text{ transactions per sec.}$$

and $$Tsd = 15 \text{ min.} \times 60 \text{ sec/min.} = 900 \text{ sec per transaction}$$

and $$U = Nt \times Tsd$$

or $$U = 1/3600 \times 900 = .25$$

These values are, of course, unrealistic but they serve to provide an intuitive example for what is meant by average utilization. For a more realistic example, assume a radio channel experiences 100 transaction per hour, or 100/3600 = .0278 transactions per second and that the average service time per transaction was 18 seconds, then, Nt = .0278 transactions per sec.

and Tsd = 18 seconds per transaction

thus: U = .0278 x 18 = .50

In this example, the channel is utilized 50 per cent of the time.

Table 2-1 provides a summary of the basic data set covered in this section required to perform a complete analysis of a dispatch system. The following section discusses how to acquire this data.

TABLE 2-1

BASIC SET OF DATA REQUIRED TO PERFORM DISPATCH SYSTEM ANALYSIS

ABBREVIATION	MEANING OF ABBREVIATION
Measured Data	
Nc	The average number of telephone calls entering and leaving the dispatch center per second
Tsc	The average CBO service time in seconds
Nt	The average number of transactions on a radio channel per second
Tsd	The average dispatcher service time per transaction in seconds
Policy Data	
Pb	The probability that an incoming call encounters a busy signal
Twc	The average waiting time for CBO service in seconds
U	The average utilization (or percentage of time busy) for each radio channel

3.0 DATA AQUISITION METHODS AND POLICY DATA STANDARDS

This section describes techniques for the gathering of required measured data types defined in Section 2. It also provides guidelines for the adoption of agency policies with regard to selection of policy data as defined in Section 2.2

3.1 DATA MEASUREMENT METHODS

3.1.1 TELEPHONE TRAFFIC MEASUREMENT

Telephone incoming and outgoing call rate statistics are best gathered by utilizing assistance from local telephone companies. Virtually all telephone companies can install call counting equipment for each line that the command and control center services. Of particular interest are CBO agency emergency lines (seven digit or 911 lines), administrative lines, and other phones that may be in place at the dispatcher console. As a minimum, call rate data on these phones must be acquired and indeed, is routinely gathered in the majority of agencies. It is less critical to gather data on phones that may be seldom used, such as animal control phones or community hot lines, however it is still desirable to gather this data as it does contribute a definite percentage to the total utilization of the personnel servicing them.

It is emphasized that simply because call rate counting equipment is intalled by a phone company, it does not automatically follow that the data provided by this method is entirely accurate. It has been found in numerous instances that such reports are less than accurate, and a method for checking their validity will be discussed in Section 3.1.2. In any case, it remains the best method.

It is not recommended that tally sheets be given to CBO's with the idea that they maintain a track of call rates. There are two distinct disadvantages to incorporating this scheme. First, an additional burden has been added to personnel whose utilizations we will be trying to measure and second, CBO's cannot be expected to maintain accurate statistics during periods when they are heavily loaded - periods in which there is the keenest interest in gathering accurate call rate information.

Call rate data should be organized to report hourly rates around-the-clock and throughout the year. Round-the-clock hourly call rate data will enable round-the-clock CBO staffing determination and data taken over a period of years will enable estimation of CBO staffing requirements in future years. This data is also critical in allowing an estimate to be made of peak call rates. The peak value will influence the number of trunk lines required.

3.1.2. MEAN CBO SERVICE TIME MEASUREMENT

The average amount of time that a CBO spends in processing a telephone call is best derived from agency tape record logs. The best method for extracting this data is to record selected hours from agency log tapes onto one hour cassette tapes. It is not necessary to select an absolute peak busy period for recording, but it is desirable to select a typically busy period from a recent months activity, for example a typical Friday or Saturday evening. This is true because the mean service time to process a call, which we shall estimate from this data, does not typically vary by any significant amount as call loads vary. CBO staffing requirements are influenced by both the CBO mean service time (which remains fairly constant) and the demand for service, or the call rate, which may vary considerably from hour to hour and day to day.

The methodology, then, is to record all phone activity at a single CBO station onto a cassette tape for a reasonably busy period. Start by recording one hour of telephone activity.

The next step is to replay the cassette tape and transcribe the voice data on a data sheet such as the one presented in Table 3.1. This data sheet is called the Radio/Telephone Voice Function Data Sheet and is the

TABLE 3.1
RADIO/TELEPHONE VOICE FUNCTION
DATA SHEET

AGENCY Aville P. D. TAPE DATE 6 Sept. 80

SUBJECT CBO No. 1 HOURS 2000 - 2100

BY J. Smith ANALYSIS DATE 10 Sept. 80

CALL TYPES:
D=dispatch; I=data base; C=case in prog.; S=status; A=admin/other

TAPE INDEX	DURATION (sec.)	IN	OUT	TYPE	REMARKS
035	35	x			Admin.
087	86	x			Robbery 5th and Main
122	47	x			Admin.
155	72	x			warrant status request
211	28		x		Admin.
346	90	x			Vacation notification
370	115		x		Warrant status call
465	109	x			415 Family
521	18	x			transfer - animal control
645	72	x			Auto accident report
663	20		x		Ambulence request
752	21	x			Admin.
					TOTAL CALLS = 12
					Tsc = 713/12 = 59 seconds

recommended form upon which to transcribe this data.

The tape index column refers to the cassette recorder index and is used to conveniently find specific calls for later replay is desired. The call origin and type are indicated in columns three, four and five when appropriate. A remarks column further aids the finding of a specific transaction on tape.

As stated earlier, the major function of this data sheet is to record CBO call durations from which mean service times can be calculated. The sheet is not intended to provide a record for detailed call handling analysis, although it can be useful for these purposes.

A stop watch is used to measure each call duration in seconds as it occurs and these durations are entered in the second column.

The Table heading indicates that the data was taken from 2000 to 2100 hours on September 6, 1980 at CBO station number 1, and that the data was extracted from the cassette recording and entered upon the data sheet by an analyst named J. Smith on September 10, 1980. The sample data sheet has a total of 12 entries over the one hour period.

The average service time, Tsc, for the CBO is calculated by adding up all the call duration entries in column two and dividing by the total number of entries, in this example 12. In the example given, the resulting value of Tsc is 59 seconds.

In agencies where more than one CBO station is implemented, tapes should ideally be analyzed for each station and the overall average service time calculated. If a large number of CBO stations exist, this can of course become cumbersome and one can avoid reducing such large volumes of data if he can gain confidence that his estimate of overall agency CBO average service time taken from just two or three one-hour CBO station tapes is reasonably close to the average that would result from reducing a larger number of CBO station tapes.

