DEVELOPMENT OF CRITERIA FOR THE SELECTION OF TERMINAL EQUIPMENT IN AN INTERCONNECT ENVIRONMENT

by

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Department of Communications
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Contract Serial No. 0SU80-00222
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LIST OF MAJOR SYMBOLS

AF	Conversion factor from salvage value to monthly value
AP	Conversion factor from initial cost to monthly cost
CI	Initial cost of Centrex scheme
CM	Monthly charge for Centrex scheme
CS	Monthly cost per Centrex station
E	Number of extension stations
EC	Equivalent monthly cost per Centrex station
EP	Equivalent monthly cost per Customer-owned PBX station
EPI	Equivalent purchase and installation cost for Customer-owned PI
EX	Equivalent monthly cost per station for PASS
JC	Total . jack charge per month
JI	Total jack installation charge
K	Coefficient of L in EPI
L	Number of lines
LCC	Line connection charge
LPW	Total premises work charge
LSS	Unit line local shared service cost per month for a Centrex station
M	Number of main stations
N	Amortization period, years
OAC	Administrative charge
OC	Total PBX options cost per month
PI	Initial cost for Customer-owned PBX
PM	Monthly cost for Customer-owned PBX
PVC	Premises visit charge

PWC	Premises work charge
R	Interest rate
S	Number of stations (main or extension)
SC	Total maintenance cost per month
SVF	Salvage value factor of the Customer-owned PBX system
T	Number of trunks
TC	Total trunk charge per month
TCG	Total government overhead trunk charge per month
TLC	Total line connection charge
TPW	Total premises work charge
UE	Unit extension cost per month
UJ	Jack charge per trunk per month
UJI	Jack installation charge per trunk
UL	Unit line cost per month for a Centrex station
UO	Options cost per station per month
USS	Maintenance cost per line per month
UT	Trunk charge per trunk per month
UTG	Government overhead charge per trunk per month
UXE	Average PBX rental charge per station per month
UXS	Average PBX installation charge per station
XE	Installation charge for PASS equipment
XI	Initial cost of PASS
XM	Monthly charge for PASS scheme
XS	PBX rental cost per month

SUMMARY

This research was performed to develop a methodology for local service terminal selection based on economic factors.

Three types of serves are compared on a cost basis:

- Centrex
- Leased PBX's
- Customer-owned PBX's

The cost sensitivity of each system to its respective parameters is also examined to facilitate prediction of the impact of future economic tariff changes on each system type.

Finally some comments are made concerning the cost comparison of various system types.

1. INTRODUCTION

Progress in telecommunications regulation toward the liberalization of the attachment of customer-provided terminal equipment to certain common carrier's networks offers a potential opportunity for government users to have alternative means of securing equipment and resources to meet their telecommunications requirements. In such an interconnect environment, they may continue the leasing arrangement with the common carriers for end-to-end telecommunications service; or, they may purchase or even lease terminal equipment with specific features from a supplier and attach it to the carrier's network to meet their day-to-day service requirements. The decision to lease or to purchase, from the carrier or from terminal equipment suppliers will be based on many factors, such as costs, service support, tariff schedule, price trends, just to name a few. The development of a set of criteria that take technical, cost and operational factors into consideration will enable a government user to determine for a given situation, the most cost-effective way of fulfilling their telecommunication needs.

The objective of this research is to identify the factors which affect the selection between leasing and purchasing terminal equipment, to determine the economic impact of these factors and to develop a methodology for the decision-making process for the choice between purchasing and leasing terminal equipment under various circumstances in the government.

During this current contract the research is confined to the National Capital Region (NCR) of the federal government.

The research consists of: studying the requirements of terminal equipment facilities in the federal government, and the current usage and arrangement of telecommunications service; studying available literature on terminal equipment and the relating tariff of the common carrier; developing a set of selection criteria applied specifically to government users. Mathematical models are developed. Factors are quantified, if possible. After the models are verified through case studies, they can be used in the future to choose the best strategy for a given telecommunications requirement.

For the purpose of this research two types of service will be examined: Centrex Service and PBX Service. Centrex Service will be defined as a government exchange wide service which meets the TBS guidelines for local telephone service. For costing purpose key systems behind the centrex will be treated as optional features within the centrex system. PBX Service will be defined as a peripheral (satellite) PBX behind the centrex. The liberalization of terminal attachments means that the user can own certain equipment, such as a number of local private branch exchanges (PBX), lease a number of trunks, pay the appropriate installation and service charges, and connect the customer-owned equipment to the carrier's network. Therefore both leased PBX's and customer-owned PBX's will be considered. While there are several leased PBX service offerings available from the common carrier , this research will be limited to the most popular Private Automatic Switching Service (PASS).

In summary, there are basically three schemes that a user can select: Centrex, PASS and Customer-owned PBX. We first look into the intangible factors which could affect the selection between purchasing and leasing equipment in the next section. In the sections that follow, we will formulate cost models for the three schemes and then determine the sensitivity of each scheme with respect to each parameter. The objective is to identify those parameters which play relatively important roles in the cost formulas and hence affect the choice when their values change. We then determine the break-even points of each pair of schemes. The purpose is to find out how the break-even points are affected by the parameters. Again, the dominant factors are identified. We conclude our report by summarizing the findings of this research.

2. INTANGIBLE FACTORS AFFECTING THE CHOICE BETWEEN PURCHASING AND LEASING

Since Centrex Service and PASS are essentially leased systems, whereas Customer-owned PBX is to own some equipment in the telecommunications systems, it is essential to compare the choice between purchasing and leasing of equipment. Among the factors which affect equivalent system costs, the following perhaps are the most important: New technology, price trend, line to trunk ratio.

