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A HYBRID CHANNEL ASSIGNMENT SCHEME FOR CELLULAR, HIGH-CAPACITY, LAND-MOBILE RADIO COMMUNICATIONS SYSTEMS WITH ERLANG-C SERVICE

by

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Submitted to The School of Graduate Studies
in partial fulfillment of the requirements
for the degree of Master of Applied Science.

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April 1979

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LIST OF ABBREVIATIONS AND SYMBOLS

BCC	Blocked-Calls-Cleared (Erlang-B) Service Discipline
BCD	Blocked-Calls-Delayed (Erlang-C) Service Discipline
BCH	Blocked-Calls-Held Service Discipline
CNR	Carrier-to Noise Ratio
DCAS	Dynamic Channel Assignment Scheme
DDD	Direct Distance Dialing
ESS	Electronic Switching System
FCAS	Fixed Channel Assignment Scheme
FCC	Federal Communication Commission
FIFO	First In First Out Queueing Discipline
FM	Frequency Modulation
HCAS	Hybrid Channel Assignment Scheme
ICG	Interference Cell Group
MCA	Metropolitan Coverage Area
MSO	Mobile Switching Office
MSQ	Mean Square Borrowing Strategy
MTS	Mobile Telephone Service
NN	Nearest Neighbour Borrowing Strategy
NN+k	Nearest Neighbour + k Borrowing Strategy
SIR	Signal-to-Interference Ratio
SNR	Signal-to-Noise Ratio
SS	Spread Spectrum Technique
SSB-AM	Single-Sideband Amplitude Modulation

A	Constant
B	Distance between a base-station and a mobile
B_0	Distance Normalizing factor
C	Normalized system cost
a,b,c	Cost indices
D	Distance between 2 base-stations reusing the same channel
d	Average number of dynamic channels per cell
f	Average number of fixed channels per cell
f_m	Random FM
I	Number of cochannel interferers
K	Normalized variable cost
L	Number of base-stations
M	Average number of channels per cell
m	Average number of channels per cell after channel partitioning
N	Minimum required number of channel sets
$\frac{N_0}{2}$	Power spectral density of additive white gaussian noise
n	Number of cells using the same channel
P	Power of the transmitted signal
P_B	Blocking probability for BCC discipline
P_C	Probability of queueing for BCD discipline
P_H	Probability of blocking for BCH discipline

P_i	Radiated power of the i^{th} cochannel interfer
P_r	Probability density of received signal power
P_s	Probability density of Rayleigh Distribution
Q	System throughput
q_i	Probability that a blocked call in cell i will be re-attempted at a later time
R	Cell radius
r_0	Mean of Rayleigh Distribution
S	Actual mean received signal power
T	Total number of available radio channels
V	Vehicle velocity
W	Audio bandwidth
Z	Number of cells in the interference cell group
γ	Minimum reuse distance
τ	Wavelength of transmitted signal
Ω	Attenuation factor
Γ	Constant
β	Modulation index
λ	Mean call attempt (arrival) rate
$\frac{1}{\mu}$	Mean call holding time
ρ	Channel utilization factor

ABSTRACT

This thesis presents a simulation study of a cellular, high-capacity, land-mobile radio communication system using the Hybrid Channel Assignment Scheme, a mixture of the Fixed and the Dynamic Channel Assignment Schemes, for Erlang-C service. The performance of this system in regard to the probability of queueing, the average queueing time and the average number of queued calls is evaluated from the results obtained and compared with that of the systems employing either the Fixed or the Dynamic Channel Assignment Scheme for the same type of service. The Hybrid Scheme is shown to yield better overall performance, for low to moderate traffic loadings, than the other two channel assignment schemes.

ACKNOWLEDGEMENTS

The author wishes to express his deepest gratitude to Dr. N.D. Georganas, his thesis supervisor, for his continued support and invaluable guidance throughout the course of the work of this thesis.

Appreciations and thanks are also expressed to Mr. R. LeHenaff, Mr. T.J. Kahwa and other graduate students for their assistance and moral support.

The financial assistance provided by the National Research Council of Canada and the Ontario Graduate Scholarship Committee in the form of Post graduate Scholarships is gratefully acknowledged.

CHAPTER 1

INTRODUCTION

The prominent advantages offered by mobile radio communications have aroused tremendous increase from both the public and private sectors of the societies around the world, especially the ones in North America and Japan. In fact, the demand for mobile radio services has enormously increased in the past two decades and is expected to continue at a growth rate of 15% per annum [11, 12, 25]. Nevertheless, the increasing demand for mobile radio communication services which include mobile telephone service (MTS), dispatch service and mobile data service has fed back a severe problem of frequency spectrum congestion. The spectrum congestion problem complicates matters in the design of mobile radio communications systems and has to be solved urgently.

To cope with the growing demand for mobile radio services and simultaneously alleviate the problem of spectrum congestion, one has to efficiently utilize the frequency spectrum allocated. The following techniques [2, 18, 19, 26, 27] have been proposed or used to achieve the desired objective of increasing the channel occupancy:

(a) Bandwidth Reduction

The bandwidth of a channel can be reduced to make room for more channels in a given frequency spectrum. However the channel bandwidth cannot be continuously reduced without degradations to the channel performance.

(b) Diversity or Pooling

Mobile transceivers are given access to many frequencies any one of which can be used if the others are busy. Service will be denied when all accessible frequencies are used.

(c) Cellular Structures

The desired service area is devided into non-overlapping zones or cells with a base station in each cell responsible for radio coverage within the zone.

(d) Spread Spectrum Techniques (SS)

The information signal is 'spread', prior to transmission, by a suitably chosen timing function over a bandwidth considerally larger than that of the modulated carrier. Upon reception, the spread signal is 'de-spread' by the multiplication by the exact replica of the spreading function at the transmitter to restore the original signal.

(e) Single-Sideband Modulation (SSB)

The idea is to use single-sideband amplitude modulation (SSB-AM) with amplitude and/or frequency compandor. The amplitude as well as the frequencies of the voice signal are compressed, in baseband, prior to transmission and expanded at the receiver. This technique yields a considerable reduction in both required power and bandwidth for transmission.

Among those prospective solutions to the spectrum congestion problem the cellular structure is highly favoured. In fact it has been considered of such importance that the Federal Communication Commission (FCC) in the U.S.A. has allocated a 75 MHz bandwidth in the 800 MHz band to the common-carriers in the states who would adopt the cellular structure to provide the public with mobile radio communication services. Out of the 75 MHz, 64 MHz is allocated for land-mobile telephone service with the remaining 11 MHz reserved for air-ground service, [12]. Developmental cellular systems have been put into operation in Chicago and Tokyo by the AT & T and Nippon companies respectively .

The cellular-structured mobile radio systems designers have had to find suitable solutions to some problems associated with the implementation of a fully operational system. The problems are identified to be as follows:

(1) the channel assignment technique;

(2) the mobiles identification and location monitoring;

(3) the switching plan between the Mobile Switching Office (MSO) and the base-stations; communication between (a) base-stations (b) mobiles and base-stations;

(4) the interconnection between the MSO and the DDD network;

(5) the proper radio equipments used in mobiles, as well as in the base-stations in regard to the required power and performance;

(6) the type of modulation used.

This thesis focuses on the problem of assigning radio frequency channels to the cells in a cellular-structured, high-capacity land-mobile radio communications system, since channel assignment is a critical issue in the design of such a system, affecting both system capacity and equipment design. Different channel assignment schemes documented in literature [1, 4-12, 14-18, 22-27] are presented along with their performance. In particular, a Hybrid Channel Assignment Scheme which is an amalgamation of the Fixed and the Dynamic Channel Assignment techniques and has been shown to give better spectrum utilization than the two amalgamated techniques for Erlang-B service [18] is discussed. A simulation study on the performance of a cellular high-capacity land-mobile radio system adopting the Hybrid Channel Assignment technique for Erlang-C service is presented.

In chapter 2 various terms; e.g. offered traffic, Erlangs, call holding time and grade of service are introduced. The Erlang-B and Erlang-C as well as the Blocked-Calls-Held service disciplines are discussed in Sec. 2-2, and the corresponding queueing models assuming a fixed number of servers are presented.

Chapter 3 is devoted to the summary of the basic concepts, system considerations and system performance characteristics of a cellular-structured radio system, based on the material documented in the literature on mobile radio communications.

We consider various channel assignment schemes in chapter 4. The two basic channel assignment techniques namely the Fixed and the Dynamic schemes are presented in sections 4-2 and 4-3 respectively. Section 4-4 concentrates on the Hybrid Channel Assignment Scheme whose performance with Erlang-B service discipline is also presented there.

The main part of this thesis lies on the simulation study of a cellular high-capacity land-mobile radio system using the Hybrid Channel Assignment Scheme for Erlang-C service. A description of the system simulated is given in chapter 5 and the associated assumptions are given in Sec. 5-1. Section 5-2 is reserved for a detailed description of the simulation flow-chart.

The simulation results regarding the performance of the system are presented in chapter 6. Section 6-2 considers the probability of queueing, while Sec 6-3 is devoted to performance from the point of view of queueing times. The performance on the average number of queued calls is presented in Sec.6-4 while the last section details the respective performance of the Hybrid scheme for Erlang-B and Erlang-C service.

Chapter 7 embodies the conclusions and remarks. A detailed GPSS flow chart of the simulation model, as well as the computer program, are included in the Appendices.

CHAPTER 2

TRAFFIC CONSIDERATIONS

2.1 Introduction

The traffic study is a well-established discipline in telephone engineering. Thus the term traffic used throughout the context of this thesis refers to telephone traffic rather than vehicular traffic.

Telephone calls are initiated by individual customers in a way that fits in their daily habits or in the conduct of their business. Thus customers' calls follow a varying pattern throughout the day with a peak demand occuring during the busy hour. Thus, sufficient facilities (trunks or radio channels) are needed to handle the time varying traffic especially in the busy hour. The basic factors involved in the provision of sufficient facilities are the call attempt rate, the call duration (holding) time, the number of channels and the grade of service.

The product of the first two forementioned factors is called as the offered traffic, which denotes the amount of time that a quantity of customers desires the use of facilities. The offered traffic is usually expressed in terms of Erlangs. An Erlang is the amount of traffic one trunk (channel) can handle in one hour if it is occupied all the time, in other words, 3600 call-seconds of traffic.

The time period in which a call fully occupies a channel is the call duration (holding) time. It comprises principally the actual conversation time and relatively small time intervals necessary for the set-up of the dedicated communication circuit between the two conversing parties. In a land-telephone network the call holding times are found to follow the negative-exponential distribution. Mobile telephone and dispatch calls are expected to have a similar distribution for their holding times [27].

Grade of service may be described in terms of either the probability of blocking (or queueing) — that is, the probability that all available channels (trunks) are busy, or the average delay encountered by the calls.

It is of general practice to assume that customers place their calls randomly and independently of each other. This assumption, however, is not strictly valid because when two customers are conversing their ability to originate calls independently is restricted. Nevertheless, in ordinary telephone network calls are found to be initiated randomly. Because of this random placement of calls and the large number of subscribers, the call initiation is a Poisson process with the inter-arrival times obeying the negative-exponential distribution. Mobile radio systems are expected to have a similar call arrival pattern. Furthermore it is also assumed that each customer over a long period of time offers the same total number of Erlangs as every other customer. Obviously the individual customer calling rate varies widely, however the average call attempt rate is used. Under this assumption, the probability that at any moment of time any particular customer will be using the telephone is then a constant.

2.2 Telephone Traffic Formulae

The disposition of the calls finding all channels busy (these calls are termed as the blocked calls from here on) depends on a number of things such as the equipment available and the habits of the caller. There are two extremes in the disposition of the blocked calls namely the Blocked-Calls-Cleared (BCC) and the Blocked-Calls-Delayed (BCD) discipline. In between these two extreme cases there is an intermediate one known as the Blocked-Calls-Held (BCH) discipline [17,20].

Probability theory together with queueing theory, enables the derivation of the traffic formulae relating the offered traffic, the number of channels and the grade of service for the three service disciplines mentioned above.

2.2.1 Blocked-Calls-Cleared (Erlang-B) Discipline

With this service discipline the blocked calls are immediately cleared from the system and no further considerations will be taken for their return in the same period, say the busy hour.

The BCC discipline can be modelled by the M/M/m/m queueing situation shown in Fig 2.1 in which there are m identical servers (channels) each having identical service times (call holding time) governed by the negative-exponential distribution with a mean of $\frac{1}{\mu}$ sec, and the calls are arriving in a Poisson fashion with a mean arrival rate of λ calls/hr.. Arrivals which occur when a channel is idle are served immediately. An arrival that occurs when all channels are busy is blocked, leaves the system and does not return.

The utilization factor (channel occupancy) ρ for the model shown in Fig. 2.1 is given by

$$\rho = \frac{\lambda(\frac{1}{\mu})}{3600\,m} \qquad (2\text{-}1)$$

or

$$m\rho = \frac{\lambda/\mu}{3600} = \text{offered load in Erlangs.}$$

The probability of blocking (the probability that all channels are busy) is given by the Erlang-B formula:

$$P_B = \frac{\frac{(m\rho)^m}{m!}}{\sum_{k=0}^{m} \frac{(m\rho)^k}{k!}} \qquad (2\text{-}2)$$

The above formula is well tabulated in [20]. Since no queue is allowed to form in the Erlang-B model, the average queueing delay is thus zero.

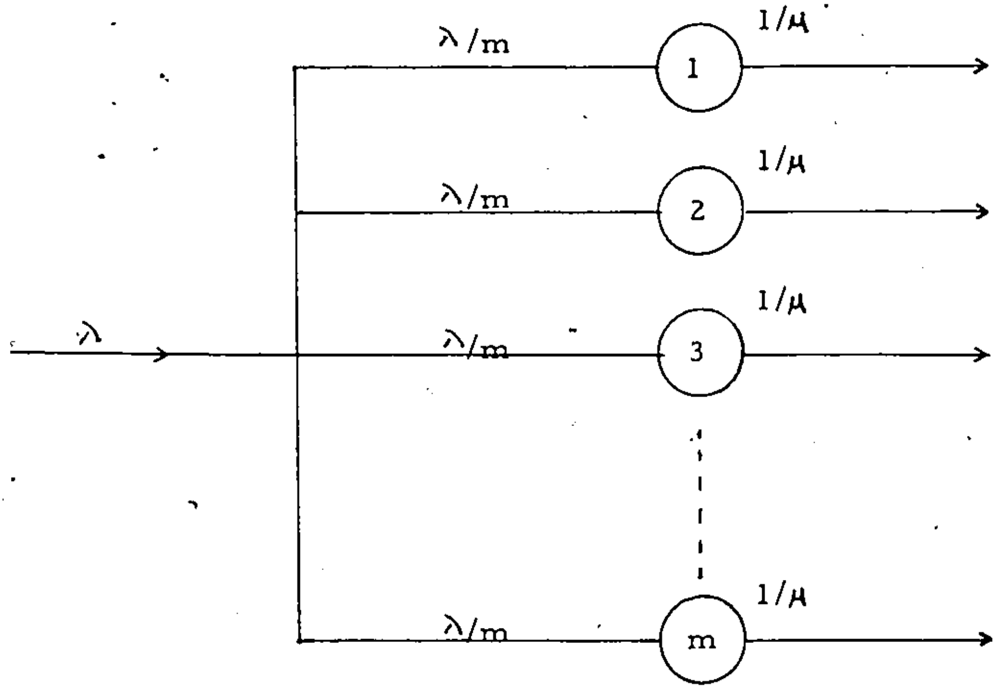


Fig. 2.1 A Queueing Model For The BCC Service Discipline.

2.2-2 Blocked-Calls-Delayed (Erlang-C) Discipline

Calls on finding no idle channel wait in suspense until one becomes free, at which time the channel is seized and occupied for the full call duration time. This discipline, blocked-calls-delayed, is the basis of the Erlang-C formula for obtaining the probability of queueing - that is, the probability that calls are denied for immediate service and have to queue up for a channel to become free.

The BCD discipline can be modelled by a M/M/m/∞ queueing situation shown in Fig 2.2. This queueing model consists of m servers having identical service times (call duration times) governed by the negative-exponential distribution with a mean of $1/\mu$ sec and call arrivals that occur according to a Poisson process with a mean arrival rate of λ calls/hr.. Furthermore the queue is of unlimited size. Calls arriving to find an idle channel (server) receive immediate service. Calls arriving when all servers are busy, queue up in the order of arrival (FIFO). If a server becomes free, when calls are waiting, the server will be seized by the call at the head of the queue and occupied for the full holding time.

However, two cases arise in the BCD model, and they are shown in the figures 2.2a and 2.2b.

Fig 2.2a depicts the situation where the calls have no preferred servers, that is, they are served by the

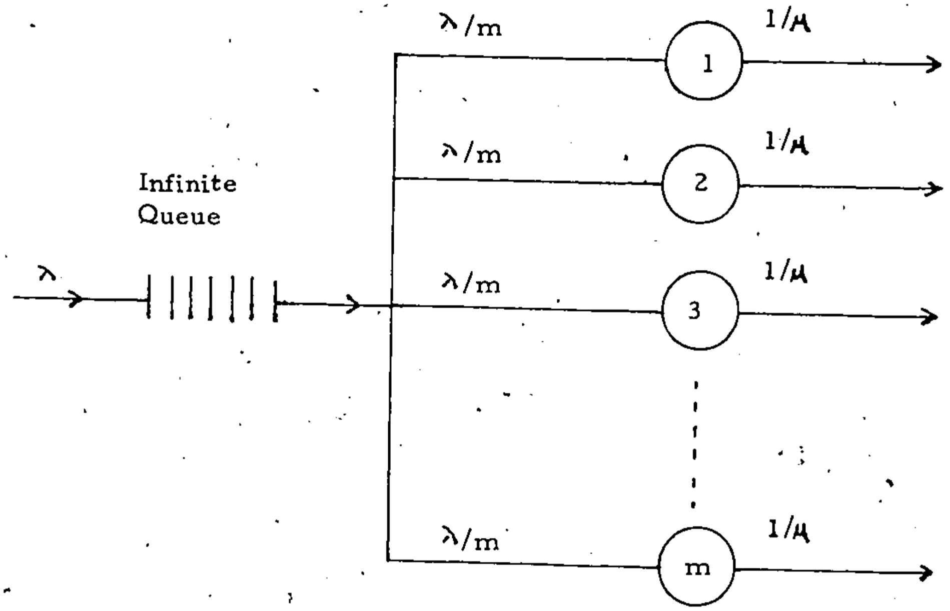


Fig. 2.2a A Multi-Server Queue With m Servers.

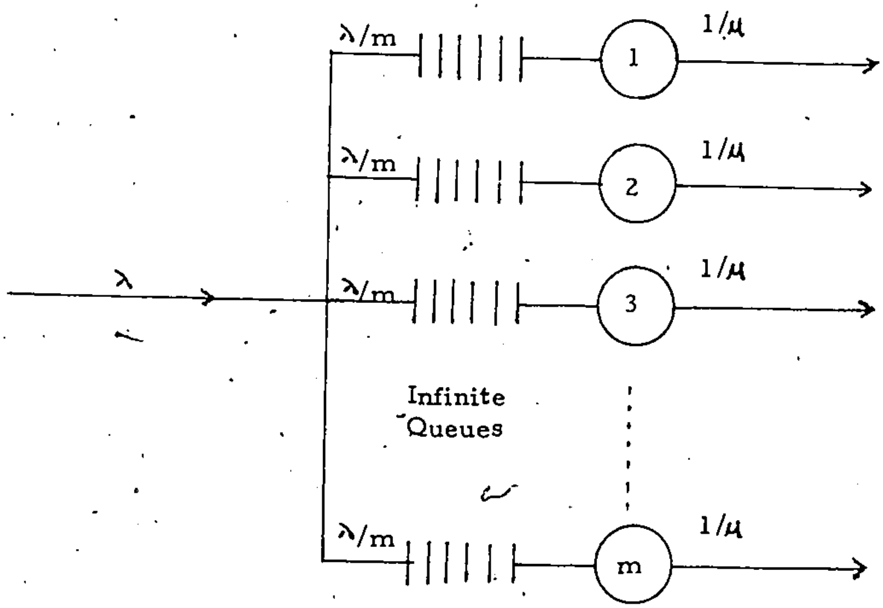


Fig. 2.2b m Single-Server Queues In Parallel.

first server whoever becomes available. In the queueing model shown in Fig 2.2b, the calls are to be served by their predetermined servers. The queueing time in the latter case is found to be greater than if the calls were able to choose the first server who became free [20].

The two queueing models shown above assume the same call characteristics. Once again the utilization factor of each server is given by

$$\rho = \frac{\lambda/\mu}{3600\,m} \qquad (2\text{-}3)$$

and the probability of queueing, for the model in Fig. 2.2a is given by the Erlang-C formula as

$$P_c = \frac{1 - \left[\dfrac{\sum_{k=0}^{m-1} \dfrac{(m\rho)^k}{k!}}{\sum_{k=0}^{m} \dfrac{(m\rho)^k}{k!}}\right]}{1 - \rho\left[\dfrac{\sum_{k=0}^{m-1} \dfrac{(m\rho)^k}{k!}}{\sum_{k=0}^{m} \dfrac{(m\rho)^k}{k!}}\right]} \qquad (2\text{-}4)$$

It is noteworthy to remark that in the Erlang-C (BCD) model no calls leave the system without receiving service from a channel. Thus the probability of blocking is zero. However, the blocked calls being allowed to wait in the system generate a non-zero average queueing delay.

2.2-3 Blocked-Calls-Held (BCH) discipline

In such a system calls arriving to find an idle channel are immediatley served. If the calls occur when all channels are busy they will remain in the system for one full call duration time. If a channel becomes available during the holding time, a waiting call will seize the channel for the remainder of the call holding time. If after one full duration time has elapsed and there is still no idle channel available, then a waiting call will leave the system.

With the same assumptions concerning the call arrivals pattern and the service times distribution as in the previous two disciplines, the probability of blocking is given by [17].

$$P_H = \sum_{k=m}^{\infty} \frac{(m\rho)^k}{k!} e^{-m\rho} \qquad (2\text{-}5)$$

where m is the number of servers and ρ the utilization factor of each server as given by equation (2-1).

The way in which the blocked calls are disposed has different influences on the probability that all channels are found busy. In the BCC model, the blocked calls do not occupy a channel and thus for a given load the probability of all channels found busy is the lowest among the three disciplines. When the blocked calls are held, they occaupy some channel time. If the probability of no idle channel is low, the blocked calls occupy nearly the full holding time. In the BCD model, the blocked calls are allowed to wait in the system and occupy the full duration time. Hence the probability of all channels being occupied is the higheat of the three disciplines. The current mobile telephone service is more likely described by the Erlang-B model while dispatch service is closer to the BCD discipline.

The Erlang-B model adopted in current mobile telephone service causes a lot of calls to be rejected when the system is heavily loaded. However, better service can be provided to the subscribers if calls, on finding no channels available at their times of initiation are allowed to stay in the system awaiting service by an idle channel. The callers on queue will be notified as soon as idle channels are available.

The Erlang-C (BCD) discipline was considered in the simulation model presented in this thesis because of the above fact.

CHAPTER 3

CELLULAR-STRUCTURED MOBILE RADIO SYSTEMS

3.1 Introduction

Most of the early mobile radio communications systems adoped the Global coverage concept, [2,17] and the conventional FM modulation technique. In this type of large radio coverage area system a high power base station antenna was usually mounted on the higheat mountain or building within the proposed service area in order to 'cover' the largest area possible.Since it was impractical to transmit the same power from the mobile units, additional receivers had to be distributed within the area to service mobile-to-base link in low-signal regions. Furthermore, due to some large terrain obstructions like hills, tunnels or buildings there are 'holes' in the radio coverage from the high base-station antenna. Eventually, secondary transmitters and antennas had to be installed to fill in some of the coverage holes. However this solution created the problem of coverage overlapping as shown in Fig. 3.1, because of frequency beats between the signals from the different transmitters. In addition, careful equalization of delay in the baseband circuits to the different transmitters was required to keep distortion at acceptable levels.

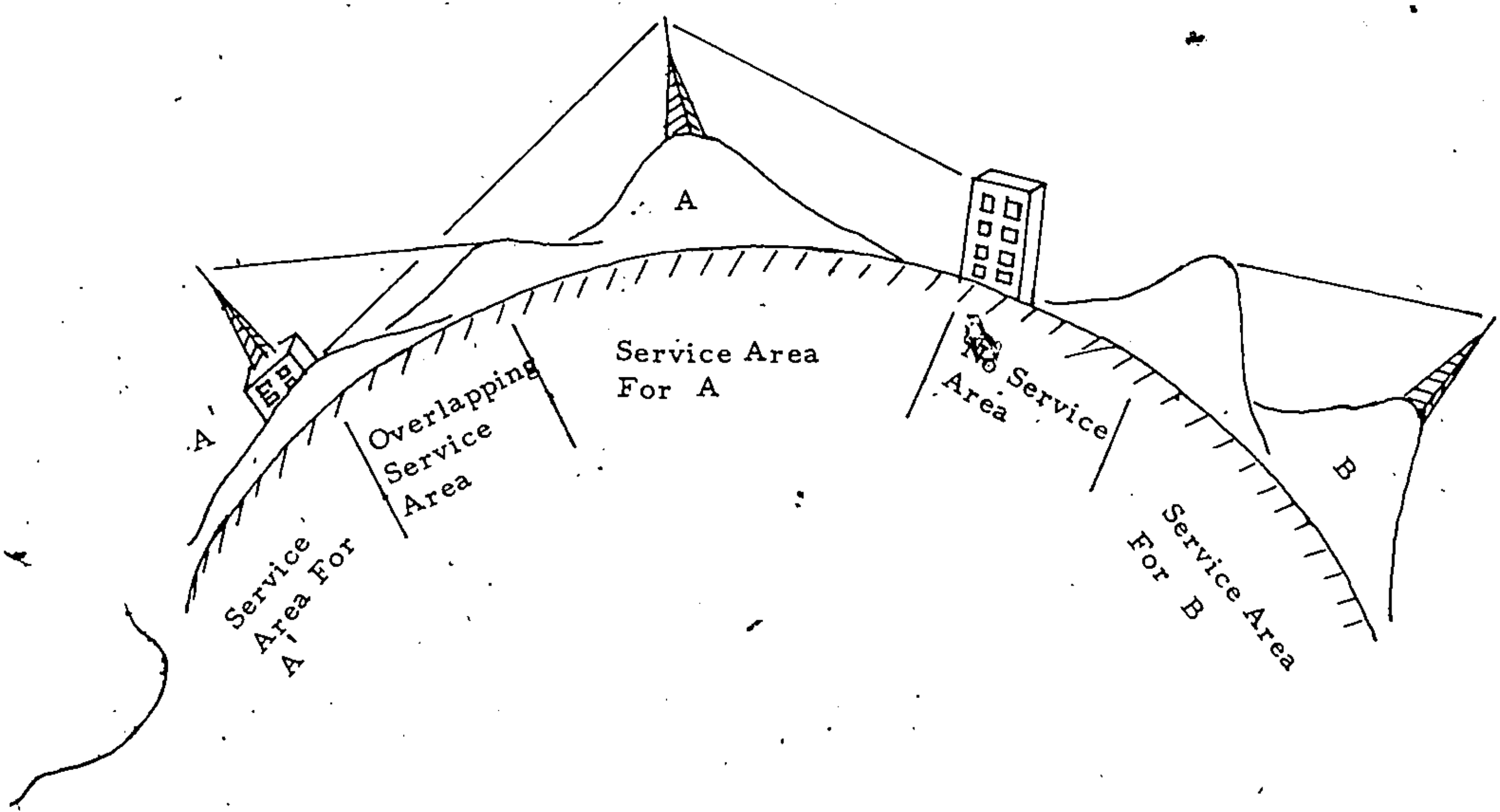


Fig. 3.1 A Global Coverage Radio System.

The global coverage system is found to be unable to meet the increasing demand for radio service because in addition to the shortcomings mentioned above channels are generally non-reusable within the service area. High-capacity mobile radio systems designers of today highly favour the cellular structure which is believed to be able to solve the channel shortage crisis and simultaneously cope with the rising demand for mobile radio service [2,5,10,14,23].

3.2 Cellular Concept

3.2-1 Basic Concept

In cellular-structured systems the entire service area is divided into non-overlapping zones or cells. A base-station equipped with a omnidirection antenna is located in each cell. A high gain antenna is not required as the base station is responsible to provide radio coverage to the mobiles within the small zone only. The base-stations are connected via land lines to the Mobile Switching Office (MSO) which is in turn connected to the DDD network via land facilities as shown in Fig. 3.2. The MSO is equipped with an Electronic Switching System (ESS) with special data terminals, trunking facilities and an unique program to achieve the required extensive centralized coordination and control to properly administer base station assignments, channel assignments and re-assignments

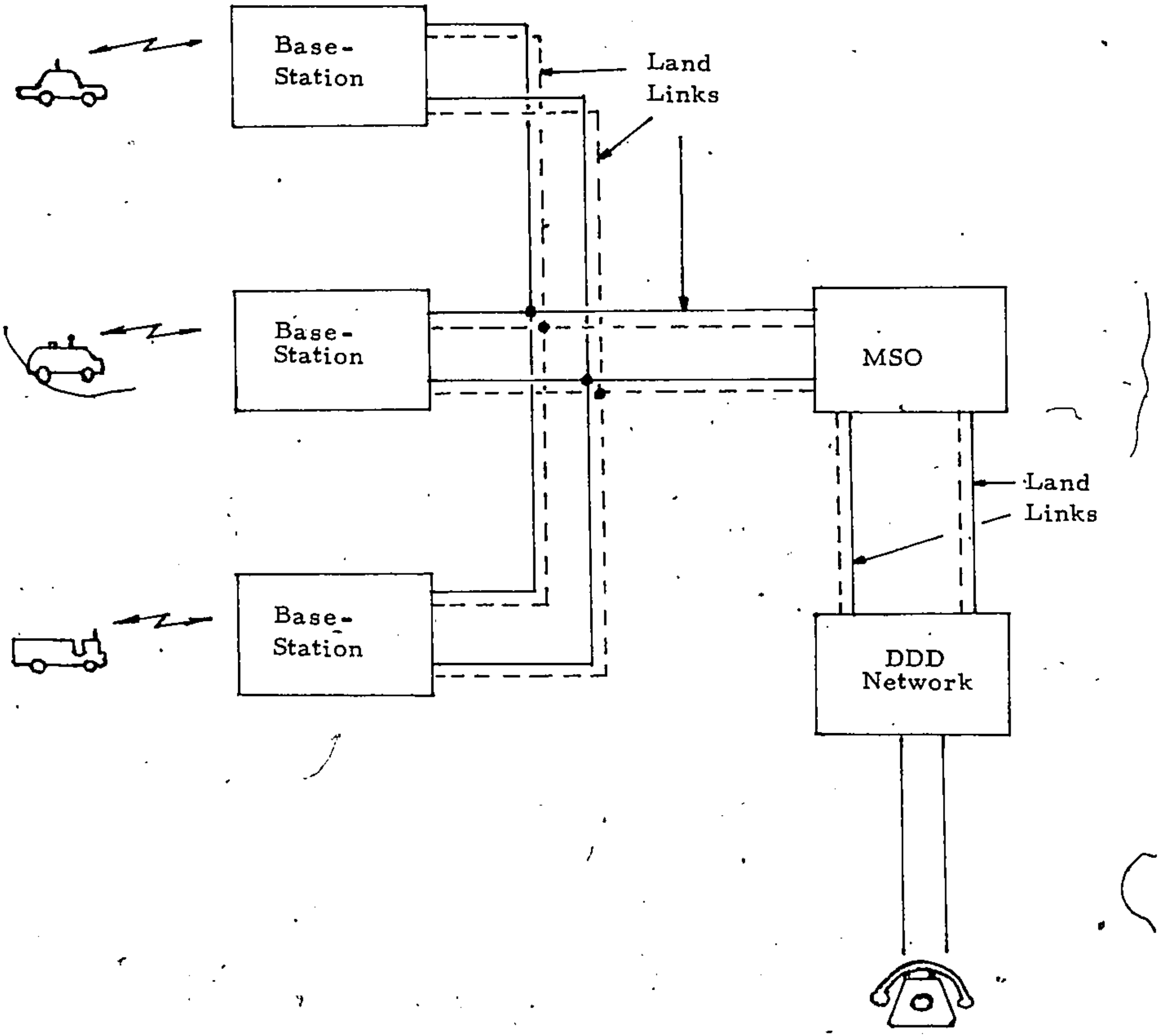


Fig. 3.2 Block Diagram Layout Of A Cellular Radio System.

and to interconnect the mobiles with each other and with the DDD network [13]. The base stations act effectively as remote frequency concentrators under the control of the MSO.

3.2-2 Mobile Call Sequence

An MTS subscriber usually subscribes service in one metropolitan coverage area (MCA), referred to his 'home MCA' which may include one or more cells. An unique directory number of the form NPA-NNX-XXX [27] is given to each individual subscriber where NPA is commonly called the "area code"; N is any digit other than 0 or 1 and X is any digit. The six-digit prefix of the directory number is used for mobile service and will be used in only one MCA.

(a) Land-to mobile calls:

When the directory number of an MTS subscriber is dialed into the DDD network, the network will route the call to the system serving the correct MCA and the called mobile will be paged throughout that MCA on a special paging channel. When the called mobile is paged, the system will send back an audible ringing to the land caller indicating that the intended receiver has been paged. At the same time the system sends out an audible signal to alert the paged mobile that a call is coming in. A mobile subscriber in MCA other than his home MCA is given 'foreign

MCA' service in which a mobile operator is brought in to complete the call.

(b) Mobile-to-land calls:
All mobile originated call initiations are accomplished on an automatic dial basis in both home and foreign MCA's. Standard Telephone dial tone will be provided as a start dialing indication.

3.3 Cellular Layout

A cellular layout of a land-mobile radio communications system is shown in Fig. 3.3. Hexagonal cells are preferred over other geometric coverage areas such as the equilateral triangular or square cells which also provide non-overlapping coverage areas, because they most nearly approach the circular pattern that can be easily produced by the base station omnidirectional antenna. Besides, a hexagonal cell has the least number of neighbours whose transmitted signals can cause cochannel interference in that cell [17, 23].

Since each base station transmits within its own cell the reuse of the same frequency channel in other cells is feasible, thus providing many voice paths in a single urban area. Efficient use of radio frequency channels requires the simultaneous assignment of channels in radio coverage cells which are spaced as close together as possible without

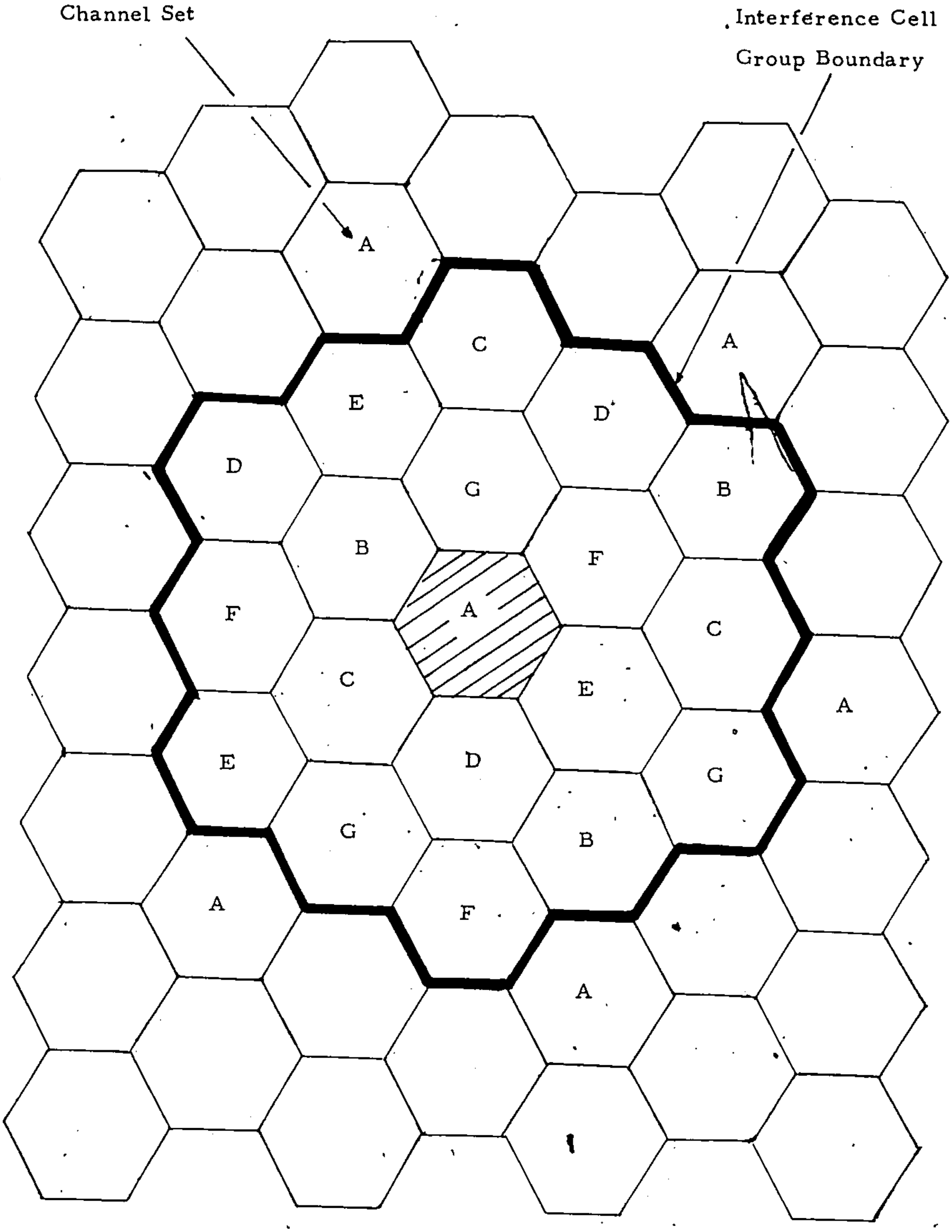


Fig. 3-3. A Cellular Layout of a High-Capacity Mobile Radio System.

incurring excessive cochannel interference. However, there exists a minimum separation within which the channel cannot be reused. This minimum separation is called the Minimum Reuse Interval or Distance (γ) and is given by:

$$\gamma = \frac{D}{R} \tag{3-1}$$

where D is the geographic separation between the two base stations using the same channel simultaneously and R is the cell radius. The minimum reuse interval is a function of the signal-to-interference (SIR) ratio, the cell size, the antenna heights and gains, the transceivers, the propagation media, the frequency of operation as well as the modulation technique employed [12,17,18,27].

For any value of γ there is an Interference Cell Group (ICG) associated with each cell. Channels assigned to a cell cannot be reused elsewhere within the ICG if already in use in that cell. Furthermore the ICG can be considered as a basic block in which each cell requires an independent channel set. This basic block may be repeated until the desired service area is covered [27]. The thick block contour in Fig. 3.3 represents the boundary of the ICG of the shaded cell. There are nineteen members in that ICG. The capital letter in each cell denotes the channel set allocated to be used there. As can be seen, any reuse of channel set A is prohibited within the ICG.

3.4 Cell Size Considerations

In general the most economical cell plan for any system capacity uses cells which are small enough to serve the maximum density of mobiles while using all channels. This minimizes the number of base station sites and assigns radio channels in the largest trunking group because in telephone traffic engineering large group of servers are more efficient than small ones.

At any system capacity the local user densities vary from high-density city centers to low-density suburbs, and the best cell size will vary accordingly. In addition system capacity also changes with time. These facts suggest a system whose cells change size continuously with location and time, but such a system is economically unfeasible. However the optimum cell size can be approximated in a system which reduces cell size in discrete steps through the addition of new base sites while leaving the existing ones in place [27], as shown in Fig. 3.4.