This confidence can be gained if it is seen from two or three CBO station tapes that the value for Tsc is in the area of 55 to 65 seconds. Average CBO service times much greater than 60 seconds usually imply that too much time is being spent in conversation with the public, and CBO service times of much less than 60 seconds on the average are seldom encountered in law enforcement telephone interaction with the general public. The question of CBO performance standards will be treated in more detail in Section 5.

Note that agency call rate data can also be estimated from these data sheets for both individual phone lines and the total of all lines. These values should be checked against call rate volumes for the same hours reported by phone

company installed call counters. If there is a discrepancy, your call count is the accurate one, and the phone company should be brought in to explain the difference.

3.1.3 MEAN RADIO TRANSACTION SERVICE TIME MEASUREMENT

The average amount of time that a dispatcher spends in processing a radio transaction is derived by utilizing the same basic procedure as that used to derive mean CBO service time.

A one-hour cassette tape should be made for each agency radio channel. As in the case for the CBO station, the Radio/Telephone Voice Function Data Sheet is used. A stop watch is used to measure the time duration in seconds for each transaction as defined in Section 2 and this data for each transaction is entered in column two of the data sheet. Table 3.2 provides an example of a filled out data sheet for a radio dispatch channel.

In this example the total number of transactions for the hour was 19 and the average service time, Tsd, which is calculated by summing all the time entries in column two and dividing by the total number of transactions for the hour is 16 seconds. Average dispatcher radio transaction service time, Tsd, can be expected to typically fall within the range of 11 to 18 seconds.

TABLE 3.2
RADIO/TELEPHONE VOICE FUNCTION
DATA SHEET

AGENCY Aville P.D. TAPE DATE 6 Sept. 80

SUBJECT Dispatch Ch. No. 1 HOURS 2000 - 2100

BY J. Smith ANALYSIS DATE 10 Sept. 80

CALL TYPES:
D=dispatch; I=data base; C=case in prog.; S=status; A=admin/other

TAPE INDEX	DURATION (sec.)	IN	OUT	TYPE	REMARKS
050	6	x		S	101 10-8
101	24		x	D	105 211 5th & Main
130	32	x		C	105 repeat discription
194	4	x		S	104 10-8
256	6	x		C	105 10-97
310	23	x		I	101 10-28
360	18	x		D	102 backup 105
401	23		x	A	107 10-20?
425	15		x	I	101 No wants/warrants
480	29	x		D	106 415 Family
502	3	x		C	106 10-97
572	5	x		S	105 code 4 10-8
580	31	x		I	104 10-27,28
608	4	x		S	101 10-7
654	35	x		D	105 T.A. cover
658	4	x		S	102 10-8
705	6		x	S	102 repeat 10-8
784	4	x		S	106 10-8
802	24	x		I	104 10-27,28 response
					TOTAL TRANSACTIONS = 19
					Tsd = 296/19 = 15.6 = 16 sec.

Values for Tsd that are much in excess of 18 seconds can generally be attributed to too much time being spent in communicating with field units (i.e. inefficient communication procedure practice) or may be due to an excessive number of repeats caused by a radio channel with poor quality of communication. Specific causes can usually be spotted by examination of these data sheets.

In carrying out this data extraction process from dispatch tapes, the analyst will find that it is more difficult to measure individual radio transaction processing times than individual CBO call processing times. This is because it is possible to have two radio transactions taking place at once. For example, a short status transaction may be imbedded in a longer transaction with a different field unit. Also, because radio procedures are not always strictly adhered to, there may be times when transactions are not properly terminated.

In these cases, the analyst must make a best judgement of what is considered to be a realistic duration measurement for each transaction that takes place. For large data samples, the effect of individual measurements will not be critical. In any case, experience in these matters is quickly gained after a few hours of tape data reduction.

3.1.4 RADIO TRANSACTION TRAFFIC MEASUREMENT

Note that the cassette recordings used for determination of CBO mean service time, Tsc, and dispatcher mean service time, Tsd, were recorded on the same hour on the same day; in our examples September 6, 1980 from 2000 to 2100 hours. It is important to do this as this information provides a method to relate the amount of radio traffic for a given radio channel to total CBO telephone traffic. For example, suppose that the total number of CBO calls (incoming and outgoing) at all CBO stations for one hour were 40 and for the same hour the total number of radio transactions on one of the radio channels, say channel 1, were 100. We would use this data, then, to estimate that the amount of transaction traffic on channel 1 is 100/40 or 2.5 times the total CBO call traffic. Despite the fact that some radio traffic is field generated, this method of estimating radio traffic based on telephone traffic appears to be adequate.

We thus have a method for estimating radio transaction volume for each channel as a function of CBO call volumes that are derived from telephone company installed call rate counters (see Section 3.1.1). Since the number of fixed radio channel resources required by an agency is related to the peak radio transaction demand,

we use this approach to estimate peak radio transaction demand from the measured peak phone call rate. This methodology for estimating radio traffic loads is sufficiently accurate to provide data for channel resource and staffing estimates discussed in Section 4.

3.2 PERFORMANCE DATA STANDARDS

3.2.1 PROBABILITY OF A BUSY SIGNAL

As a rule, a sufficient number of telephone trunk lines should be utilized for law enforcement emergency call purposes to insure that the probability of a caller encountering a busy signal, Pb, is at least as small as 1 call in 1000. It is not uncommon in emergency systems that sufficient trunk lines are employed such the Pb is 1 in 10,000.

It is recommended that when carrying out the analysis procedures outlined in Section 4, that telephone call systems should be designed with Pb small enough so that no more than 1 call in 1000 encounters a busy signal. This is considered to be a minimum performance design point.

3.2.2 AVERAGE CBO WAITING TIME

Once a caller succeeds in obtaining an emergency line (that is, once the phone begins to ring at the agency) a waiting time before the phone is answered by a CBO will be encountered. This average waiting time, as defined in Section 2, is denoted as Twc.

In keeping with performance levels routinely achieved by law enforcement agencies throughout the United States, it is recommended that Twc should not exceed 6 seconds. Given the general rule that most phones ring for about 2 seconds, followed by a silent period of approximately 4 seconds, etc., this 6 second average waiting time criteria equates to a CBO answering a ringing phone just prior to the second ring on the average. This level of performance is considered good practice. An agency designing for an average waiting time much less than 6 seconds will find rapidly increasing costs in CBO staffing requirements. Agencies designing for average wait times in excess of 6 seconds will find an increase in occasional incidents where waiting times for specific calls to be serviced are excessive.