2.1 New Technology

As a direct result of the development of new technology there has been a substantial reduction in the physical size of - hardware packages. This implies considerable savings in space requirement and power consumption. The reduction in power consumption reduces the amount of heat generated thereby eliminating the need for mechanical cooling devices. No specialized location is thus needed to place hardware devices. Besides the reduction in the initial installation cost due to space reduction, the savings in power consumption per month could go as high as fifty percent.

The introduction of more software has made the packages more flexible, reliable and efficient. One package can now be programmed by different users for their specific needs. Programming has been simplified to make implementation easier. Training personnel in the use of software is usually provided as a free service and does not involve a lot of time. Changes in the system at a later stage do not require specialized personnel from the vendor. The operating costs are thus reduced in terms of both time and money. Expansion and changes of the system are faster and simpler to perform since some systems provide built-in features. In some cases, changes can be made on site or through the use of remote terminals even while the equipment is in use.

The rapid development in technology could take the form of new equipment with improved facilities and more options being offered by competing vendors. In case of purchased equipment, an innovation could simply out-date the equipment with little or no salvage value. The equipment costs would, practically, be a writeoff. On the other hand, when the equipment is leased, the user can turn to more cost effective new equipment on expiration of a lease.

2.2 Price Trend

It is difficult to predict a definitive price trend but the following factors will help show its direction.

2.2.1 Reduced Cost of Manufacturing

Ever since the introduction of the "chip" in electronics, the cost of manufacturing equipment has decreased. The bulkiness of the equipment has given way to lighter and smaller packages. The savings on the material required to form the container has also contributed to a reduction in cost.

2.2.2 Competition

Due to the fact that communication equipment may now be owned by the user, it is expected that some firms will enter the market, thereby making it more competitive. The new technology emphasizes the use of simple software for greater user flexibility. Buyers will therefore be enticed by the introduction of new software options. Prices should tend to be competitive and a price hike, if any, is expected to be within inflationary limits.

2.2.3 Volume

A high volume of equipment sold usually results in a reduction of prices. The trend is that more computer installations will use telecommunications equipment. As a result, there will be an increase in the market volume which in turn will attract some competitors. Thus the trend will be a drop in future price.

In general, if future prices are predicted to go down, the user is better off with leasing.

2.3 Quality of Service

Besides bearing direct relationship to cost, the line to trunk ratio affects the performance of a telecommunications system. All other factors being equal, a higher ratio means a higher probability of getting a busy line. Blocking and other related problems can be analyzed by queueing models.

2.4 Service Support

Good service support means that the customer does not have to worry about the consequence of equipment breakdown. Some of the good qualities that a customer wants from the vendor or carrier include a simple and direct mechanism for reporting equipment malfunction, existence of local service representatives and prompt response to service calls. The objective is to avoid inconvenience and reduce service interruption time.

2.5 Other Factors

Besides the above factors, the following points may influence the decision making process at a later stage: In case the equipment has been purchased and the premises being used are on a lease then relocation of offices due to the expiration of the lease implies added installation costs for the new location. Similar arguments apply if a department is relocated as a result of government policy. For leasing equipment the lease can be arranged such that it expires at the time the department is relocated. In selecting the amortization period for purchased equipment the above factor should be taken into consideration. The lease on equipment may be subject to price change in the tariff rates. Purchased equipment is protected against such a change.

Another factor that deserves some consideration is space and/or other special requirements of the equipment. For example, if the equipment requires large space, humidity control, air conditioning or large power supply, then it is not as good as another equivalent equipment which does not have any of these requirements.

In the next section, we formulate cost models for all schemes by taking into account all tangible factors that affect the cost in each scheme.

3. COST MODELS

In this section, we present the cost models for the three schemes that we are going to analyze. Generally speaking, in each scheme, there are costs which are incurred monthly such as line and trunk charges, and there are initial costs such as installation and purchase price of equipment. It is therefore necessary to separate the costs into two categories: monthly cost and initial cost. For meaningful comparisons of the cost of the three schemes, the initial costs are converted to their equivalent monthly costs and the cost per station per month for each scheme is computed.

3.1 Cost Components

Before developing the cost formulas, we want to define some terms for the purposes of this research. A main station is defined in this report as the first telephone set provided with a telephone line, and an extension station as any subsequent set on the same line. A station is either a main or an extension station. A trunk is a telephone line from a central office to a customer premises switch. A line is a telephone line from a main telephone set to the nearest switching equipment.

Let L, T, S, M and E be the number of lines, trunks, stations, main stations and extension stations respectively. The cost components of each scheme are discussed below.

3.1.1 Centrex

This is an exchange wide service with similar features to Centrex II. The monthly cost includes charges for telephone lines, main stations, extension stations and governmental local shared service charge. It will be assumed that the number of main stations is equal to the number of extension stations and the number of lines. Therefore

$$M = E \tag{1}$$

$$M = L \tag{2}$$

In the tariff schedule the unit line cost includes the cost of a main station. Normally the optional equipment and features, supplied as part of the centrex service, do not exceed seventy-five percent of the average station cost. A local shared service charge is imposed on each main station to recover the cost of governmental overhead. Thus the average monthly cost per station is

$$CS = \frac{UL + UE}{2} * 1.75 + \frac{LSS}{2} \tag{3}$$

where

UL is the unit line cost per month

UE is the unit extension cost per month

LSS is the unit line main station local shared service cost per month

The average monthly Centrex cost is

$$CM = [\frac{UL + UE}{2} * 1.75 + \frac{LSS}{2}] * S \tag{4}$$

The initial cost for centrex stations consists of administrative charge, premises vist charge, line connection charge and premises work charge. Both administrative and premises visit charges are a single charge for each order. Line connection charge is proportional to the number of lines. Premises work charge is proportional to the number of stations. Therefore, the initial cost for a centrex system is

$$CI = OAC + PVC + PWC * S + LCC * L \tag{5}$$

where

OAC is the adminitrative charge

PVC is the premises visit charge

PWC is the premises work charge per station

LCC is the line connection charge per line

Since $S = M + E$ and $M = E = L$,

$$CI = OAC + PVC + PWC * S + LCC * S/2 \tag{6}$$

3.1.2 PASS

This is a leased PBX service. Monthly costs include standard feature PBX rental charges, tariffs for trunks and optional features, and government shared service overhead.