The lower bound on cell size is primarily controlled by the practical constraints on the amount of data processing required to keep track of moving vehicles and to switch voicepaths as the mobiles move from cell to cell. Cells of about one-mile radius are possible to-day and that even smaller cells may become feasible in the future

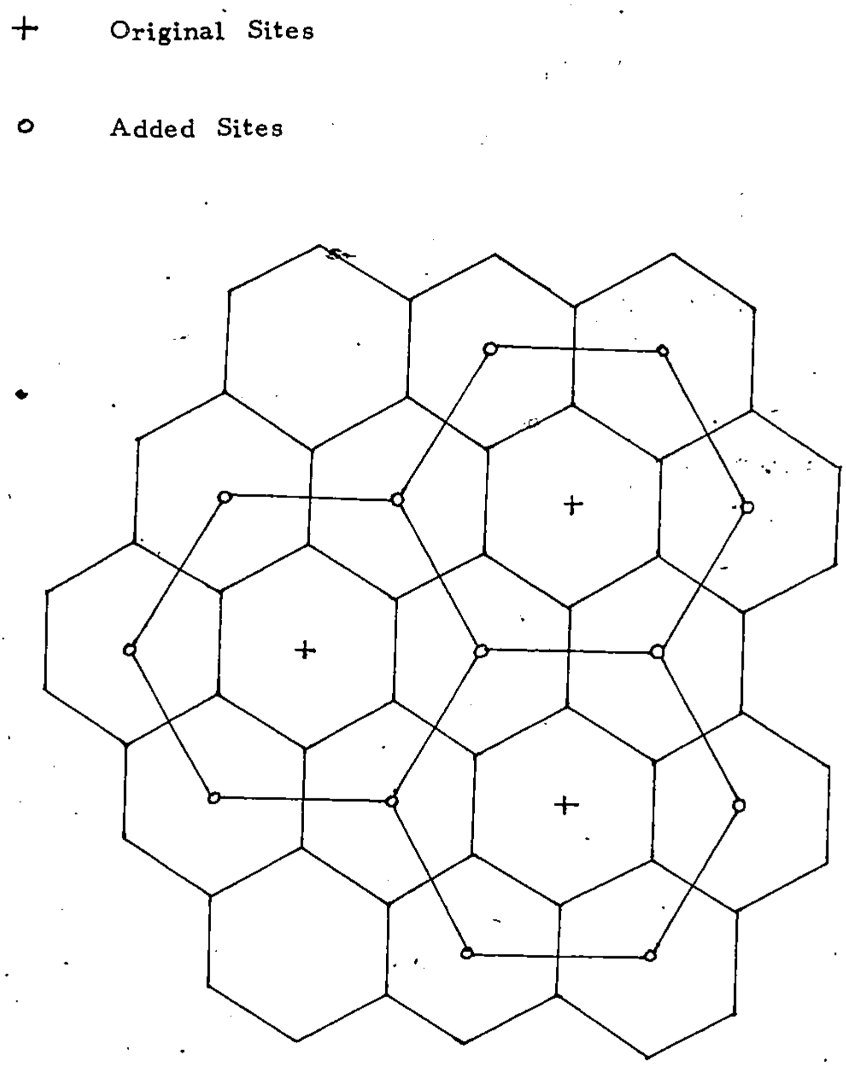


Fig. 3.4 Cell Size Reduction.

due to the rapid advancement in microprocessing technology. The upper bound of cell size is a function of the mobile (or base) transmitter power, channel bandwidth, receiver design, antenna heights and gains, minimum required SNR and is also dependent on whether diversity is employed. Cells of about twenty-mile radius are possible today.

3.5 Noise and Interference

It is a general phenomenon that signals transmitted over a transmission media are bound to be degraded due to interference and noise. Radio signals in mobile radio environments bear no exception to such degradations which come from the following sources [12,17,27]:

(a) Fast Rayleigh Fading

As the propagation characteristic between the mobile and the base station changes continuously as the vehicle moves, the multiple reflected waves transmitted from a single source may interfere destructively to varying degrees. This interference causes the signal envelope to vary in intensity in accordance with the Rayleigh distribution:

$$P_r(\alpha) = \begin{cases} 0 & , \alpha < 0 \\ \left(\frac{\alpha}{r_0}\right) e^{\frac{-\alpha^2}{2r_0}} & , \alpha \geq 0 \end{cases} \qquad (3\text{-}2)$$

where r_0 is the mean power of the distribution.

(b) Slower Log-Normal Fading

The actual value of the mean received signal level

$$S = \sqrt{\frac{\pi r_o}{2}} \qquad (3\text{-}3)$$

varies slowly with respect to the wavelength as the distance between the mobile and the base station changes. This slow variation is well approximated by a log-normal distribution. Thus r_θ varies as $B^{-\Omega}$ where B is the distance between the base station and the mobile and Ω the attenuation factor which lies between 2 and 4. More specifically the probability density of the mean received signal expressed in dB is given by

$$P_s(\alpha) = \frac{1}{\sqrt{2\pi}\,\sigma} \exp\left[-\frac{(\alpha-\alpha_0)^2}{2\sigma^2}\right] \qquad (3\text{-}4)$$

where α, α_0 and σ are expressed in dB and the expected value α_0 of the received mean signal is

$$\alpha_0 = A - 10\,\Omega\,\log\left(\frac{B}{B_0}\right) \qquad (3\text{-}5)$$

where the constant A depends on terrain and environment, antenna heights and gains, and carrier frequency, and B_0 is radius of the cell.

(c) Cochannel Interference

The reuse of radio frequency channels by mobiles and base stations in geographically separated radio coverage cells causes cochannel interference which does not occur in conventional point-to-point communication links. The interference level depends on the propagation factor, the reuse separation distance, the message statistics, the modulation index and also the receiver structure.

(d) Adjacent Channel Interference

Information transmitted in channels adjacent to the local channel provides another source of interference. The level of interference depends on the frequency separation of the local and adjacent channels, the modulation index, the propagation factor, geographic proximity and the receiver design.

(e) Selective Frequency Fading

There are often serveral paths of transmission between the base-station and the mobile. The interference between these paths may, at any moment, be either constructive, destructive or neither depending on the frequency of the transmitted signal. Since the instantaneous frequency of a modulated FM signal depends on the amplitude of the message signal, fluctuations in the received signal power may occur even when the mobile is stationary.

(f) Random FM

As the mobile moves about, the instantaneous phase of the received signal may change abruptly due to the sudden change in preferred signal paths. The result is output noise which is referred to as random FM which is proportional to:

$$f_m = \frac{V}{\tau} \qquad (3\text{-}6)$$

where V is the vehicle velocity and τ the wavelength of the transmitted signal.

(g) Macroscopic Shadowing

Large terrain features such as mountains and buildings cause variations in the received signal strength. These shadow variations occur over tens or hundreds of feet.

3.6 Diversity Considerations

In a general sense diversity involves the use of multiple independent 'branches' of transmission in the communication paths to saveguard against the failure of any single branch. In a radio system these branches can be achieved by using either different carrier frequencies on the same path or a single carrier frequency with different paths, polarizations or times of transmission [27].

The technique most often used in MTS systems is Space Diversity in which different base sites or antenna positions create a multiplicity of base-mobile paths, and in which the critical parameter is the degree of separation between paths that is necessary to achieve independence.

(a) Diversity Against Rayleigh Fading

(i) Space Diversity

Since an area tens or hundreds of feet in extent tends to have a constant local mean about which the Rayleigh variable is distributed, then in the enviroment at 850 MHz, antennas spaced by as little as several inches will provide independent Rayleigh fading signals with the same local mean. Such small spacing of antennes makes practical implementation of space diversity at the mobile possible.

(ii) Polarization Diversity

Signals of vertical and horizontal polarizations even when transmitted and received by essentially unseparated antennas will exhibit independent Rayleigh fading signals. If both orthogonally polarized signal are simultaneously transmitted at the mobile, closely spaced polarized antennas at the base station would provide independent diversity branches.

(b) Diversity Against Shadowing

In typical systems using a base station transmitting at the center of each cell, shadowing by large obstructions in the radio path leads to 'holes' in the coverage area. These holes can be filled in by using a satellite base station. However the use of a satellite per cell is astronomically costly. Instead, space diversity against shadowing within each cell can be achieved by placing base sites at alternate corners of the hexagonal cell as shown in Fig. 3.5.

Such coverage plan requires only one base site per cell since while each cell is being served by three base sites, each site is serving three cells simultaneously. The use of inward directive antennas at the three base sites can increase the signal levels within the cell and reduce cochannel interference radiated in other directions.

3.7 System Performance Characteristics

3.7-1 Required Signal-to-Noise (SNR) Ratio

As FM signals undergoing severe rapid fading in mobile radio environment so are the noise and interference. This complicates the FM receiver design. During a single fading cycle, the receiver passes through a sequence of

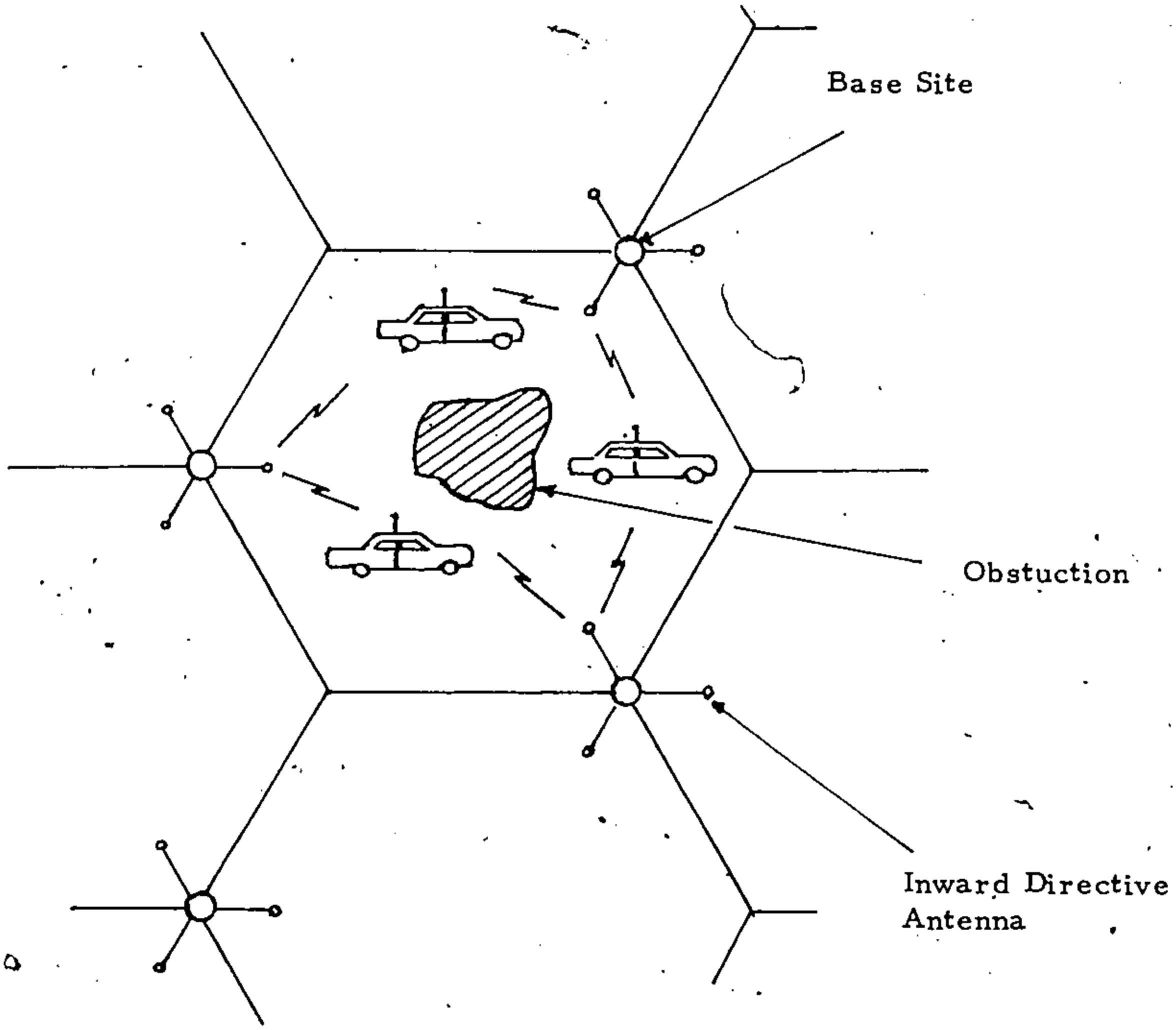


Fig. 3. 5 Space Diversity Against Shadowing.

several different conditions:

(1) While the signal level is substantially above that of the interference the circuit quality is good;

(2) When the signal level drops and approaches the interference level distortion begins to occur;

(3) When the signal level falls below the interference level a "click" results;

(4) When the interference dominates crosstalk is heard.

As the signal rises out of fade the same sequence of conditions is repeated but in the reverse order.

In the presence of cochannel interference and for good diversity and/or carrier-to-noise (CNR) ratio high enough to keep the signal above threshold, the minimum required SNR for a cell is given by [12]

$$\mathrm{SNR} = \left\{ \left[\Gamma \sum_{i=1}^{I} \left(\frac{R}{D_i}\right)^{\Omega} \frac{P_i}{P} \right] \beta^{-3} + \left[\frac{1.5\beta^2}{R^{\Omega}} \mathrm{CNR} \right]^{-1} \right\}^{-1} \qquad (3\text{-}7)$$

where $\frac{P_i}{P}$ = ratio of the power of the i^{th} cochannel interferer to the radiated power of the signal in question.

D_i = geographic separation between the distant (i^{th}) transmitter and the local receiver.

R = cell radius.

I = number of cochannel interferers.

Γ = constant depending on I, the amount of fading suffered by both the signal and the interference and on the average signal characteristics.

β = modulation index.

Ω = attenuation factor which lies between 2 and 4.

CNR = carrier -to-noise ratio at a unit distance from the transmitter ($= \frac{P}{N_0 W}$).

W = audio bandwidth.

$\frac{N_0}{2}$ = power spectral density of additive white gaussian noise.

The first term of equation 3-7 accounts for the cochannel interference while the second one for the additive white gaussian noise. Furthermore equation 3-7 gives an average SNR over the cell at radius R. Local variations in SNR are caused by variations in terrains, buildings, antenna heights and gains and other environmental conditions. The quality range important to mobile radio is 15 to 30 dB SNR.

3.7-2 System Cost

System cost includes cost of base stations, cost of associated land links and of supporting facilities such as license fee, design cost, equipment maintenance cost etc. The total system cost can be expressed as the sum of the fixed costs and the variable costs. Fixed costs are those incurred in the establishment of a minimum facility, while variable costs are those additional costs required to provide an improved system which results from improved SNR, increasing number of base stations and increasing number of channels. The normalized system cost is expressed as follows [12]:

$$C = 1 + KL^{b-1} \sum_{i=1}^{L} M_i^a (CNR_i)^c \qquad (3\text{-}8)$$

where K = variable cost factor normalized over the fixed cost.

L = number of cells

M_i = number of channels in cell i

CNR_i = carrier-to-noise ratio in cell i

a,b,c = cost indices determining the rate of change in variable cost; $a < 1$, $b < 1$ and $c > 1$.

For all base stations having identical values of CNR_i and M_i and each channel is assigned to one and only one cell then with $CNR_i = CNR$ and $M_i = \frac{M}{L}$

$$C = 1 + KL^{b-a} M^a (CNR)^c \qquad (3\text{-}9)$$

where M is the total number of radio channels.

3.7-3 System Throughput

The system throughput Q is defined as the number of calls which will be served in a given period of time.

For Erlang-B service discipline the system throughput is given by [12]

$$Q = \sum_{i=1}^{L} \lambda_i (1 - P_{B_i}) \frac{1}{\mu}$$

$$= \sum_{i=1}^{L} \rho_i (1 - P_{B_i}) \qquad (3\text{-}10)$$

where L = number of cells

λ_i = mean call attempt rate in cell i

P_{B_i} = the probability of blocking in cell i

$\rho_i = \frac{\lambda_i}{\mu}$ = the channel utilization in cell i

$\frac{1}{\mu}$ = mean call holding time.

For Erlang-C service discipline, calls are never denied of service. Thus the blocking probability (P_{B_i}) is zero and hence

$$Q = \sum_{i=1}^{L} \rho_i \qquad (3\text{-}11)$$

For other service disciplines blocked calls will generally be re-attempted at a later time. Owing to this, the mean call attempt rate will be modified as follows

$$\lambda_i' = \lambda_i \left[1 + q_i P_{B_i} + (q_i P_{B_i})^2 + (q_i P_{B_i})^3 + \dots \right]$$

$$= \frac{\lambda_i}{1 - q_i P_{B_i}} \qquad (3\text{-}12)$$

where q_i is the probability that a blocked call in cell i will be re-attempted at a later time.

The cellular structure enables radio channels to be reused within the desired service area thus enhancing the utilization of the allocated frequency spectrum. In addition the cellular structure systems require lower transmission power levels which in turn produce lower interference level to other systems and reduce mobile and base equipment costs considerably. However more accurate information on vehicle locations are needed in this kind of structure. As seen earlier, the cell size, shape and location, the use of diversity, the transmission power, the number of channels, the number of base stations, the SIR as well as other factors have tremendous effects on the performance characteristics of a cellular-structure mobile radio system.

CHAPTER 4

CHANNEL ASSIGNMENT SCHEMES

4.1 Introduction

In cellular radio systems, each base station is responsible for radio coverage within its assigned cell only. Hence channels assigned to one cell can be reused elsewhere within the service area under certain constraint. An immediate interesting question arises as how should the radio channels be allocated to the cells in a high-capacity, cellular mobile radio system so as to maximize the channel occupancy, thus utilizing the frequency spectrum more efficiently without incurring excessive cochannel interference. The channel assignment becomes a critical issue in designing high-capacity cellular mobile radio systems since it affects both system capacity and equipment design. Thus the channel assignment problem has received a great deal of attention ever since the cellular concept was proposed. Various channel assignment schemes were developed, studied and their performance evaluated by people like L.G. Anderson [1], D.C. Cox and D.O. Reudink [5-9], J.S. Engel [10, 11], T.J. Kahwa and N.D. Georganas [18], just to mention a few.

This chapter first presents two basic channel assignment schemes namely the Fixed and the Dynamic Channel Assignment Schemes together with their performance. The insight to these basic channel assignment schemes leads to the conception of the Hybrid Channel Assignment Scheme to be presented in the final section of this chapter. Throughout the discussion on the various channel assignments scheme the following assumption is made. The power radiated from the base station antenna in each cell is sufficient to provide an adequate SNR ratio at the cell's boundary and may be a little beyond. Thus the coverage limitation is due to interference, essentially the cochannel interference and to a small extent the intermodulation interference, but not due to the lack of sufficient signal power or the presence of thermal noise.

4.2 Fixed Channel Assignment Scheme (FCAS)

The Fixed Channel Assignment Scheme assumes a definite relationship between the channels and the cells at any time. That is to say once channels are assigned to a cell they will be the only channels allowed to be used there at all times. These channels are known as the nominal channels of the cell. Conversely speaking, the cell to which the channels are assigned is called the nominal cell.

The Fixed Channel Assignment Scheme tackles the question of how to allocate channels to various cells in the system under the interference constraint in the following manner. The total available radio channels are divided into a number of channel sets. There is a minimum number of channel sets required to serve the entire service area. This minimum number (N) of channel sets is governed by the minimum reuse distance (γ) in the following fashion [14, 17]:

$$N = \frac{1}{3}\gamma^2 \quad \text{for hexagonal cells} \qquad (4\text{-}1)$$

where N can assume only integer values 3,4,7,9,... etc. as generally represented by the series $(i + j)^2 - ij$ with i and j being integers.

The N channel sets are then assigned to the cells in the system respecting the minimum reuse distance and are to be exclusively used in their nominal cells at any time. Fig. 4.1 shows an example of the allocation of channel sets to various cells in the system with a γ of 5 radii. The capital letter in each cell represents the nominal channel set while the superscript associated with each letter indicates the number of times that channel set is reused within the system.

All the N channel sets will be of the same size if the customer offered traffic has a spatial uniform distribution. If the spatial traffic is non-uniformly distributed then the number of channels in the channel sets can be appropriately 'tailored' to suit the traffic demands.

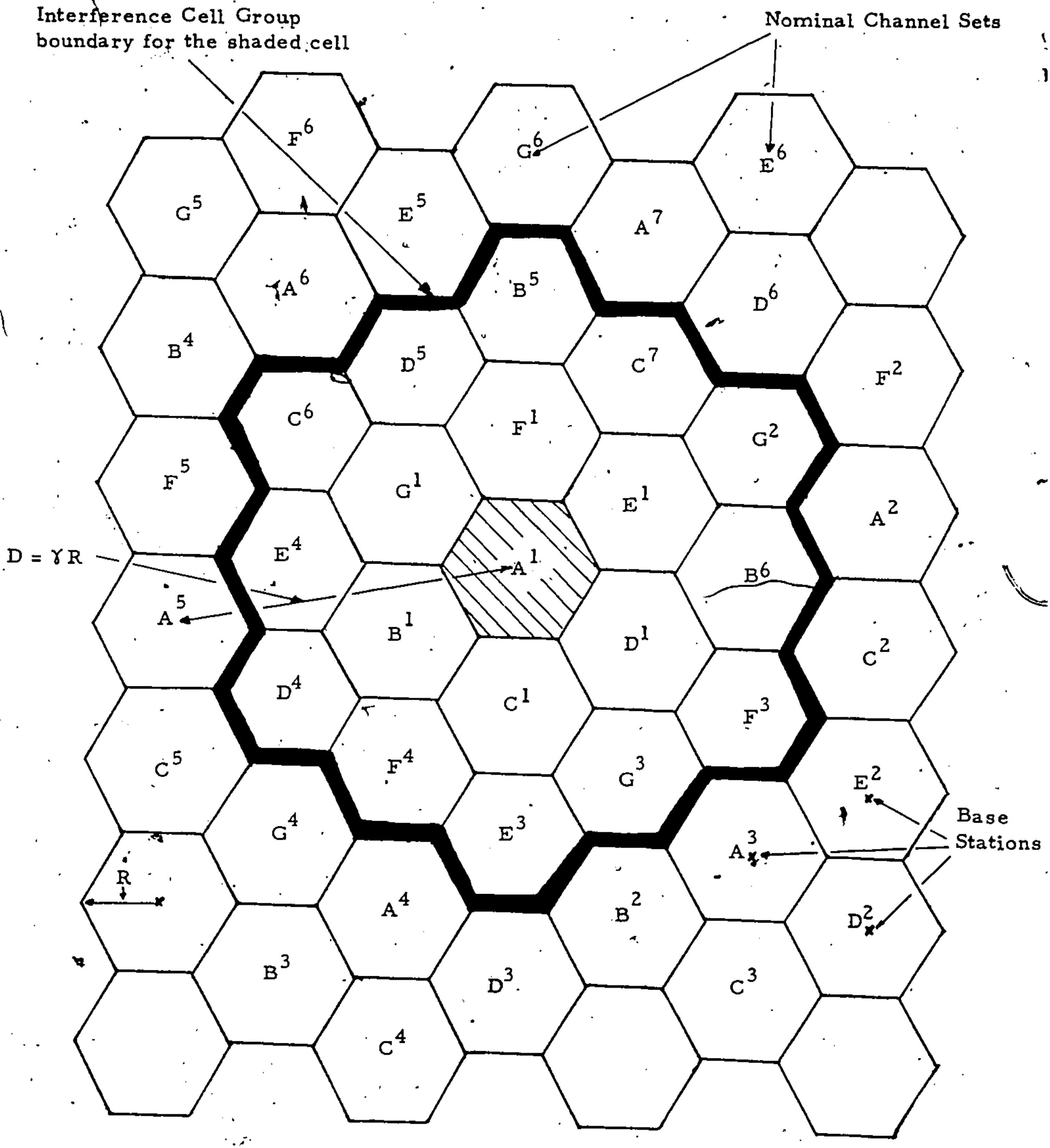


Fig. 4.1 Allocation Of Channel Sets With The Fixed Channel Assignment Scheme.

This tailoring technique is called the 'Static Borrowing' [11].

When a call is initiated in cell i, the MSO will assign a nominal channel to service the call if one is available. Otherwise, the call will not be serviced and will be disposed in a manner according to the service discipline adopted in the system. That is to say, the call on finding no nominal channels available at the time of initiation will be blocked and cleared from the system (Erlang-B), or delayed (Erlang-C) or even held. Now when the call-in-progress is crossing a cell boundary into an adjacent cell, it will have to be served by the base station of the new cell into which it is entering. Since the new cell has its own nominal channel set which is different from the channel set allocated to the former cell, a new fixed channel will have to be assigned to service that call. This switching of channels is called the 'hand-off' which is performed while the call is still in progress. If no idle fixed channel is found in the new cell, the call-in-progress, on entering into the new cell will be forced to a premature termination. The probability of such occurrences was found to be small [6, 7].

The main advantage of the Fixed Channel Assignment Scheme lies in the fact that the channels are used to the maximum possible number of times within the system, thus increasing the channel occupancy. The drawback of this scheme is that when the nominal channels in a cell are fully occupied, another call request will be rejected though there might be one or more of the neighbouring cells having one or more of their nominal channels idle at the time, which could be temporarily borrowed for use.

4.3 Dynamic Channel Assignment Scheme (DCAS)

In sharp contrast to the FCAS, the DCAS bears no definite relationship between cells and channels. In other words it is needless to assign different channel sets to different cells in the system. Instead, all the radio channels available to the system belong to a central pool. The channels can be temporarily borrowed by any cell to serve calls on a real time basis provided that the minimum reuse distance γ is respected at the time of borrowing. (The resulting average spacing between the cells using the same channel at the same time may be greater then γ depending on the borrowing strategy). Upon completion of service, the channels will be returned to the central pool for the next assignment.

During 'hand-off' the call-in-progress is allowed to keep the channel that it has been using provided that channel is not currently in use in the cell into which that call is entering or elsewhere within the interference cell group of that cell. Otherwise, the call will have to be switched onto a new channel which satisfies the interference constraint in the new cell at that moment. If no channel is found capable to serve the call, the call will be forced to terminate prematurely.

Usually there is more than one channel in the central pool suitable for borrowing. Then one has to decide which channel out of the eligible candidates to borrow for use. The following borrowing strategies have been widely investigated [6, 7, 8]:

(a) First Available

The very first channel encountered in the channel search, that satisfies the cochannel interference constraint, that is, a channel not being used in the 'to-be' assigned cell and elsewhere within the ICG of that cell, is borrowed to service the call.

(b) Nearest Neighbour (NN)

This strategy chooses for assignment the channel which is in use in a cell closest to the to-be assigned cell, but still at least γ cell radii away. By doing so the distance D, over the available channels, between the first cell using that channel and the to-be assigned cell is minimized. If there are more than one such channels the first one encountered in the channel search will be assigned to the cell in question.

(c) Nearest Neighbour + k (NN + K)

This strategy is similar to the NN except that it minimizes the distance

$$D < \gamma + k \quad , \; k = 1,2,3,\ldots \qquad (4\text{-}2)$$

over the available channels. This algorithm tends to allow more calls to keep their assigned channels upon cell boundaries crossings. If no such channel exists at the time of borrowing, the channel with $D = \gamma$ will be assigned to the borrowing cell.

(d) Maximum Usage

This strategy selects a channel that is being used most at a distance γ cell radii away from the to-be assigned cell. That is, a channel, which is currently in use in most cells just outside the interference cell group boundary of the cell in question is chosen. If there is more than one such candidate the first one encountered will be assigned to the borrowing cell.

(e) Mean Square (MSQ)

This strategy minimizes the quantity

$$\frac{1}{n}\sum_{j=1}^{n} D_j^2 \quad . \; \gamma \leq D_j \leq 2\gamma \qquad (4\text{-}3)$$

where D_j is the distance between the to-be assigned cell and the cell currently using the same channel within the interval $[\gamma, 2\gamma]$, and n the number of cells using the same channel within this interval. The interval $[\gamma, 2\gamma]$ is chosen because the channel in use a distance greater than 2γ cell radii away from the cell in question would allow the reuse of that channel at another cell within that distance. If $n = 0$ for some channel, that is, the channel is not being used in any cell within the specified interval, then the first such channel encountered will be assigned to serve the call requesting service at the cell in question.

It has been shown [6, 7, 8] that the five dynamic channel assignment strategies have similar performance characteristices. However, the NN philosophy gives the best overall performance in terms of blocking probability, system throughput and percentage of forced terminations, the MSQ and NN + k strategies are the next best choices on the system performance list. The first available tactics results in performance which does not deviate too much from the other channel assignment strategies. In most cases, it performs very similarly to the NN + k philosophy. Nevertheless, the first available strategy is the simplest and most economical one to implement as it requires much less data processing involved in channel assignments. Thus the first available strategy lends itself to the dynamic channel assignment invoked in the Hybrid Channel Assignment Scheme to be discussed later in this chapter.

Simulation studies on the performance of systems adopting either the Fixed or the Dynamic Channel Assignment Schemes with BCC service discipline have been conducted by L.G. Anderson [1], D.C. Cox and R.O. Reudink [2-7, 9] and J.S. Engel and M. Peritsky [11]. Results obtained from those studies show one common phenomenon concerning the performance of the two channel assignment schemes. At light traffic loadings the Dynamic Channel Assignment technique blocks fewer calls, carries more traffic and forces fewer call to prematured termination than its rival. However, the Fixed system outperforms its counterpart at and above moderate offered traffic. This inferiority experienced by the Dynamic system is a consequence of the fact that dynamic channels are assigned to serve random calls originated at cells which are spaced apart a distance generally greater than the minimum required reuse separation γ. Thus the channels cannot be used most efficiently.

The simulation results also show that systems employing Dynamic Channel Assignment Scheme are rather insensitive to time and spatial changes in offered traffic, giving rise to almost stable grades of service in each cell [8]. On the other hand, in the Fixed system the said changes in offered traffic very much worsen the service deviation, a measure of the fluctuations in the grade of service from one cell to another.

4.4 Hybrid Channel Assignment Scheme (HCAS)

The distinctive performance of the Fixed and the Dynamic Channel Assignment Schemes enlightens the conception of the Hybrid Channel Assignment which is an amalgamation of the Fixed and the Dynamic assignment techniques [18].

In the Hybrid Channel Assignment the total number (T) of available radio channels is first divided in N channel sets, assuming a static assignment scheme, where N is the minimum required number of channel sets governed by equation 4-1. Each cell in the system is allocated one of the N channel sets, observing the minimum reuse distance γ. If the spatial distribution of the offered traffic is uniform, then the average number of channels per cell will be given by

$$M = \frac{T}{N} \qquad (4\text{-}4)$$

However the number of channels per cell can be appropriately tailored to suit the traffic demands if they are distributed unevenly from cell to cell.

After the preliminary division of channels, each of the N channel sets is partitioned into a number of fixed channels (f) per cell and a number of dynamic channels (d) per cell such that

$$f + d = M \qquad (4\text{-}5)$$

The optimal channel partition ratio f:d which will yield the best system performance depends on the offered traffic loading, as will be seen later. All the f fixed channels are to be exclusively used in their nominal cells, whereas the d dynamic channels will be donated to the system for dynamic assignment. Thus there are altogather Nd dynamic channels in the central pool, which can be temporarily borrowed for service by any cell in the system provided the cochannel interference constraint is conformed there at the time of borrowing.

The partitioning of the channel sets yields an average number of channels per cell given by [18]

$$m = f + \frac{Ndj}{Z} \qquad (4\text{-}6)$$

where Z is the number of cells in the ICG of the cell and j the number of times each dynamic channel can be reused within the ICG. Generally it does not require as many channel sets as there are members in the ICG, that is, N < Z. Thus the average number of channels per cell, after channel partitioning, is generally smaller than the one before partitioning. In other words, with the Hybrid Channel Assignment Scheme each cell uses, on the average, fewer channels than the Fixed Channel Assignment procedure.

Calls requesting service at a particular cell will prefer to be served by the fixed channels if any are available. Otherwise, the cell will borrow the eligible dynamic channels from the system pool to service the calls. If neither nominal fixed channels nor dynamic channels are idle at the time of initiation of a call in the cell, the call will be disposed of in accordance with the service discipline adopted.

Since calls are initiated randomly, different dynamic channels will be assigned to service the calls in a random fashion. The consequence of this randomness is well reflected in that calls using the same channel are generally located in cells separated by a distance greater than the minimum reuse distance γ. Hence the channels may not be used to the maximum possible number of times [9, 12] within the system. On the other hand, fixed channels are allocated to cells observing the minimum reuse distance γ. So in order to maximize the channel occupancy, calls using dynamic channels should be switched, whenever possible, onto permanent channels. Owing to this fact, a channel reassignment technique is incorporated in the Hybrid Channel

Assignment Scheme so as to enhance the channel as well as spectrum utilization.

The performance of systems using the Hybrid Channel Assignment Scheme with Erlang-B (BCC) service discipline has been studied through simulation [18]. The following table summarizes the results obtained in regard to the performance characteristic namely the blocking probability of the systems.

Table 4-2 Performance of systems using HCAS with Erlang-B service discipline

Load Increase from Base Load*	Channel partition giving lowest blocking probabilities
0-15%	with most dynamic channels
15%-35%	with medium member of dynamic channels
35%-50%	with fewest dynamic channels
above 50%	with only fixed channels.

* Base Load is the offered traffic in Erlangs which gives a grade of service of 0.018.

For Erlang-B traffic, systems adopting the Hybrid Channel Assignment Scheme give better overall performance than the two amalgamated techniques at low to moderate traffic loadings. As the systems become heavily loaded the FCAS prevails over the other schemes. This unsurprisingly reflects the general characteristics of both the Fixed and the Dynamic Channel Assignment Schemes.

CHAPTER 5

DESCRIPTION OF THE SYSTEM SIMULATED

5.1 Development of the Simulation Model

The system simulated is shown in Fig. 5.1. A system of forty cells was chosen merely due to the system limitations of the GPSS/360 [15, 16].

In developing the simulation model we considered a cellular, high-capacity, land-mobile radio communication system employing the Hybrid Channel Assignment technique, in which:

(a) all cells are of uniform size and shape;

(b) the customer offered traffic is uniformerly distributed over the entire system;

(c) the call initiation is a Poisson process with a mean call arrival rate of λ calls/hr.;

(d) the call holding time is exponentially distributed with a mean of 120 sec.;

(e) blocked calls are delayed, i.e. Erlang-C service discipline;

(f) the minimum reuse distance γ is equal to 3 cell radii;

(g) the First Available channel assignment strategy is adopted for reasons mentioned in sec. 4.3.

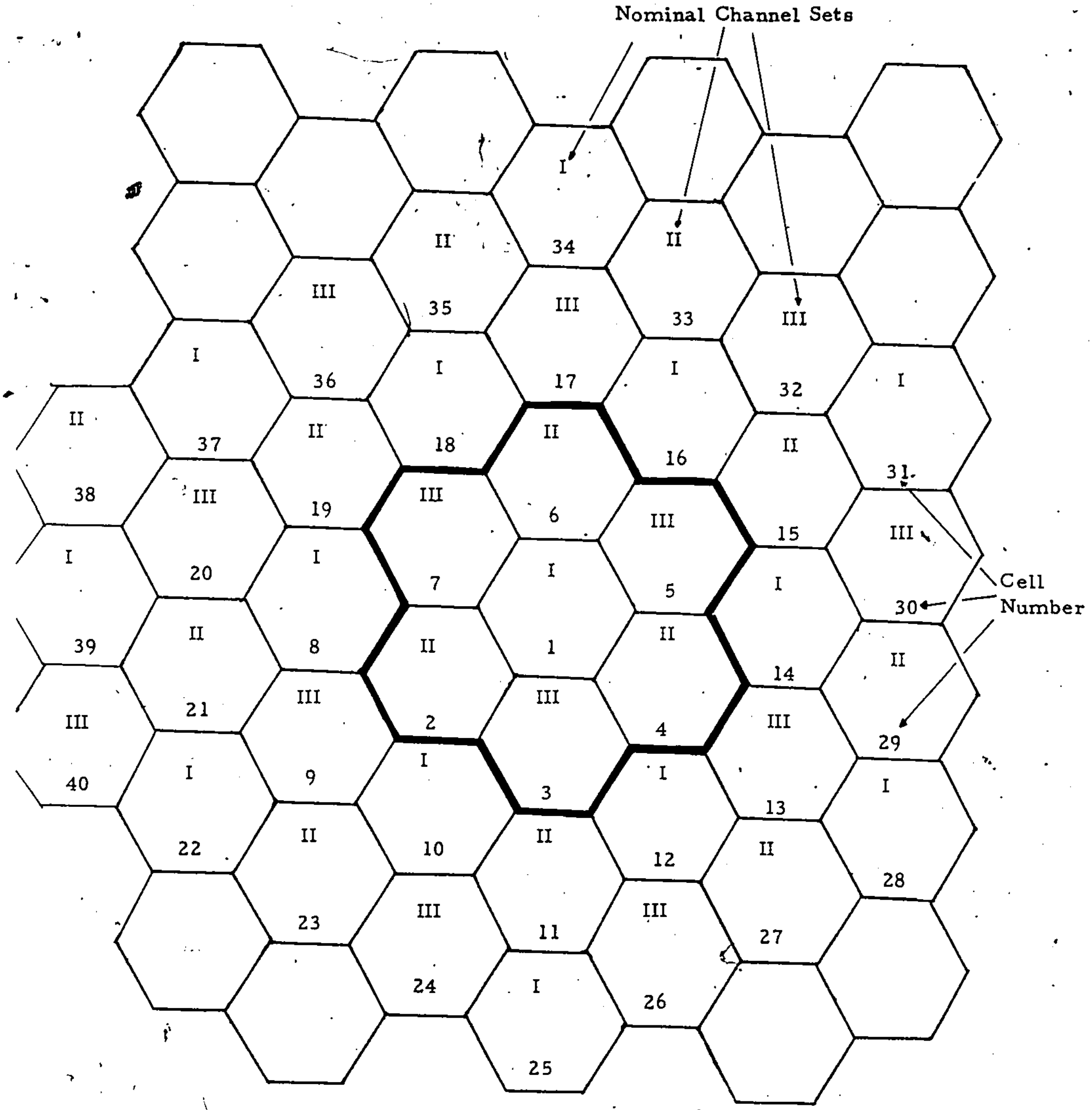


Fig. 5.1 The Cellular-Structured Mobile Radio System Of 40 Cells That Was Simulated.

Also the following assumptions were made:

(a) all mobiles are identifiable and could operate on any frequency as dictated by the base stations;

(b) all base stations could transmit on any frequency at all times as assigned by the system controller i.e. the MSO;

(c) the power level radiated from a base station antenna is sufficient to give an adquate SNR ratio at the cell's boundary. Thus the coverage limitation is mainly due to the cochannel interference;

(d) calls that are assigned to the channels remain on for the full call duration time specified by the exponential distribution;

(e) there are no cell boundaries crossings for all calls in-progress.

With a minimum reuse distance of 3 cell radii, the number (N) of channel sets required to service the desired coverage area, as given by equation 4-1, is equal to 3 while the number (Z) of members in the ICG equals 7. Also, the average number (m) of channels per cell resulting from the channel partitioning is given by $f + \frac{3dj}{7}$.