3.2.3 AVERAGE RADIO CHANNEL UTILIZATION

For a given radio channel, the average channel utilization, U, is determined by multiplying the average number of radio transactions per second on the channel, Nt, by the mean service time per transaction in seconds, Tsd.

For example, suppose a given channel experienced an average transaction rate of 90 transactions per hour, or 90/3600 = .025 transactions per second, (Nt = .025),

and suppose the mean service time per transaction was determined to be 15 seconds, (Tsd = 15). Then the average radio channel utilization would be:

$$U = Nt \times Tsd = .025 \times 15 = .375$$

or approximately 38%

As stated in Section 3.1.3, values for Tsd should fall within a range of 11 to 18 seconds. Radio channel mean transaction times of less than 11 seconds are seldom encountered, and values for Tsd greater than 18 seconds are almost always due either to inefficient or inconsistent radio procedures, or due to a high number of "repeats" attributable to poor radio coverage - or a combination of the above.

Thus, a measurement for Tsd, following the procedures outlined in Section 3.1.3, that results in a radio transaction mean service time of greater than 18 seconds should be interpreted as a warning that performance can be improved.

The value determined for channel utilization, U, is a critical value for it has a dramatic effect on average waiting time for channel access. The same average waiting time for channel access is experienced by the dispatcher and his/her field units, since they are both using the same resource.

Table 3.3 shows the effect of an increasing channel utilization on average channel waiting time for three different values of Tsd of 12, 15 and 18 seconds. (The formula given at the bottom of Table 3.3 can be used to calculate the values entered in the table, or other values if desired).

In the example given above, an average transaction rate of 90 per hour (Nt = .025) and a Tsd of 15 seconds resulted in an average utilization, U, of .38.

Table 3.3 indicates that the resulting average waiting time for channel access for these values would be approximately 9 seconds (that is, slightly under the 10 second value shown for Tsd = 15 and U = .40).

The table clearly shows the dramatic increase in average channel access waiting time as U increases, or putting it another way, as the average transaction rate increases for a given transaction mean service time.

Note that reasonable average channel access waiting times are experienced for values of U around .30 and .40. It should be born in mind that these are average values, so that a system designed for a value of U = .40 will still experience peak utilization values of .80 if we adopt the guideline that peak transaction rates are approximately two times average transaction rates.

TABLE 3.3

AVERAGE WAITING TIMES (in seconds) FOR RADIO CHANNEL ACCESS FOR THREE MEAN SERVICE TIMES AS CHANNEL UTILIZATION INCREASES

UTILIZATION (U)	Tsd=12	Tsd=15	Tsd=18
.10	1.3	1.6	2.0
.20	3.0	3.8	4.5
.30	5.1	6.4	7.7
.40	8.0	10.0	12.0
.50	12.0	15.0	18.0
.60	18.0	22.5	27.0
.70	28.0	35.0	42.0
.80	48.0	60.0	72.0
.90	108.0	135.0	162.0

NOTE: The formula used to produce this table is;

Average channel wait time = U x Tsd / (1 - U)

Example: For Tsd = 12, and U = .30 ,

Average channel wait time is

$$\frac{.30 \times 12}{1 - .30} = \frac{3.6}{.70} = 5.1 \text{ sec.}$$

Thus, it is recommended that radio channel resources be allocated such that the average utilization does not exceed .30, so that at peak transaction rates the value for U is approximately .60.

It is very common in law enforcement agencies, that average channel utilizations are found to be in the .40 to .50 range, and sometimes higher. The consequences at peak transaction rates are evident from Table 3.3.

It is recognized that obtaining additional radio channels is often quite difficult. Sometimes, radio channel utilization problems can be alleviated by balancing transaction loads through redefining districts. If districts are fairly evenly loaded and average utilization values are greater than .40 on each channel, it should be interpreted as an immediate need to initiate a new radio plan.

4.0 DATA ANALYSIS

This section presents the methodology for making use of the basic data types outlined in Section 3 to determine telephone trunk line requirements, CBO staffing requirements, dispatcher staffing requirements and estimates of total command and control center throughput capability.

4.1 DETERMINING THE NUMBER OF TELEPHONE TRUNK LINES REQUIRED

The number of telephone trunk lines required is determined by;

a. The peak number of incoming and outgoing telephone calls encountered by the agency per second. This value is referred to as Ncp (see Sections 2.1 and 3.1.1).

b. The average amount of time required to process a telephone call by a CBO. This value is referred to as Tsc . (Sections 2.1 and 3.1.2).

c. The desired design point for the probability that an incoming call will encounter a busy signal. This value is referred to as Pb (see Sections 2.2 and 3.2.1).

Given this data, the number of trunk lines required is determined by first calculating the units of trunk work load and then using Figure 4.1 to find the solution, as described below.

The value for units of trunk work load is simply found by multiplying the peak call rate (Ncp) by the average CBO service time (Tsc). Thus the units of work load = Ncp x Tsc.

By way of example, assume data measurements were carried out using the techniques discussed in Section 3 that resulted in a peak agency call load of 25 calls per hour and an average CBO service time of 40 seconds.

Then, the peak number of calls per second, Ncp, is;

Ncp = 25/3600 = .007 calls per second

(3600 seconds per hour)

The value for units of work load is then calculated by;

Units of Work Load = .007 x 40 = .28

Suppose, also, that the agency wished to use a sufficient number of trunk lines so that the probability of a caller encountering a busy signal, Pb, was to be 1 call in 1000. This would result in a probability of busy, Pb, equal to ;

Pb = 1/1000 = .001

or, in terms of percentages, .1 % of the calls would encounter a busy signal.