The PBX rental charge consists of two components. One component, denoted by XS(L), is a piecewise linear function of the number of lines. The other component is a linear function of the number of extension stations. Usually there is one station per line (S = L). Therefore, the second component can be omitted.

Tariff for trunks is proportional to the number of trunks, T, that is

$$TC = UT * T \tag{7}$$

where

TC is the total trunk charge per month

UT is the unit trunk charge per month

Similarly, governmental shared service overhead is proportional to the number of trunks,

$$TCG = UTG * T \tag{8}$$

where

TCG is the total overhead trunk charge per month

UTG is the overhead trunk charge per trunk per month

It will be assumed that optional features costs, if chosen, are directly proportional to the number of lines,

$$OC = UO * L \tag{9}$$

where

OC is the total options cost per month

UO is the average options cost per station per month

Adding all components together, the monthly cost for PASS is

$$XM = XS(L) + TC + TCG + OC \tag{10}$$

Substituting (7), (8), (9) into (10),

$$XM = XS(L) + (UT + UTG) * T + UO * L \quad (11)$$

Initial costs for PASS consist of an installation charge for the PBX common equipment, connection and work charges for trunks and lines, and administrative and premises visit charges.

Installation charge for PBX common equipment is a step function of number of lines. That is, for a given range of number of lines, the charge is the same. This cost component is denoted by XE(L).

Line connection and premises work charges for trunks are proportional to the number of trunks. Therefore,

$$TLC = LCC * T \quad (12)$$

$$TPW = PWC * T \quad (13)$$

where TLC and TPW are total trunk connection and work charges respectively,

LCC and PWC are the same as defined before.

There is no line connection charge for PBX lines. Premises work charges for lines are proportional to the number of lines,

$$LPW = PWC * L \quad (14)$$

where

LPW is the total premises work charge for lines

In summary, the initial cost for PASS is

$$XI = XE(L) + TLC + TPW + LPW + OAC + PVC \quad (15)$$

Substituting (12), (13), (14) into (15)

$$XI = XE(L) + (LCC + PWC) * T + PWC * L + OAC + PVC \quad (16)$$

3.1.3 Customer-Owned PBX

In this scheme, the PBX common equipment, main and extension stations are privately owned. The equipments have to meet the carrier's standard.

Monthly costs incurred in this scheme include trunk and trunk jack charges by the carrier, government overhead charge and monthly maintenance charge.

Presently, tariffs for trunks and government shared service overhead are the same as those for PASS, (7) and (8).

Trunk jack charge is directly proportional to the number of trunks,

$$JC = UJ * T \quad (17)$$

where

JC is the total jack charge per month

UJ is the jack charge per trunk per month

Maintenance charge of the equipment is proportional to the number of lines,

$$SC = USS * L \quad (18)$$

where

SC is the total maintenance cost per month

USS is the maintenance cost per line per month

In summary, the monthly cost for Customer-owned PBX is

$$PM = TC + TCG + JC + SC \quad (19)$$

Substituting (7), (8), (17), (18) into (19)

$$PM = (UT + UTG + UJ) * T + USS * L \quad (20)$$

Initial costs for Customer-owned PBX consist of the purchase price and installation of the PBX system, trunk connection and work charges, jack installation charge, administrative and premises visit charges.

The cost of a PBX system, including the engineering, furnishing and installation of the Customer-owned PBX common equipment, lines and sets is a function of the number of trunks and the number of lines. Let this cost be denoted by EPI(T,L). General cost formula is not known. However, from the quotations available for specific trunk and line combinations, the following empirical formula is reasonably accurate over the same range of lines as served by PASS:

$$EPI(T,L) = K * L + 400 * T \quad (21)$$

where

$$500 \leq K \leq 1000$$

Trunk connection and work charges are the same as (12) and (13) for PASS.

Jack installation charge is proportional to the number of trunks,

$$JI = UJI * T \quad (22)$$

where

JI is the total of jack installation charges

UJI is the jack installation charge per trunk

The initial cost for purchased PBX is

$$PI = EPI(T,L) + TLC + TPW + JI + OAC + PVC \quad (23)$$

Substituting (12), (13), (21) and (22) into (23)

$$PI = (400 + LCC + PWC + UJI) * T + K * L + OAC + PVC \quad (24)$$

3.2 Average Monthly Cost

For comparisons to be meaningful a standard cost measure has to be defined so that the different schemes can be compared on the same basis. An obvious approach is to determine the cost per station per month for each scheme. It means that the initial costs have to be converted into equivalent monthly costs. An amortization period has to be selected. The length of the period depends on factors such as the expected life of the equipment, how long the same equipment will be used. At the end of the amortization period, certain equipment can be kept for other uses, some equipment can be sold. In other words, some components of the initial cost may have some salvage value, and should be properly credited.