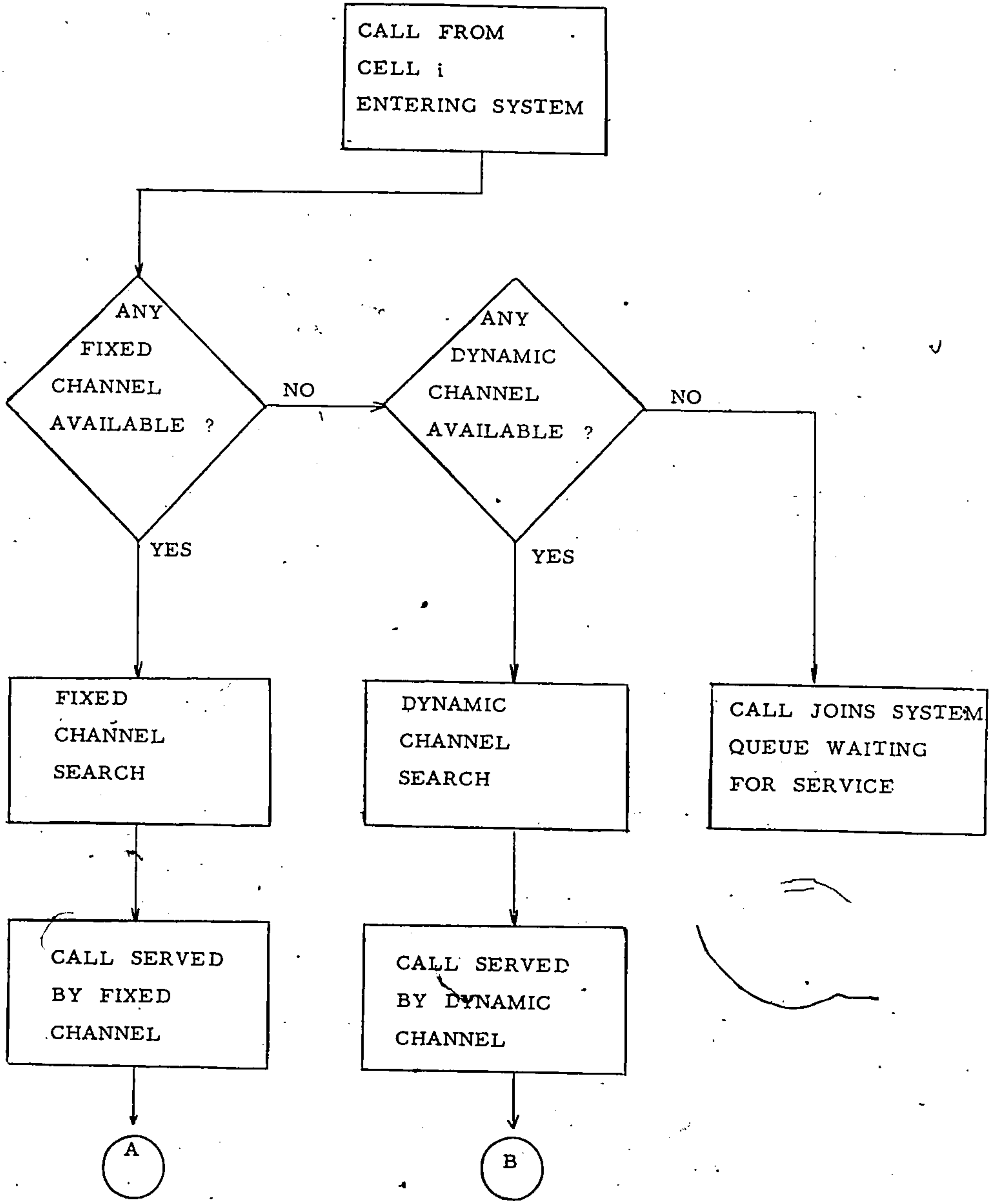
The input parameters to the simulation model are the mean call attempt rate λ and the channel division ratio f:d.

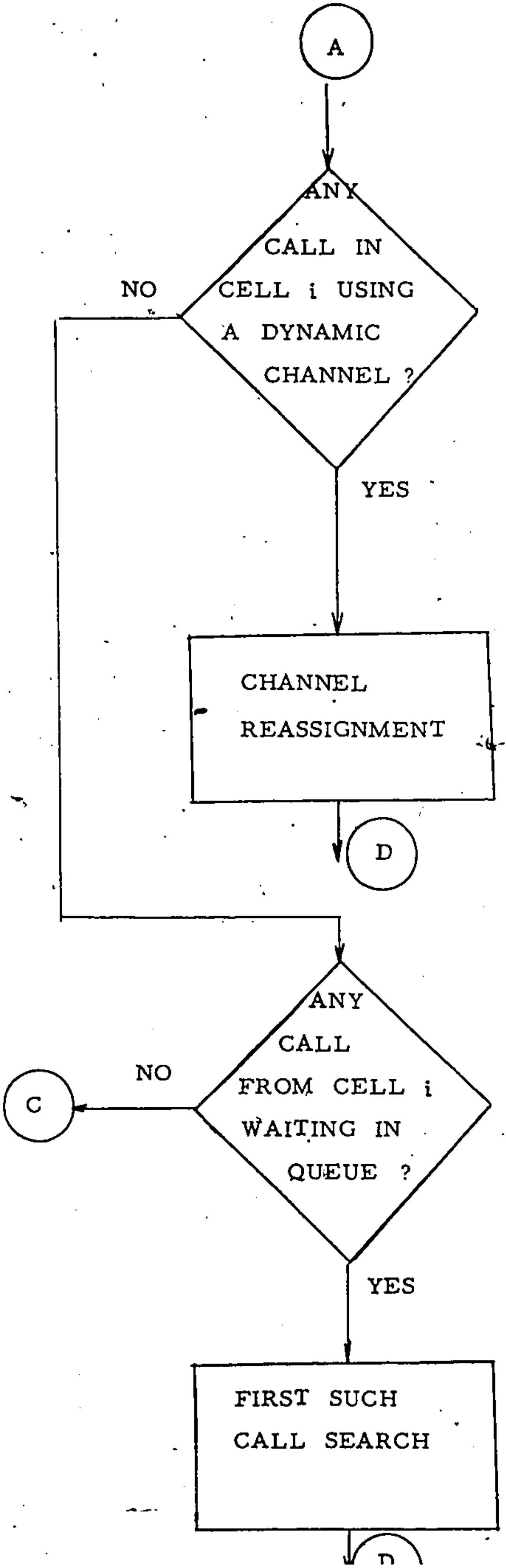
In order to study the system performance an infinite cellular layout should be used. The reason for doing so is that for a cellular system of finite size, cells near the edges of the system will have fewer neighbouring cells to induce cochannel interference. As a result, calls originating from the edge cells will have a greater chance of seizing the dynamic channels than those coming from the centrally located cells. This gives rise to higher probabilities of queueing in the central cells. Due to this edging effect we decided to collect system statistics from the central twenty cells in order to approximate an infinite system with a finite one.

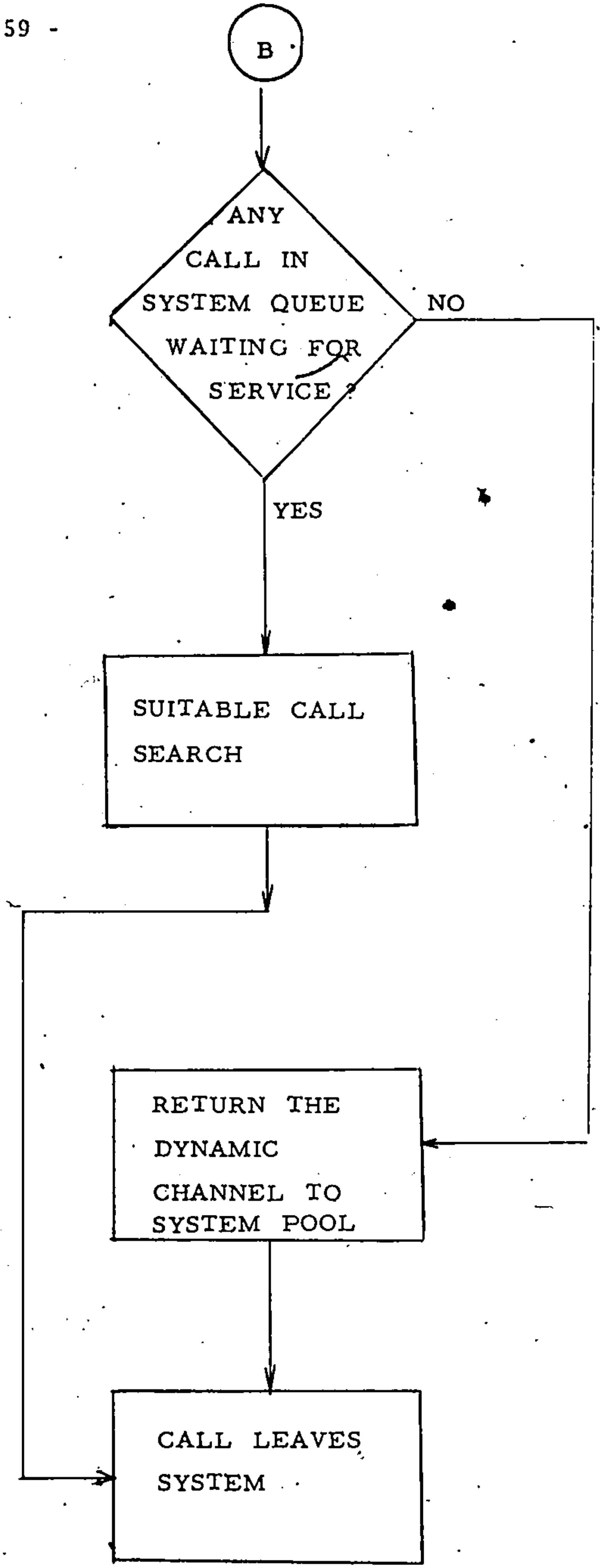
5.2 Simulation Flow-Chart

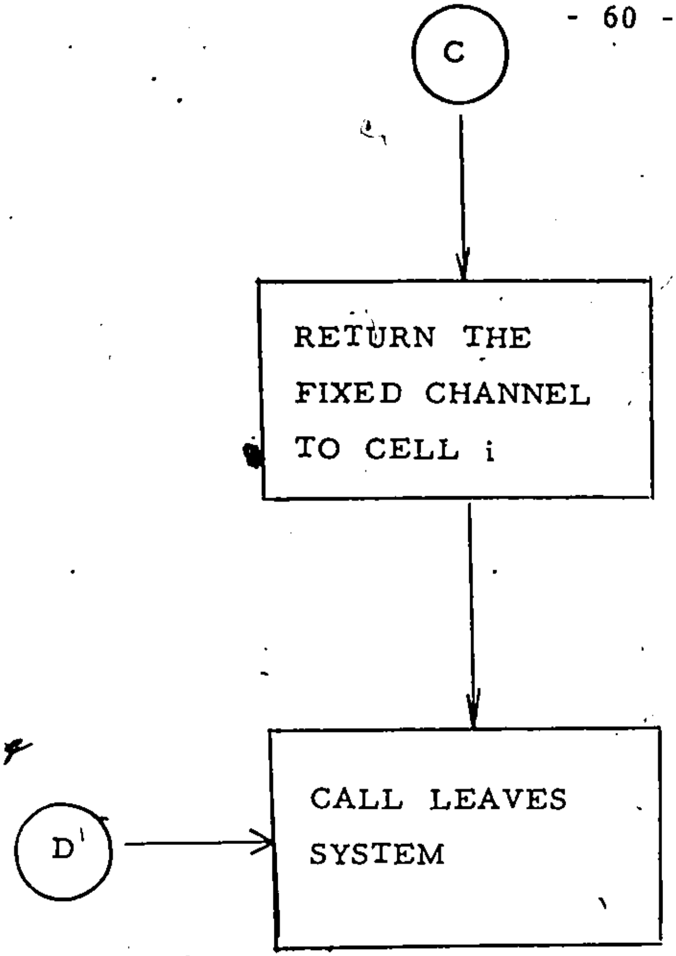
The flow in the simulation model can be easily followed with the aid of the flow-chart shown in Fig. 5.2. An incoming call (say x) originated from cell i on entering into the system will follow one of the three paths as shown in the flow-chart, after some preliminary tests on the current activities of the fixed as well as the dynamic channels in cell i. If call x passes the availability test of the fixed channels in cell i, it will search for the first available fixed channel allocated to cell i and will then receive immediate service by that channel. If call x finds all fixed channels occupied in cell i, it will proceed to the next test on the availabity of dynamic channels which could be borrowed for use in cell i at that

Fig. 5.2 Flow-Chart For The Simulation Model Of The Cellular Mobile System Employing The Hybrid Channel Assigment Scheme With Erlang-C Service Discipline.




A
ANY CALL IN CELL i USING A DYNAMIC CHANNEL ?
NO
YES
CHANNEL REASSIGNMENT
D
ANY CALL FROM CELL i WAITING IN QUEUE ?
NO
C
YES
FIRST SUCH CALL SEARCH


B
ANY CALL IN SYSTEM QUEUE WAITING FOR SERVICE ?
NO
YES
SUITABLE CALL SEARCH
RETURN THE DYNAMIC CHANNEL TO SYSTEM POOL
CALL LEAVES SYSTEM


C
RETURN THE FIXED CHANNEL TO CELL i
CALL LEAVES SYSTEM
D'

moment of time. On passing that test, call x will search for the first available dynamic channel satisfying the cochannel interference constraint and will then seize the channel for a full call duration time. With odds against it, call x can find neither fixed nor dynamic channels available at the time of its initiation will have to join the system queue, in a 'FIFO' fashion awaiting service by an idle channel.

Upon completion of service by a fixed channel call x releases the channel. Before returning the channel to cell i, call x first checks if other calls from the same cell are currently being served by dynamic channels. If so, Channel Reassignment is initiated. In the channel reassigning process, call x hands-off the released fixed channel to the first such call-in-progress, thus freeing the dynamic channel which that call previously occupied. The reassigned call will continue to converse on the newly assigned fixed channel for the remainder of the call holding time while call x leaves the system. The freed dynamic channel instead of returning to the central pool will redeem the 'suitable' queued call.

If there is no call currently using a dynamic channel in cell i, call x will then proceed to check whether there are calls originated from cell i that are waiting in the system queue for service. If so, it will forward the vacated fixed channel to the 'suitable' candidate before leaving the system. Otherwise, it will simply return the released fixed channel to cell i for the next assignment before terminating its mission.

If served by a dynamic channel, call x will vacate the dynamic channel at the end of the call duration time. Before returning the channel to the central pool, call x first examines the current status of the system queue. Suppose that the queue is non-empty at that moment, call x will release the vacated dynamic channel to service the 'suitable' queued call before exiting the system. If the queue is empty at that time, call x will simply return the dynamic channel to the system pool before leaving the system.

At this point it is noteworthy to elaborate on the 'suitable' call search routine as marked in the flow-chart as well as the strategy adopted in assigning a just vacated channel to the suitable queued call. If the just vacated channel is of permanent nature and is allocated to be exclusively used in cell i, then it will be assigned to the first call in the system queue, that originates from cell i since the blocked calls are queued in the order of their arrival times. Now suppose the just relieved channel is a dynamic one. Matters become slightly complicated. Recalling that dynamic channels can be temporarily borrowed for use by any cell, if and only if the cochannel interference constraint is satisfied there at the time of borrowing, thus the call at the head of the queue would be prohibited from being served by the redeeming dynamic channel if the borrowing conflicts the interference constraint at the origin of that call. Under this circumstance the queue will be scanned from the top. In the scanning process, the redeeming dynamic channel will be assigned to service the first call encountered at whose origin the interference criterion is conformed. The queued call so found is termed as the 'suitable' call which has been previously referred to. Hence, even though the blocked calls are queued in a FIFO fashion they are not guaranteed with such a service discipline due to the interference constraint, but the FIFO service is definitely provided to the queued calls originated from the same cell regardless of the nature of the redeeming channel. In other words, a constrainted FIFO queueing discipline has been imposed on all the queued calls.

CHAPTER 6

SIMULATION RESULTS

6.1 System Configurations Simulated

The cellular system shown in Fig. 5.1 was simulated. The simulation was done using GPSS/360 version 01 Level 03 [15, 16]and was run on the IBM/360, The simulation was started initially with no calls on in the system. The simulated system took about 20 min to reach the steady state. Statistics were collected at the end of each simulation run.

The table below summarizes the different system configuratious simulated.

TABLE 6.1

DIFFERENT SYSTEM CONFIGURATIONS INVESTIGATED

AVERAGE NUMBER OF CHANNELS PER CELL IN SYSTEM WITH UNIFORM TRAFFIC & FIXED CHANNEL ASSIGNMENT SCHEME	CHANNEL PARTITIONS FIXED : DYNAMIC	TRAFFIC LOADINGS IN ERLANGS USED IN THE SIMULATION
10	10 : 0 8 : 2 5 : 5	*5, 6, 7, 8, 9, 10
18	16 : 2 14 : 4 12 : 6	*11, 12, 13, 14, 15
28	26 : 2 24 : 4 20 : 8	*20, 22, 23, 24, 27
35	33 : 2 31 : 4 25 : 10	*26, 28, 30, 32, 34

* Base Load.

6.2 System Performance

6.2-1 Probability of Queueing

In the case of 10 fixed channels, on the average, per cell, the Fixed Channel Assignment Scheme (i.e. the channel division 10 : 0) was simulated for the sake of validating the simulator program. In Fig. 6.2 to Fig. 6.5, the Y-axis represents the average percentage of incoming calls that have to queue up for service as all channels are busy at their times of initiation. This percentage is computed, on a per cell basis, by simply taking the ratio of the number of calls having to queue up to the total number of calls initiated in the cell in a given period of time. As mentioned earlier in section 5.1, these ratios are taken only from the central twenty cells and are then averaged out to give the average percentage of calls having to queue up. Also in these figures, the X-axis represents the percentage increase in load over the base leads for the desired grades of service which are interpreted here as the probability of queueing. The percentage of load increase was calculated in the following manner. We first found from the Erlang-C traffic formula given by equation 2-4, the offered traffic, in Erlangs, required to give a desired grade of service with a certain average number of fixed channel per cell. This required traffic load is termed as the base load which was then used as the basis for computing the percentage increase in offered traffic. For example, in the 10 fixed channels case, with a mean call holding time of 120 sec, the base load corresponding to the probability of queueing of 0.036 is 5 Erlangs (i.e. $\lambda = 150$ calls/hr). Having determined the base load, the traffic was then increased from 5 Erlangs to 10 Erlangs in steps of 1 Erlang.

In Fig. 6.2, the simulated results for the Fixed Channel Assignment Scheme were plotted along with the theoretical values obtained from the Erlang-C formula. The close matching of these two sets of data indicates that the simulator program was working as desired. This figure also shows that for load increases of up to about 16% above base load the 5 : 5 system gives the lowest probability of queueing, whereas the channel division of 8 : 2 performs better for load increases between 16% to 50% over base load. However, beyond 50% increase in traffic, the system having 10 fixed channels yields the lowest probabilities of queueing.

From Fig. 6.3 we find that for load increases below 15% above base load the channel partition of 12 : 6 gives the lowest probabilities of queueing. As the load is increased from 15% to about 34% above base load the 14 : 4 system yields better results. From 34% to about 39% increase in traffic, the channel division of 16 : 2 outperforms the

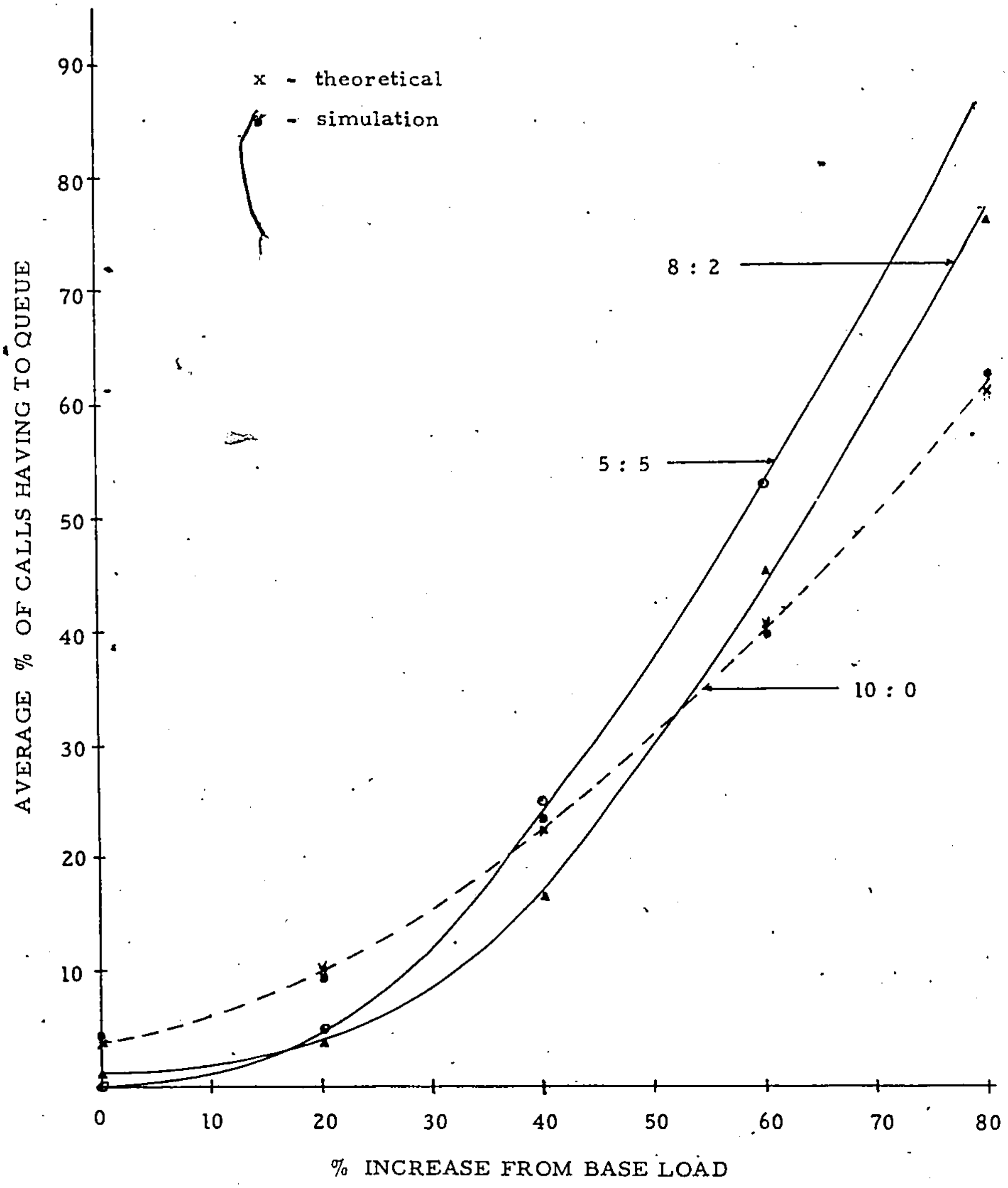


Fig. 6. 2 Average percentage of calls having to queue for the system with initially 10 fixed channels per cell.

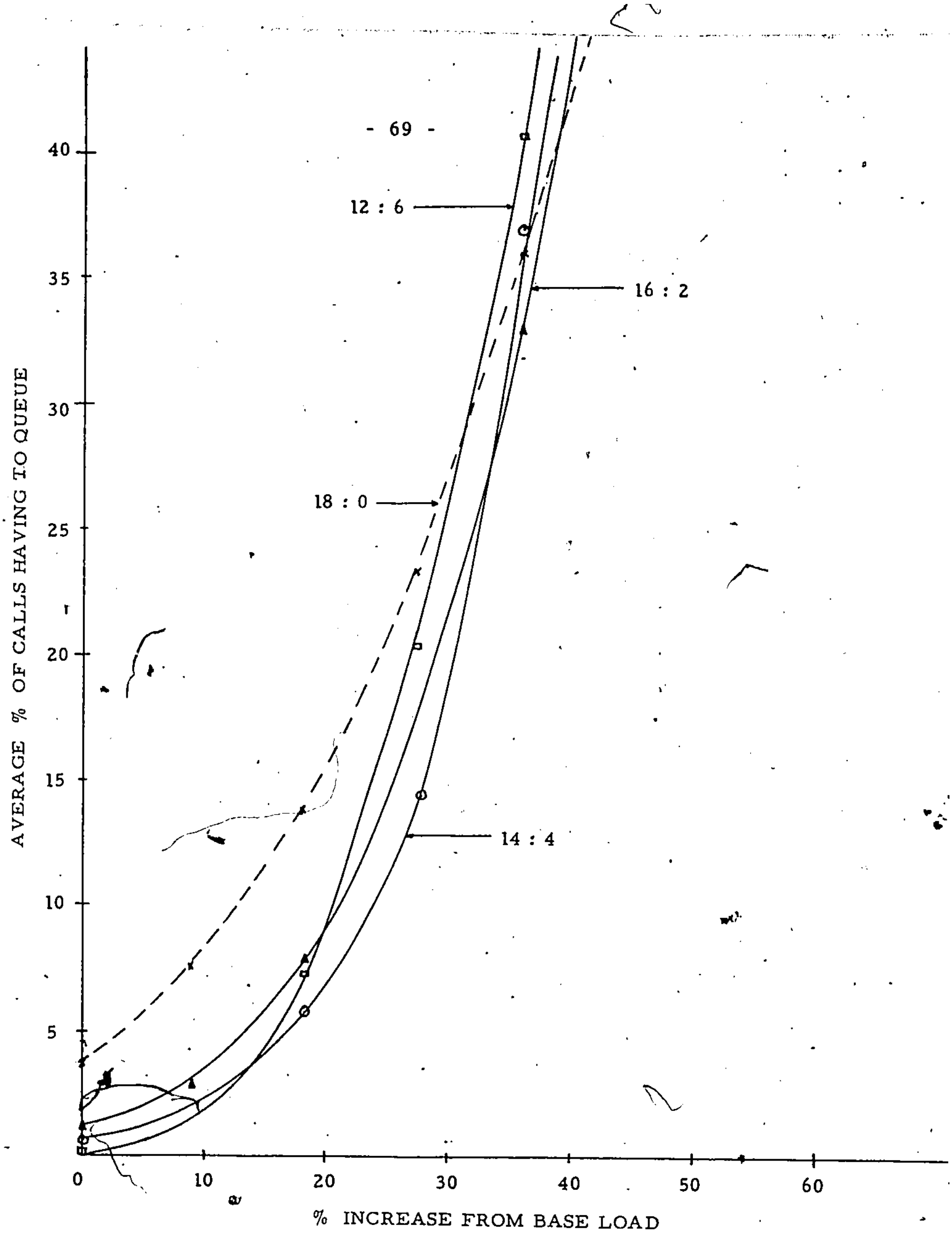


Fig. 6. 3 Average percentage of calls having to queue for the system with initially 18 fixed channels per cell.

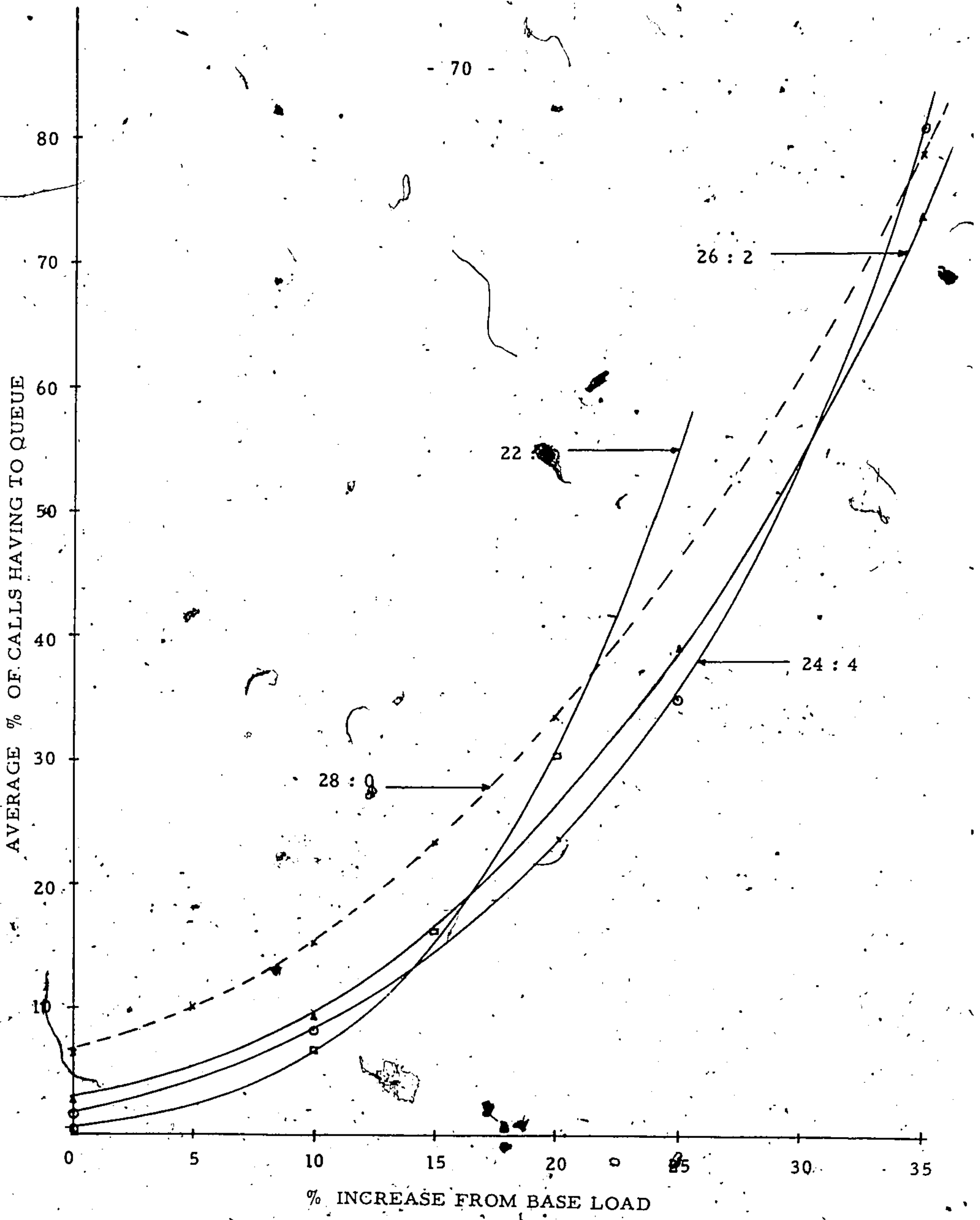


Fig. 6. 4 Average percentage of calls having to queue for the system with initially 28 fixed channels per cell.

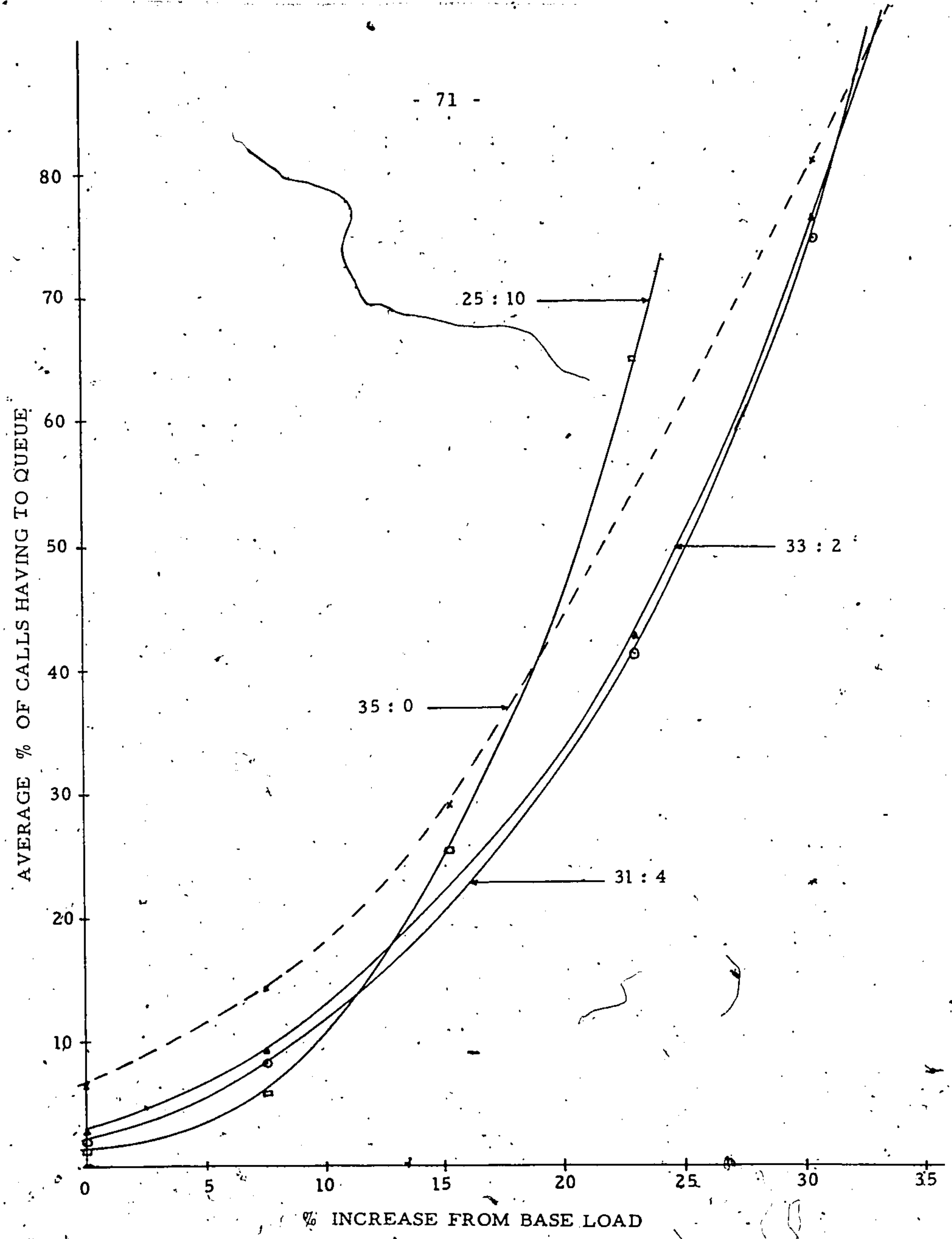


Fig. 6. 5 Average percentage of calls having to queue for the system with initially 35 fixed channels per cell.

others. Once again, for load increases beyond about 40% from base load the fixed system outmatches all its rivals.

The performance of the different channel divisions used, with an average of 28 fixed channels per cell are presented in Fig. 6.4. The figure shows that for load increases of up to about 13% above base load the 20 : 8 system has the fewest calls having to queue up for service while the system having, on the average, 24 fixed channels and 4 dynamic channels per cell gives the best results for load increases from about 13% to 32% from base load. When the load increases lie in the range 32% to 38% the channel division of 26 : 2 performs the best. Beyond about 38% load increase, it is found that the Fixed Channel Assignment Scheme regains its reign over all its competitors.

From Fig. 6.5 we once again observe that at low traffic loadings up to about 12% increase from base load, the 25 : 10 system having the most dynamic channels gives the lowest probabilities of queueing. On the other hand, the system having a channel partition of 31 fixed channels and 4 dynamic channels outmatches the rest when the load is increased from 12% to about 31%, above base load. And the 33 : 2 system takes the lead in the range of about 31% to 33% load increase. Beyond 33% load increase the Fixed Channel Assignment Scheme has the fewest calls having to join the system queue.

The results presented above show a remarkable general trend for the performance of the various system configurations simulated in regard to the probability of queueing. That is, systems with more than approximately 30% of their fixed channels being used in a dynamic mode yield the lowest probabilities of queueing for load increases of up to about 15% from base loads. With load increasing from about 15% to 30% of their fixed channels used as dynamic ones cause fewer calls to queue up for service. And systems having less than 10% of the permanent channels donated for dynamic use perform best as the offered traffic is increased from about 30% to 40% above base loads. Beyond 40% load increase, the Fixed Channel Assignment technique prevails over both the Hybrid and the Dynamic Channel Assignment Schemes.

The general behaviour of the Hybrid Channel Assignment Scheme with Erlang-C service discipline is unsurprisingly reasonable in light of the performance of the Fixed and Dynamic Channel Assignment Schemes published in early literature, [5,6,9]. The Hybrid Channel Assignment Scheme behaves, at low traffic offerings, as if the load offered to the dynamic channels is low because the load is shared among the fixed and dynamic channels. However, at high offered traffic, systems with many dynamic channels substantially force a lot of calls to queue up for service. This, however, is the general characteristics of the

Dynamic Assignment technique. On the other hand, systems with only fixed channels force fewer calls to queue up for service at high load offerings simply due to their optimal re-use of the channels.

6.2-2 Average Queueing Time

Here we define the average queueing time as the average time that a call, on finding all channels busy at its time of initiation, spends in the system queue before receiving service by an idle channel. We are able to deal with the average queueing time for the entire system since in our simulation model we assumed uniform spatial offered traffic over the whole system. Thus we are able to average out the average queueing time per cell over the central twenty cells for reasons mentioned in section 5.1. However if the offered traffic is non-uniformly distributed, then we could only talk of the average queueing time for each individual cell.

The average queueing times obtained for the different system configurations simulated were plotted against the percentages of load increase from base load. These plots are shown in Fig. 6.6 through Fig. 6.9.

In Fig. 6.6 we see that the 5 : 5 channel division has the lowest average queueing times for load increases of up to about 16%. As the load is increased beyond 16% above base load, the 8 : 2 channel partition performs best. Surprising as seen, the Fixed Channel Assignment technique is inferior to the Hybrid Channel Assignment Scheme for all traffic loadings. This rather unusual phenomenon can be

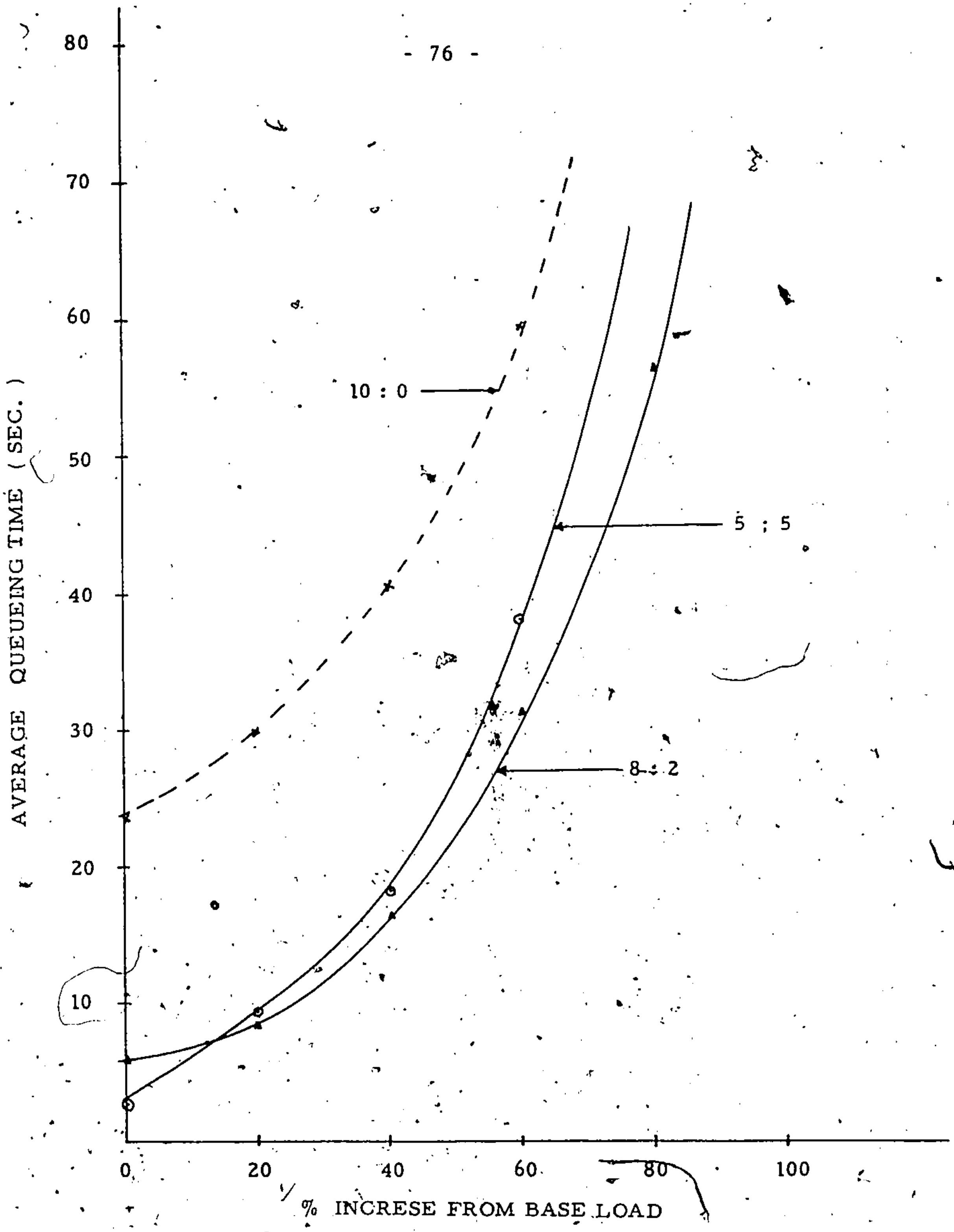


Fig. 6.6 Average queueing time for the system with initially 10 fixed channels per cell.