FIG. 4-1

NUMBER OF TRUNK LINES

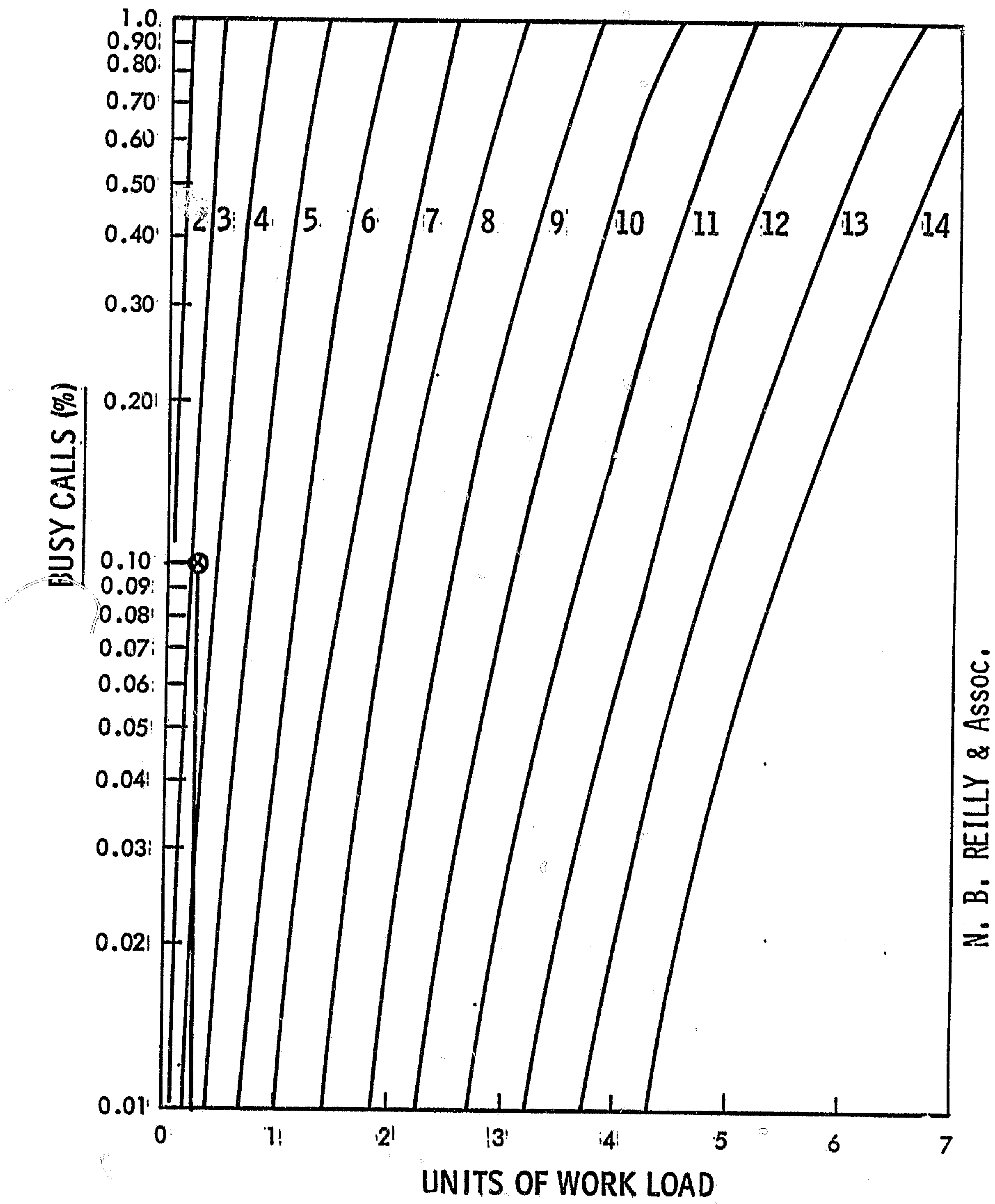

Figure 4.1 is now used to find the intersection point for units of work load equal to .28 and a busy call percentage of .1%. This intersection point, indicated by an encircled cross, lies between the figure curves that represent 3 and 4 trunk lines. The next value to the right of the intersecting point, in this case 4, is the value that should be selected. Thus, it is determined for this example that 4 trunk lines are required.

Note that if a Pb value of 1 in 10,000 was desired, then;

Pb = 1/10,000 = .001

for a percentage of .01, and 5 trunk lines would be required.

For a second example, the reader can now verify that for a call rate of 120 calls per hour and a CBO service time of 50 seconds, and a desired probability of busy equal to 1 call in 10,000, that 9 trunk lines would be required (Ncp = .033 and busy call percentage = .01).

4.2 DETERMINING CBO STAFFING

The number of CBOs required is determined by;

a. The average number of phone calls handled by the agency per second by all CBOs, both incoming and outgoing. This value is denoted by Nc (see Sections 2.1 and 3.1.1)

b. The average amount of time required to process a telephone call by the CBO. This value is

denoted by Tsc, the same value used in the trunk line calculation (see Sections 2.1 and 3.1.2)

c. The desired design point for average waiting time a caller will experience before CBO service begins. This value is referred to as Twc (see Sections 2.2 and 3.2.2)

With this data the number of CBOs required is determined by first calculating the CBO units of work load and the CBO units of delay, as described below, and then using Figure 4.2 to find the solution.

The CBO units of work load is simply found by multiplying the average call rate for the entire agency (Nc) by the average CBO service time (Tsc). Thus,

CBO Units of Work Load = Nc x Tsc

The units of delay is calculated by dividing the average CBO waiting time design value (Twc) by the average CBO service time (Tsc). Thus,

CBO Units of Delay = Twc / Tsc

By way of example, suppose data measurements were carried out using the techniques illustrated in Section 3 that resulted in an average call load of 62 calls per hour, and an average CBO service time of 35 seconds.

Then the average number of calls per second, Nc, is

Nc = 62 / 3600 = .017 calls per second

(3600 seconds per hour)