Let N be the amortization period in years not longer than the life of the equipment, R be the interest rate, IC and SV be the initial cost and salvage value, respectively. The equivalent monthly cost, A, is:

$$A = AP * IC - AF * SV \quad (25)$$

where

$$AP = \frac{R(1 + 0.5R)^{2N}}{2(6 + 1.75R)\left[(1 + 0.5R)^{2N} - 1\right]} \qquad (26)$$

$$AF = \frac{R}{2(6 + 1.75R)\left[(1 + 0.5R)^{2N} - 1\right]} \qquad (27)$$

The derivations of AP and AF are shown in Appendix I.

3.2.1 Centrex

There is no salvage value. The equivalent monthly cost per station is

$$EC = (CM + CI * AP)/S \qquad (28)$$

Substituting (4), (6) into (28)

$$EC = 0.875(UL + UE) + 0.5 * LSS + AP * \left[(PWC + 0.5 * LCC) * S + OAC + PVC\right] /S \qquad (29)$$

3.2.2 PASS

There is no salvage value. The equivalent monthly total cost per station is

$$EX = (XM + XI * AP)/S \qquad (30)$$

Substituting (11) and (16) into (30) and observing the fact that L = S,

$$EX = \left\{ XS(S) + (UT + UTG) * T + S * UO + \left[XE(S) + (LCC + PWC) * T + PWC * S + OAC + PVC\right] * AP \right\} /S \qquad (31)$$

3.2.3 Customer-Owned PBX

Let SVF be the salvage value factor of the customer-owned PBX system, the equivalent monthly total cost per station is

$$EP = (PM + PI * AP - SVF * EPI * AF)/S \qquad (32)$$

Substituting (20),(21) and (24) into (32), and S for L,

$$\begin{aligned} EP = \{ & (UT + UTG + UJ) * T + USS * S \\ & + [(400 + LCC + PWC + UJI) * T \\ & + K * S + OAC + PVC] * AP \\ & - SVF * (400 * T + K * S) * AF\}/S \end{aligned} \qquad (33)$$

4. SENSITIVITY ANALYSIS

In the previous section, we have shown that the average monthly cost per station in each scheme is a function of many parameters, such as carrier's tariff, service charge, number of lines, number of trunks, length of amortization period, discount rate, etc. For a given set of parameter values, one particular scheme would be least expensive. However, the value of a parameter may vary because of changes in tariff schedule, changes in equipment prices or changes in user's requirements. Depending on the particular situation, the change in one parameter may drastically change the cost of one or more schemes in such a way that a different scheme may become the cheapest. Sensitivity analysis gives the communication system designer a convenient tool to determine the effect of a particular parameter on a particular scheme. In this section, the effect of each parameter on the average monthly cost in each scheme is examined analytically.

4.1 Sensitivity Formulas

Let f be a cost function and p be a parameter. The sensitivity of f to p is defined as

$$\frac{\delta f}{\delta p} = \frac{f(p + \delta p) - f(p)}{\delta p} \qquad (34)$$

where

δp is the change in parameter value,

$f(p)$ and $f(p + \delta p)$ are the values of f for the parameter values p and $p + \delta p$, respectively.

The following statements are not difficult to prove:

1. If $f = f_1 + f_2$, where f_1 and f_2 are functions of p, then

$$\frac{\delta f}{\delta p} = \frac{\delta f_1}{\delta p} + \frac{\delta f_2}{\delta p} \tag{35}$$

2. If $f = af_1$, where a is a constant and f_1 is a function of p, then

$$\frac{\delta f}{\delta p} = a\frac{\delta f_1}{\delta p} \tag{36}$$

3. If $f = pf_1$, where f_1 is a function of p, then

$$\frac{\delta f}{\delta p} = p\frac{\delta f_1}{\delta p} + f_1(p + \delta p) \tag{37}$$

4. If $f = f_1/p$, where f_1 is a function of p, then

$$\frac{\delta f}{\delta p} = \frac{1}{p+\delta p}\left[\frac{\delta f_1}{\delta p} - \frac{f_1(p)}{p}\right] \tag{38}$$

The sensitivity of the cost functions (29), (31) and (33) to each parameter can be determined with the help of (35) - (38). We state the results as follows.

4.1.1 Centrex

$$\frac{\delta EC}{\delta UL} = \frac{\delta EC}{\delta UE} = 0.875 \quad (39)$$

$$\frac{\delta EC}{\delta LSS} = 0.5 \quad (40)$$

$$\frac{\delta EC}{\delta PWC} = AP \quad (41)$$

$$\frac{\delta EC}{\delta LCC} = 0.5 * AP \quad (42)$$

$$\frac{\delta EC}{\delta OAC} = \frac{\delta EC}{\delta PVC} = \frac{AP}{S} \quad (43)$$

$$\frac{\delta EC}{\delta S} = - \frac{(OAC + PVC) * AP}{S(S + \delta S)} \quad (44)$$

$$\frac{\delta EC}{\delta N} = \frac{[S * (PWC + 0.5 * LCC) + OAC + PVC] * \delta AP}{S * \delta N} \quad (45)$$

$$\frac{\delta EC}{\delta R} = \frac{[S * (PWC + 0.5 * LCC) + OAC + PVC] * \delta AP}{S * \delta R} \quad (46)$$