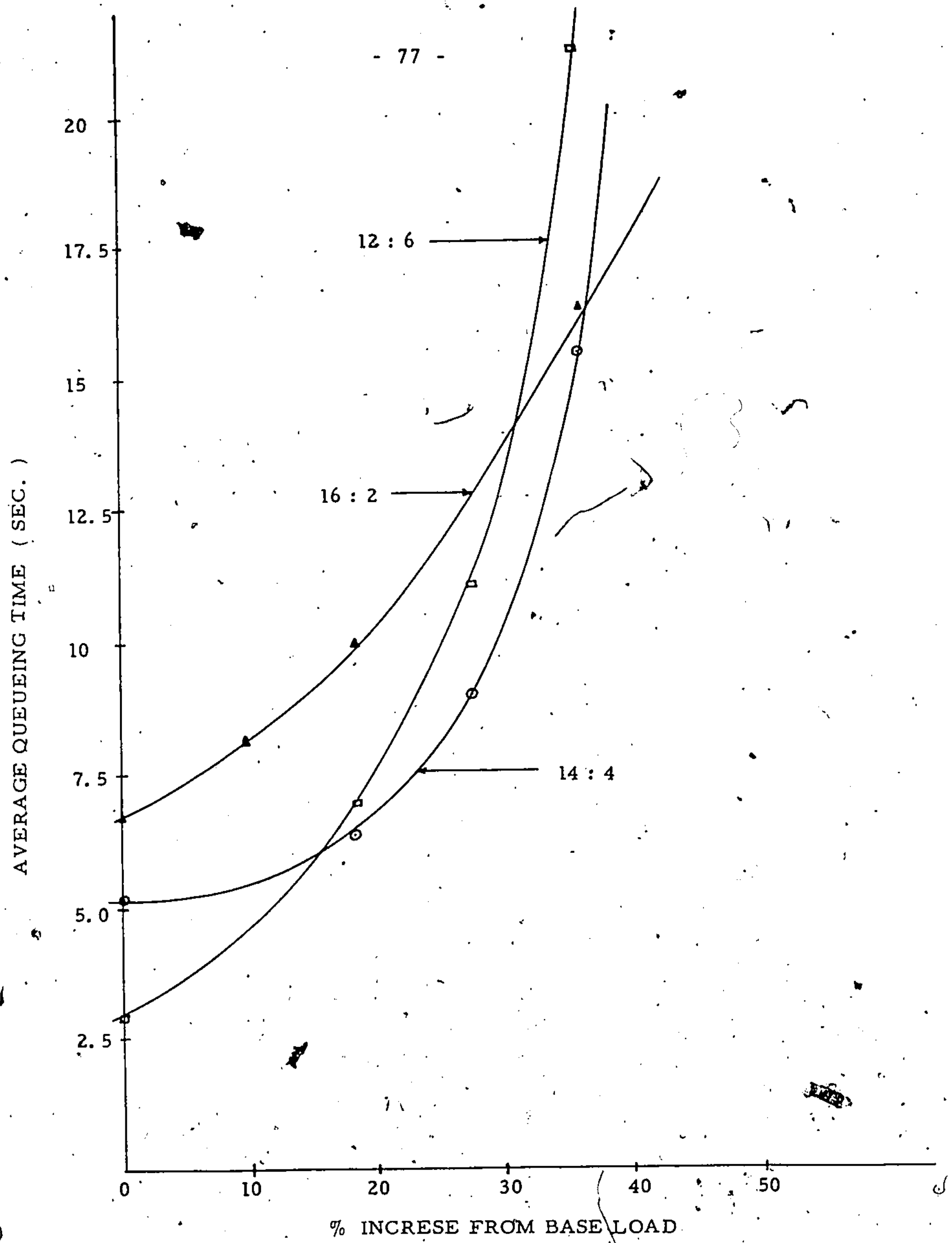


Fig. 6.7 Average queueing time for the system with initially 18 fixed channels per cell.

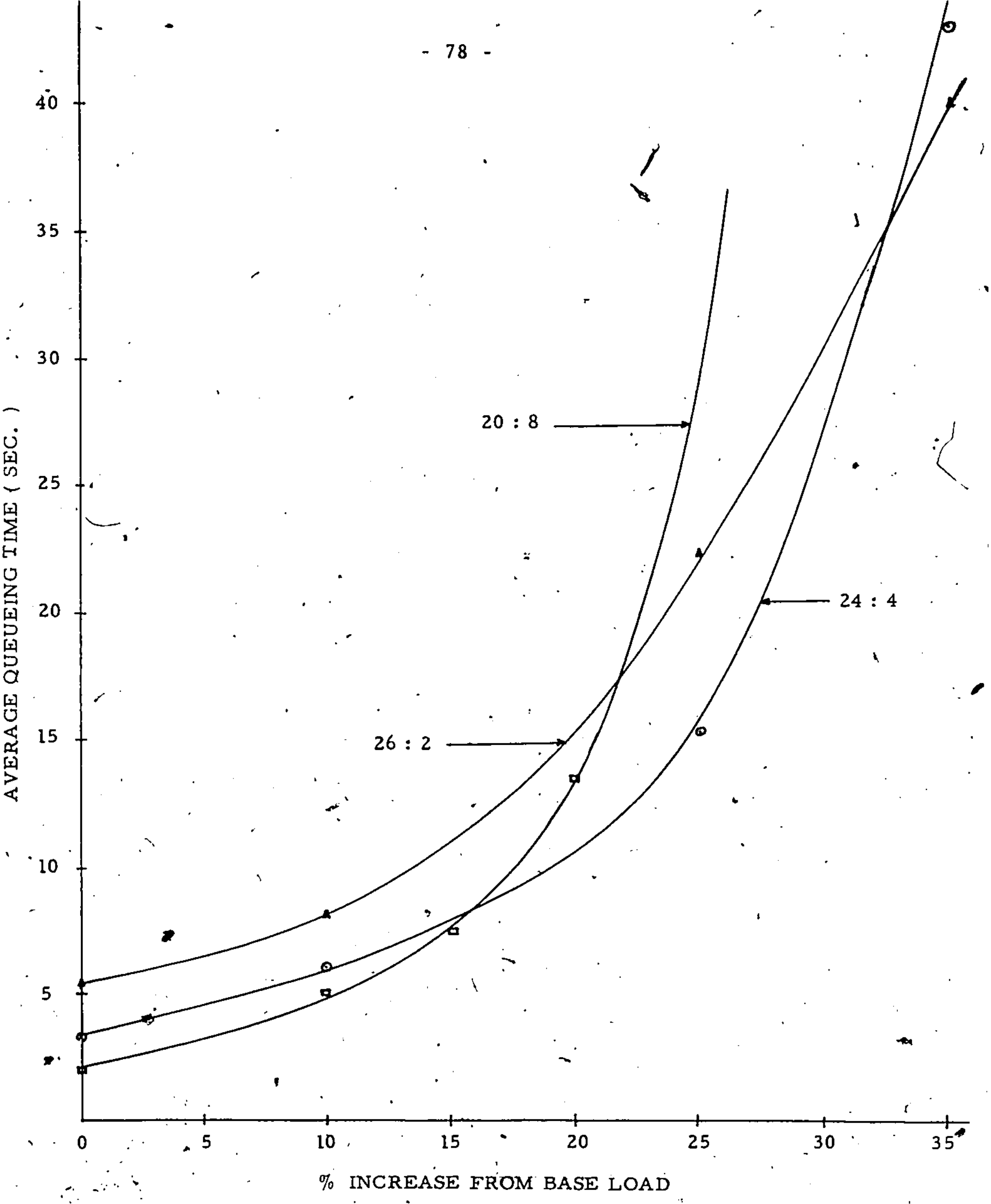


Fig. 6.8 Average queueing time for the system with initially 28 fixed channels per cell.

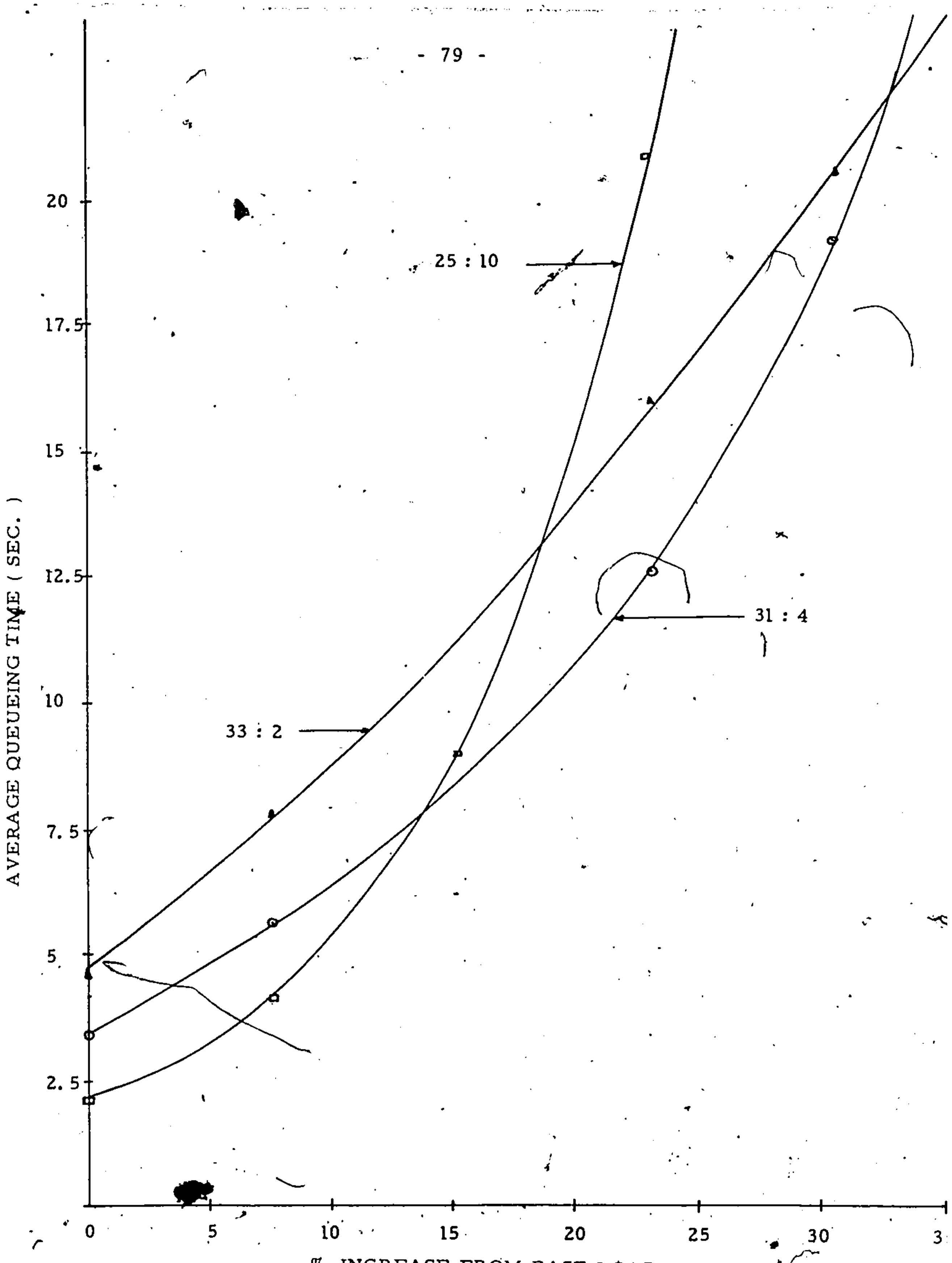


Fig. 6.9 Average queueing time for the system with initially 35 fixed channels per cell.

explained as follows. Since in the Fixed Channel Assignment Scheme channels are permanently assigned to each cell and are exclusively used there, thus calls entering into the system will have to be served by their preferred channels. This situation is analogous to the queueing case consisting of M single-server queues in parallel. Both these two cases assume Poisson arrivals, exponential service time with servers (channels) having identical service time distributions and each customer (call) having its own preferred server. However in the Hybrid Channel Assignment Scheme, each cell facililates a hybrid formation of a multi-server queue with Nd servers in which items (calls) have no predetermined servers and f single-server queues in parallel. That is to say some calls are served by their 'preferred' permanent channels while some have to be served by the first eligible dynamic channels which become available. Queueing theory states that the total queueing time for a group of items (calls) served by predetermined servers is larger than if they were able to choose the first of these servers who became free [20]. This explains the observed phenomenon that the average queueing times in the Fixed system are, at all times, greater than those in the Hybrid system.

Fig. 6.7 shows that the system with, on the average, 12 fixed channels and 6 dynamic channels per cell outperforms the other channel division ratios for load increases of up to about 13% above base load. As the offered traffic is increased from about 13% to 36% above base load the 14 : 4 channel partition yields the smallest average queueing times. Beyond 36% load increase the system with the least number of dynamic channels recaptures its once lost superiority.

The average queueing times for both the 28 and 35 fixed channels per cell follow the same pathern. For load increases of up to about 15% above base loads systems with most dynamic channels give the smallest average queueing delays, while those with a medium number of dynamic channels prevail as the load is increased from 15% to about 33% above base loads. Above 33% load increase systems having the least number of dynamic channels perform best.

This observed trend of behaviour of the average queueing times follows the one for the average percentage of queued calls. As the average percentage of calls having to queue up for service increases, the average time that a queued call spends in waiting for an idle channel increases accordingly. Furthermore, as there are more calls waiting in the queue, longer processing time is required to search for the 'suitable' queued calls to be assigned to the just vacated channels, especially the ones of dynamic nature.

As seen in the four plots, the average queueing time varies almost exponentially with the channel occupancy. As the channel utilization factor approaches unity the average queueing time rises steeply to some huge value.

This phenomenon is once again expected as with any queueing situation.

6.3-3 Average Number of Queued Calls

Once again we are able to speak of the average number of queued calls for the whole system due to the assumed uniformly distributed spatial offered traffic. Fig. 6.10 to Fig. 6.13 present the variations of the average number of queued calls with the percentages of load increase above base loads.

Fig. 6.10 shows that with load increasing up to about 15% from base load the average number of queued calls is the lowest for the system having equal number of fixed and dynamic channels per cell. Once the traffic is increased beyond that point, the system with, on the average, 8 fixed channels and 2 dynamic channels per cell starts to bring forth the smallest average number of queued calls.

This trend can be traced through Fig. 6.11 to Fig. 6.13. That is, systems employing more than 30% of the fixed channels to be used in a dynamic mode yield the smallest average number of queued calls for load increases of up to about 15% from base loads. As the load offerings are increased from about 15% to 32% above base loads systems comprising approximately 10% to 30% of the fixed channels for dynamic use have, on the average, fewer calls waiting

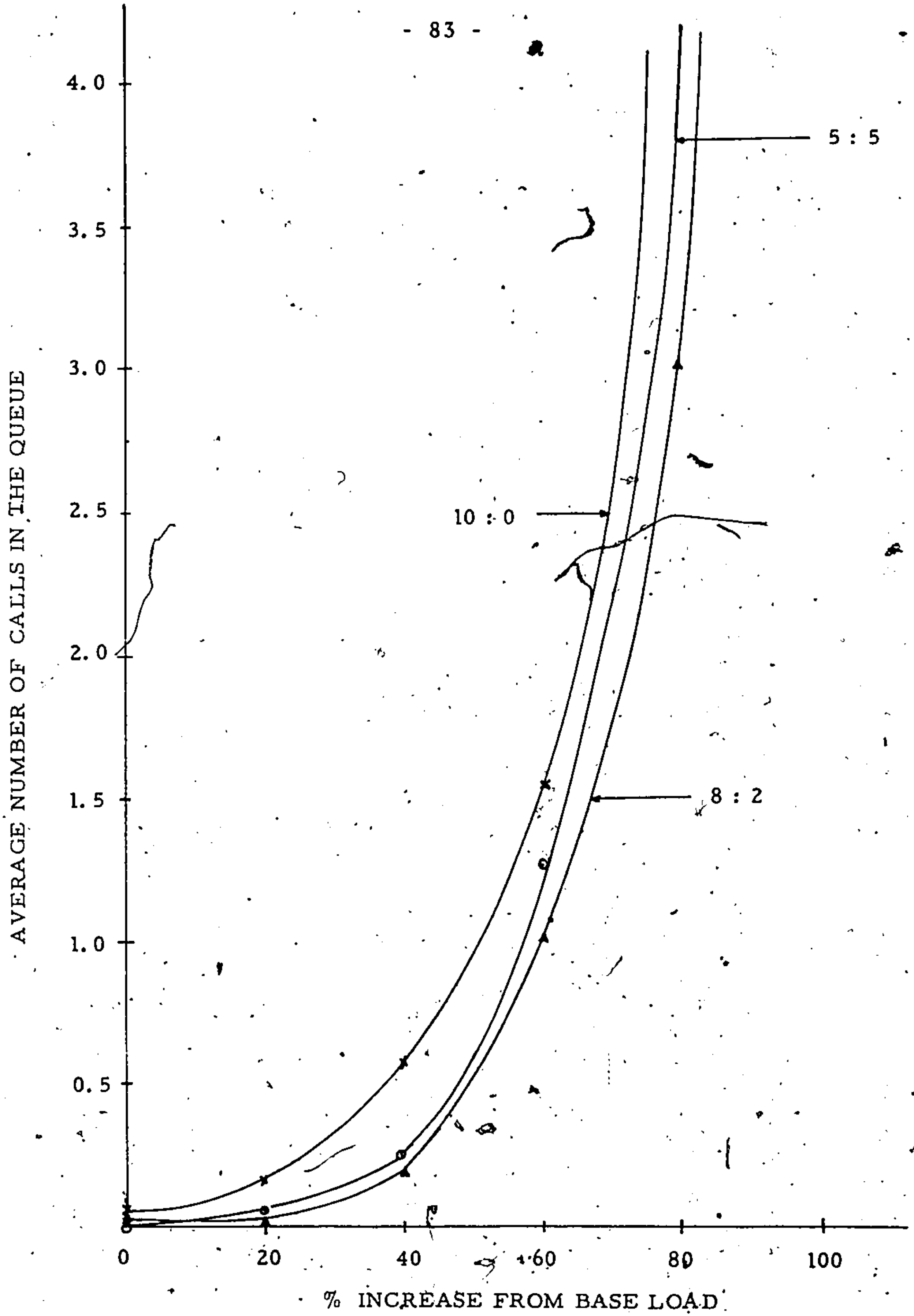


Fig. 6. 10 Average number of calls in the queue for the system with initially 10 fixed channels per cell.

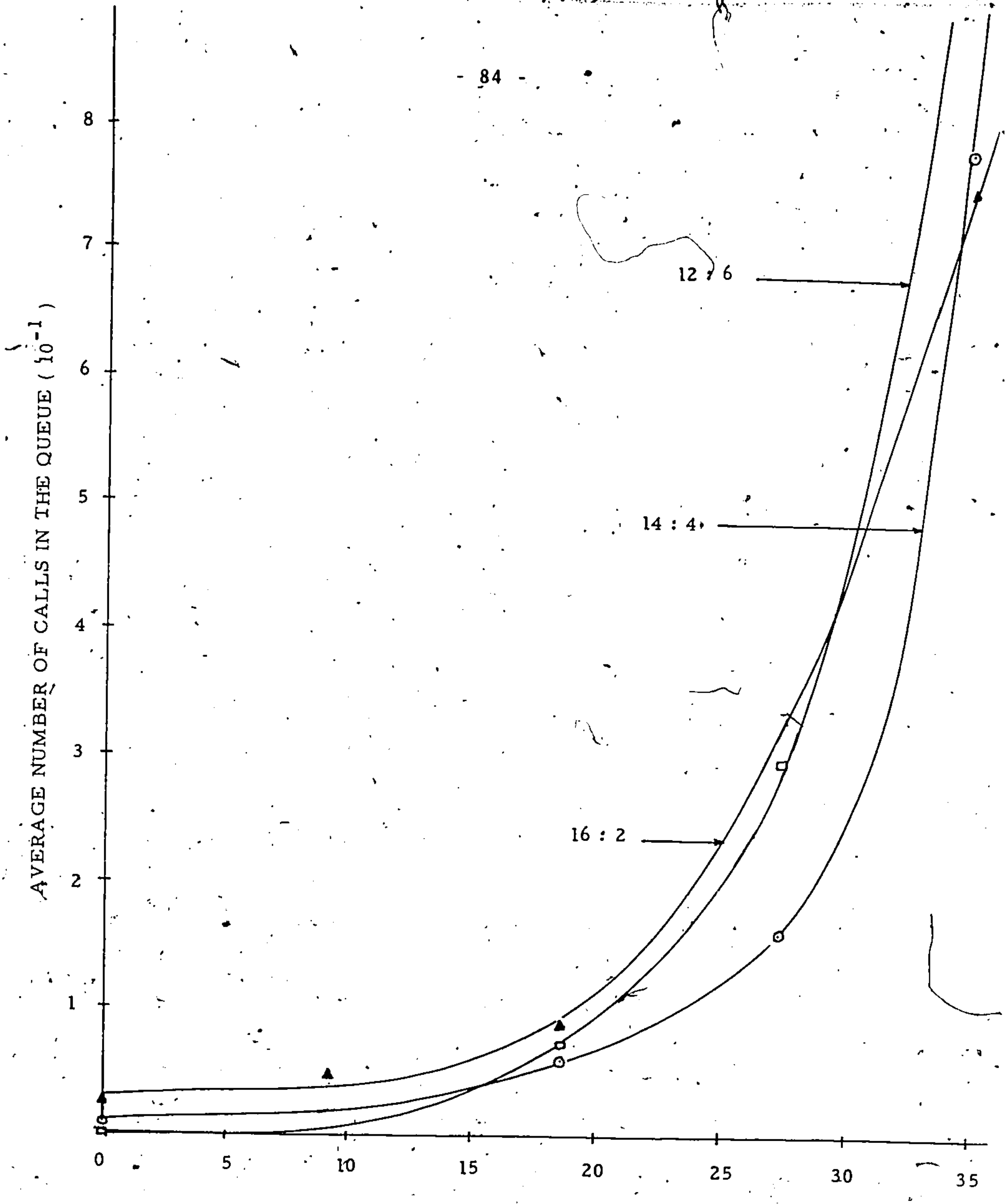


Fig. 6. 11 Average number of calls in the queue for the system with initially 18 fixed channels per cell.

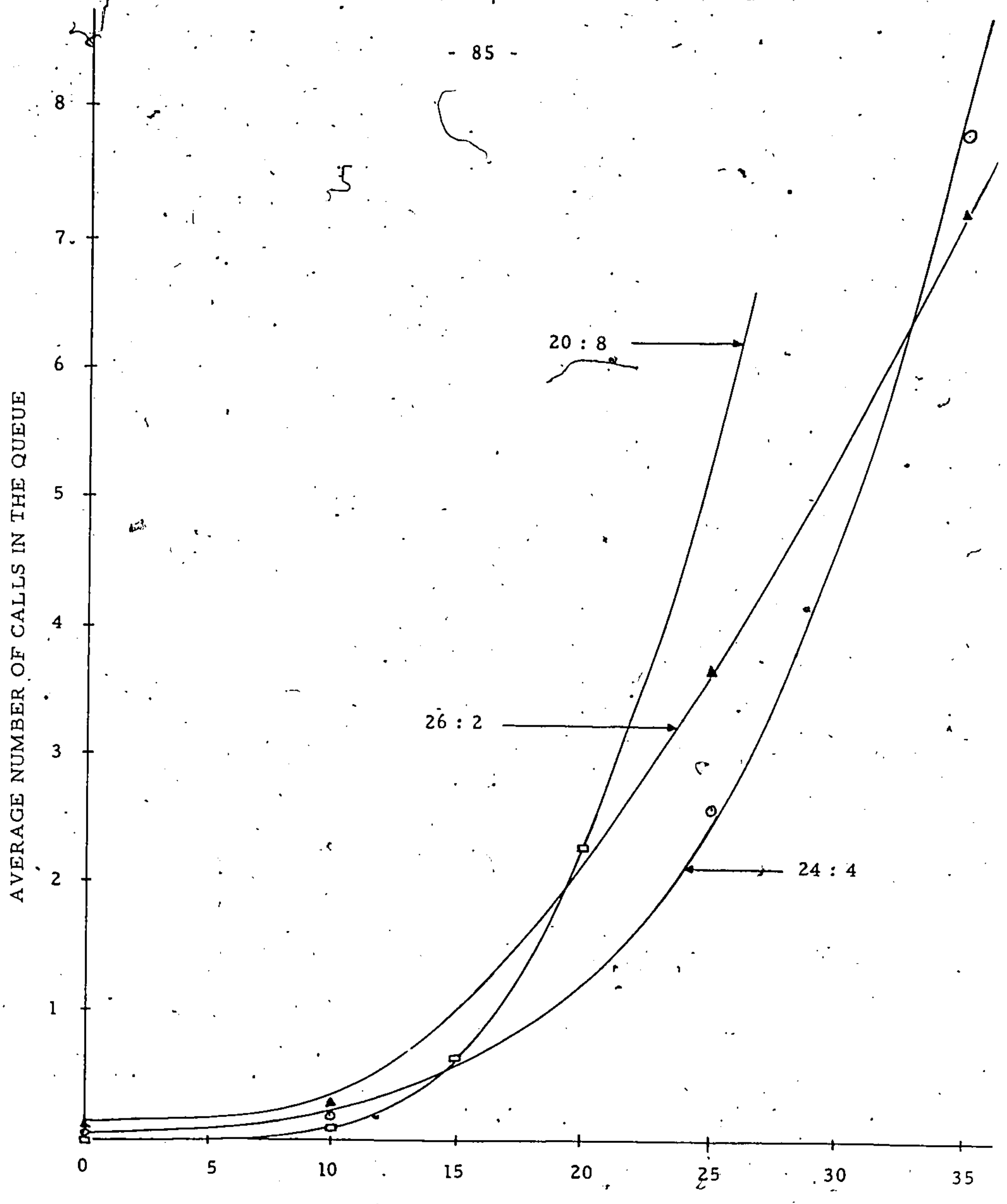


Fig. 6. 12 Average number of calls in the queue for the system with initially 28 fixed channels per cell.

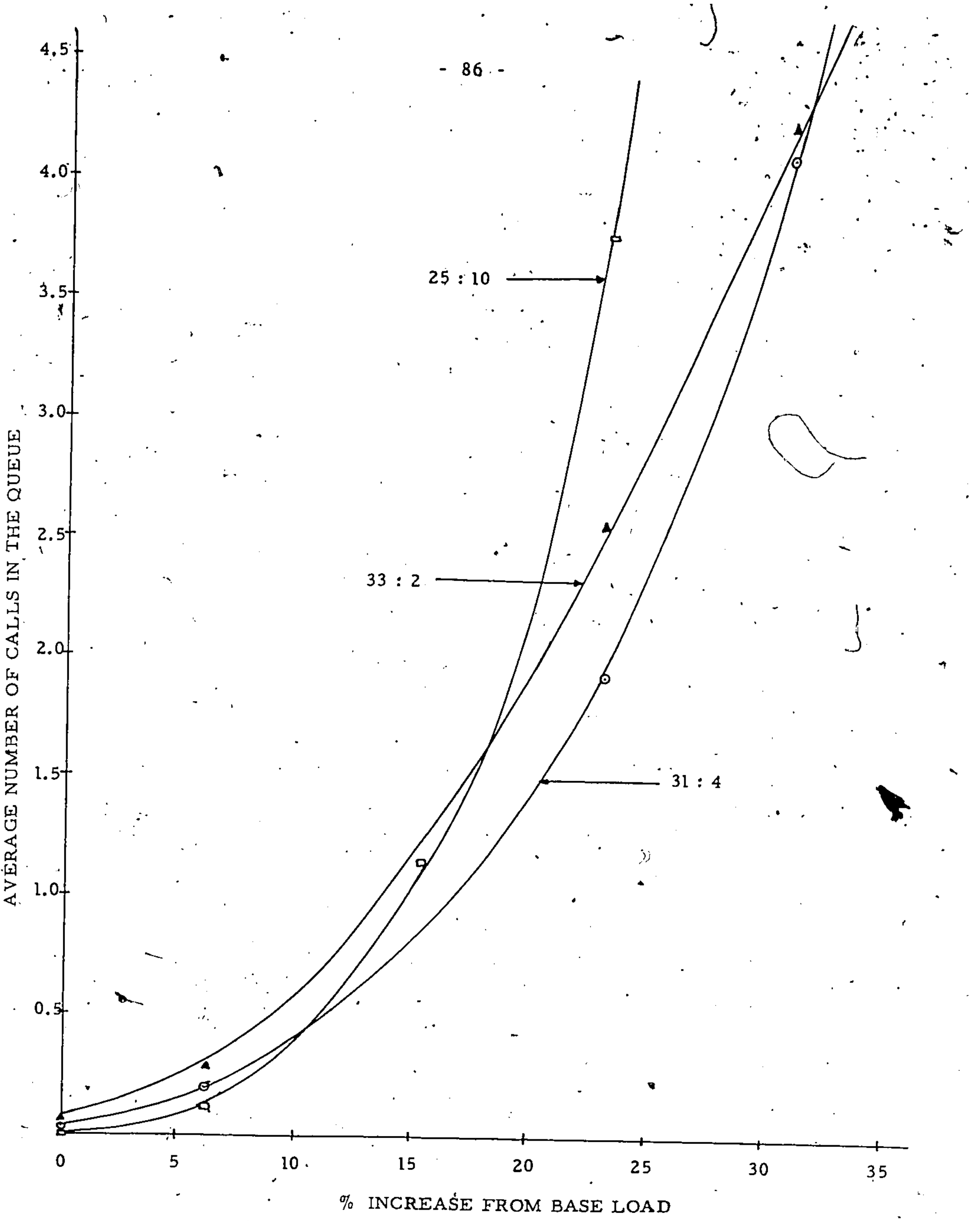


Fig. 6. 13 Average number of calls in the queue for the system with initially 35 fixed channels per cell.

in the queue. Within approximately 32% to 40% load increase systems with less than 10% of the fixed channels for dynamic assignment give the smallest average number of queued calls.

From the four graphs on the average number of queued calls versus the percentage increase in load we could give estimates on the average buffer size required for each of the system configurations simulated. With, on the average, 10 fixed channels per cell, a maximum of 3 buffers is required as we rarely drive the system to such a point that the channel occupancy is over 90% which corresponds to a load increase of above 60% from base load. For the 18 fixed channels case 2 buffers will be sufficient to handle all traffic loadings up to about 45% above base load, which corresponds to a channel utilization of 89%. For the system having, on the average, 28 fixed channels per cell, it needs a maximum of 6 buffers to deal with various load increases of up to about 30% above base load, which corresponds to a channel occupancy of about 90%. Finally, with, on the average, 35 fixed channels per cell, 3 buffers are adequate to provide decent service for all loadings of up to about 23% above base load.

6.2-4 Performance with Regard to Erlang-B and Erlang-C Service Disciplines

Erlang-B (BCC) service discipline yields a non-zero probability of blocking, whereas the average queueing time is zero because the calls once blocked are immediately cleared from the system. On the contrary, with Erlang-C (BCD) service discipline the probability of blocking vanishes while the average queueing time is non-zero due to the fact that calls on finding no channels available at their times of initiation are allowed to queue for service. In addition, the latter discipline has a queue of unlimited size. Thus the throughput in the Erlang-C case is always greater than the one in the Erlang-B case [11]. Hence the performance of the Hybrid Channel Assignment Scheme with regard to Erlang-B and Erlang-C service disciplines can only be compared on the basis of the average percentage of time that all available channels are occupied.

In Fig. 6.14 to Fig. 1.17, the Y-axis represents the average percentage of time that all channels are busy. The X-axis represents the percentage of load increase from base loads. The curves for the Erlang-B case are extracted from Ref. 18.

All the four graphs show one common fact that at all times, for the same amount of load increase above base

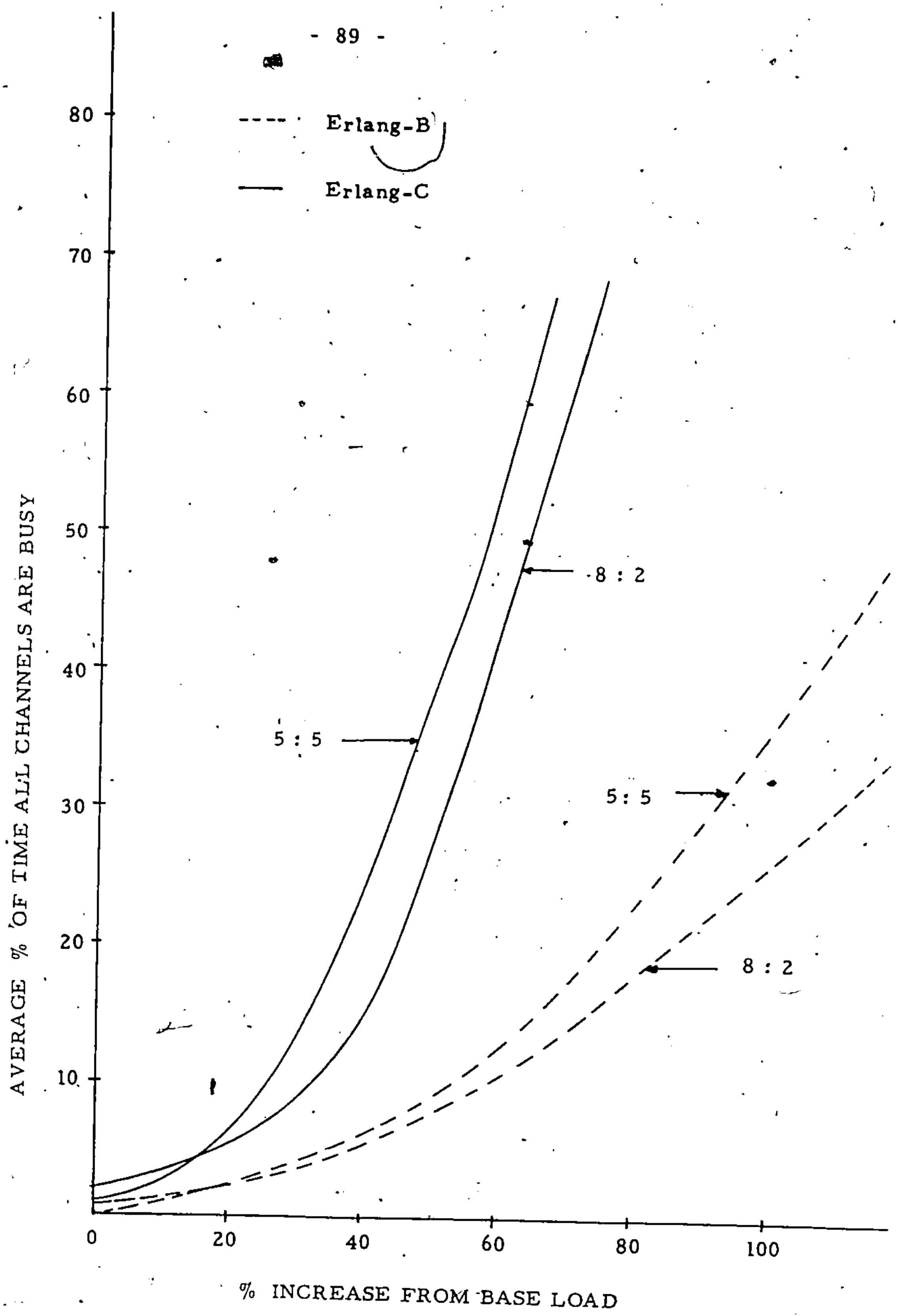


Fig. 6. 14 Performance of the system with initially 10 fixed channels per cell for Erlang-B and Erlang-C service disciplines.

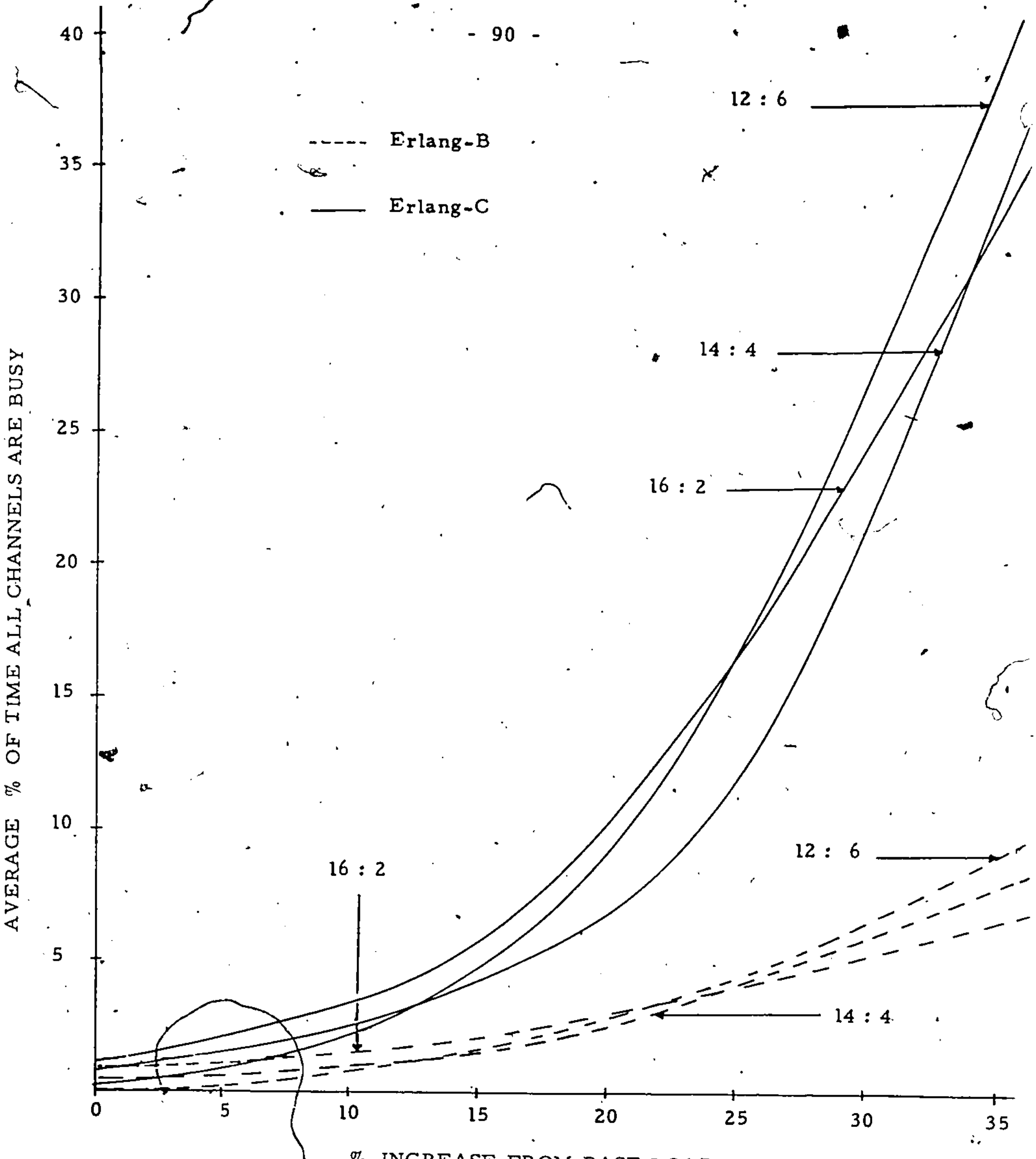


Fig. 6. 15 Performance of the system with initially 18 fixed channels per cell for Erlang-B and Erlang-C service disciplines.