FIG. 4-2

COMPLAINT BOARD OPERATOR POSITION DESIGN

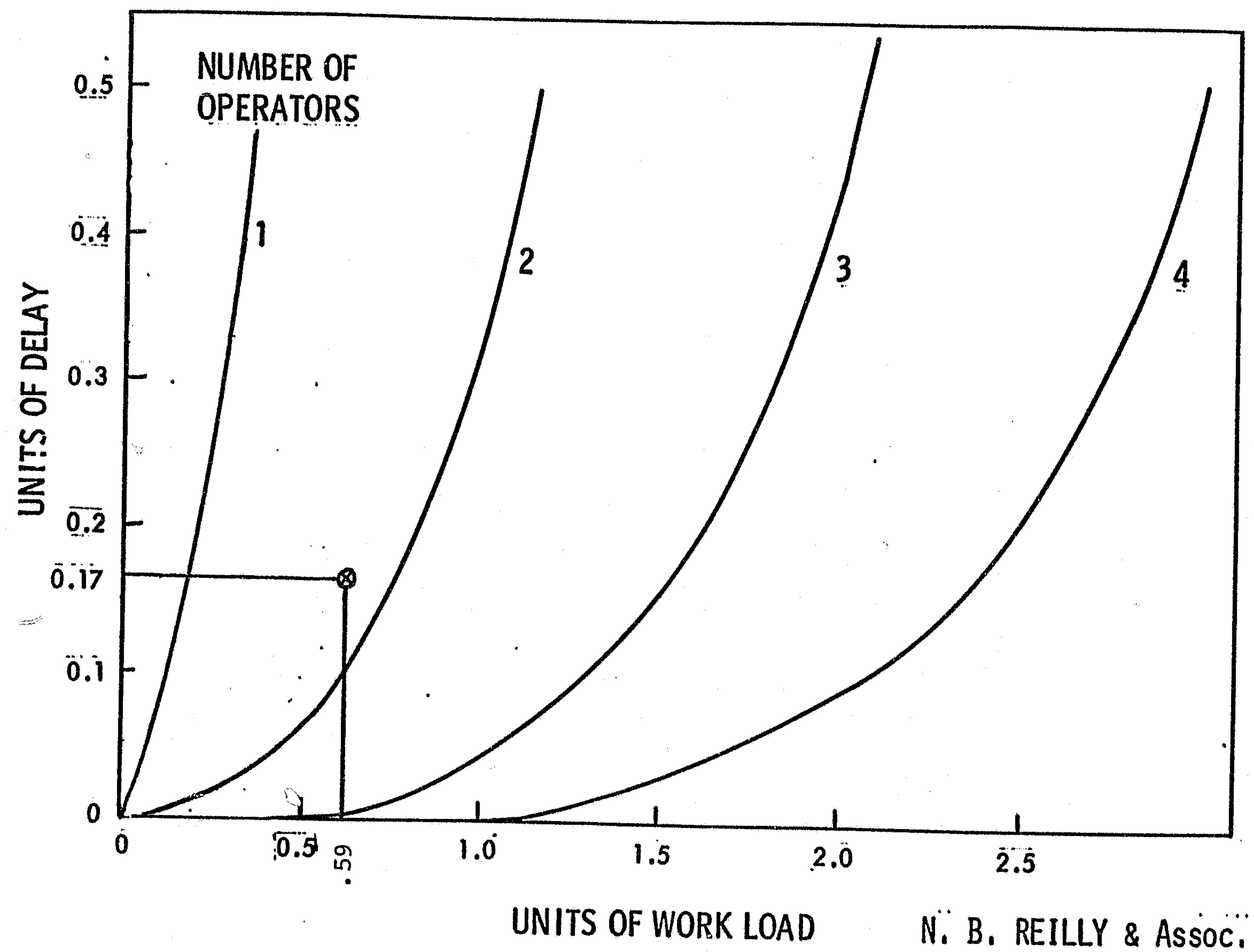

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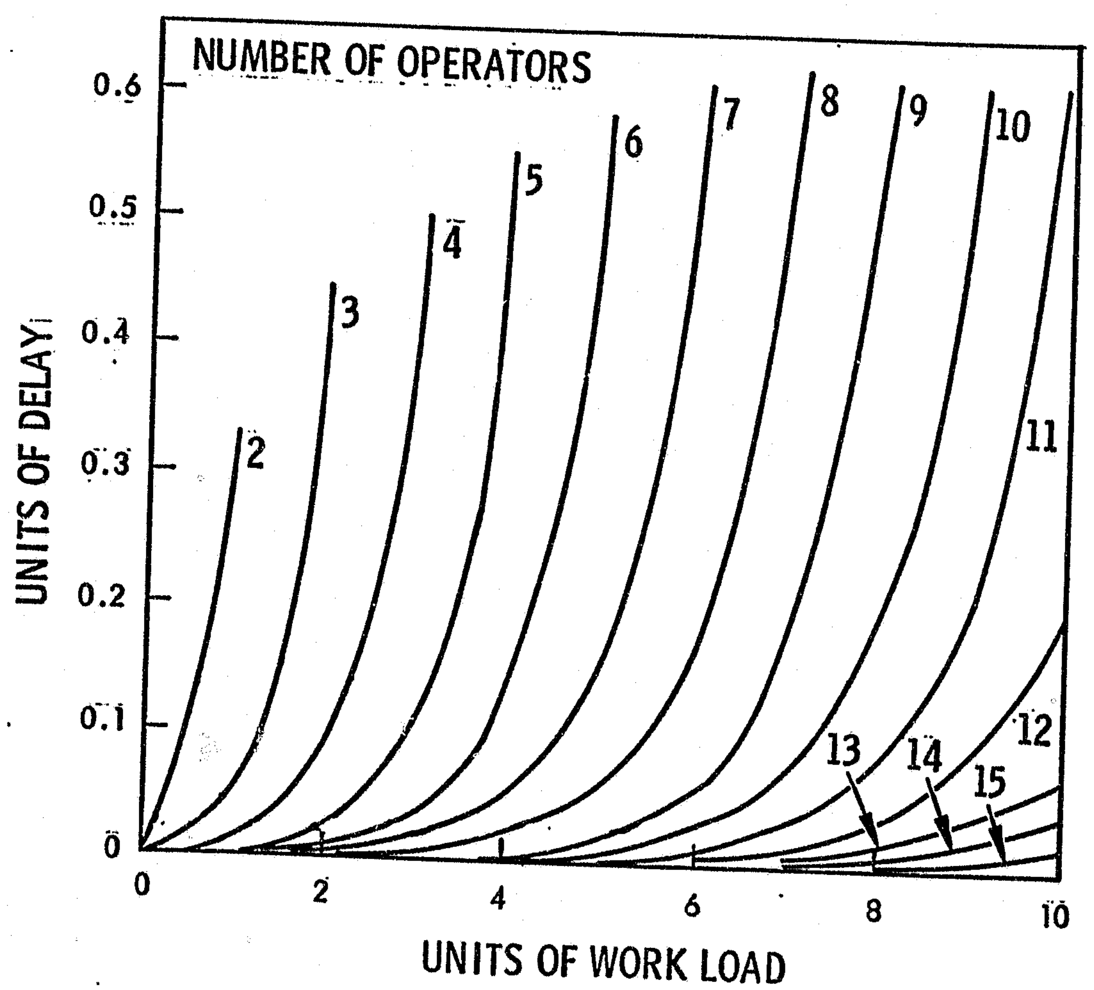
FIG 4-3

COMPLAINT BOARD OPERATOR POSITION DESIGN



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The CBO mean service time, Tsc, does not vary significantly from busy periods to slack periods. Thus, if call rate data values, Nc, are gathered on an hourly basis, the above procedure can be used to estimate staffing requirements on a round-the-clock basis. If call rates vary significantly by day-of-week or season, the same techniques can be applied at these times of interest. Therefore, once we have measured Tsc and arrived at a policy value for Twc, we need only to apply varying values of Nc to determine staffing value requirements as a function of time-of-day, etc. Thus, round-the-clock call rate data is an important and key statistic to gather.