4.1.2 PASS

$$\frac{\delta EX}{\delta XS} = \frac{1}{S} \quad (47)$$

$$\frac{\delta EX}{\delta UT} = \frac{\delta EX}{\delta UTG} = \frac{T}{S} \quad (48)$$

$$\frac{\delta EX}{\delta UO} = 1 \quad (49)$$

$$\frac{\delta EX}{\delta XE} = \frac{\delta EX}{\delta OAC} = \frac{\delta EX}{\delta PVC} = \frac{AP}{S} \quad (50)$$

$$\frac{\delta EX}{\delta LCC} = \frac{AP * T}{S} \quad (51)$$

$$\frac{\delta EX}{\delta PWC} = \frac{AP * (T + S)}{S} \quad (52)$$

$$\frac{\delta EX}{\delta S} = \frac{1}{S+\delta S}\left[\frac{\delta XS+AP*\delta XE}{\delta S} - \frac{XS(S)+AP*XE(S)}{S}\right] - \frac{1}{S*(S+\delta S)}\left\{T*[(UT+UTG+AP*(LCC+PWC)]+AP*(OAC+PVC)\right\} \quad (53)$$

$$\frac{\delta EX}{\delta T} = \frac{1}{S}[UT + UTG + AP * (LCC + PWC)] \quad (54)$$

$$\frac{\delta EX}{\delta N} = \frac{\delta AP}{S*\delta N}[XE(S)+(LCC+PWC)*T+PWC*S+OAC+PVC] \quad (55)$$

$$\frac{\delta EX}{\delta R} = \frac{\delta AP}{S*\delta R}[XE(S)+(LCC+PWC)*T+PWC*S+OAC+PVC] \quad (56)$$

4.1.3 Customer-Owned PBX

$$\frac{\delta EP}{\delta UT} = \frac{\delta EP}{\delta UTG} = \frac{\delta EP}{\delta UJ} = \frac{T}{S} \quad (57)$$

$$\frac{\delta EP}{\delta USS} = 1 \quad (58)$$

$$\frac{\delta EP}{\delta LCC} = \frac{\delta EP}{\delta PWC} = \frac{\delta EP}{\delta UJI} = \frac{AP*T}{S} \quad (59)$$

$$\frac{\delta EP}{\delta K} = AP - AF * SVF \quad (60)$$

$$\frac{\delta EP}{\delta OAC} = \frac{\delta EP}{\delta PVC} = \frac{AP}{S} \quad (61)$$

$$\frac{\delta EP}{\delta SVF} = -\frac{AF * (400 * T + K * S)}{S} \tag{62}$$

$$\frac{\delta EP}{\delta S} = -\frac{1}{S*(S+\delta S)}\Big\{T*[UT+UTG+UJ+AP*(400+LCC+PWC+UJI) - 400AF*SVF]+AP*(OAC+PVC)\Big\} \tag{63}$$

$$\frac{\delta EP}{\delta T} = \frac{1}{S}[UT+UTG+UJ+AP*(400+LCC+PWC+UJI)-AF*SVF*400] \tag{64}$$

$$\frac{\delta EP}{\delta N} = \frac{\delta AP}{S*\delta N}[(400+LCC+PWC+UJI)*T+K*S+OAC+PVC] - \frac{SVF*(400*T + K*S)*\delta AF}{S*\delta N} \tag{65}$$

$$\frac{\delta EP}{\delta R} = \frac{\delta AP}{S*\delta R}[(400+LCC+PWC+UJI)*T+K*S+OAC+PVC] - \frac{SVF*(400*T + K*S)*\delta AF}{S*\delta N} \tag{66}$$

4.2 Relative Sensitivity

Since different parameters have a different magnitude and not all parameters are measured in the same unit, it is difficult to compare the significance of parameters by simply comparing the sensitivities. It is more meaningful if a normalized unit is used. Therefore we propose to use the term relative sensitivity as a measure of the effect of the change of a parameter on a function, denoted by r(f,p), as follows:

$$r(f,p) = \frac{\delta f}{f} / \frac{\delta p}{p} \tag{67}$$

The relative sensitivity is the ratio of fractional change of cost function to fractional change in parameter value, and is dimensionless. $r(f,p)=r_1$ means that the fractional change in f is

r_1 times that in p. A negative r-value indicates a reduction in f for an increase in r. With the above definition in mind, we estimate the significance of each parameter on each scheme as follows. In each relative sensitivity formula, those terms that are at least one order of magnitude smaller than the other terms for the range of parameter values under consideration in this study are eliminated. Afterwards, the upper and lower bounds of each r(f,p) will be estimated.

The following ranges of parameter values are used:

i) $500 \leq K \leq 1000$

ii) $0.1 \leq SVF \leq 0.2$

iii) $0.1 \leq R \leq 0.14$

iv) $3 \leq N \leq 5$

The above parameters do not have a fixed value. They have to be determined on an individual basis. For all tariff items, the current schedule is used. The values are:

i) UT = 40.75

ii) UTG = 17.5

iii) UO = 12

iv) LCC = 13

v) PWC = 24

vi) UJ = 1.35

vii) USS = 2.5

viii) UJI = 28.5

ix) UL = 21.25

x) UE $= 3.75$

xi) LSS $= 1.75$

xii) OAC $= 12$

xiii) PVC $= 6$

xiv) $11.8 \leq XS/S \leq 27.5$

xv) $56.7 \leq XE/S \leq 135$

We assume that

i) $1 \leq S/T \leq 20$

ii) $S \leq 540$

The latter assumption is made because this is the upper limit of PASS.

With the above assumptions, we have found that the following conditions are valid.

i) $0.02 \leq AP \leq 0.035$

ii) $0.01 \leq AF \leq 0.025$

iii) $23 \leq EC \leq 24$

iv) $18 \leq EX \leq 92$

v) $15 \leq EP \leq 110$

The following observations help to reduce the complexity of relative sensitivities:

i) Terms that contain OAC and PVC are negligible in comparison with other terms because both OAC and PVC are small initial costs. The share of each station after amortization is in cents or fractions of a cent. Those terms can be omitted.

ii) Terms that have a factor AP usually are not significant because AP is very small.