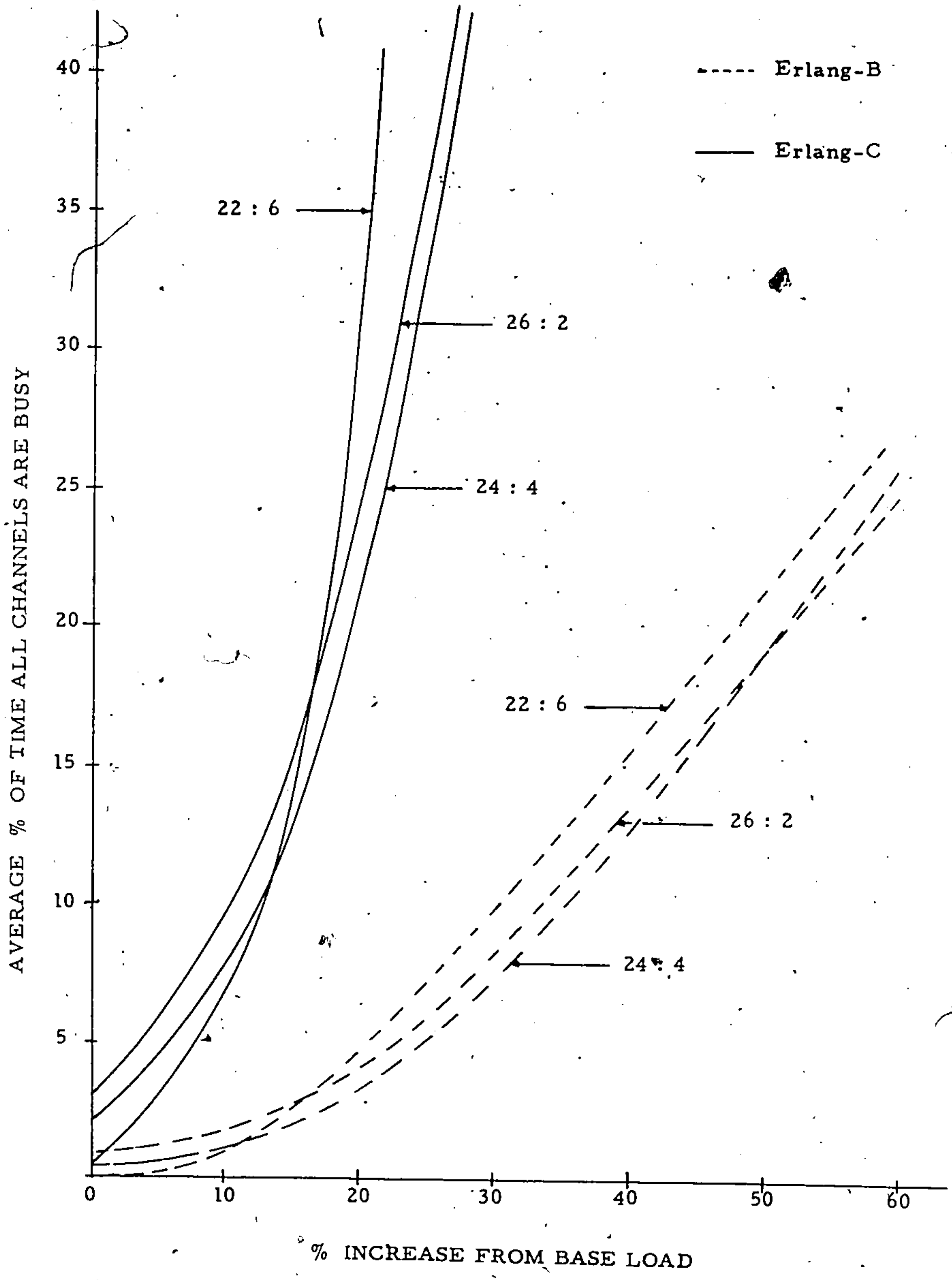


Fig. 6. 16 Performance of the system with initially 28 fixed channels per cell for Erlang-B and Erlang-C service disciplines.

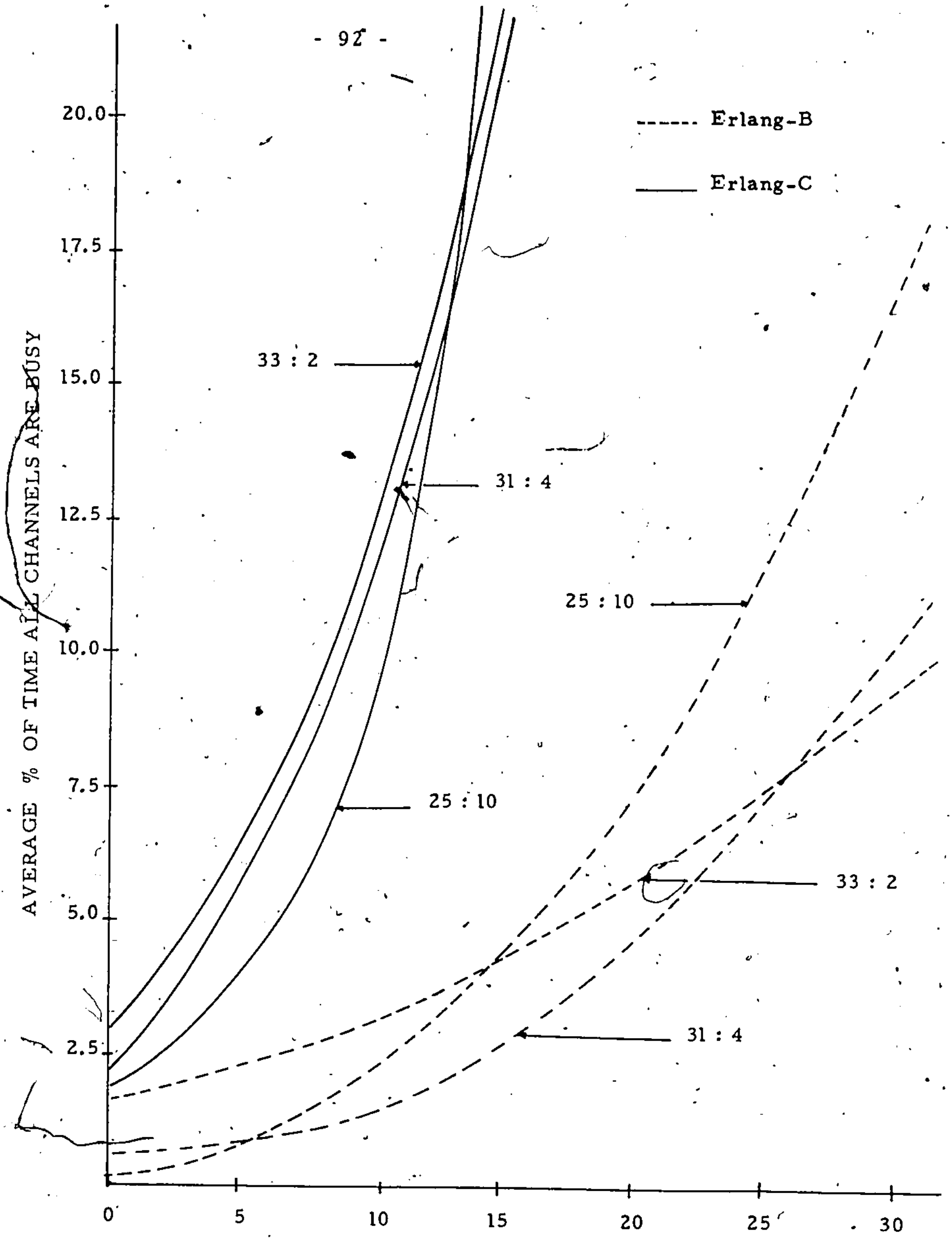


Fig. 6. 17 Performance of the system with initially 35 fixed channels per cell for Erlang-B and Erlang-C service disciplines.

loads, systems employing the HCAS coupled with Erlang-C service discipline heighten the average percentage of time that all available channels are found busy. This phenomenon is, however, expected as with Erlang-C service discipline calls on finding no channels available are permitted to queue until they can be served by some idle channels. Thus a channel on completing its service to a call, instead of becoming idle and returning to its nominal cell or to the system pool waiting for the next assignment, will be assigned to service one of the queued calls. Consequently, the channels are more frequently occupied in the Erlang-C case than in the Erlang-B case.

Apart from this discrepancy in performance, the behaviour of the Hybrid Channel Assignment Scheme for Erlang-C and Erlang-B traffic falls in the same pattern. For light loadings, systems with most dynamic channels maintain the leading role in producing the best performance. System having a medium number of the fixed channels for dynamic use, perform oustandingly when the systems are moderately loaded. At relatively high traffic loadings, systems comprising a few dynamic channels prevail over all others. Eventually, the Fixed Channel Assignment technique recovers its 'lost grounds' when the systems are heavily loaded.

CHAPTER 7

CONCLUSIONS

In the simulation of the cellular system employing the Hybrid Channel Assignment Scheme with Erlang-C service discipline we assigned up to 33% of the channels available per cell to be used in a dynamic mode. For all system configurations simulated the results obtained displayed the same general pattern. That is, systems with most dynamic channels gave the lowest probability of queueing, the lowest average queueing time and the smallest average number of queued calls for load increases of up to about 15% above base loads. As the load is increased from 15% to about 32% from base loads, systems with a medium number of dynamic channels gave the best performance indices. Systems with a small number of dynamic channel yielded the least in probability of queueing, average queueing time as well as average number of queued calls, for load increases from 32% to about 40% above base loads. Beyond 40% load increase, systems with no dynamic channels performed best.

This general pattern unsurprisingly reflects the characteristics of the Fixed and the Dynamic Channel Assignment techniques under high and low offered traffic. It may be surprising to see that though the average number of channels per cell after channel partitioning is smaller than the one before partitioning, systems using the Hybrid Channel Assignment Scheme perform better than those employing either the Fixed or the Dynamic Channel Assignment technique, for low to moderate load increases. This is the consequence of the sharing of the offered traffic between the fixed and dynamic channels. However, dynamic channels are not always used to the maximum possible number of times within the entire service area. Thus more calls are blocked and queued for service at high traffic loadings. On the other hand, systems with only fixed channels perform best at high load offerings due to their optimal channel re-use.

Although we have not considered systems with non-uniform traffic distributions and cell boundaries crossings in our simulation model, we would expect a similar general pattern for the performance of the Hybrid Channel Assignment Scheme for these systems. We believe that the Hybrid Channel Assignment Scheme would show its overwhelming performance with non-uniform spatial traffic since there are dynamic channels to move around to serve the normal random fluctuations in the offered-traffic.

We hope that these simulation results will be of use to those designing cellular high-capacity ~~land~~-mobile radio communications systems.

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APPENDIX A

GPSS FLOW-CHART

TABLE OF DEFINITIONS

Time unit = 1 msec.

TRANSACTIONS

Model Segment-1	Calls originated from cells.

Parameters of each transaction

P1	Contains the cell number (origin) of each call.
P2.	Contains the channel division ratio.
P3	Contains the fixed channel number , if a call is to served by a fixed channel.
P4	Contains the dynamic channel number, if a call is to be served by a dynamic channel.
P9	Contains either a zero or the number -900 depending on whether the call has been queued for service.
P10	Contains the queue number.

Model Segment-2	Dynamic channels, seeded by the master channel via the split block.

Parameters of each transaction

P1-P40	Each of these 40 parameters contains the cell number of the borrowing call, whenever the dynamic channel is borrowed for use there.
P46	Contains the channel divison ratio.
P47	Contains the serialization number of the dynamic channels.
P48	Contains the dynamic channel number.
P49	Contains a varying number which facilitates the search of an eligible queued call to be served by a just vacated dynamic channel.
P50	Contains the cell number of the call that wants to borrow a dynamic channel.
P51	Contains a varying number corresponding to P10 of the call from Segment-1 to facilitate the eligible queued call search.

SAVEVALUES

1	Stores the channel division ratio.
2	Stores the origin of the call that wishes to borrow a dynamic channel.
4	Stores the number of the dynamic channel that has been found suitable for borrowing to the requesting call.
6	Stores the number of the borrowed dynamic channel for immediate communication purpose.
7	Stores the origin of the call that has just released a fixed channel upon completion of service.
8	Stores the number of the dynamic channel which is going to be relieved by a just vacated fixed channel.
9	Stores the number of the fixed channel which is going to free a dynamic channel.
10	Stores the column number of the matrix JOYAL, corresponding to that of the fixed channel which is about to relieve a dynamic channel.
11	Stores a zero.
12	Stores the origin of the call that wishes to borrow a dynamic channel.
14	Stores the cell number of the call that has just released a fixed channel.

15	Stores the column number of the matrix JOYAL, corresponding to that of the just released fixed channel.
16	Stores the number of the just released fixed channel.
17	Stores the origin of the call that has just released a dynamic channel.
18	Stores the number of the just vacated dynamic channel.
19	Stores the queue number of the call which has just completed service by either a dynamic channel or a reassigned fixed channel.

VARIABLES

1-40	Variable i gives the cochannel interference criterion to be met by any intended borrowing of a dynamic channel at cell i .
41-55	Means of assigning dynamic channel numbers to the transactions from Segment-2 according to the channel division ratio.
56	The run time.
57	The mean call holding time.
59	Contains the number P3-2*P3. A negative value indicates that all the nominal fixed channels of the cell in question are busy.
60	The total number of calls in the system.
61	The mean call-interarrival-time.

BOOLEAN VARIABLES

1-40	Boolean variable i indicates the current activity of the dynamic channels within the interference cell group of cell i .
50	Controls the simulation run.

TABLES

SUCES	Tabulates the calls that have been served immediately upon arrival.
CWS	Tabulates the calls that have been served after awaiting service for some period of time.
WAIT	Tabulates the calls that have queued up for service.
FAIL	Tabulates the calls that have been denied of service completely. (just for checking purpose)

STORAGES

1-40	Cell storages.
49 (HELEN)	System storage.

CHAINS

ATTEND	Chain where calls waiting for dynamic channels to be found available for service.
BLOC	Chain where calls queue for service.
FILE	Chain used to assign the dynamic channel

	numbers to the copies split from the master dynamic channel.
POOL	Chain that keeps track of all the dynamic channels in the system.

GROUPS

1-40	Group i contains the calls from cell i which are currently using dynamic channels.
45	Contains all dynamic channels in the system.
51-90	Group j contains the calls from cell j which are in the queue awaiting service.

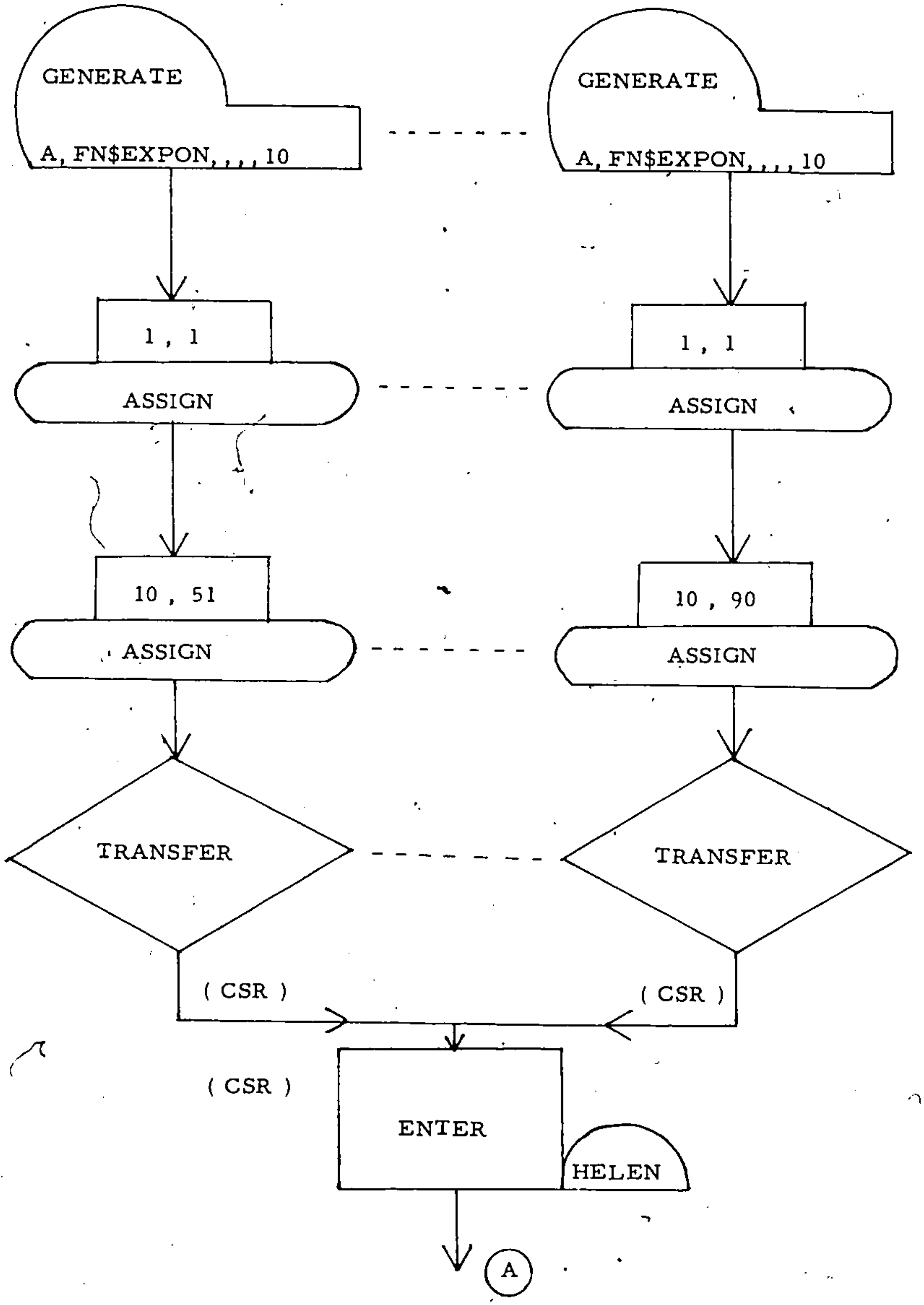
SWITCHES

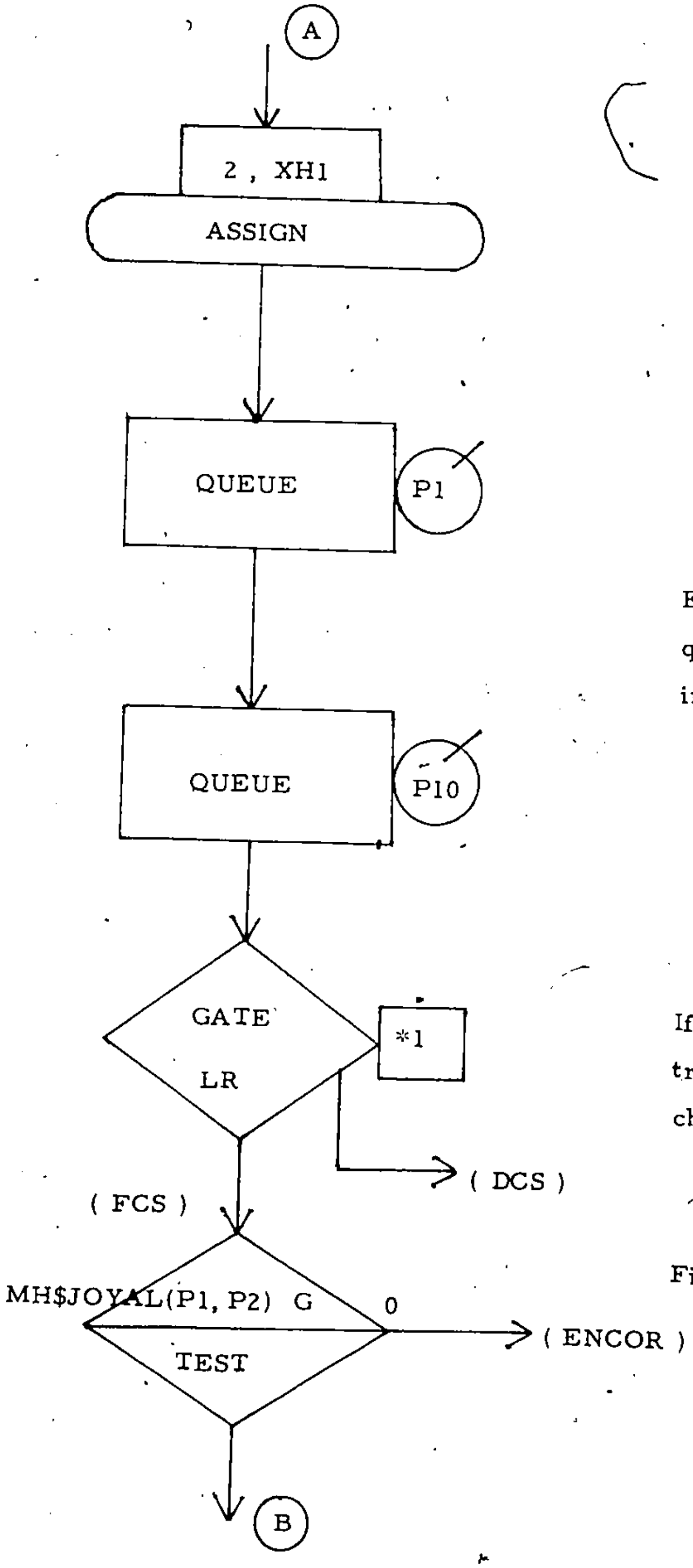
1-40	Switch i informs all incoming calls from cell i about the current availability of the nominal fixed channels of that cell.
51-90	Switch j informs all incoming calls from cell j about the current availability of dynamic channels that can be borrowed for use in that cell.

FUNCTION

EXPON	This function is used to generate the Poisson arrivals of calls and the exponential call holding times.

MODEL SEGMENT-1

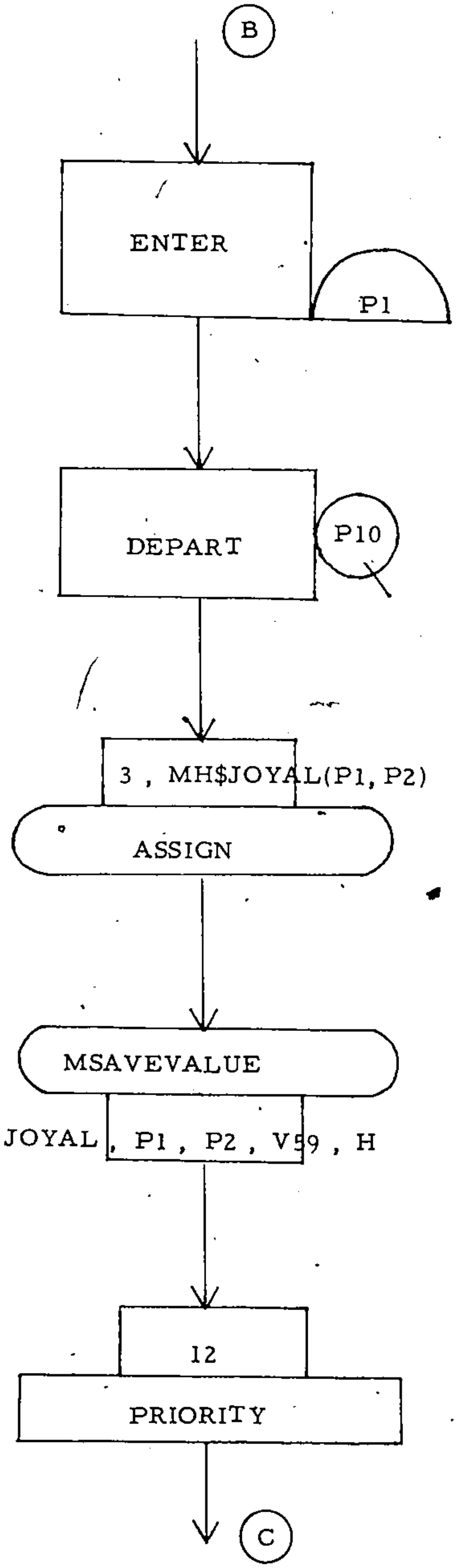




Enter in the corresponding queues to gather the queueing statistics.

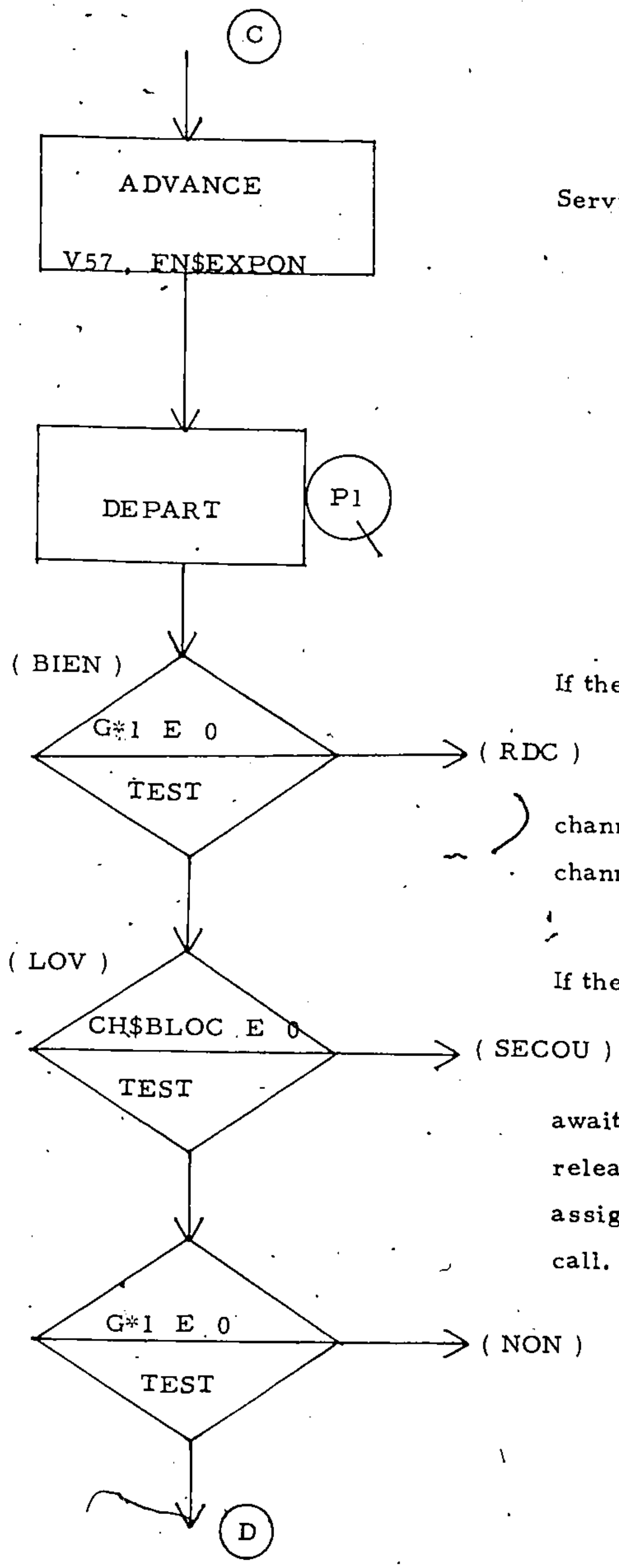
If no fixed channel available, try to find a suitable dynamic channel.

Find the first fixed channel that is not in use.



Enter in the particular cell P1.

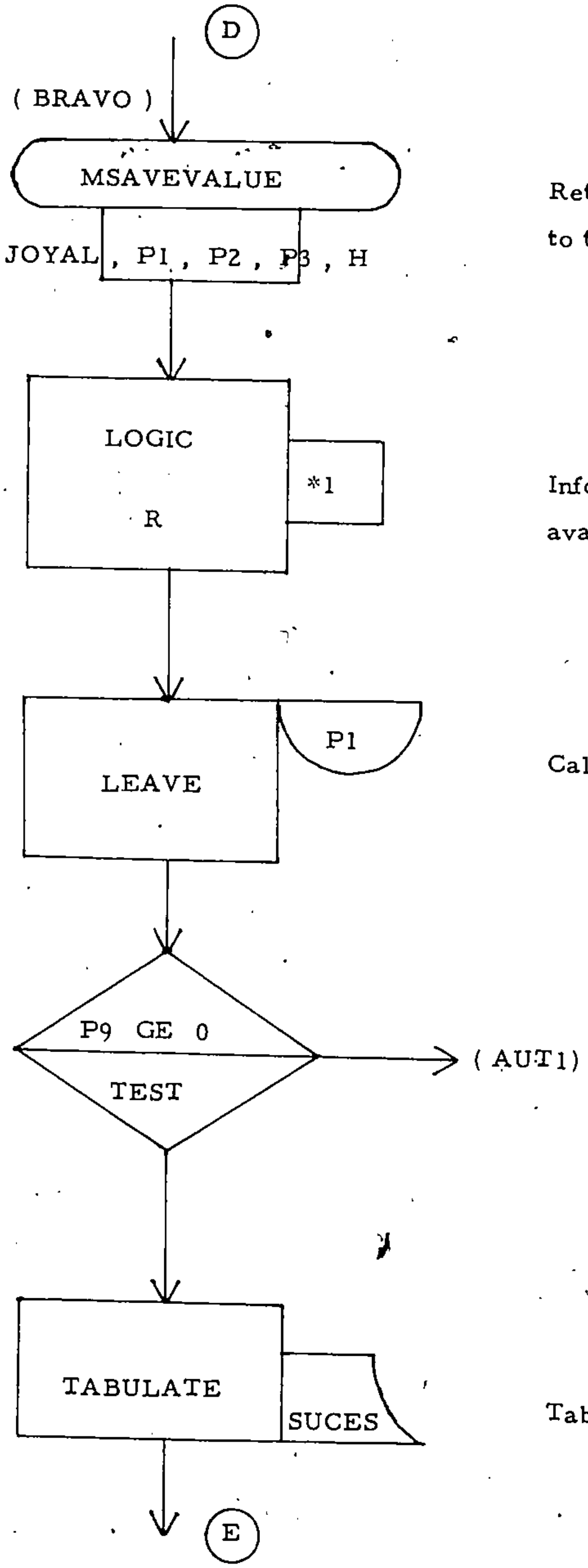
Eliminate the assigned fixed channel from the cell P1.



Service by the fixed channel.

If there is a call from the particular cell using a dynamic channel, go free that channel.

If there are calls from the same cell in the system queue awaiting service, the released fixed channel is assigned to the first such call.



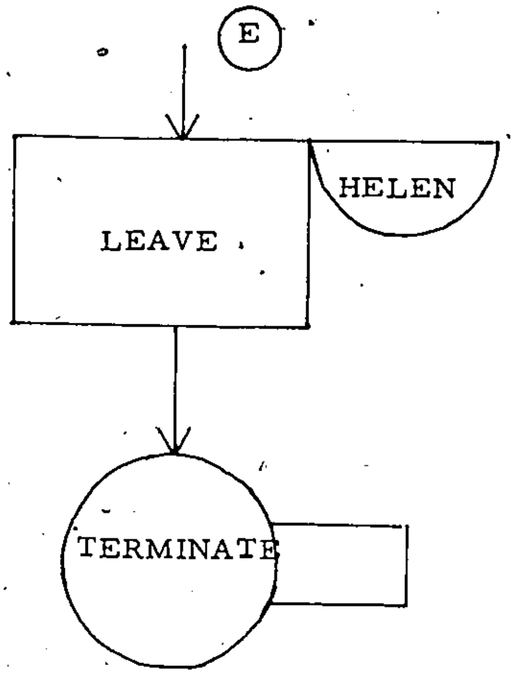
Return the fixed channel to the cell.

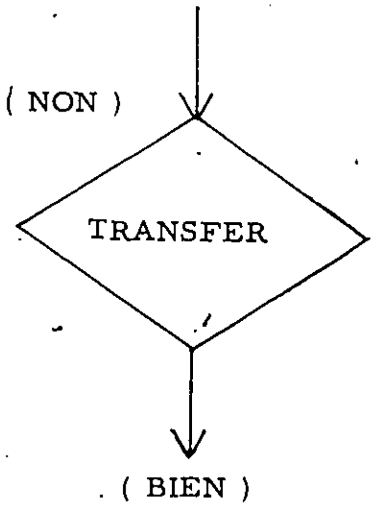
Inform incoming calls of available fixed channel(s).

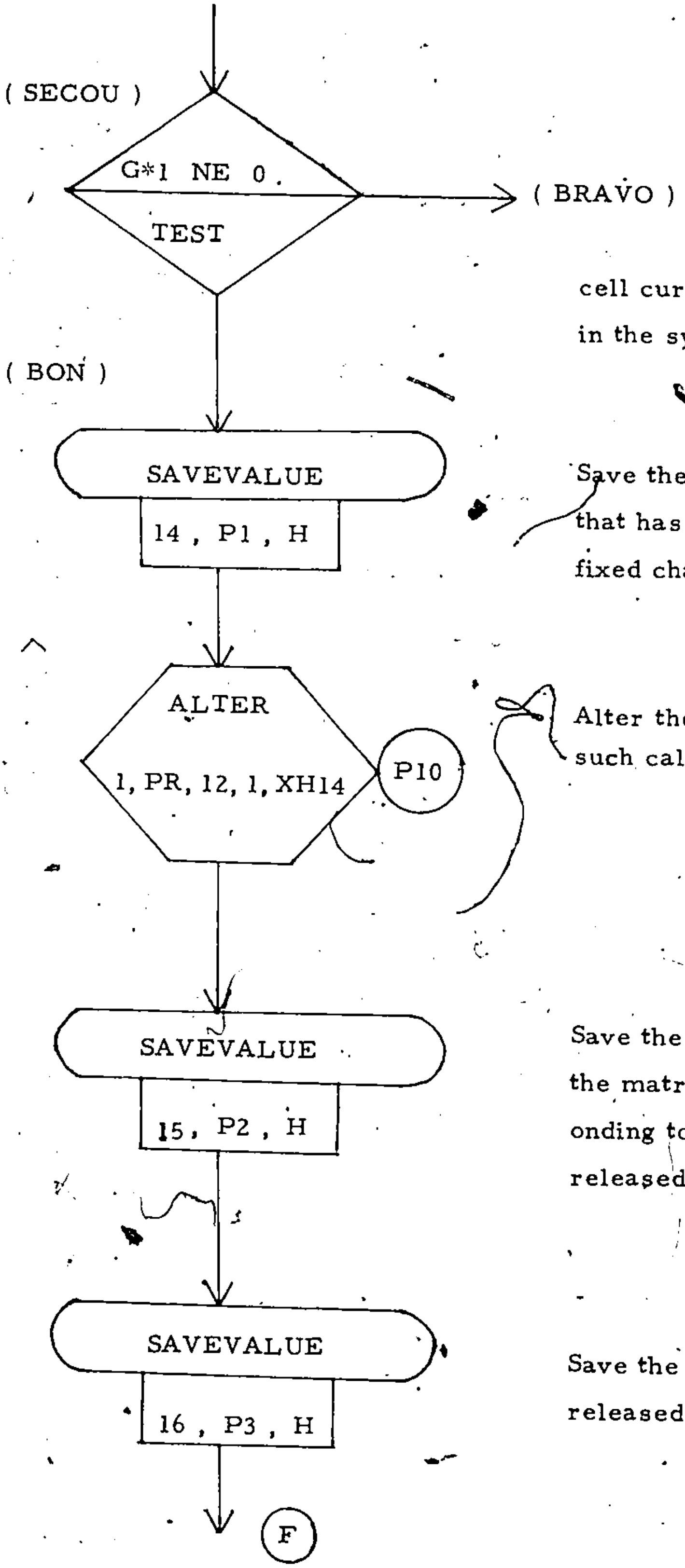
Call leaves the cell P1.

See if that call had been in the queue.

Tabulate the served call.


E
LEAVE
HELEN
TERMINATE


(NON)
TRANSFER
(BIEN)



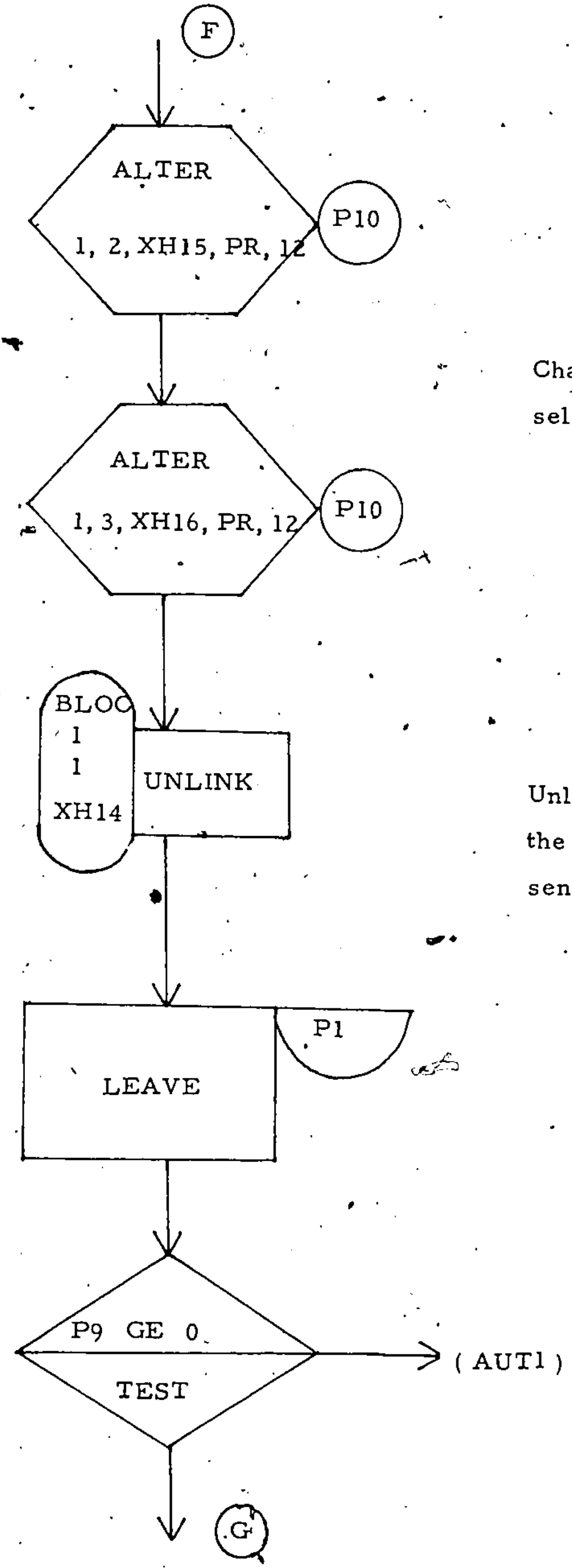
Check if there there are calls from the same cell currently awaiting service in the system queue.

Save the origin of the call that has just released the fixed channel.

Alter the priority of the first such call in the group P10.

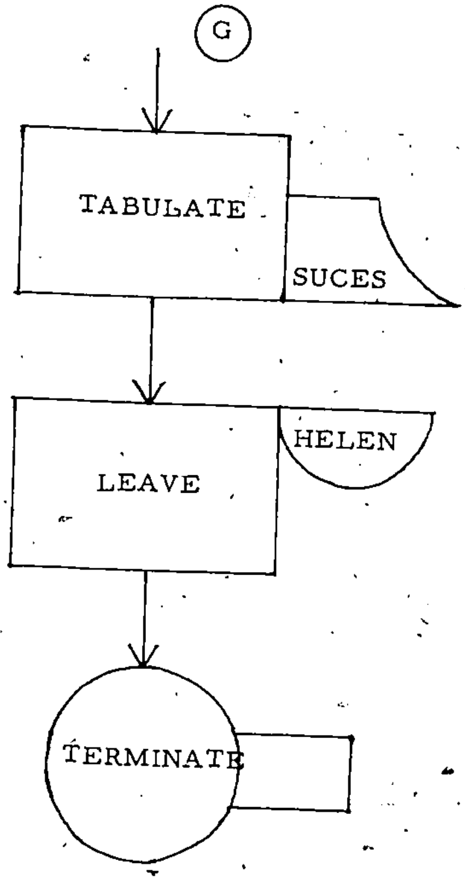
Save the column number of the matrix JOYAL corresponding to that of the just released fixed channel.