The technique can also be used to estimate at what time points in the future increases in staffing will be required if future call rates can be predicted from past years data.

4.3 DETERMINING DISPATCHER STAFFING

The total number of dispatchers required by an agency is determined by;

a. The average number of radio transactions that the agency handles per second. This value

is determined by summing the average number of radio transaction on each channel, (see Section 2.1).

b. The average amount of time required to process a radio transaction or the average service time per transaction per second, referred to as Tsd, (see Section 2.1 and 3.1.3).

The basic consideration that determines the number of dispatchers required is channel utilization, U, and its effect on average channel waiting time. In Section 3.2.3 it was stated that it is desirable to maintain U on a given channel at less than .40, and preferably nearer to .30.

The analysis can be approached in various ways. Beginning with a simple example, consider an agency with a single radio channel. Suppose we estimated an average number of radio transactions per hour at 75 using the technique outlined in Section 3.1.4, and we measured the dispatcher mean service time at 15 seconds.

Thus;

$$Nt = 75 / 3600 = .021$$

(3600 seconds per hour)

and

$$Tsd = 15 \text{ seconds}$$

From Section 3.2.3, the channel utilization, U, is given by;

U = Nt x Tsd

or

U = .021 x 15 = .32

We see the channel utilization is less than .40. Also note that from Table 3.3 for Tsd = 15 seconds and U slightly greater than .30, the resulting average channel waiting time that can be expected is slightly greater than 6.4 seconds - or approximately 7 seconds. Thus, we would determine that one dispatcher is sufficient for the present system.

Suppose, however, we estimated the hourly transaction rate at 130, that is, suppose the channel were more heavily loaded. In this case;

Nt = 130 / 3600 = .036

and for Tsd = 15, the utilization is

U = .036 x 15 = .54

For these values, Table 3.3 shows an average channel waiting time in excess of 15 seconds. This is not considered satisfactory and we conclude that the agency needs two dispatchers, thus the agency requires two dispatch channels.

Ideally, the new channel would enable the division

of the transaction load evenly between the two channels. If this were the case, the transaction load of 130 per hour on one channel would be reduced to 65 transactions per hour on each channel on the average. For each channel, then, the new transaction rate per second would be;

Nt = 65 / 3600 = .018

and with Tsd still = 15 seconds

the utilization per channel would be;

U = .018 x 15 = .27

Again, from Table 3.3, the average channel waiting time is now estimated at less than 6.4 seconds per channel. It is recommended that average channel waiting time does not exceed 10 seconds as a maximum. In the present example the design is satisfactory with two channels and provides system growth capacity as well.

This approach assumed that the mean service time estimate is valid for all dispatchers. Values for Tsd for experienced dispatchers and those still in training may vary and if there is some question as to whether values for Tsd may vary among your dispatchers, then Tsd should be measured for each of them and the appropriate values used to determine resulting channel utilizations for each.

Some agencies employ a separate channel for the handling of vehicle stops (wants/warrants, vehicle/license checks, etc.) The mean service time for this type of channel will not be the same as for a main dispatch channel because the call mix is different. Average service times on these channels may be expected to run in the 20 to 30 second area.

In any case, a knowledge of the average number of transactions per second and the average service time per transaction is required to estimate utilization and its effect upon average channel waiting time.

4.4 ESTIMATING SYSTEM RESPONSE TIME

The average system response time is simply the sum of average waiting and service times through the system. For the purposes of dispatch center analysis, the system response time is measured as the time interval from the time that an incoming phone line begins to ring and the time that a dispatch is completed - assuming that a field unit is available. Of course, field units are not always available, but patrol force allocation represents a separate design problem and involves a separate queuing analysis not treated in this manual.

It is also recognized that incoming phone calls

that result in dispatches are usually prioritized and that the more urgent calls naturally move through the system faster than the sum of average waiting and service times for all calls would suggest.

Consideration of the total average response time, then, really only has meaning as a kind of figure of merit. It is, however, very useful in helping to pinpoint specific areas that need design improvements by isolating those particular components that lead to an excessive figure of merit.

In Section 3.2, performance standards were discussed. These "standards" are based upon observation of over 20 law enforcement agencies throughout the United States and represent waiting time and service time values that are routinely achieved in many agencies independent of whether they are CAD or manual systems.

The average values presented in Table 4.1 for each component of the system lead to an overall figure of merit for system response time of 100 seconds. Any of the values shown in the table can be adjusted slightly. The point is that if a system response time is estimated that exceeds approximately 100 seconds, then improvements are probably possible. The approach also helps to pinpoint the specific components that lead to an excessive figure of merit.

TABLE 4.1

COMPONENT CONTRIBUTING TO
SYSTEM RESPONSE TIME

COMPONENT	TIME (sec.)
Average wait time for CBO	6
CBO average service time	60
CBO to dispatcher transmittal	8
Average channel wait time	8
Average radio transaction service time	18
TOTAL	100 seconds

When excessive times are associated with particular components, improvements in performance may be realized either through improving procedures or improving equipment resources - or a combination of both. Table 4.2 indicates possible causes of excessive waiting or service times associated with each component.

Each of the causes depicted in Table 4.2 can be directly related to either a traffic load (Nc or Nt) or to a service time. Thus, impacts of specific proposed system component improvements can be analyzed in advance by identifying those improvements with specific traffic load reductions and/or service time reductions, and making use of the design techniques presented earlier in Section 4.

TABLE 4.2

POSSIBLE CAUSES OF EXCESSIVE QUEUE TIMES BY DISPATCH CENTER COMPONENT

COMPONENT	CAUSE(S)
Excessive CBO wait time	1. Insufficient CBOs on duty 2. Excessive CBO service time
Excessive CBO service time	1. CBO call handling procedures
Excessive CBO to dispatcher transmittal	1. Slow belt 2. Inefficient manual handling
Excessive channel wait time	1. High channel utilization 2. Long radio transaction time
Excessive radio transaction time	1. Poor radio procedures 2. Poor radio channel

5.0 SAMPLE CASE STUDIES

This Section provides two sample case studies designed to make use of and clarify the analysis techniques presented in this manual.