4.2.1 Centrex

r(EC,UL) = 0.875*UL/EC

It can be shown that this is between 0.77 and 0.81.

r(EC,UE) = 0.875*UE/EC

It can be shown that this is about 0.14.

r(EC,LSS) = 0.5*LSS/EC

It can be shown that this is about 0.04.

r(EC,PWC) = AP*PWC/EC

It can be shown that this is between 0.02 and 0.04.

r(EC, LCC) = 0.5*AP*LCC/EC

Its range is between 0.005 and 0.01.

r(EC,OAC) and r(EC,PVC) are negligible.

r(EC,S) = -(OAC + PVC) * AP/ [S * (S + δS) * EC]

Again, this is negligible.

$$r(EC,N) = \frac{[S*(PWC + 0.5*LCC) + OAC + PVC]*\delta AP*N}{S*\delta N*EC}$$

A change of N from 3 to 5 corresponds to a change of about -0.01 for the interest rates under consideration. In this case, the ratio of N/δN is about 2. After omitting the terms of OAC and PVC and substituting the values of δAP and N/δN to the formula, r(EC,N) turns out to be approximately -0.014.

$$r(EC,R) = \frac{[S*(PWC + 0.5*LCC) + OAC + PVC]*\delta AP*R}{S*\delta R*EC}$$

It is observed that a change of 2 percentage points in interest rate corresponds to a change of between 0.0008 and 0.0009 in AP for the R's and N's under consideration. In other words, δAP*R/δR is between 0.004 and 0.0063. Omitting the terms of OAC and PVC, and substituting the values of PWC, LCC and EC, the range of r(EC,R) is 0.005 to 0.008.

From the results found above, it can be concluded that the most important parameter for Centrex is UL. This is followed by UE, LSS, PWC, LCC, N and R in the order.

4.2.2 PASS

r(EX,XS) = XS/(S*EX)

Direct substitution of the range of values of XS/S and EX into the formula shows that r(EX,XS) is between 0.13 and 1.53. The range is larger than one would expect. In practice, for a small number of stations, XS/S is high (27.5) and EX is also (92) as a direct consequence. Similarly, the low end of EX(18) corresponds to a low XS/S (11.8). If we consider this fact, then the range of r(EX,XS) is between 0.3 and 0.66. This is perhaps a more accurate measure of the relative sensitivity.

r(EX,UT) = T*UT/(S*EX)

Again, direct subsititution of line to trunk ratio and EX yields an exaggerated range of between 0.022 and 2.26. A more accurate range would be 0.11 to 0.44.

r(EX,UTG) = T*UTG/(S*EX)

Following the arguments of the above parameters, the range can be shown to be between 0.05 to 0.19.

r(EX,UO) = UO/EX

The range is between 0.011 and 0.067.

r(EX,XE) = AP*XE/(S*EX)

By substituting the range of values of XE/S, AP and EX into the formula, the range of r(EX,XE) can be shown to be between 0.012 and 0.26. Again, if one considers that high EX is associated with high XE/S, then the range is shrunk to between 0.03 and 0.11.

r(EX,OAC) and r(EX,PVC) are negligible.

r(EX,LCC) = AP*LCC*T/(S*EX)

By making EX reflect its relation with line to trunk ratio and then substituting the range of parameter values, r(EX,LCC) can be shown to be between 0.0007 and 0.0049.

r(EX,PWC) = AP*(1 + T/S)*PWC/EX

The smaller range of the above expression is 0.01 to 0.049.

$$r(EX,S) = \frac{1}{S+\delta S}\left[\frac{\delta XS+AP*\delta XE}{\delta S} - \frac{XS+AP*XE}{S}\right] - \frac{1}{S*(S+\delta S)}\left\{T\left[UT+UTG+AP*(LCC+PWC)\right]+AP*(OAC+PVC)\right\}*\frac{S}{EX}$$

The terms that contain OAC, PVC, LCC and PWC can be omitted because they are relatively small. If δS/S is very small, then r(EX,S) can be reduced to

$$r(EX,S) = \frac{1}{EX}\left[\frac{\delta XS}{\delta S}+\frac{AP*\delta XE}{\delta S} - \frac{XS}{S} - \frac{AP*XE}{S} - \frac{T}{S}*(UT+UTG)\right]$$

The first term corresponds to the cost of an additional station which can be taken as XS/S. Therefore, the first and third terms cancel each other. The second term is a highly discrete function. Its value is zero if increasing S does not move the cost of XE to the next category. At the threshold points, an increase of one station could mean an increase of XE from 400 to 3800 for the additional station. In practice, such a change will not occur. A meaningful estimate of $\delta XE/\delta S$ is to assume that it is equal to XE/S, the cost per station. In that case, the second term cancels the fourth. Therefore, we are left with the last term. Substituting the values of the parameters and assuming that high EX corresponds to high T/S, the range for r(EX,S) is between -0.16 and -0.63.

$$r(EX,T) = [UT + UTG + AP * (LCC + PWC)] * \frac{T}{S*EX}$$

After removing the terms with a factor AP, the expression is the same as that for r(EX,S), except for the sign. Therefore, its range is between 0.16 and 0.63.

$$r(EX;N) = \frac{\delta AP*N}{\delta N*EX}*[\frac{XE}{S} + \frac{T}{S}*(LCC+PWC) + PWC + \frac{OAC+PVC}{S}]$$

The last term is relatively small for most practical situations and can be omitted. Substituting the appropriate values to each term and observe that high EX corresponds to high XE/S and T/S, the range can be shown to be between -0.043 and -0.092.

$$r(EX,R) = \frac{\delta AP*R}{\delta R*EX}*[\frac{XE}{S} + \frac{T}{S}*(LCC+PWC)+PWC+\frac{OAC+PVC}{S}]$$

The expression is similar to that for N with $\delta AP*R/\delta R$ substituting for $\delta AP*N/\delta N$. The expression is about one-fifth of that for N. The range is between 0.0086 and 0.0184.