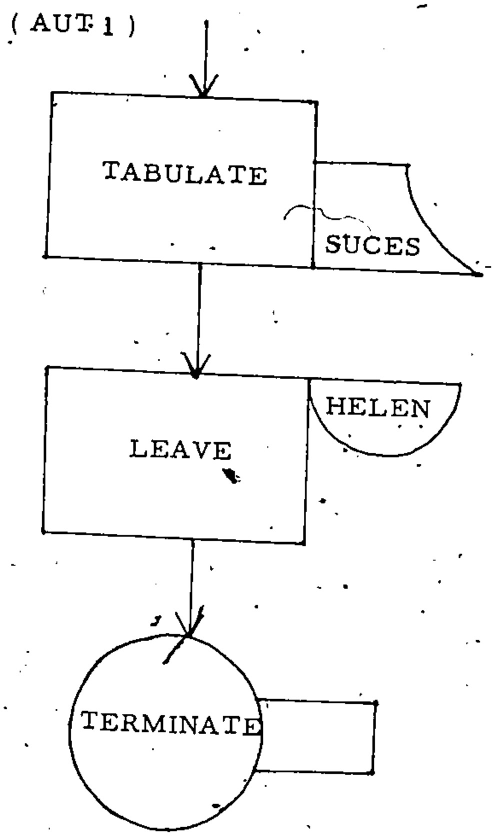
Save the number of the just released fixed channel.

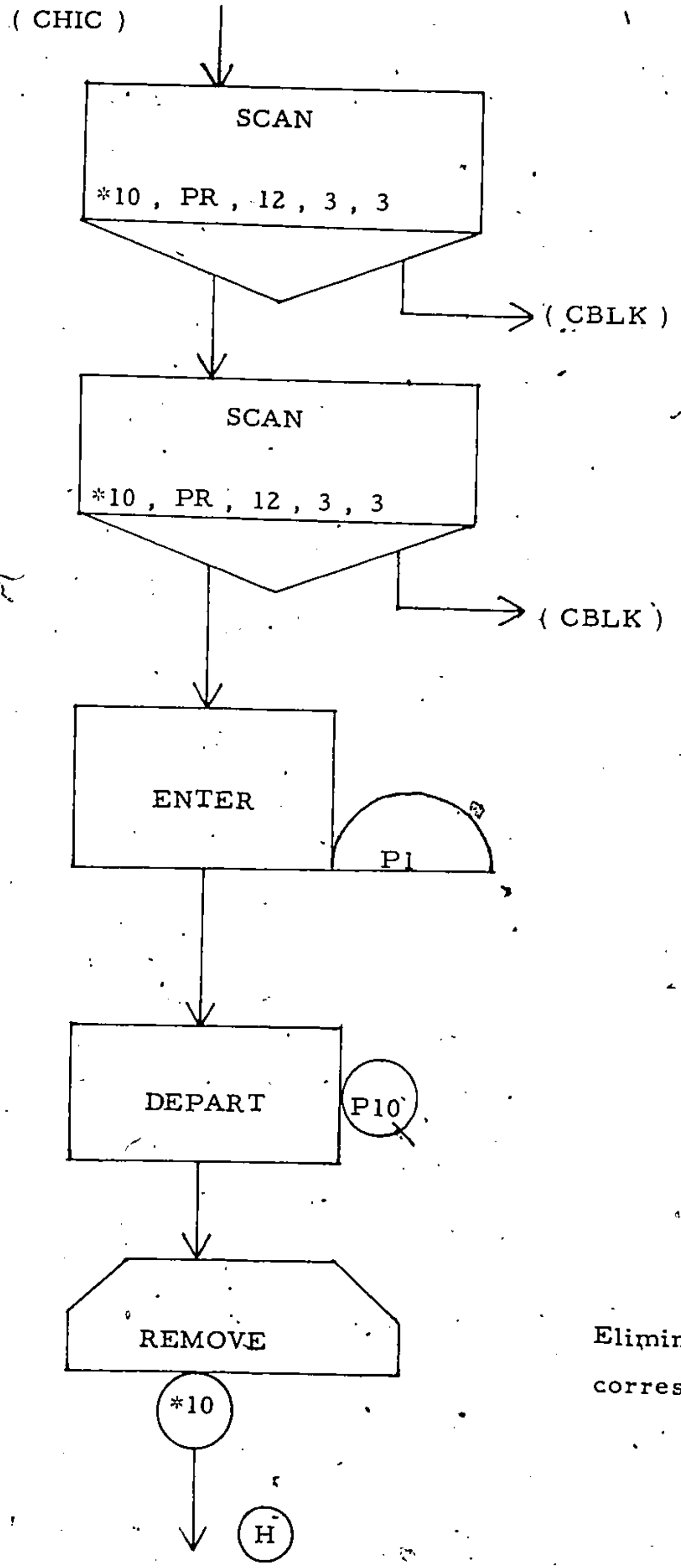


Change P2 and P3 of the selected call in the group P10.

Unlink the selected call from the user chain BLOC and send it to CHIC.

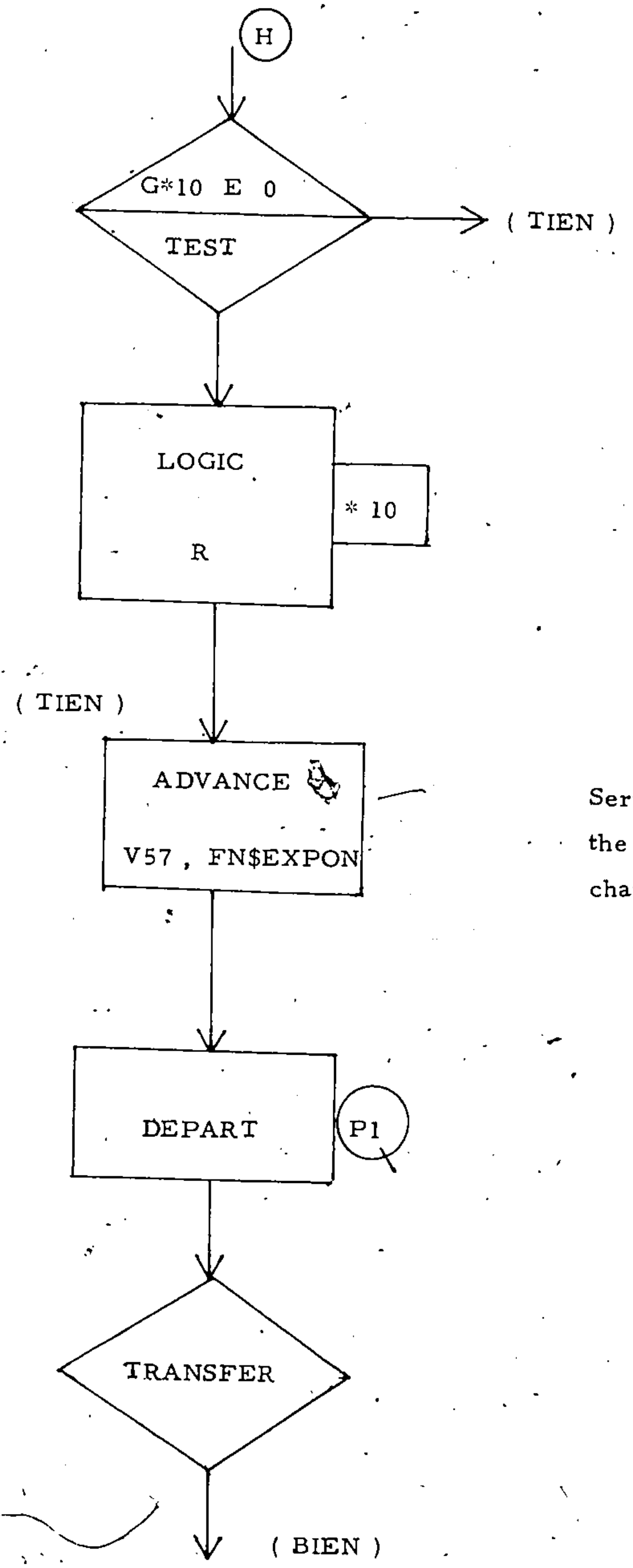

G
TABULATE
SUCES
LEAVE
HELEN
TERMINATE


(AUT 1)
TABULATE
SUCES
LEAVE
HELEN
TERMINATE

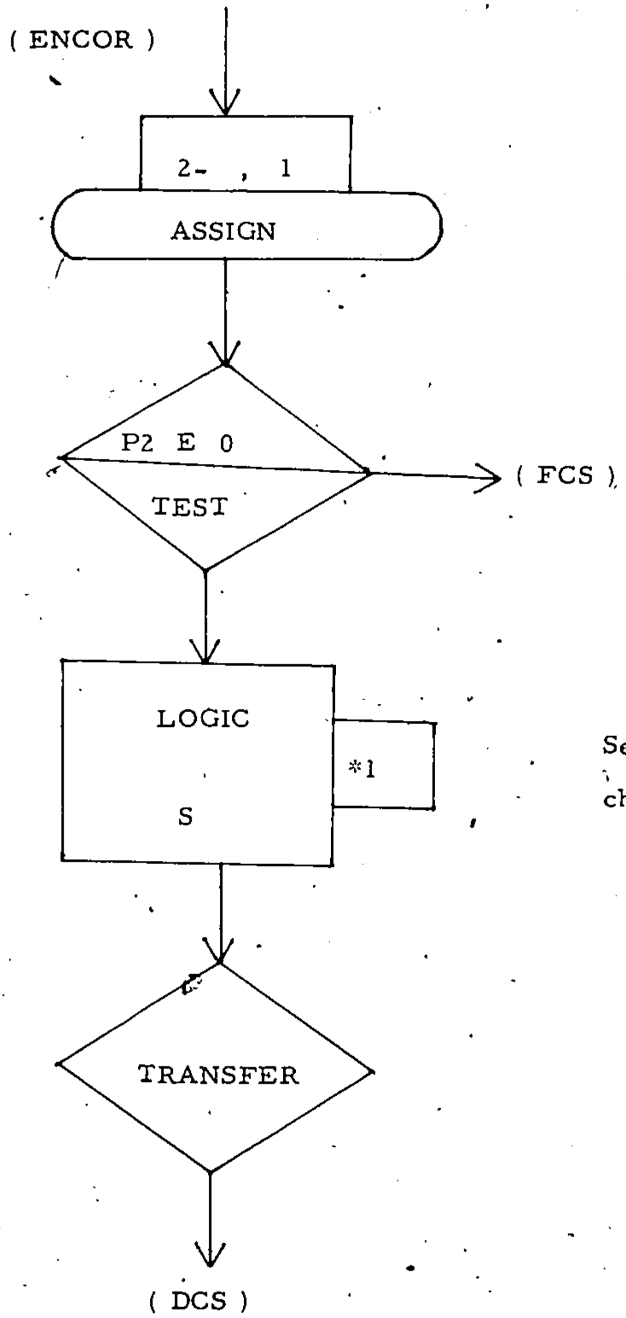


Pass on the number of the fixed channel and the matrix column number to the unlinked call from BLOC.

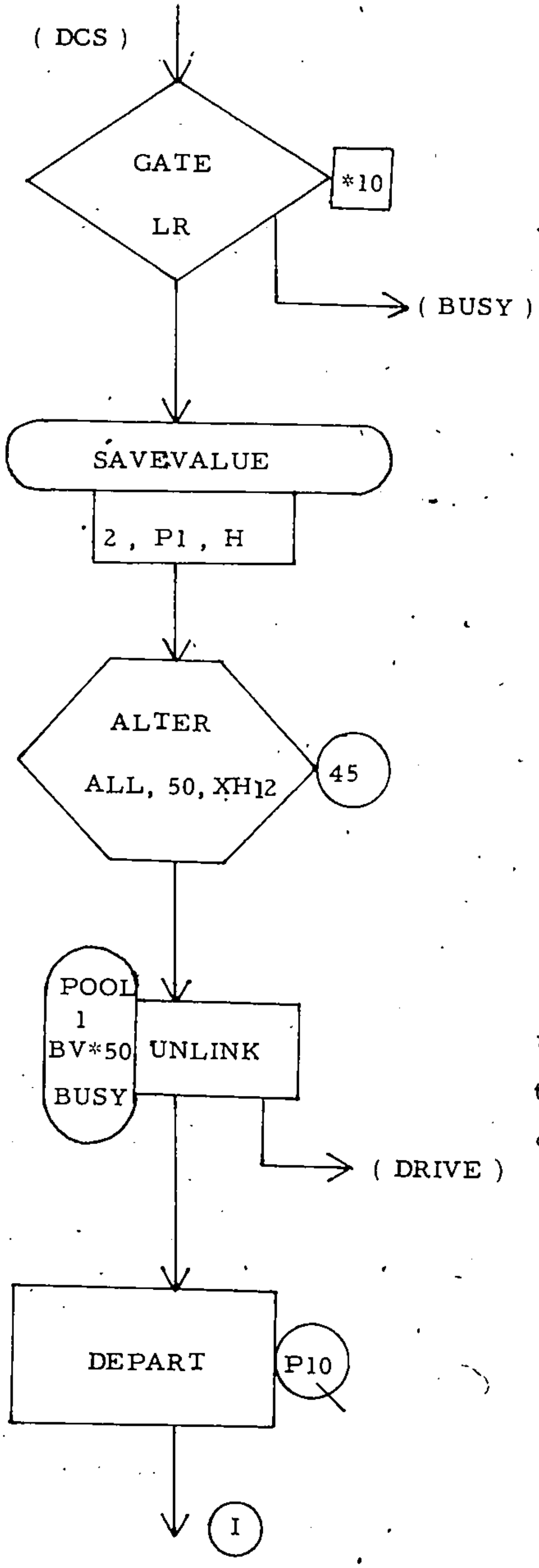
Eliminate that call from the corresponding group P10.



Service the queued call by the just released fixed channel.



Set switch P1 if all fixed channels are busy.

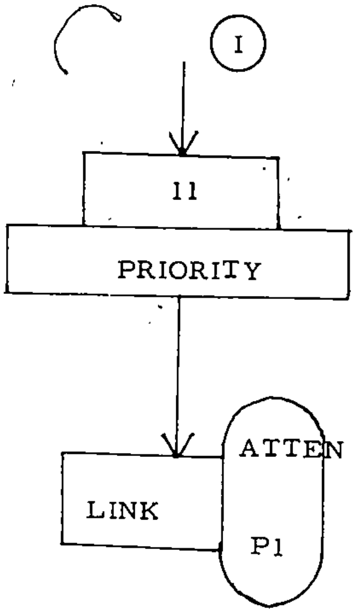


If switch P10 is set, indicating that no dynamic channel can be borrowed for use in the cell P1, the call will have to join the system queue.

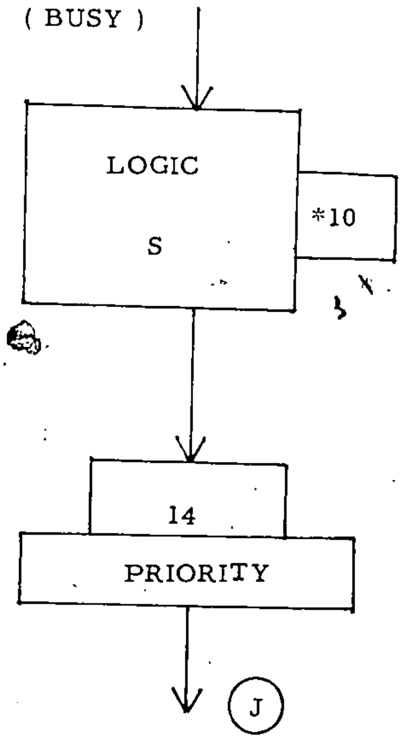
Save the origin of the borrowing call.

Inform all dynamic channels in group 45 about the call wishing to borrow one of them.

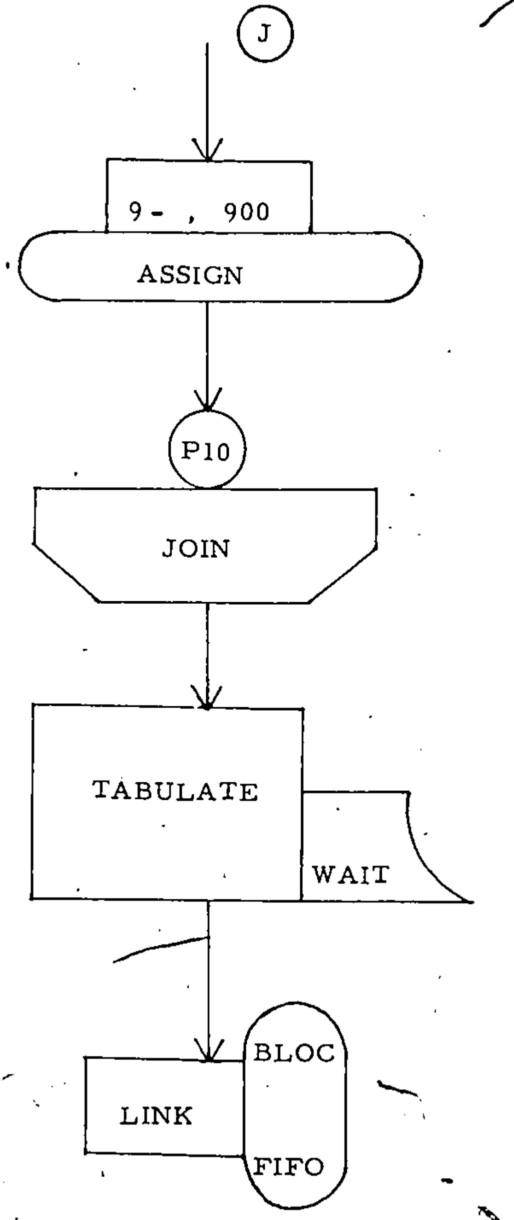
Unlink the dynamic channel that satisfies the interference criterion.



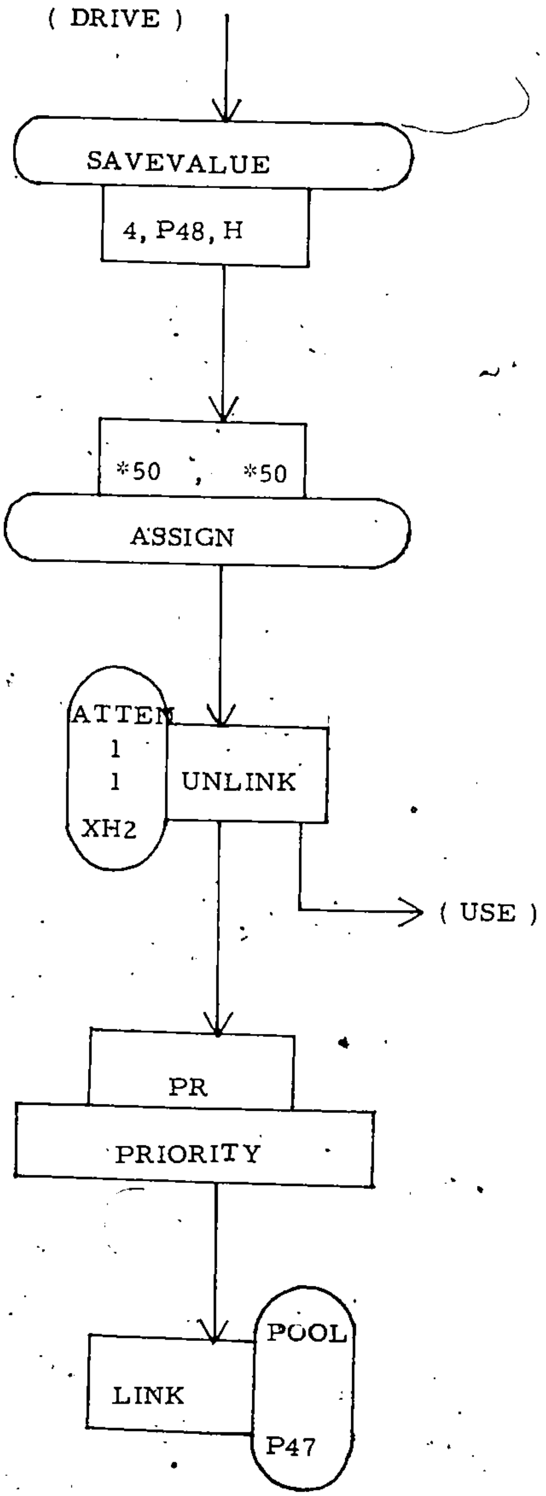
The call is put in the user chain ATTEN ~~to wait~~ for the free dynamic channel.



Set switch P10, indicating that no dynamic channel can be found to meet the interference criterion.



Call is put in the user chain BLOC awaiting service.

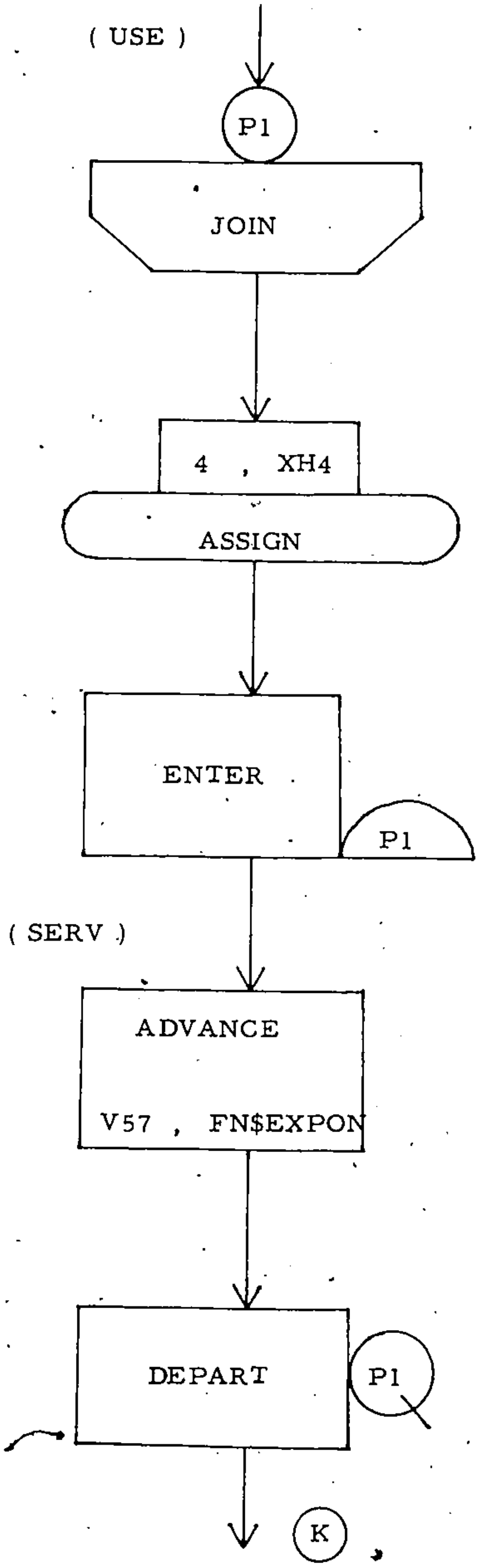


Save the number of the selected dynamic channel.

Put the cell number in the appropriate parameter of the dynamic channel, indicating that the channel is being used there.

Unlink the borrowing call from ATTEN.

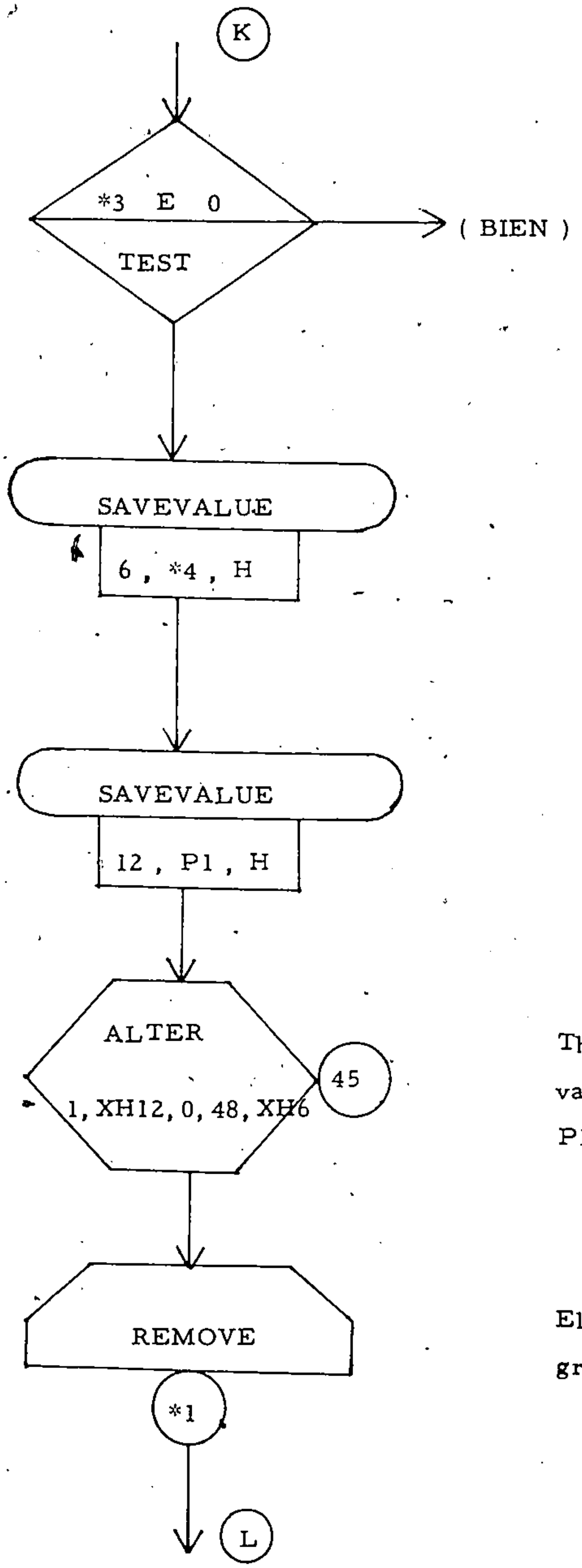
Put the dynamic channel back in the chain POOL.



Join the group P1 containg calls currently using dynamic channels.

Call seizes the selected dynamic channel.

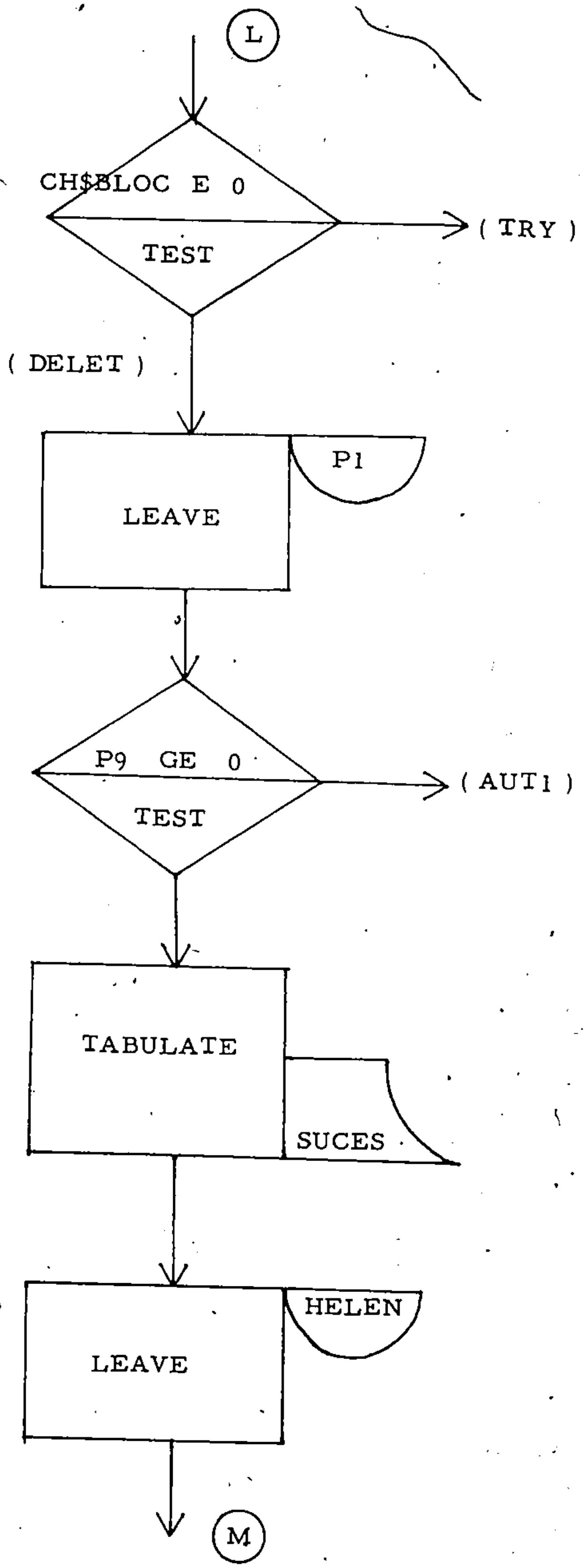
Service the call by the dynamic channel.



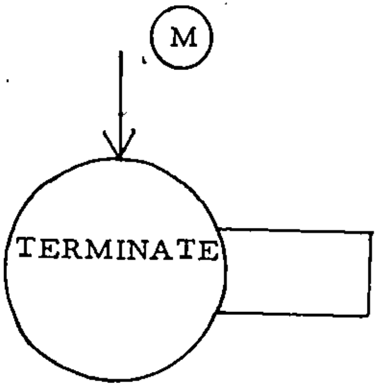
Check if it is a re-assigned call.

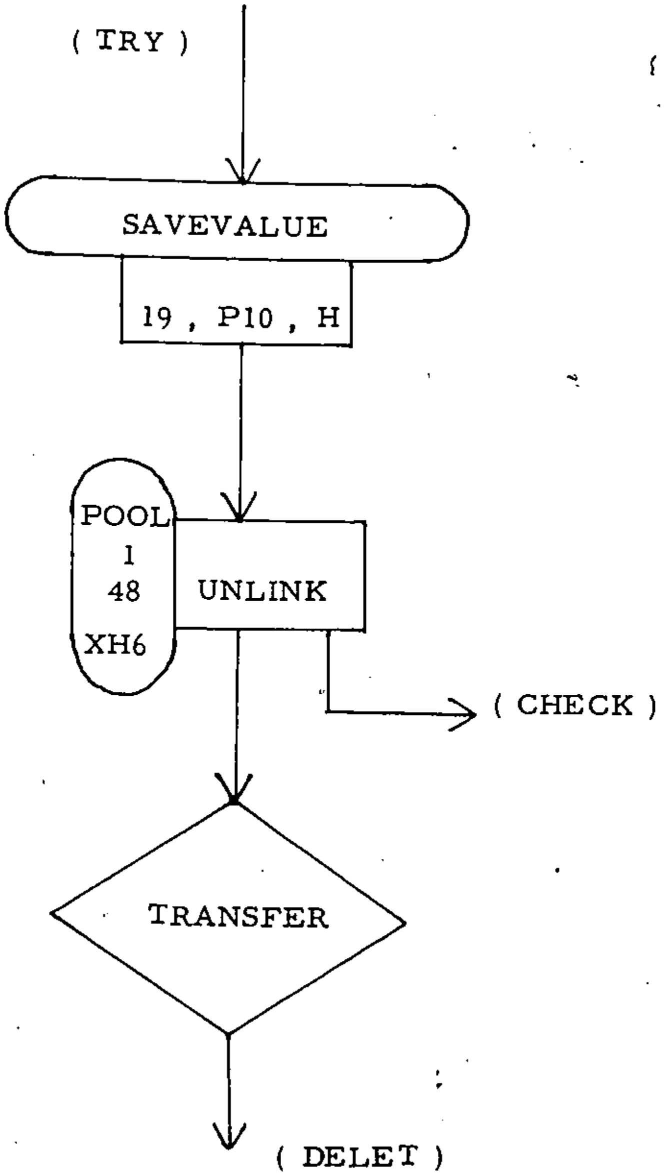
The dynamic channel is vacated from use in the cell P1.

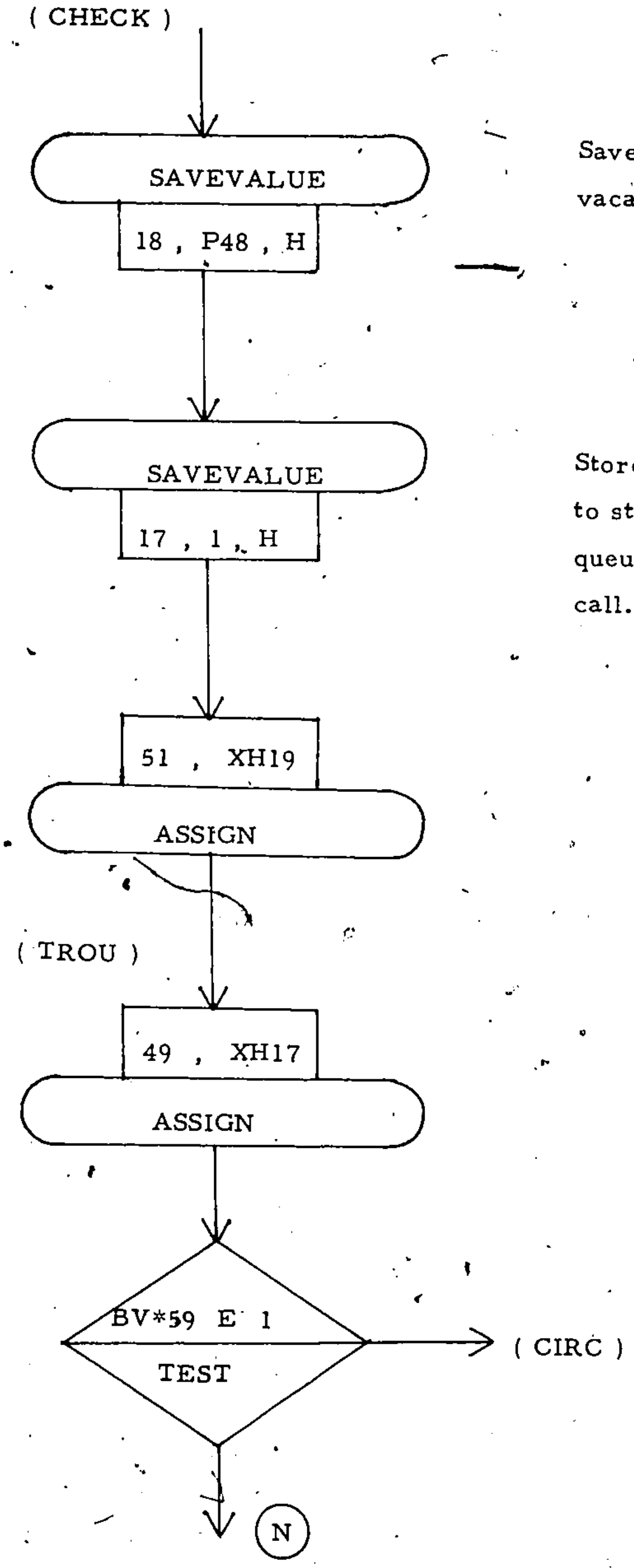
Eliminate the call from group P1.



If the system queue is not empty, the vacated dynamic channel will go to service one of the queued calls.


M
TERMINATE

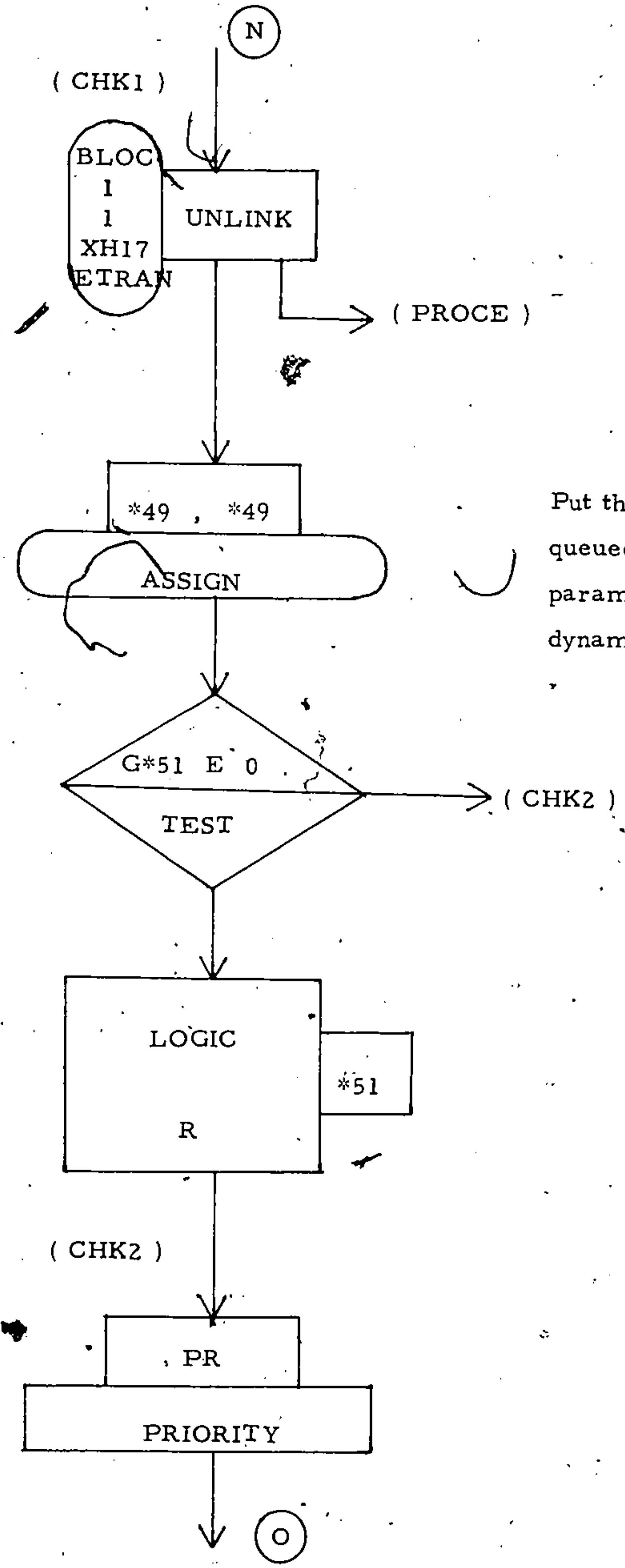

(TRY)
SAVEVALUE
19 , P10 , H
POOL
1
48
XH6
UNLINK
(CHECK)
TRANSFER
(DELET)



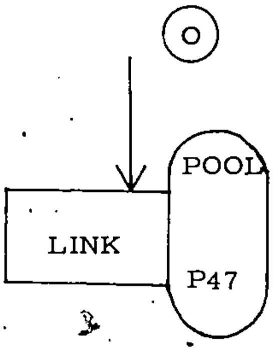
Save the number of the just vacated dynamic channel.

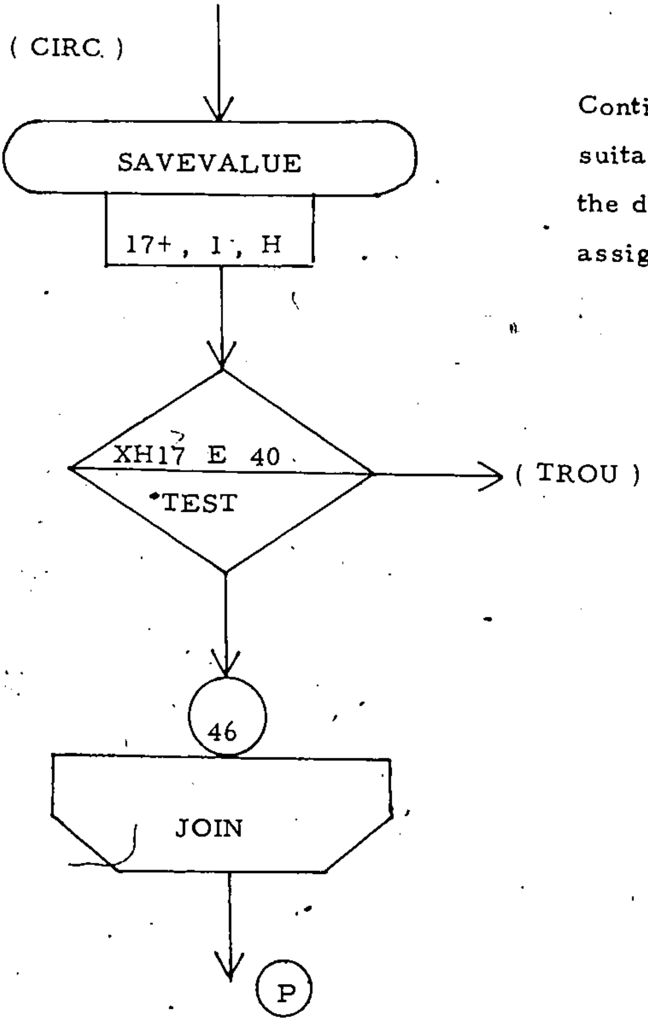
Store 1 in XH17 in order to start scanning the system queue for a suitable queued call.