5.1 SAMPLE CASE 1

The Aville P.D. currently has eight telephone trunk lines into the agency consisting of eight seven-digit numbers (125-3330 through 125-3337). The agency also has two CBOs on duty during the peak hour. The call load is distributed to the CBOs evenly. Two dispatchers are utilized - one on each of two main dispatch channels - channels A and B.

During peak hours the CBOs seem heavily loaded and the supervisor is complaining that she needs to spend too much time backing up as a CBO. Also, field officers on channel A have been complaining lately about channel congestion, citing numerous instances when they were caused to wait too long to get on the air.

You set about investigating the situation. The first thing you do is tape both CBOs and dispatchers on cassette tapes recorded from the agency log tapes. You select what you believe to be a busy hour. You then listen to the tapes and measure the time duration of each

CBO call and dispatch transactions.

The data that results from one of the CBO tapes is shown in Table 5-1. There are 36 calls shown for the hour 2000-2100 on 6 September 1980. For both CBOs the total call load for the hour was 72.

The average CBO service time is determined by adding up the 36 values and dividing by 36. The value for Tsc is thus determined to be 60 sec.

After performing a similar data reduction on channels A and B you find that there were 110 radio transactions on channel A between 2000 and 2100 and 70 on channel B.

The average service time per transaction for the dispatchers is then calculated and you find they are both approximately the same - 16 seconds.

We now have all the measured data that is required as follows:

$$Nc = \frac{72}{3600} = .02 \text{ calls per sec.}$$

$$Tsc = 60 \text{ seconds}$$

Channel A $$Nt = \frac{110}{3600} = .03 \text{ transactions per sec.}$$

Channel B $$Nt = \frac{70}{3600} = .02 \text{ transactions per sec.}$$

$$Tsd = 16 \text{ seconds}$$

TABLE 5.1
RADIO/TELEPHONE VOICE FUNCTION
DATA SHEET

AGENCY Aville P. D. TAPE DATE 6 Sept. 80

SUBJECT CBO No. 1 HOURS 2000 - 2100

BY J. Smith ANALYSIS DATE 10 Sept. 80

CALL TYPES:
D=dispatch; I=data base; C=case in prog.; S=status; A=admin/other

TAPE INDEX	DURATION (sec.)	IN	OUT	TYPE	REMARKS
010	35	x			Admin.
025	86	x			459 5th and Main
041	47	x			Admin.
062	72	x			Warrant Status Request
108	28	x			Admin.
120	90	x			Vacation notification
135	115		x		Warrant Status Call
180	109	x			415 Family
195	18	x			Transfer Animal Control
210	72	x			Auto Accident Report
230	20		x		Ambulance Request
242	21	x			Admin.
258	34	x			Admin.
310	9	x			Transfer
350	63	x			415 Children
362	47	x			Court Question
375	85	x			Ambulance Follow Up
390	27	x			Fire - Transfer
405	73	x			Vehicle Blocking Drive
423	105		x		Warrant Status Call
430	152	x			Deranged Citizen

TABLE 5.1 (cont.)
RADIO/TELEPHONE VOICE FUNCTION
DATA SHEET

AGENCY Aville P. D. TAPE DATE 6 Sept. 80

SUBJECT CBO No. 1 HOURS 2000 - 2100

BY J. Smith ANALYSIS DATE 10 Sept. 80

CALL TYPES:
D=dispatch; I=data base; C=case in prog.; S=status; A=admin/other

TAPE INDEX	DURATION (sec.)	IN	OUT	TYPE	REMARKS
445	80	x			211 9th and Broadway
472	28	x			Admin.
482	54		x		Admin.
500	75	x			Officer Location Request
510	92	x			415 Children (repeat)
523	35	x			Dept. Transfer
564	90	x			211 (second call)
571	47	x			Admin.
590	63	x			Admin.
600	25	x			Dept. Transfer
620	82	x			Personnel Roster
631	34		x		Admin.
662	75		x		Officer Location Callback
720	48	x			Admin.
752	30	x			Dept. Transfer

Next you confer with management with regard to their desired performance goals. These goals involve the desired probability that an incoming call receives a busy signal (Pb), the average waiting time for CBO service (Twc) and the channel utilization goal (U).

You decide to design to the following goals:

Pb is at least 1 in 10,000

Twc = 6 seconds

U = .40 per channel

The value of U = .40 is determined by estimating from Table 3.3 that for a Tsd of 16 seconds, the average channel wait time would be approximately 11 seconds.

Number of Trunk Lines Required

The number of trunk lines required is determined by using Figure 4.1. The required percent of busy calls is:

$$\frac{1}{10,000} = .0001 \text{ or } .01 \%$$

You have determined that 72 calls per hour came into the agency at what you consider to be a peak hour. For 72 calls per hour as a peak call rate, Ncp, and a Tsc of 60 seconds, the units of workload are given by (see Section 4.1):

$$\text{Units of workload} = \text{Ncp} \times \text{Tsc}$$

$$= \frac{72}{3600} \times 60 = 1.2$$

From Figure 3-1, for units of workload equal to 1.2 and the busy call percentage equal to .01 we see that eight trunk lines are sufficient.

However, you notice that if the value for work units were to increase a small amount to about 1.4 then an additional line would be required (125-3338). You are interested, therefore, in determining at what peak hourly call load would this ninth line be required. This can be determined by using the following equation:

$$Ncp = \frac{(\text{units of workload}) \times 3600}{Tsc}$$

Thus, for units of workload equal to 1.4 and Tsc = 60 seconds:

$$Ncp = \frac{1.4 \times 3600}{60} = 84 \text{ calls per hour}$$

You similarly determine from Figure 4-1 that a tenth line will be required when the units of workload reach approximately 1.8. The hourly call rate at this point would be:

$$Ncp = \frac{1.8 \times 3600}{60} = 108 \text{ calls per hour}$$

You thus conclude that the agency is very close to requiring a ninth line if the desire to maintain a probability of busy at 1 call in 10,000 is to be maintained. As a result, you recommend that a new line be added now.

Number of CBOs Required

The number of CBOs required is determined by using Figure 4-2.

At a call rate of 72 per hour it was determined that the units of workload are 1.2 for a CBO Tsc value of 60 seconds.

The agency has specified that the average wait time for CBO service is to be 6 seconds (before the second phone ring).