In summary, the most important parameters are XS, S and T, they are followed by UT, UTG, XE, UO and PWC. The following parameters are of minor importance: N, R and LCC.

4.2.3 Customer-Owned PBX

r(EP,UT) = T/S * UT/EP

By taking into consideration of the fact that high EP corresponds to high T/S, the range of the above expression is between 0.14 and 0.37.

By similar arguments, r(EP,UTG) has a range between 0.058 and 0.16, and r(EP,UJ) has a range of 0.0045 to 0.0122.

r(EP,USS) = USS/EP

It has a range of 0.023 to 0.17.

r(EP,LCC) = AP * T/S * LCC/EP

It has a range between 0.00087 and 0.0041.

r(EP,PWC) = AP * T/S * PWC/EP

Its range is between 0.0016 and 0.0076.

r(EP,UJI) = AP * T/S * UJI/EP

Its range is between 0.0019 and 0.0091.

r(EP,K) = (AP - AF*SVF)*K/EP

Substituting AP = 0.035, AF = 0.025, SVF = 0.2, K = 1000 and EP = 110 for the lower bound and AP = 0.020, AF = 0.01, SVF = 0.1, K = 500 and EP = 15 for the upper bound, the range can be shown to be between 0.17 and 1.

$$r(EP,SVF) = -AF*(400*T/S + K)*SVF/EP$$

Substituting AF = 0.01, T/S = 0.05, K = 500, SVF = 0.1 and EP = 15 for the lower bound and AF = 0.025, T/S = 1, K = 1000, SVF = 0.2 and EP = 110 for the upper bound, the range is found to be between -0.064 and -0.35.

$$r(EP,S) = \frac{-1}{S*(S+\delta S)}\left\{T*[UT+UTG+UJ+AP*(400+LCC+PWC+UJI) -400*AF*SVF] + AP*(OAC+PVC)\right\} * \frac{S}{EP}$$

The expression can be simplified by observing that the terms that contain OAC and PVC are very small, and for a small change of S, S+δS is approximately equal to S.

$$r(EP,S) = -\left\{\frac{T}{S}*[UT+UTG+UJ+AP*(400+LCC+PWC+UJI) -400*AF*SVF]\right\}/EP$$

Substituting T/S = 1, AP = 0.035, AF = 0.01, SVF = 0.1 and EP = 110 for the upper bound, and T/S = 0.05, AP = 0.02, AF = 0.2 and EP = 15 for the lower bound, r(EP,S) is found to be between -0.22 and -0.69.

$$r(EP,T) = \frac{T}{S*EP} *[UT+UTG+UJ+AP*(400+LCC+PWC+UJI) -AF*SVF*400]$$

This is the same as the simplified expression for r(EP,S). Therefore it has the same range, except for the sign, that is, between 0.22 and 0.69.

$$r(EP,N) = \frac{\delta AP*N}{\delta N*EP} * \left[\frac{T}{S}*(400+LCC+PWC+UJI)+K+\frac{OAC+PVC}{S} \right]$$

$$- \frac{SVF*\delta AF*N}{\delta N*EP} * (400 * \frac{T}{S} + K)$$

Ignoring the terms OAC and PVC, substituting the following values for the upper and lower bounds:

i) T/S = 1, EP = 110, K = 1000, SVF = 0.2

ii) T/S = 0.05, EP = 15, K = 500, SVF = 0.1

and setting the terms δAP*N/δN and δAF*N/δN to be -0.02 and -0.022, respectively, the range of r(EP,N) is found to be between -0.21 and -0.62.

$$r(EP,R) = \frac{\delta AP*R}{\delta R*EP} * \left[\frac{T}{S}*(400+LCC+PWC+UJI) + K + \frac{OAC+PVC}{S} \right]$$

$$- \frac{SVF*\delta AF*R}{\delta R*EP} * (400 * \frac{T}{S} + K)$$

This expression is similar to that for r(EP,N) except that R is used in place of N. With similar substitution as the previous expression except that

δAP*R/δR = 0.0054 and δAF*R/δR = 0.0042

the range can be shown to be between 0.064 and 0.174.

In summary, the most important parameters are K, S, T and N. They are followed by UT, SVF, R, UTG and USS. The following parameters are of minor importance: UJ, UJI, PWC and LCC. Table 1 is a summary of relative sensitivities of the average monthly costs to the parameters.