Check if the interference criterion is satisfied at the origin of the scanned call.



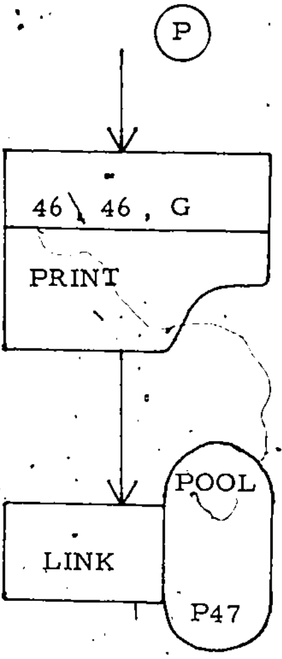
Put the origin of the suitable queued call in the appropriate parameter of the redeeming dynamic channel.



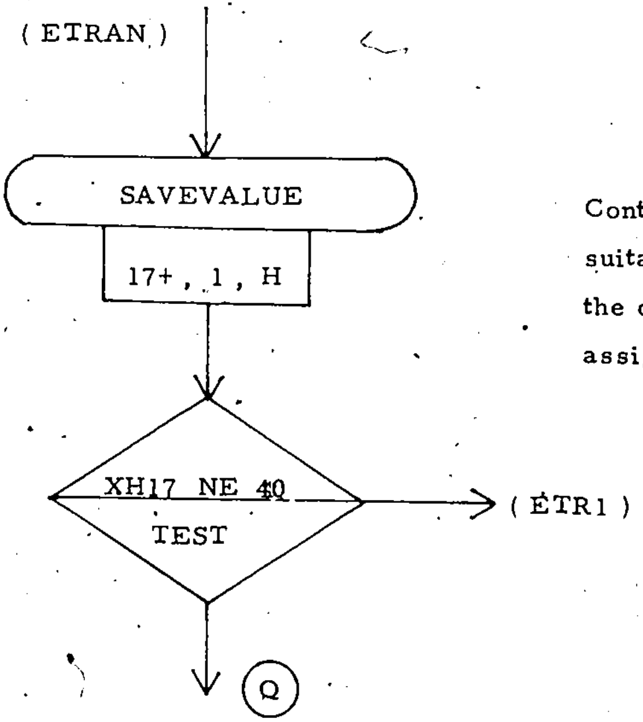


Continue searching for the suitable queued call to which the dynamic channel can be assigned.

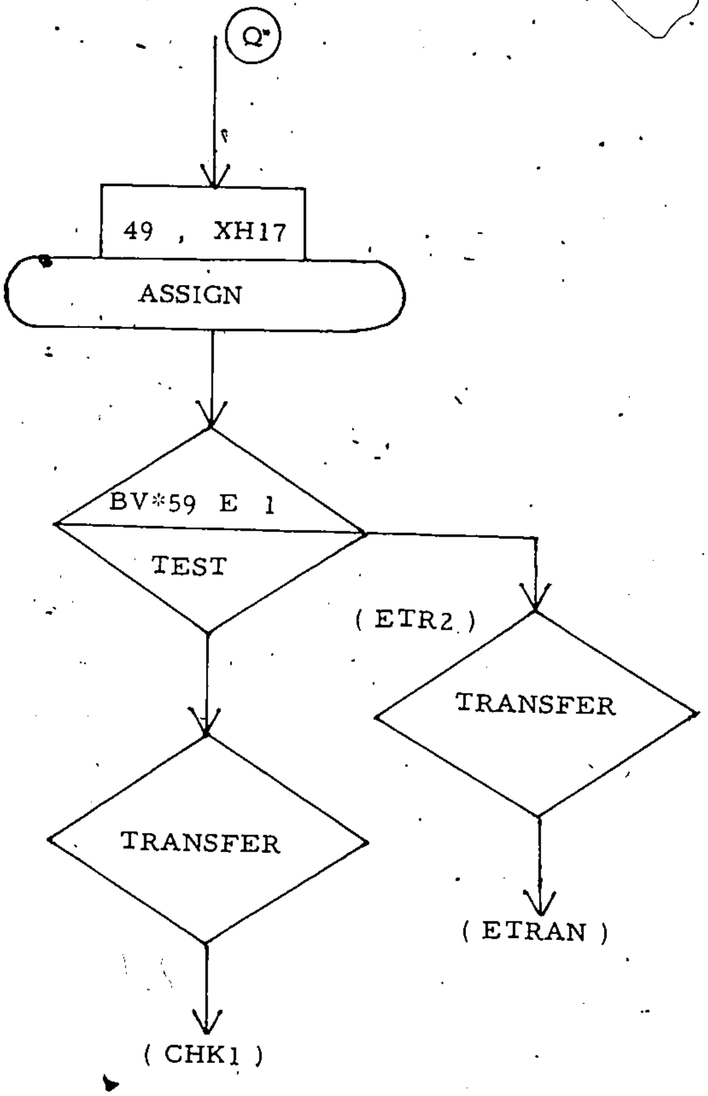
If no suitable queued call can be found, something has gone wrong.

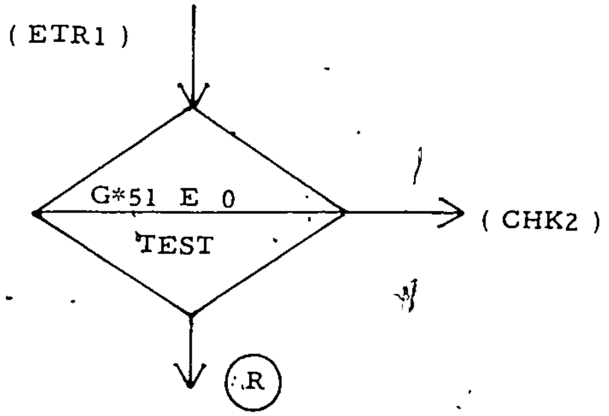


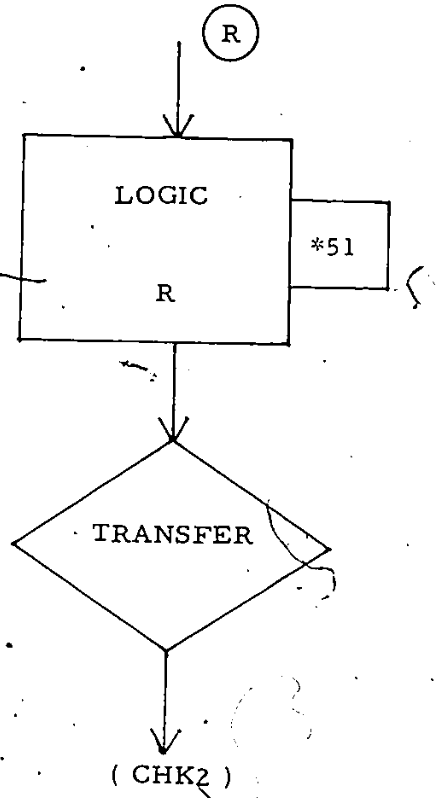
Print out the dynamic channel that cannot find a suitable queued call.

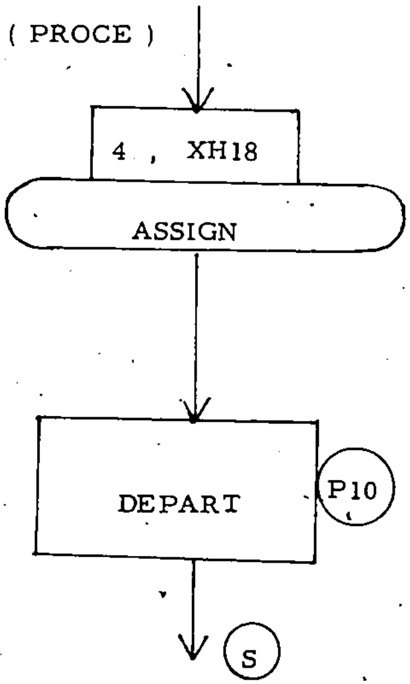


Continue the search for a suitable queued call to which the dynamic channel can be assigned.

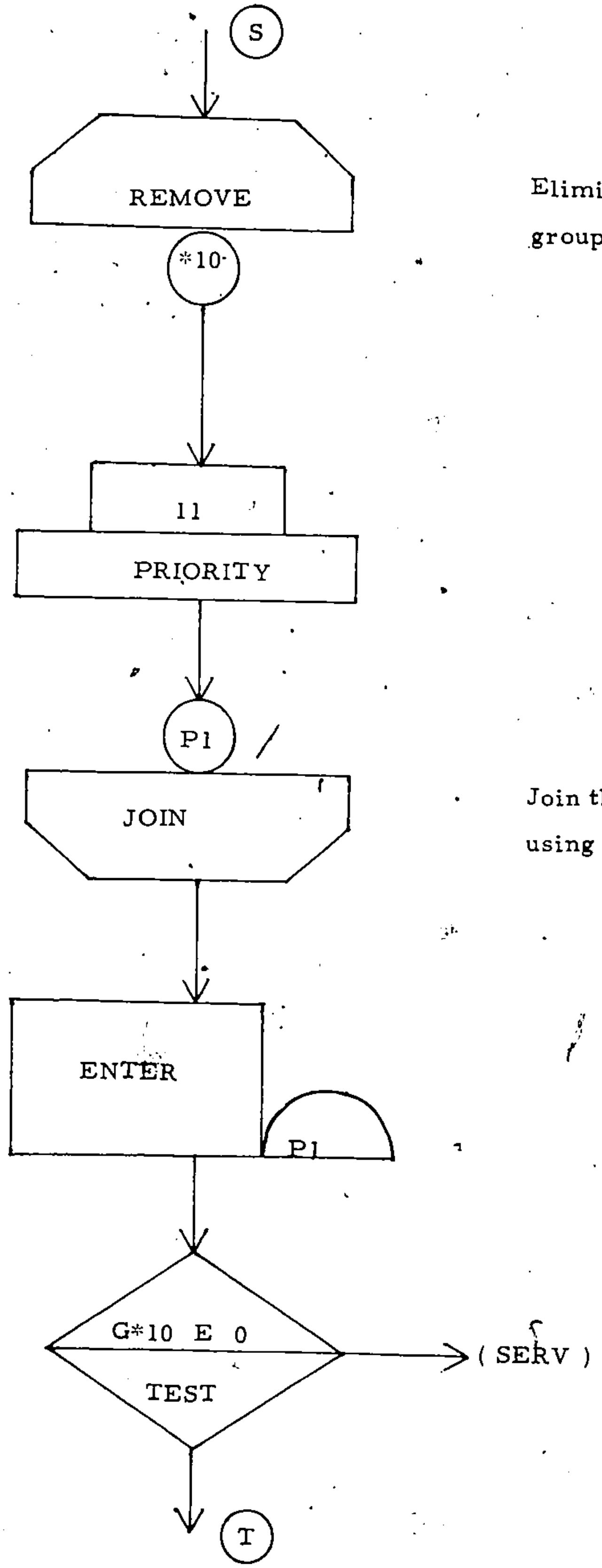

Q
49 , XH17
ASSIGN
BV*59 E 1
TEST
(ETR2)
TRANSFER
(ETRAN)
TRANSFER
(CHK1)


(ETR1)
G*51 E 0
TEST
(CHK2)
R



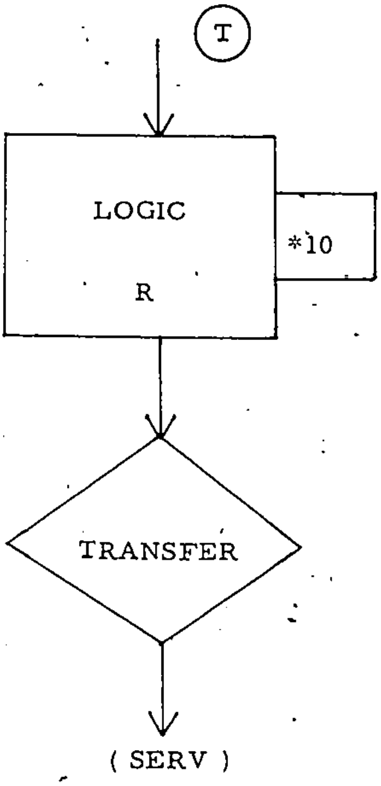


The selected queued call seizes the dynamic channel.

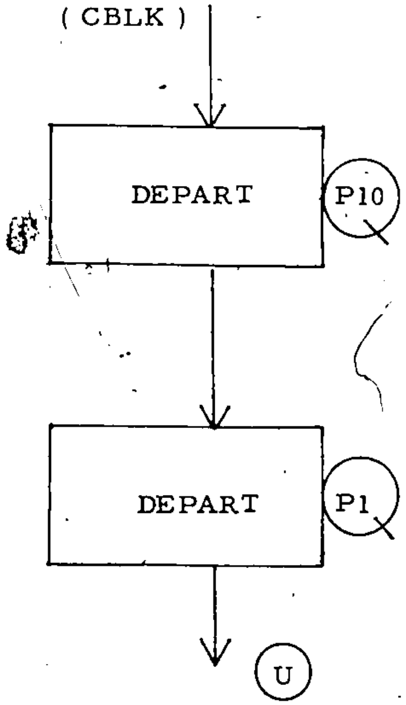


Eliminate that queued call group P10.

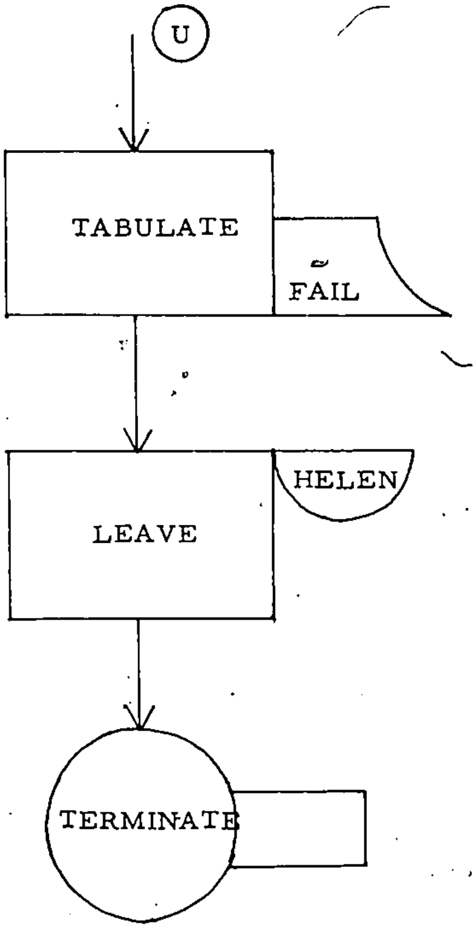
Join the group P10 of calls using dynamic channels.

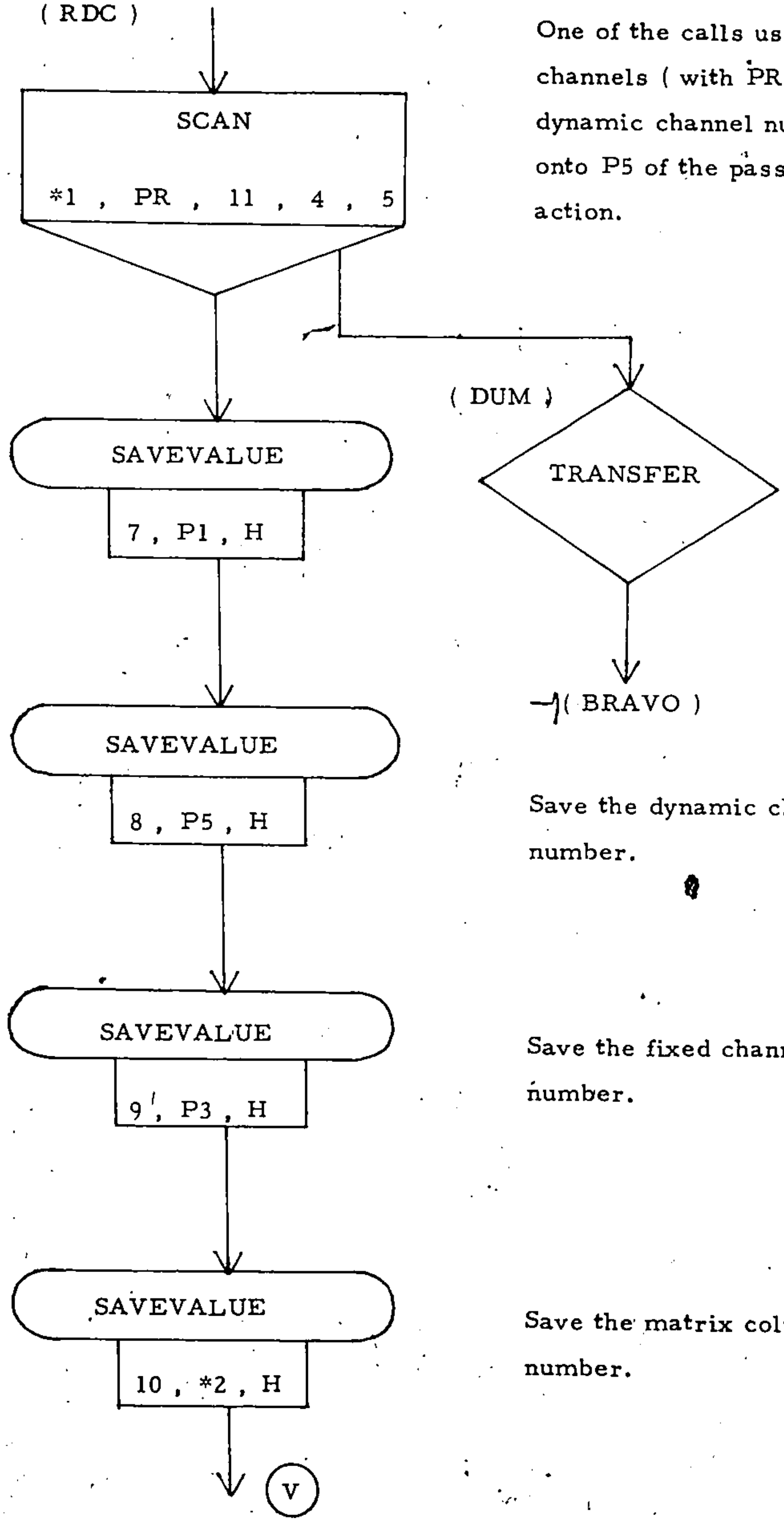


Reset switch P10, indicating that no call from cell P1 is awaiting service in the system queue.



Check in case any call is denied of service completely.


U
TABULATE
~FAIL
LEAVE
HELEN
TERMINATE

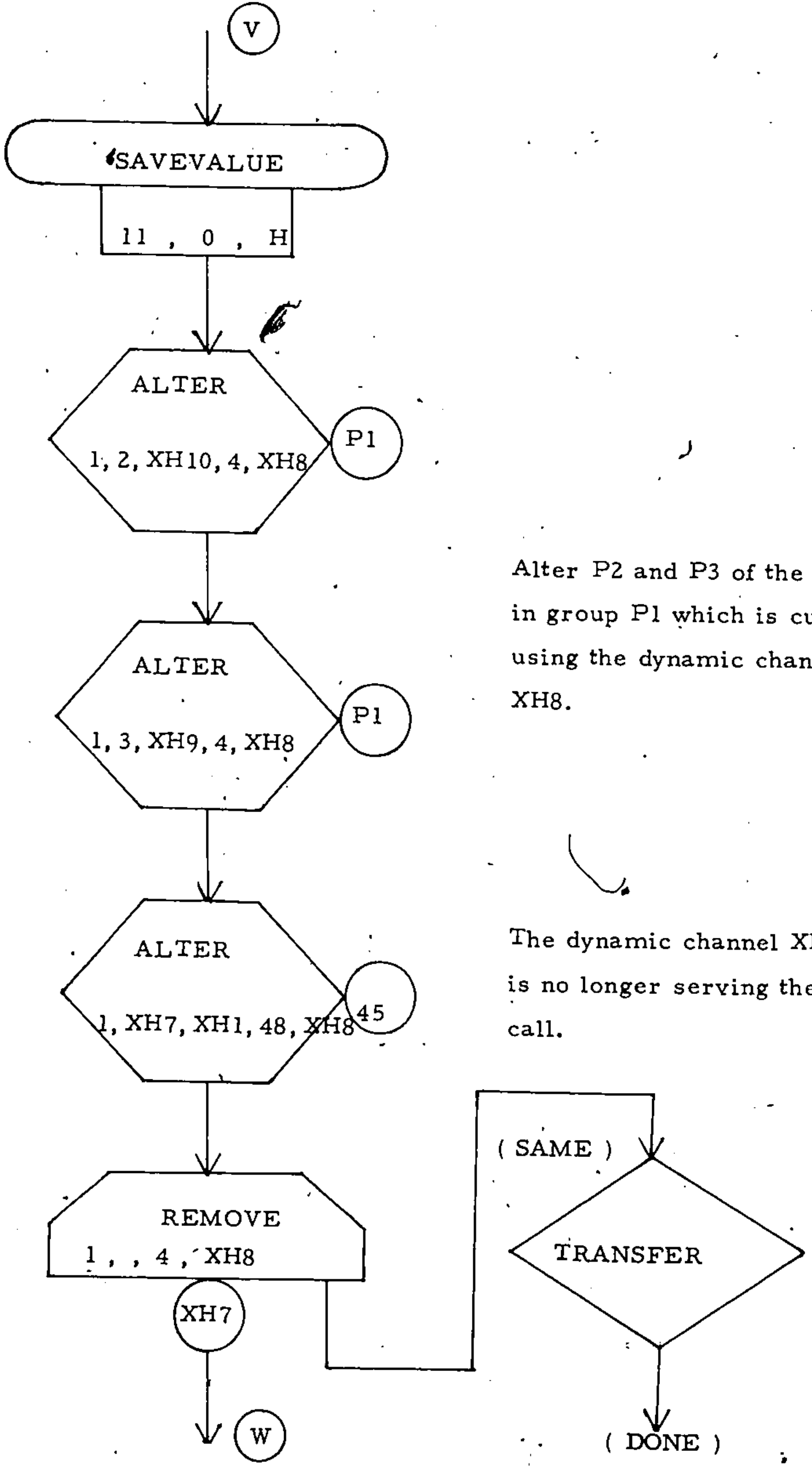


One of the calls using dynamic channels (with PR=11) has its dynamic channel number passed onto P5 of the passing transaction.

Save the dynamic channel number.

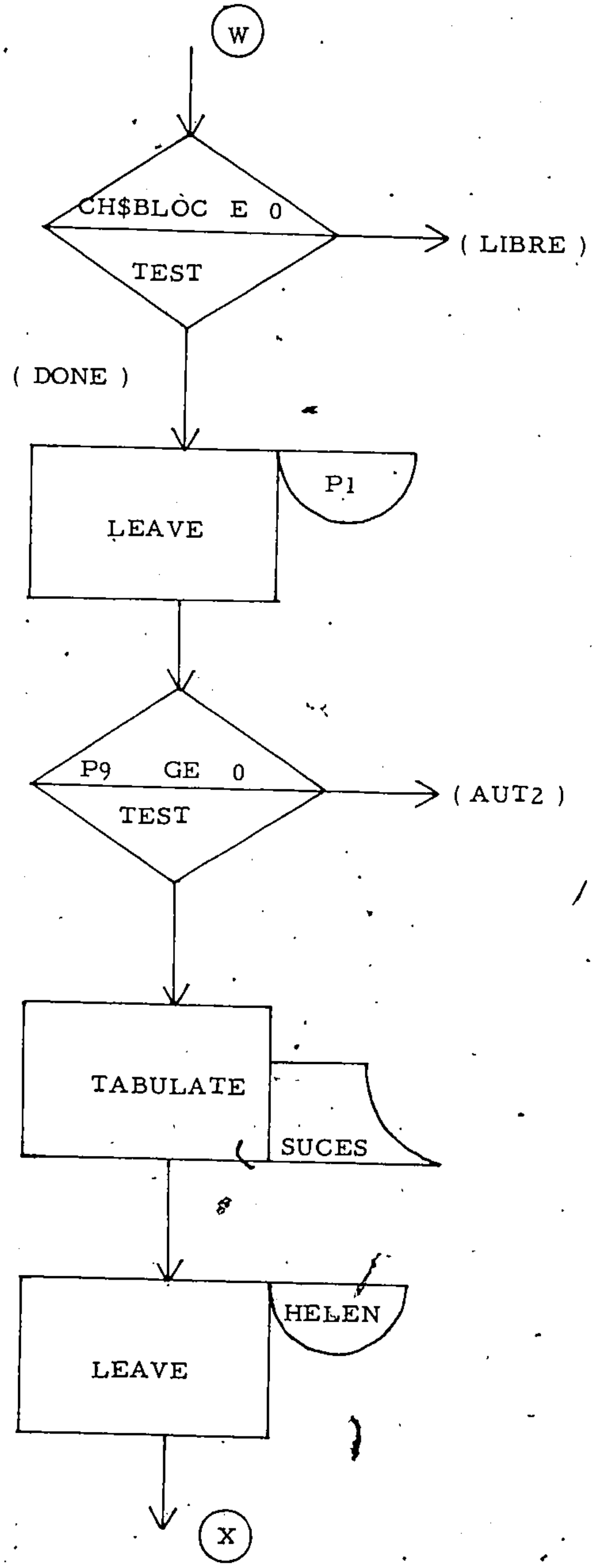
Save the fixed channel number.

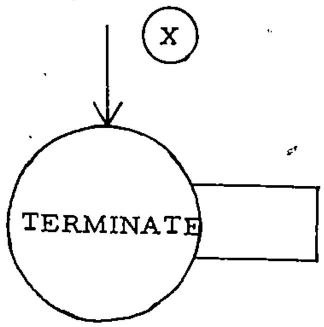
Save the matrix column number.

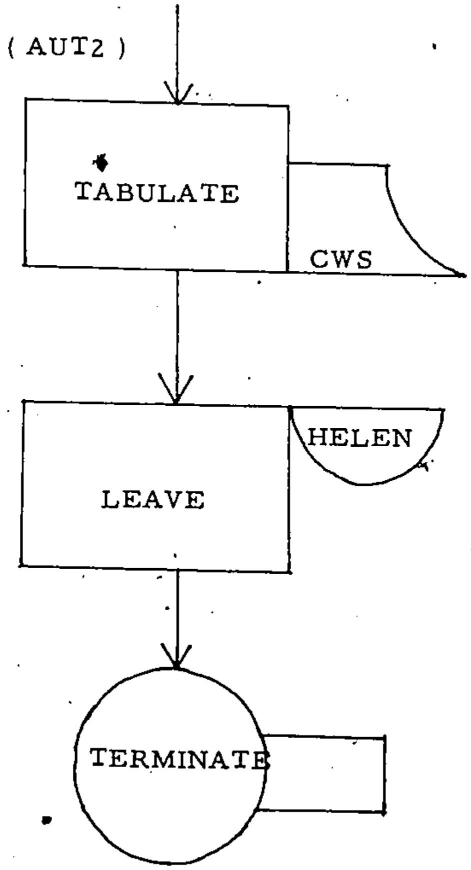


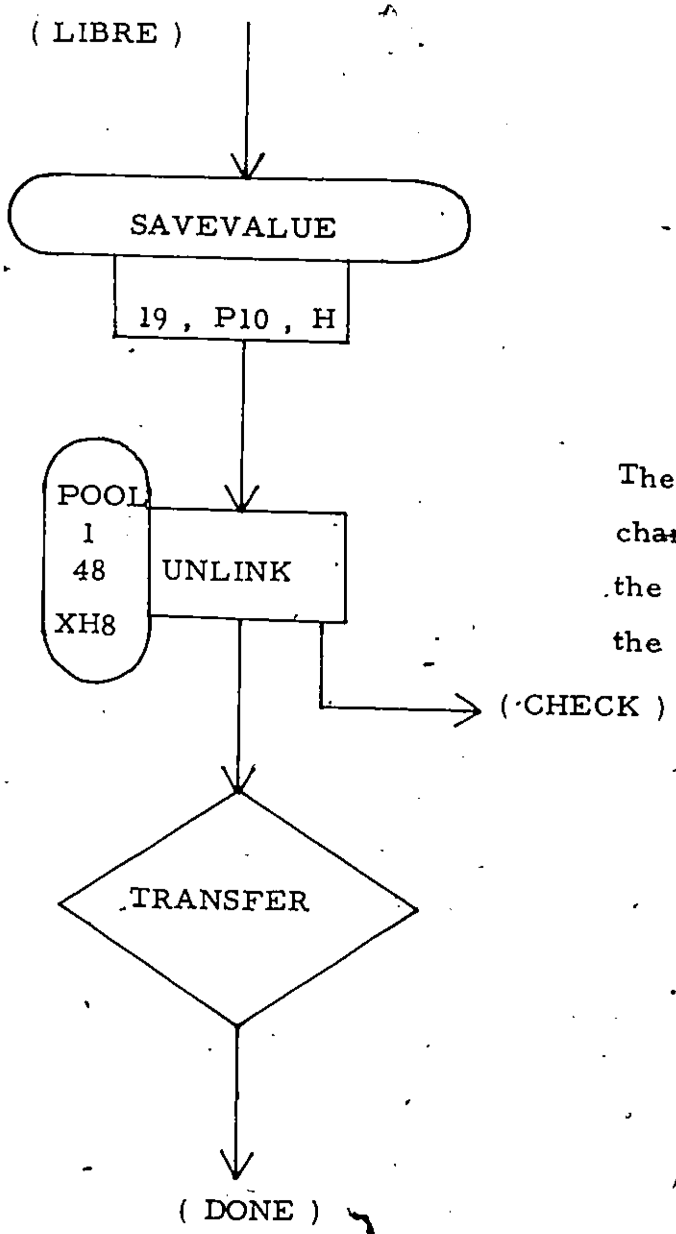
Alter P2 and P3 of the call in group P1 which is currently using the dynamic channel XH8.

The dynamic channel XH8 is no longer serving the call.


W
CH$BLOC E 0
TEST
(LIBRE)
(DONE)
LEAVE
P1
P9 GE 0
TEST
(AUT2)
TABULATE
SUCES
LEAVE
HELEN
X

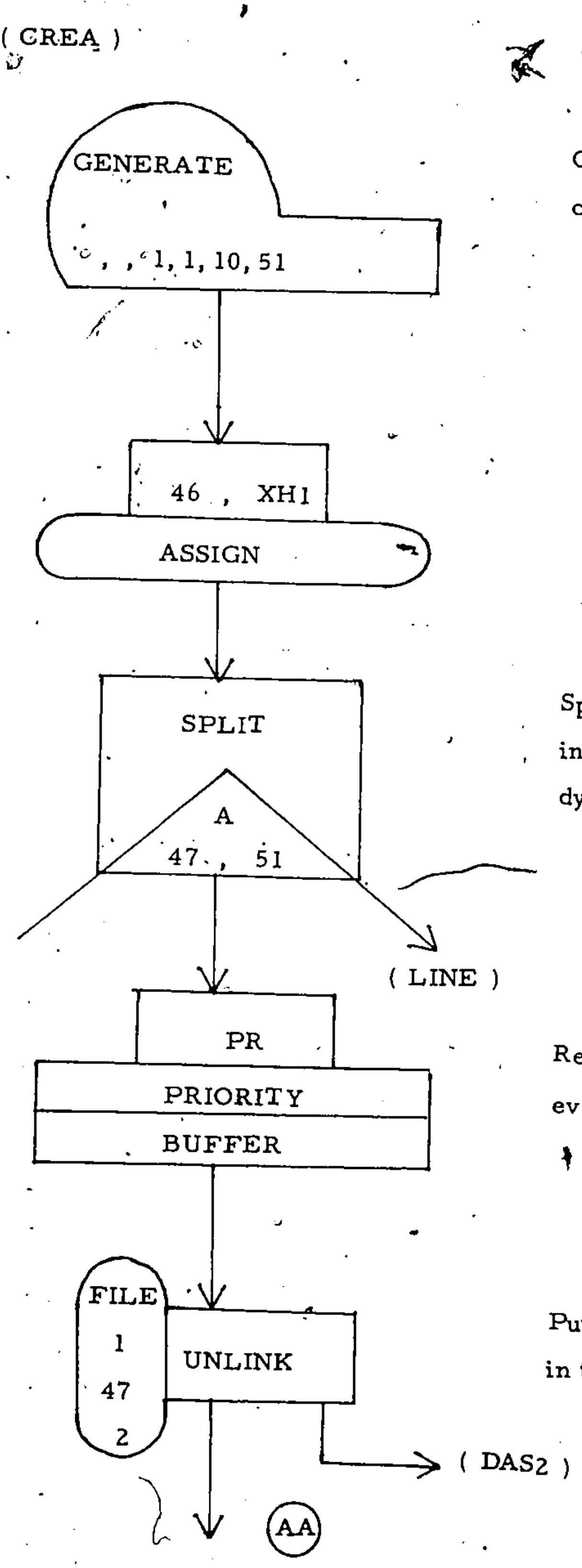

X
TERMINATE


(AUT2)
TABULATE
CWS
LEAVE
HELEN
TERMINATE



The just released dynamic channel is unlinked from the chain POOL to service the suitable queued call.

MODEL SEGMENT-2

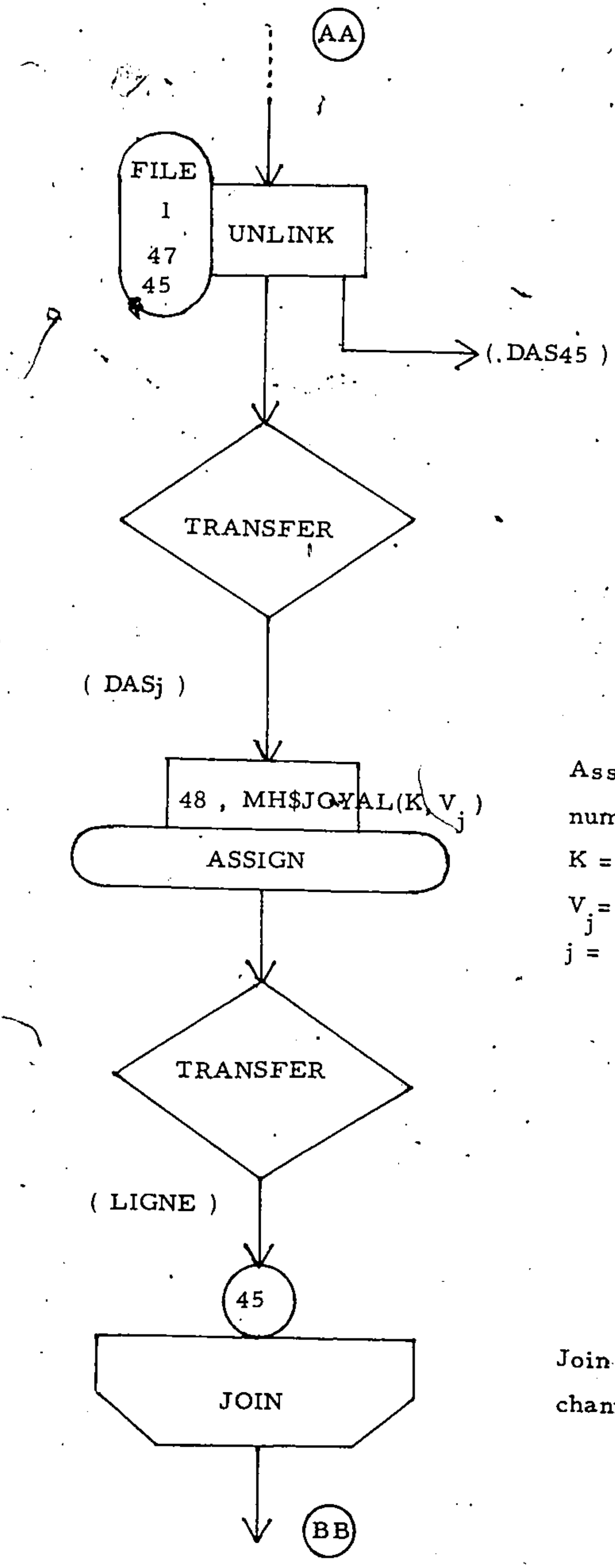


Create the master dyanmic channel.

Split the master channel into a desired number of dynamic channels.

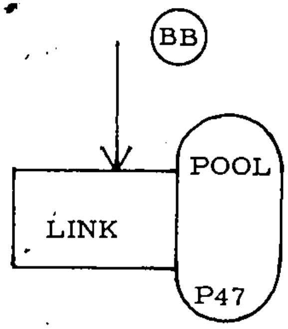
Re-starst scan of the current event chain.

Put the dynamic channels in the user chain FILE.

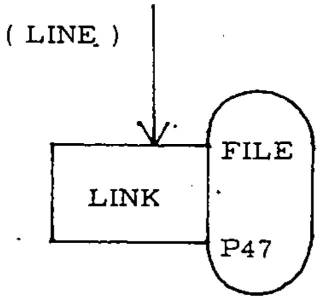


Assign the dynamic channel number to the channel copies.
K = matrix row number
V_j = matrix column number
j = 1, 2, ... , 45

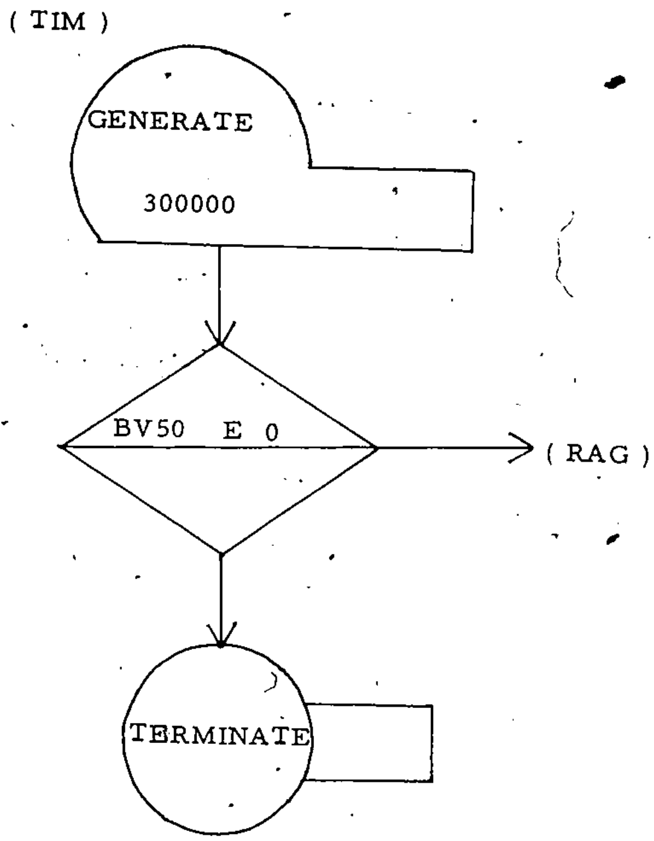
Join the group of dynamic channels.