From Section 4.2, you determine the CBO units of delay from:

$$\text{Units of Delay} = \frac{Twc}{Tsc} = \frac{6}{60} = .10$$

Using Figure 4-2 with units of workload equal to 2.1 and units of delay equal to .10 it is seen that three CBOs are required. It is clear now why the supervisor is complaining during peak periods. You recommend addition of a third CBO at peak periods.

Channel Utilization and Dispatcher Analysis

During the busy period during which measurements were made, the transaction rate on channel A was estimated at .03 per second, and .02 per second on channel B. Both dispatchers exhibited a similar average transaction service time of 16 seconds. Channel utilization for channels A and B are estimated as follows using the formula:

$$U = Nt \times Tsd$$

Thus:

Channel A $U = .03 \times 16 = .48$

Channel B $U = .02 \times 16 = .32$

Reference to Table 3-3 shows that for U = .48 and Tsc = 16 the average channel wait time would be just under 16 seconds. The estimate of channel A waiting time justifies the field complaints.

The average waiting time on Channel B however, is estimated from Table 3-3 with U = .32 and Tsd = 16 at approximately 7 seconds.

You observe that if the total radio transaction load of 180 transactions per hour was more evenly divided between the two channels, then the waiting time on channel A may be reduced.

Suppose the channels were evenly loaded so that each channel carried 90 transactions per hour. Then:

$$U = \frac{90}{3600} \times 16 = .40$$

Again, from Table 3-3 this would result in an average waiting time on each channel of approximately 11 seconds.

Note that the waiting time can be estimated more closely by using the formula given at the bottom of Table 3-3. Thus:

$$\text{Average channel wait time} = \frac{U \times Tsd}{(1-U)}$$

which in our example becomes:

$$\frac{.40 \times 16}{(1-.4)} = \frac{6.4}{.60} = 10.7$$

This waiting time meets your design criteria. Your recommendation, then, is to look into reassignment of district lines to attempt to even out channel loading. But you also realize that as traffic grows over the next few years, even this system will be taxed. Redistricting then, is really only a temporary solution, and negotiations for a new channel should be initiated. You recognize it will take time and may be difficult to get a new channel allocated. But you decide to start now and use your analysis to support your application.

Table 5-2 summarizes your findings.

TABLE 5-2

PRESENT AND RECOMMENDED SYSTEMS
AT PEAK CALL LOADS

ITEM	PRESENT SYSTEM	RECOMMENDED SYSTEM
No. of trunks	8	9
No. of CBOs	2	3
No. of channels	2	2*

* institute redistricting and initiate new channel acquisition.

5.2 SAMPLE CASE 2

In sample case 1 an understanding of the present Aville P.D. dispatch system performance was gained and justifications for specific recommendations to effect performance improvements resulted from the analysis.

However, the analysis was carried out only after CBO supervisor and field officer complaints were registered.

The Aville P.D. now desires to use the same analysis techniques to provide some visability as to when future system changes may be required.

After analyzing past records of incoming call rates and radio transaction rates, you estimate future traffic growth at 10% per year.

A work sheet based on Table 5-3 is set up to carry out requirements predictions.

In the upper portion of the table design criteria and measured values based on SAMPLE CASE 1 are entered to be used in the calculations that follow. In the main table itself, values that denote 10% increases per year in calls per hour and radio transactions per hour are entered in columns two and seven respectively for

TABLE 5-3

FIVE YEAR RESOURCE REQUIREMENTS

BUSY PERIOD PREDICTIONS

Pb = 1/10,000 Tsc = 60 Tsd = 16 Twc = 6 U = .40

CBO units of delay = .10

YEAR	CALLS FOR SERVICE PER/HR	Nc	CBO UNITS OF WORK LOAD	NO. TRUNKS REQ'D	NO. CBOs REQ'D	RADIO TRANS-ACTION PER/HR	Nt	U (TOTAL)	No. CHANNEL/ DISPATCH-ERS REQUIRED
1980	80	.022	1.3	8	3	180	.050	.8	2
1981	88	.024	1.4	8	4	198	.055	.88	3
1982	97	.027	1.6	9	4	218	.061	.98	3
1983	107	.030	1.8	10	4	240	.067	1.07	3
1984	118	.033	2.0	10	4	264	.073	1.17	3
1985	130	.036	2.2	10	5	290	.081	1.30	4

the years denoted in column one. These values are next divided by 3600 to yield values for Nc and Nt entered in columns three and eight.

Next, values are entered in column four for CBO units of workload by multiplying each yearly value for Nc by Tsc (60 sec.).

With these yearly values for CBO units of workload and the appropriate values given in the upper portion of the table, yearly requirements for the number of trunklines and the number of CBOs can be determined using Figs. 4-1 and 4-2.

Similarly, the total utilization for all channels can be calculated for each year by multiplying appropriate Nt values by Tsd (16 sec.) These total utilization values entered in column nine are then divided down until the utilization is less than or equal to .40. The resulting value is entered in column ten and represents the number of approximately evenly loaded radio channels required.

In this manner, the agency now has an increased visability as to the timing of future requirements. Of course, traffic level growths should be closely monitored over the coming years in order to refine such

predictions. But even this simple exercise helps to provide insight into the sequence of funding requirements that will arise in the future.

6.0 SOURCE AND LIMITATIONS OF THE ANALYTIC APPROACH

The analytic approach presented in this manual is based on queuing theory. In particular, the design graph used for trunk line determination, Fig. 4-1, is a graphical solution of the Erland B distribution which provides the probability of busy for queues in which customers leave the queue when service is not available. The design graph in Fig. 4-2 is derived from the average waiting time for multiple server queues in which the probability of all servers being busy is given by the Erland C distribution.

The interested reader is directed to Chapters 30 and 31 of "Systems Analysis for Data Transmission," by James Martin and published by Prentice-Hall in 1972.

The design graphs of Figure 4-1 and 4-2 are based on certain assumptions which are listed below along with comments on the applicability of the assumptions to dispatching operations.

Assumption	Applicability
1. Requests for service arrive in a random manner.	This assumption is generally true.
2. Preference is not given to functions with shorter service times.	Generally true.
3. Dispatching is on a first-in first-out basis.	True when dispatcher loading is not excessive.
4. Requests for service are not neglected (i.e. no items leave the queue).	Generally true.
5. The standard deviation of service times is less than or equal to the average service time (ts).	Generally true. A correction may be necessary if this is not the case.

Assumptions 1 through 4 will usually apply to law enforcement dispatching operations. They are listed here for completeness and so that the analyst may be aware of their existence. Assumption 5 is usually true, but the analyst should calculate the standard deviation of service times to verify the validity of the assumption.

END