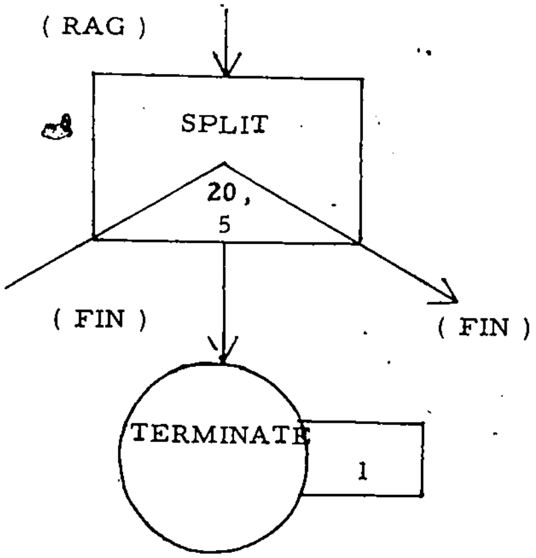


Temporarily put the dynamic channels in the user chain POOL.



MODEL SEGMENT-3





APPENDIX B.

COMPUTER PROGRAM

```
          REALLOCATE BLO,500,FAC,1,FUN,1,STO,42,LOG,95,FMS,1,HMS,1,QUE,95
          REALLOCATE HSV,20,FSV,1,TAB,4,CHA,4,VAR,70,BVR,60,GRP,90
          REALLOCATE COM,181882,XAC,3000
*
*
*  JOYAL IS A MATRIX OF DIMENSION (40,60). THE CELLS IN THE SYSTEM
*  ARE SSIGNED BY NUMBERS FROM 1 TO 40 CORRESPONDING TO THE ROW NO.
*  OF JOYAL. THE COLUMN NO. OF JOYAL REPRESENTS THE NO. OF CHANNELS
*  ALLOCATED TO A CELL
*
*
          SIMULATE
*
*
*  THE FOLLOWING INITIALIZATION CARDS ASSIGN VALUES (THE CHANNEL
*  NUMBERS) TO THE ENTRIES OF THE MATRIX JOYAL.
*
*
 JOYAL MATRIX         H,40,60
          INITIAL     XH1,2
          INITIAL     MH$JOYAL(1,1),101
          INITIAL     MH$JOYAL(2,1),111
          INITIAL     MH$JOYAL(3,1),121
          INITIAL     MH$JOYAL(4,1),131
          INITIAL     MH$JOYAL(5,1),141
          INITIAL     MH$JOYAL(6,1),151
          INITIAL     MH$JOYAL(7,1),161
          INITIAL     MH$JOYAL(8,1),171
          INITIAL     MH$JOYAL(9,1),181
          INITIAL     MH$JOYAL(1,2),102
          INITIAL     MH$JOYAL(2,2),112
          INITIAL     MH$JOYAL(3,2),122
          INITIAL     MH$JOYAL(4,2),132
          INITIAL     MH$JOYAL(5,2),142
          INITIAL     MH$JOYAL(6,2),152
          INITIAL     MH$JOYAL(7,2),162
          INITIAL     MH$JOYAL(8,2),172
          INITIAL     MH$JOYAL(9,2),182
          INITIAL     MH$JOYAL(1,3),103
          INITIAL     MH$JOYAL(2,3),113
          INITIAL     MH$JOYAL(3,3),123
          INITIAL     MH$JOYAL(4,3),133
          INITIAL     MH$JOYAL(5,3),143
          INITIAL     MH$JOYAL(6,3),153
          INITIAL     MH$JOYAL(7,3),163
          INITIAL     MH$JOYAL(8,3),173
          INITIAL     MH$JOYAL(9,3),183
          INITIAL     MH$JOYAL(1,4),104
          INITIAL     MH$JOYAL(2,4),114
          INITIAL     MH$JOYAL(3,4),124
```

```
             INITIAL     MH$JCYAL(39,59),549
             INITIAL     MH$JCYAL(40,59),649
             INITIAL     MH$JCYAL(10,60),550
             INITIAL     MH$JCYAL(11,60),600
             INITIAL     MH$JCYAL(12,60),550
             INITIAL     MH$JCYAL(13,60),650
             INITIAL     MH$JCYAL(14,60),550
             INITIAL     MH$JCYAL(15,60),600
             INITIAL     MH$JCYAL(16,60),550
             INITIAL     MH$JCYAL(17,60),650
             INITIAL     MH$JCYAL(18,60),550
             INITIAL     MH$JCYAL(19,60),600
             INITIAL     MH$JCYAL(20,60),650
             INITIAL     MH$JCYAL(21,60),600
             INITIAL     MH$JCYAL(22,60),550
             INITIAL     MH$JCYAL(23,60),600
             INITIAL     MH$JCYAL(24,60),650
             INITIAL     MH$JCYAL(25,60),550
             INITIAL     MH$JCYAL(26,60),650
             INITIAL     MH$JCYAL(27,60),600
             INITIAL     MH$JCYAL(28,60),550
             INITIAL     MH$JCYAL(29,60),600
             INITIAL     MH$JCYAL(30,60),650
             INITIAL     MH$JCYAL(31,60),550
             INITIAL     MH$JCYAL(32,60),650
             INITIAL     MH$JCYAL(33,60),600
             INITIAL     MH$JCYAL(34,60),550
             INITIAL     MH$JCYAL(35,60),600
             INITIAL     MH$JCYAL(36,60),650
             INITIAL     MH$JCYAL(37,60),550
             INITIAL     MH$JCYAL(38,60),600
             INITIAL     MH$JCYAL(39,60),550
             INITIAL     MH$JCYAL(40,60),650
*
*
* DEFINITIONS OF EQUIPMENT ENTITIES.
*
*
            STORAGE      S1-S40,50
 HELEN EQU               41,S
*                                                        MAKE HELEN TO BE
 HELEN STORAGE                                           ASSIGNED THE NO. 49
*
*
* DEFINITIONS OF COMPUTATIONAL ENTITIES.
*
*
 EXPON FUNCTION    RN4,C24
0,0/.1,.104/.2,.222/.3,.355/.4,.509/.5,.69/.6,.915/.7,1.2/.75,1.38  EXPONENTIAL DIST. FCT
.8,1.6/.84,1.83/.88,2.12/.9,2.3/.92,2.52/.94,2.81/.95,2.99/.96,3.2
.97,3.5/.98,3.9/.99,4.6/.995,5.3/.998,6.2/.999,7/.9998,8
 1       VARIABLE    P1+P2+P3+P4+P5+P6+P7                    THESE VARIABLES STATE
```

```
2     VARIABLE    P2+P9+P10+P3+P1+P7+P8              THE COCHANNEL INTER
3     VARIABLE    P3+P10+P11+P12+P4+P1+P2            CRITERION OF THE ICG.
4     VARIABLE    P4+P3+P12+P13+P14+P5+P1            OF THE CORRP.CELL
5     VARIABLE    P5+P1+P4+P14+P15+P16+P6
6     VARIABLE    P6+P7+P1+P5+P16+P17+P18
7     VARIABLE    P7+P8+P2+P1+P6+P18+P19
8     VARIABLE    P8+P21+P9+P2+P7+P19+P20
9     VARIABLE    P9+P22+P23+P10+P2+P8+P21
10    VARIABLE    P10+P23+P24+P11+P3+P2+P9
11    VARIABLE    P11+P24+P25+P26+P12+P3+P10
12    VARIABLE    P12+P11+P26+P27+P13+P4+P3
13    VARIABLE    P13+P12+P27+P28+P29+P14+P4
14    VARIABLE    P14+P4+P13+P29+P30+P15+P5
15    VARIABLE    P15+P5+P14+P30+P31+P32+P16
16    VARIABLE    P16+P6+P5+P15+P32+P33+P17
17    VARIABLE    P17+P18+P6+P16+P33+P34+P35
18    VARIABLE    P18+P19+P7+P6+P17+P35+P36
19    VARIABLE    P19+P20+P8+P7+P18+P36+P37
20    VARIABLE    P20+P39+P21+P8+P19+P37+P38
21    VARIABLE    P21+P40+P22+P9+P8+P20+P39
22    VARIABLE    P22+P23+P9+P40+P21
23    VARIABLE    P23+P24+P10+P9+P22
24    VARIABLE    P24+P25+P11+P10+P23
25    VARIABLE    P25+P26+P11+P24
26    VARIABLE    P26+P27+P12+P11+P25
27    VARIABLE    P27+P28+P13+P12+P26
28    VARIABLE    P28+P29+P13+P27
29    VARIABLE    P29+P30+P14+P13+P28
30    VARIABLE    P30+P31+P15+P14+P29
31    VARIABLE    P31+P32+P15+P30
32    VARIABLE    P32+P33+P16+P15+P31
33    VARIABLE    P33+P34+P17+P16+P32
34    VARIABLE    P34+P35+P17+P33
35    VARIABLE    P35+P36+P18+P17+P34
36    VARIABLE    P36+P37+P19+P18+P35
37    VARIABLE    P37+P38+P20+P19+P36
38    VARIABLE    P38+P39+P20+P37
39    VARIABLE    P39+P40+P21+P20+P38
40    VARIABLE    P40+P22+P21+P39
1     BVARIABLE   V1'E'0
2     BVARIABLE   V2'E'0
3     BVARIABLE   V3'E'0
4     BVARIABLE   V4'E'0
5     BVARIABLE   V5'E'0
6     BVARIABLE   V6'E'0
7     BVARIABLE   V7'E'0
8     BVARIABLE   V8'E'0
9     BVARIABLE   V9'E'0
10    BVARIABLE   V10'E'0
11    BVARIABLE   V11'E'0
12    BVARIABLE   V12'E'0
13    BVARIABLE   V13'E'0
```

```
 14     BVARIABLE   V14'E'0
 15     BVARIABLE   V15'E'0
 16     BVARIABLE   V16'E'0
 17     BVARIABLE   V17'E'0
 18     BVARIABLE   V18'E'0
 19     BVARIABLE   V19'E'0
 20     BVARIABLE   V20'E'0
 21     BVARIABLE   V21'E'0
 22     BVARIABLE   V22'E'0
 23     BVARIABLE   V23'E'0
 24     BVARIABLE   V24'E'0
 25     BVARIABLE   V25'E'0
 26     BVARIABLE   V26'E'0
 27     BVARIABLE   V27'E'0
 28     BVARIABLE   V28'E'0
 29     BVARIABLE   V29'E'0
 30     BVARIABLE   V30'E'0
 31     BVARIABLE   V31'E'0
 32     BVARIABLE   V32'E'0
 33     BVARIABLE   V33'E'0
 34     BVARIABLE   V34'E'0
 35     BVARIABLE   V35'E'0
 36     BVARIABLE   V36'E'0
 37     BVARIABLE   V37'E'0
 38     BVARIABLE   V38'E'0
 39     BVARIABLE   V39'E'0
 40     BVARIABLE   V40'E'0
 41     VARIABLE    XH1+1
 42     VARIABLE    XH1+2
 43     VARIABLE    XH1+3
 44     VARIABLE    XH1+4
 45     VARIABLE    XH1+5
 46     VARIABLE    XH1+6
 47     VARIABLE    XH1+7
 48     VARIABLE    XH1+8
 49     VARIABLE    XH1+9
 50     VARIABLE    XH1+10
 51     VARIABLE    XH1+11
 52     VARIABLE    XH1+12
 53     VARIABLE    XH1+13
 54     VARIABLE    XH1+14
 55     VARIABLE    XH1+15
 56     VARIABLE    10800000                         THIS VARIABLE IS
*                                                    THE RUN TIME
 57     VARIABLE    120000                           THIS VARIABLE IS ASSIGN
*                                                    THE MEAN SERVICE TIME
*                                                    OF EACH CALL
 58     VARIABLE    2400000
 59     VARIABLE    P3-2*P3
*
 60     VARIABLE    TC$SUCES+TC$CWS+TC$WAIT          THE TOTAL NO.OF CALLS
*                                                    SERVED&BLOCKED
```

```
 61     VARIABLE    26667
 50     BVARIABLE   (C1'LE'V56)*(V60'LE'60000)       'INTERARRIVAL TIME
*
*
* DEFINITIONS OF STATISTICAL ENTITIES
*
*
 SUCES TABLE        P1,1,1,41
 FAIL  TABLE        P1,1,1,41
 WAIT  TABLE        P1,1,1,41
 CWS   TABLE        P1,1,1,41
*
*
* MODEL SEGMENT-1:GENERATION OF CALLS FROM THE CELLS IN A
* POISSON FASHION & ASSIGNMENT OF CHANNELS TO SERVE THE CALLS
*
*
 CEL1   GENERATE    V61,FN$EXPON,,,,10
        ASSIGN      1,1                            ATTACH 10 PARMS TO EACH
        ASSIGN      10,51                          CALL GENERATED AND TAG
        TRANSFER    ,CSR                           THE CELL NO TO EACH
 CEL2   GENERATE    V61,FN$EXPON,,,,10             CALL GENERATED BY STORE
        ASSIGN      1,2                            IT IN P1
        ASSIGN      10,52
        TRANSFER    ,CSR
 CEL3   GENERATE    V61,FN$EXPON,,,,10
        ASSIGN      1,3
        ASSIGN      10,53
        TRANSFER    ,CSR
 CEL4   GENERATE    V61,FN$EXPON,,,,10
        ASSIGN      1,4
        ASSIGN      10,54
        TRANSFER    ,CSR
 CEL5   GENERATE    V61,FN$EXPON,,,,10
        ASSIGN      1,5
        ASSIGN      10,55
        TRANSFER    ,CSR
 CEL6   GENERATE    V61,FN$EXPON,,,,10
        ASSIGN      1,6
        ASSIGN      10,56
        TRANSFER    ,CSR
 CEL7   GENERATE    V61,FN$EXPON,,,,10
        ASSIGN      1,7
        ASSIGN      10,57
        TRANSFER    ,CSR
 CEL8   GENERATE    V61,FN$EXPON,,,,10
        ASSIGN      1,8
        ASSIGN      10,58
        TRANSFER    ,CSR
 CEL9   GENERATE    V61,FN$EXPON,,,,10
        ASSIGN      1,9
        ASSIGN      10,59
```

```
         TRANSFER     ,CSR
CEL10    GENERATE     V61,FN$EXPON,,,,10
         ASSIGN       1,10
         ASSIGN       10,60
         TRANSFER     ,CSR
CEL11    GENERATE     V61,FN$EXPON,,,,10
         ASSIGN       1,11
         ASSIGN       10,61
         TRANSFER     ,CSR
CEL12    GENERATE     V61,FN$EXPON,,,,10
         ASSIGN       1,12
         ASSIGN       10,62
         TRANSFER     ,CSR
CEL13    GENERATE     V61,FN$EXPON,,,,10
         ASSIGN       1,13
         ASSIGN       10,63
         TRANSFER     ,CSR
CEL14    GENERATE     V61,FN$EXPON,,,,10
         ASSIGN       1,14
         ASSIGN       10,64
         TRANSFER     ,CSR
CEL15    GENERATE     V61,FN$EXPON,,,,10
         ASSIGN       1,15
         ASSIGN       10,65
         TRANSFER     ,CSR
CEL16    GENERATE     V61,FN$EXPON,,,,10
         ASSIGN       1,16
         ASSIGN       10,66
         TRANSFER     ,CSR
CEL17    GENERATE     V61,FN$EXPON,,,,10
         ASSIGN       1,17
         ASSIGN       10,67
         TRANSFER     ,CSR
CEL18    GENERATE     V61,FN$EXPON,,,,10
         ASSIGN       1,18
         ASSIGN       10,68
         TRANSFER     ,CSR
CEL19    GENERATE     V61,FN$EXPON,,,,10
         ASSIGN       1,19
         ASSIGN       10,69
         TRANSFER     ,CSR
CEL20    GENERATE     V61,FN$EXPON,,,,10
         ASSIGN       1,20
         ASSIGN       10,70
         TRANSFER     ,CSR
CEL21    GENERATE     V61,FN$EXPON,,,,10
         ASSIGN       1,21
         ASSIGN       10,71
         TRANSFER     ,CSR
CEL22    GENERATE     V61,FN$EXPON,,,,10
         ASSIGN       1,22
         ASSIGN       10,72
```

```
       TRANSFER   ,CSR
CEL23  GENERATE   V61,FN$EXPON,,,,10
       ASSIGN     1,23
       ASSIGN     10,73
       TRANSFER   ,CSR
CEL24  GENERATE   V61,FN$EXPON,,,,10
       ASSIGN     1,24
       ASSIGN     10,74
       TRANSFER   ,CSR
CEL25  GENERATE   V61,FN$EXPON,,,,10
       ASSIGN     1,25
       ASSIGN     10,75
       TRANSFER   ,CSR
CEL26  GENERATE   V61,FN$EXPON,,,,10
       ASSIGN     1,26
       ASSIGN     10,76
       TRANSFER   ,CSR
CEL27  GENERATE   V61,FN$EXPON,,,,10
       ASSIGN     1,27
       ASSIGN     10,77
       TRANSFER   ,CSR
CEL28  GENERATE   V61,FN$EXPON,,,,10
       ASSIGN     1,28
       ASSIGN     10,78
       TRANSFER   ,CSR
CEL29  GENERATE   V61,FN$EXPON,,,,10
       ASSIGN     1,29
       ASSIGN     10,79
       TRANSFER   ,CSR
CEL30  GENERATE   V61,FN$EXPON,,,,10
       ASSIGN     1,30
       ASSIGN     10,80
       TRANSFER   ,CSR
CEL31  GENERATE   V61,FN$EXPON,,,,10
       ASSIGN     1,31
       ASSIGN     10,81
       TRANSFER   ,CSR
CEL32  GENERATE   V61,FN$EXPON,,,,10
       ASSIGN     1,32
       ASSIGN     10,82
       TRANSFER   ,CSR
CEL33  GENERATE   V61,FN$EXPON,,,,10
       ASSIGN     1,33
       ASSIGN     10,83
       TRANSFER   ,CSR
CEL34  GENERATE   V61,FN$EXPON,,,,10
       ASSIGN     1,34
       ASSIGN     10,84
       TRANSFER   ,CSR
CEL35  GENERATE   V61,FN$EXPON,,,,10
       ASSIGN     1,35
       ASSIGN     10,85
```

```
         TRANSFER    ,CSR
   CEL36 GENERATE    V61,FN$EXPON,,,,10
         ASSIGN      1,36
         ASSIGN      10,86
         TRANSFER    ,CSR
   CEL37 GENERATE    V61,FN$EXPON,,,,10
         ASSIGN      1,37
         ASSIGN      10,87
         TRANSFER    ,CSR
   CEL38 GENERATE    V61,FN$EXPON,,,,10
         ASSIGN      1,38
         ASSIGN      10,88
         TRANSFER    ,CSR
   CEL39 GENERATE    V61,FN$EXPON,,,,10
         ASSIGN      1,39
         ASSIGN      10,89
         TRANSFER    ,CSR
   CEL40 GENERATE    V61,FN$EXPON,,,,10
         ASSIGN      1,40
         ASSIGN      10,90
         TRANSFER    ,CSR
 *
 *
  CSR    ENTER       HELEN
         ASSIGN      2,XH1                              P2 ASSIGNED THE MAX.NO
         QUEUE       P1                                 OF F.CH.
         QUEUE       P10
         GATE LR     *1,DCS                             IF NO F.CH.
 *                                                      AVAILABLE GO FIND
 *                                                      A D.CH.
 *
 *
 *    THIS PART OF THE PRAGRAME SEARCHES FOR AN AVAILABLE FIX. CHANN. BY
 *    SCANNING THRO. THE SET OF FIX. CHANN. ASSIGNED TO THAT PARTICULAR
 *    CELL FROM WHERE THE CALL ORIGNATES
 *    IF A FIX. CHANN. IS FOUND AVAILABLE. THE CALL WILL THEN SEIZE AND
 *    USE IT
 *
 *
  FCS    TEST G      MH$JOYAL(P1,P2),0,ENCOR            A NEGATIVE ELEMENT
         ENTER       P1                                 DENOTES A FIX.CHANN.
         DEPART      P10                                BEING IN USE
         ASSIGN      3,MH$JOYAL(P1,P2)                  P3 CARRIES THE FIX.CHA
         MSAVEVALUE  JOYAL,P1,P2,V59,H                  ELIMINATE THAT FIX.
 *                                                      CHANN.FROM THAT CALL'S
 *                                                      SET OF FIX.CHANN.
         PRIORITY    12                                 GIVE A HIGHER PR.TO
 *                                                      THE CALL USING A F.CH.
         ADVANCE     V57,FN$EXPON                       SERVICING THE CALL
         DEPART      P1
  BIEN   TEST E      G*1,0,RDC                          IF A D.CH.BEING IN USE
 *                                                      IN THAT CELL.LET THE
```

```
*                                               JUST RELEASED FIX.CHANN
*                                               FREE IT
 LOV    TEST E      CH$BLOC,0,SECCU             IF THERE IS A WAITING
        TEST E      G*10,0,NON                  CALL,IT WILL GET THE
*                                               JUST VACANT F.CH.
 BRAVC  MSAVEVALUE  JOYAL,P1,F2,F3,H            THE JUST SERVED CALLS
*                                               RETURNED THE F.CH.TOCEE
        LOGIC R     *1                          INFORM ALL INCOMING
        LEAVE       P1                          CALLS OF F.CH.
        TEST GE     P9,0,AUT1                   BEING AVAILABLE
        TABULATE    SUCES
        LEAVE       HELEN
        TERMINATE
 NON    TRANSFER    ,BIEN
*
*
*
*
*
* THE FOLLOWING SUBROUTIN HANDLES THE QUEUED CALLS. WHEN THERE IS
* A FREE FIX CHANNEL AVAILABLE
*
*
 SECOL  TEST NE     G*10,0,BRAVC
 BON    SAVEVALUE   14,P1,H                     THE ORIGIN OF THE
*                                               CALL IS SAVED
*
        ALTER       P10,1,PR,12,1,XH14          CHANGE THE PR.OF
        SAVEVALUE   15,P2,H                     THE QUEUED CALLFROM
        SAVEVALUE   16,P3,H                     THE SAME CELL.
        ALTER       P10,1,2,XH15,PR,12          CHANGE P2 & P3 OF
        ALTER       P10,1,3,XH16,PR,12          THE CALL TO THOSE OF
        UNLINK      BLOC,CHIC,1,1,XH14          THE PASSING XAC
        LEAVE       P1
        TEST GE     P9,0,AUT1
        TABULATE    SUCES
        LEAVE       HELEN
        TERMINATE
 AUT1   TABULATE    CWS
        LEAVE       HELEN
        TERMINATE
*
*
 CHIC   SCAN        *10,PR,12,2,2,CBLK          ASSIGN THE JUST
        SCAN        *10,PR,12,3,3,CHLK          VACATED F.CH.TO THE
*                                               CALL
        ENTER       P1
        DEPART      P10
        REMOVE      *10                         ELIMINATE THAT CALL
        TEST E      G*10,0,TIEN                 FROM GRP.P10
        LOGIC R     *10
 TIEN   ADVANCE     V57,FN$EXPON
```

```
       DEPART      P1
       TRANSFER    ,BIEN
*
*
*  THE FOLLOWING SUBROUTINE HANDLES THE SEARCH OF A VACANT F.CH. BY
*  SCANNING THRU. THE ROW OF THE MATRIX JOYAL CORRP. TO THE CELL NO.
*  IN QUESTION
*
*
 ENCOR ASSIGN      2-,1
       TEST E      P2,0,FCS
       LOGIC S     *1                                  INFORM INCOMING CALLS
*                                                      OF NO AVAIL.F.CH.
*
       TRANSFER    ,DCS
*
*
*   THE FOLLOWING SUBROUTINE TAKES CARE OF THE BORROWING OF AN AVAIL.
*   D.CH.
*
*
 DCS   GATE LR     *10,BUSY
       SAVEVALUE   2,P1,H                              STORE THE ORIGIN OF
*                                                      THE CALL THAT WANTS
*                                                      TO BORROW A D.CH.
       ALTER       45,ALL,50,XH2                       INFORM ALL THE D.CH.IN
*                                                      THE SYSTEM GRP.OF THE
*                                                      D.CH.OF THE ORIGIN OF
*                                                      THE CALL
       UNLINK      POOL,DRIVE,1,BV*50,,BUSY            SELECT A D.CH.WHICH
       CLPART      P10                                 SATIFIES THE COCHANNEL
*                                                      UNTFER CONST.
       PRIORITY    11                                  MAKE THE CALL WAIT FOR
       LINK        ATTEN,P1                            A D.CH.TO BE ASSIGNED
*                                                      BY LOWERING ITS PR.
 BUSY  LOGIC S     *10                                 NO D.CH.AVAILABLE
       PRIORITY    14                                  GIVE HIGHER PRIORITY TO
*                                                      THE BLOCKED & QUED CALL
       ASSIGN      9-,900                              PS OF THE QUED
       JOIN        P10                                 CALL IS ET TO -900
       TABULATE    WAIT
       LINK        BLOC,FIFO                           QUEUED CALLS PUT IN
*                                                      CHAIN " BLOC "
 DRIVE SAVEVALUE   4,P48,H                             STORE THE D.CH.NO.WHICH
*                                                      SATISFIES THE CONST.FOR
*                                                      BORROWING
       ASSIGN      *50,*50                             STORE THE ORIGIN OF THE
*                                                      CALL IN THE APPRO.PARAM
*                                                      OF THE D.CH. INDICATING
*                                                      THAT THIS D.CH. WILL BE
*                                                      BORROWED TO THAT CALL
*                                                      IN THAT CELL
```

```
          UNLINK      ATTEN,USE,1,1,XH2
*                                                     UNLINK THE 1ST CALL
          PRIORITY    PR                              WHOSE ORIGINMATCHES XH2
*                                                     CHOSEN D.CH. IS GIVEN
          LINK        POOL,P47                        A HIGHER PR.
 USE      JOIN        P1
          ASSIGN      4,XH4
*                                                     ASSIGN SELECTED D.CH.
          ENTER       P1                              NO.TO THE CALL
 SERV     ADVANCE     V57,FN$EXPON
          DEPART      P1                              SERVICE THE CALL BY
          TEST E      *3,0,BIEN                       A D.CH.
*                                                     IF THE CALL IS USING A
*                                                     D.CH.WITHOUT REASSIG-
*                                                     MENT.P3=0.THE D.CH.
          SAVEVALUE   6,*4,H                          WILL BE RELEASED
          SAVEVALUE   12,P1,H
          ALTER       45,1,XH12,0,48,XH6
          REMOVE      *1                              RELEASE BORROWED D.CH
          TEST E      CH$BLOC,0,TRY
*
 DELET    LEAVE
          TEST GE     P9,0,AUT1                       RELEASED D.CH.WILL BE
          TABULATE    SUCES                           RETURNED TO THE
          LEAVE       HELEN                           SYSTEM POOL.
*
          TERMINATE
 TRY      SAVEVALUE   19,P10,H
          UNLINK      POOL,CHECK,1,48,XH6             RELEASED D.CH.WILL GO
          TRANSFER    ,DELET                          SERVICE A SUITABLE
*                                                     QUEUED CALL
*
* THIS PART OF THE PROGRAMME HANDLES THE QUEUED CALLS WHEN
* A D.CH. BECOMES AVAILABLE
*
*
 CHECK    SAVEVALUE   18,P48,H
          SAVEVALUE   17,1,H                          SAVE THE D.CH.NO.
          ASSIGN      51,XH19
 TROU     ASSIGN      49,XH17
          TEST E      BV*49,1,CIRC
 CHK1     UNLINK      BLOC,FRGCE,1,1,XH17,ETRAN       START SCANNING THE
          ASSIGN      *49,*49                         QUEUE TO FIND THE
          TEST E      G*51,0,CHK2                     1ST CALL AT WHOSE
          LOGIC R     *51                             ORIGIN THE D.CH.
*                                                     SATISFIES THE INTER-
 CHK2     PRIORITY    PR                              FERENCE CRITERION
          LINK        POOL,P47
*
 CIRC     SAVEVALUE   17+,1,H
          TEST E      XH17,40,TROU
          JOIN        46
```

```
        PRINT       46,46,G
        LINK        POCL,F47
 ETRAN  SAVEVALUE   17+,1,H
        TEST NE     XH17,40,ETR1
        ASSIGN      49,XH17
        TEST E      BV*49,1,ETR2
        TRANSFER    ,CHK1
 ETR1   TEST E      G*51,0,CHK2
        LOGIC R     *51
        TRANSFER    ,CHK2
 ETR2   TRANSFER    ,ETRAN
 PROCE  ASSIGN      4,XH18
        DEPART      P10                                THE QUED CALL FOUND
        REMOVE      *10                                SEIZES THE D.CH.
        PRIORITY    11
        JOIN        P1
        ENTER       P1
        TEST E      G*10,0,SERV
        LOGIC R     *10
        TRANSFER    ,SERV
*
*
* THIS PART OF THE PROGRAMME HANDLES THE BLOCKED CALLS
* FOR CHECKING PURPOSE
*
*
 CBLK   DEPART      P10
        DEPART      P1
        TABULATE    FAIL
        LEAVE       HELEN
        TERMINATE
*
*
*   THE FOLLOWING SUBROUTINE HANDLES THE RELIEFING OF A IN-USE D.CH.
*   REASSIGNING THE IN-PROGRESS CALL TO A JUST VACANT F.CH. IN THE CELL
*
*
 RDC    SCAN        *1,PR,11,4,5,DUM
*                                                      TRYING TO FIND A CALL
*                                                      USING A D.CH.IN THEGP.
*                                                      CORRP. TO THE CELL IN
*                                                      QUEST. STORE IN P5 OF
*                                                      THE PASSINGXAC THE NO.
        SAVEVALUE   7,P1,H                             D.CH.USED BY THE CALL
        SAVEVALUE   8,P5,H                             STORE THE ORIGIN OF CAL
*                                                      STORE THE D.CH.NO.THAT
        SAVEVALUE   9,P3,H                             WILL BE RELIEVED
*                                                      STORE THE F.CH.WHICH
        SAVEVALUE   10,*2,H                            WILL REPLACE THE D.CH.
*                                                      STORE THE COLUMN NO.OF
        SAVEVALUE   11,0,H                             JOYAL CORRP.TO F.CH.NO.
        ALTER       P1,1,2,XH10,4,XH8
                                                       NOTIFY THE CALL INWHICH
```

```
*                                                    COLUMN OF JOYAL TO
*                                                    RETURN THE F.CH.
         ALTER       P1,1,3,XH9,4,XH8                ASSIGN TO THIS CALL THE
*                                                    F.CH.NO.WHICH IS GOING
*                                                    TO RELIEF THE D.CH.
         ALTER       45,1,XH7,XH11,48,XH8            RESETTING CORRP.PARAM.
         REMOVE      XH7,1,,4,XH8,SAME               OF THE D.CH.TO SIGNIFY
         TEST E      CH$BLOC,C,LIBRE                 THAT THAT D.CH.IS NO
*                                                    LONGER USED BY THE CALL
*                                                    IN THAT CELL
*
 DONE    LEAVE       P1
         TEST GE     P9,0,AUT2                       IF NO CALLS IN THE
         TABULATE    SUCES                           QUEUE,THE RELIEVED
         LEAVE       HELEN                           D.CH.WILL BE RETURNED
         TERMINATE                                   TO SYSTEM POOL
 SAME    TRANSFER    ,DONE
 AUT2    TABULATE    CWS
         LEAVE       HELEN
         TERMINATE
 LIBRE   SAVEVALUE   19,P10,H
         UNLINK      POOL,CHECK,1,48,XH8             OTHERWISE THE D.CH.
         TRANSFER    ,DONE                           WILL GO SERVE AN-
 DUM     TRANSFER    ,BRAVO                          OTHER SUITABLE CALL
*
*
* MODEL SEGMENT-2: CREATION OF DYNAMIC CHANNELS AND THE
* ASSIGNMENT OF THEIR NUMERICAL VALUES.
*
*
 CREA    GENERATE    ,,1,1,10,51
*                                                    GENERATE ONLY THEMASTER
*                                                    D.CH. AT TIME=1.WITH
         ASSIGN      46,XH1                          PR=10 & 50 PARAMS
         SPLIT       5,LINE,47,51
*                                                    SPLIT THE MASTER D.CH.
*                                                    INTO 5 COPIES WITH P47
         PRIORITY    PR,BUFFER                       USED FOR SERIALIZATION
         UNLINK      FILE,DAS2,1,47,2
         UNLINK      FILE,DAS3,1,47,3
         UNLINK      FILE,DAS4,1,47,4
         UNLINK      FILE,DAS5,1,47,5
         UNLINK      FILE,DAS6,1,47,6
         UNLINK      FILE,DAS7,1,47,7
         UNLINK      FILE,DAS8,1,47,8
         UNLINK      FILE,DAS9,1,47,9
         UNLINK      FILE,DAS10,1,47,10
         UNLINK      FILE,DAS11,1,47,11
         UNLINK      FILE,DAS12,1,47,12
         UNLINK      FILE,DAS13,1,47,13
         UNLINK      FILE,DAS14,1,47,14
         UNLINK      FILE,DAS15,1,47,15
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         UNLINK      FILE,DAS16,1,47,16
         UNLINK      FILE,DAS17,1,47,17
         UNLINK      FILE,DAS18,1,47,18
         UNLINK      FILE,DAS19,1,47,19
         UNLINK      FILE,DAS20,1,47,20
         UNLINK      FILE,DAS21,1,47,21
         UNLINK      FILE,DAS22,1,47,22
         UNLINK      FILE,DAS23,1,47,23
         UNLINK      FILE,DAS24,1,47,24
         UNLINK      FILE,DAS25,1,47,25
         UNLINK      FILE,DAS26,1,47,26
         UNLINK      FILE,DAS27,1,47,27
         UNLINK      FILE,DAS28,1,47,28
         UNLINK      FILE,DAS29,1,47,29
         UNLINK      FILE,DAS30,1,47,30
         UNLINK      FILE,DAS31,1,47,31
         UNLINK      FILE,DAS32,1,47,32
         UNLINK      FILE,DAS33,1,47,33
         UNLINK      FILE,DAS34,1,47,34
         UNLINK      FILE,DAS35,1,47,35
         UNLINK      FILE,DAS36,1,47,36
         UNLINK      FILE,DAS37,1,47,37
         UNLINK      FILE,DAS38,1,47,38
         UNLINK      FILE,DAS39,1,47,39
         UNLINK      FILE,DAS40,1,47,40
         UNLINK      FILE,DAS41,1,47,41
         UNLINK      FILE,DAS42,1,47,42
         UNLINK      FILE,DAS43,1,47,43
         UNLINK      FILE,DAS44,1,47,44
         UNLINK      FILE,DAS45,1,47,45
         TRANSFER    ,DAS1
LINE     LINK        FILE,P47                       MAKE ALL COPIES WAIT IN
*                                                   FILE IN ASCENDING ORDER
*                                                   OF THEIR SERIAL NO.
DAS1     ASSIGN      48,MH$JOYAL(1,V41)             ASSIGN THE D.CH.NO.
*                                                   TO P48 OF XAC
         TRANSFER    ,LIGNE                         MAKE THE D.CH. WAIT
*                                                   FOR ASSIGNMENT
DAS2     ASSIGN      48,MH$JOYAL(2,V41)
         TRANSFER    ,LIGNE
DAS3     ASSIGN      48,MH$JOYAL(3,V41)
         TRANSFER    ,LIGNE
DAS4     ASSIGN      48,MH$JOYAL(1,V42)
         TRANSFER    ,LIGNE
DAS5     ASSIGN      48,MH$JOYAL(2,V42)
         TRANSFER    ,LIGNE
DAS6     ASSIGN      48,MH$JOYAL(3,V42)
         TRANSFER    ,LIGNE
DAS7     ASSIGN      48,MH$JOYAL(1,V43)
         TRANSFER    ,LIGNE
DAS8     ASSIGN      48,MH$JOYAL(2,V43)
         TRANSFER    ,LIGNE
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DAS9   ASSIGN      48,MH$JOYAL(3,V43)
       TRANSFER    ,LIGNE
DAS10  ASSIGN      48,MH$JOYAL(1,V44)
       TRANSFER    ,LIGNE
DAS11  ASSIGN      48,MH$JOYAL(2,V44)
       TRANSFER    ,LIGNE
DAS12  ASSIGN      48,MH$JOYAL(3,V44)
       TRANSFER    ,LIGNE
DAS13  ASSIGN      48,MH$JOYAL(1,V45)
       TRANSFER    ,LIGNE
DAS14  ASSIGN      48,MH$JOYAL(2,V45)
       TRANSFER    ,LIGNE
DAS15  ASSIGN      48,MH$JOYAL(3,V45)
       TRANSFER    ,LIGNE
DAS16  ASSIGN      48,MH$JOYAL(1,V46)
       TRANSFER    ,LIGNE
DAS17  ASSIGN      48,MH$JOYAL(2,V46)
       TRANSFER    ,LIGNE
DAS18  ASSIGN      48,MH$JOYAL(3,V46)
       TRANSFER    ,LIGNE
DAS19  ASSIGN      48,MH$JOYAL(1,V47)
       TRANSFER    ,LIGNE
DAS20  ASSIGN      48,MH$JOYAL(2,V47)
       TRANSFER    ,LIGNE
DAS21  ASSIGN      48,MH$JOYAL(3,V47)
       TRANSFER    ,LIGNE
DAS22  ASSIGN      48,MH$JOYAL(1,V48)
       TRANSFER    ,LIGNE
DAS23  ASSIGN      48,MH$JOYAL(2,V48)
       TRANSFER    ,LIGNE
DAS24  ASSIGN      48,MH$JOYAL(3,V48)
       TRANSFER    ,LIGNE
DAS25  ASSIGN      48,MH$JOYAL(1,V49)
       TRANSFER    ,LIGNE
DAS26  ASSIGN      48,MH$JOYAL(2,V49)
       TRANSFER    ,LIGNE
DAS27  ASSIGN      48,MH$JOYAL(3,V49)
       TRANSFER    ,LIGNE
DAS28  ASSIGN      48,MH$JOYAL(1,V50)
       TRANSFER    ,LIGNE
DAS29  ASSIGN      48,MH$JOYAL(2,V50)
       TRANSFER    ,LIGNE
DAS30  ASSIGN      48,MH$JOYAL(3,V50)
       TRANSFER    ,LIGNE
DAS31  ASSIGN      48,MH$JOYAL(1,V51)
       TRANSFER    ,LIGNE
DAS32  ASSIGN      48,MH$JOYAL(2,V51)
       TRANSFER    ,LIGNE
DAS33  ASSIGN      48,MH$JOYAL(3,V51)
       TRANSFER    ,LIGNE
DAS34  ASSIGN      48,MH$JOYAL(1,V52)
       TRANSFER    ,LIGNE
```

```
DAS35  ASSIGN      48,MH$JOYAL(2,V52)
       TRANSFER    ,LIGNE
DAS36  ASSIGN      48,MH$JOYAL(3,V52)
       TRANSFER    ,LIGNE
DAS37  ASSIGN      48,MH$JOYAL(1,V53)
       TRANSFER    ,LIGNE
DAS38  ASSIGN      48,MH$JOYAL(2,V53)
       TRANSFER    ,LIGNE
DAS39  ASSIGN      48,MH$JOYAL(3,V53)
       TRANSFER    ,LIGNE
DAS40  ASSIGN      48,MH$JOYAL(1,V54)
       TRANSFER    ,LIGNE
DAS41  ASSIGN      48,MH$JOYAL(2,V54)
       TRANSFER    ,LIGNE
DAS42  ASSIGN      48,MH$JOYAL(3,V54)
       TRANSFER    ,LIGNE
DAS43  ASSIGN      48,MH$JOYAL(1,V55)
       TRANSFER    ,LIGNE
DAS44  ASSIGN      48,MH$JOYAL(2,V55)
       TRANSFER    ,LIGNE
DAS45  ASSIGN      48,MH$JOYAL(3,V55)
       TRANSFER    ,LIGNE
LIGNE  JOIN        45
       LINK        POOL,F47
*
*
*  MODEL SEGMENT-3: SIMULATION RUN TIME CONTROL
*
*
TIM    GENERATE    300000
       TEST E      BV50,1,RAG
       TERMINATE   1
RAG    SPLIT       20,FIN,5
FIN    TERMINATE   1
       TERMINATE   1
       START       1,NP
       RESET       S41
       START       48,,6
       END
```

VITAE

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