Table 1 - Relative Sensitivity Ranges

Parameter Category	Parameter Symbol	Centrex	PASS	Customer-Owned PBX
Monthly recurring charges (tariff)	UL	0.77/0.81		
	UE	0.14		
	XS		0.3/0.66	
	UT		0.11/0.44	0.14/0.37
	UTG		0.05/0.19	0.058/0.16
	UO		0.011/0.067	
	UJ			0.0045/0.0122
	USS			0.023/0.17
Initial and installation charges (tariff)	XE		0.03/0.11	
	UJI			0.0019/0.0091
	PWC	0.02/0.04	0.01/0.049	0.0016/0.0076
	LCC	0.005/0.01	0.0007/0.0049	0.00087/0.0041
	OAC	0	0	0
	PVC	0	0	0
Gov't monthly charges	LSS	0.04		
	UTG		0.05/0.19	0.058/0.16
Others (estimated)	K			0.17/1.0
	SVF			-0.064/-0.35
	N	-0.014	-0.043/-0.092	-0.21/-0.62
	R	0.005/0.008	0.0086/0.0184	0.064/0.174
Others (variable)	T		0.16/0.63	0.22/0.69
	S	0	-0.16/-0.63	-0.22/-0.69

5. BREAK-EVEN ANALYSIS

The purpose of break-even analysis is to find the location of the cross-over point between two cost curves. In addition, if the locus of the corss-over point can be expressed in terms of the cost parameters, one can predict the movement of the cross-over point as a result of changes in some parameters in the cost formulas. We attempt to determine the locus of the cross-over point between each pair of schemes in this section. After the general equation is developed, we will estimate how the locus will move when a parameter changes its value.

It will be shown later that the equation of the cross-over point of any two cost curves can be approximated by the following equation:

$$S = \frac{A + Bp}{C + Dp} \qquad (68)$$

where S is the number of stationsat which cross-over occurs,

p is a parameter,

A, B, C, D are considered constants .

Sensitivity analysis of the cross-over point is meaningful only for the combination of parameter values which yields the same sign in the numerator and the denominator.

Differentiating (68) with respect to p,

$$\frac{dS}{dp} = \frac{BC - AD}{(C + Dp)^2}$$

It can be shown that

$$\frac{dS}{S} = \left(\frac{Bp}{A + Bp} - \frac{Dp}{C + Dp} \right) \frac{dp}{p} \tag{69}$$

Let us call the term inside the parenthesis the influence factor of p. The influence factor is therefore the ratio of the percentage change in S to that in p. Note that it can take any value. In particular, a negative influence factor means that the cross-over point moves to the left when p is increased. The cross-over point does not move as fast as the parameter when the magnitude of the influence factor is less than unity.

From (69), we can see that the influence factor is the difference between the weights of the p-terms in the numerator and in the denominator.

Since cross-over of cost curve exists for only an appropriate combination of parameter values, it is difficult to determine the influence factors in the general case. In the rest of this section, we compute the influence factors in a particular situation. The parameter values are taken from those of Figure 2 of the Case Studies in Appendix II. In addition, T is chosen to be 20. The purpose of the study is to gain some insight into the relative importance of different parameters on the cross-over point.

5.1 Centrex vs PASS

At the break-even point, EC = EX. That is

0.875*(UL+UE)+0.5*LSS+AP*[(PWC+0.5*LCC)*S+OAC+PVC]/S

= {XS+(UT+UTG)*T+UO*S+AP*[XE+(LCC+PWC)*T+PWC*S+OAC+PVC]}/S

After cancelling common terms and rearranging, the equation of the locus of S is

$$0.875*(UL+UE)+0.5*LSS+0.5*AP*LCC-UO-(XS+AP*XE)/S$$
$$-[UT+UTG+AP*(LCC+PWC)]*T /S = 0 \qquad (70)$$

This is an implicit equation in S because both XS and XE are functions of S. To simplify the determination of the sensitivity of the cross-over points to the cost parameters, let UXS and UXE be the average PBX rental charge per station per month and the average PBX installation charge per station, respectively, that is,

$$UXS = XS/S \qquad (71)$$

$$UXE = XE/S \qquad (72)$$

Then (70) becomes

$$S = \frac{T*[UT+UTG+AP*(LCC+PWC)]}{0.875*(UL+UE)+0.5*LSS+0.5*AP*LCC-UO-UXS-AP*UXE} \qquad (73)$$

It can be shown that the weight of each term in the equation is as below:

T*UT	0.69
T*UTG	0.30
T*AP*LCC	0.00
T*AP*PWC	0.01
0.875*UL	3.05
0.875*UE	0.54
0.5*LSS	0.14
0.5*AP*LCC	0.02
-UO	-0.20
-UXS	-2.29
-AP*UXE	-0.27

The influence factors of the parameters are

LCC	-0.02
LSS	-0.14
AP	0.26
PWC	0.01
T	1
UT	0.69
UTG	0.3
UE	-0.54
UL	-3.05
UO	0.20
UXE	0.27
UXS	2.29

It is observed from the results shown above that UL, UXS and T are the most significant parameters in this case. They are followed by UT, UE, UTG, UXE, AP, UO and LSS. PWC and LCC are of minor significance.

5.2 PASS vs Customer-Owned PBX

At the break-even point,

XS+(UT+UTG)*T+UO*S+AP*[XE+(LCC+PWC)*T+PWC*S+OAC+PVC]

= (UT+UTG+UJ)*T+USS*S+AP*[(400+LCC+PWC+UJI)*T+K*+OAC+PVC] -

AF*SVF*(400*T+K*S)

After eliminating the common terms, substituting UXS and UXE for XS/S and XE/S, respectively, and rearranging, the above equation becomes

$$S = \frac{T*[UJ+(AP-AF*SVF)*400+AP*UJI]}{UO-USS+AP*PWC-K*(AP-AF*SVF)+UXS+AP*UXE} \quad (74)$$

The weight of each term in (74) is shown below:

T*UJ	0.15
T*AP*400	0.90
T*AF*SVF*400	-0.11
T*AP*UJI	0.06
UO	0.93
USS	-1.94
AP*PWC	0.39
K*AP	-13.03
K*AF*SVF	1.60
UXS	11.86
AP*UXE	1.19

The influence factors of the parameters are

K	11.43
AP	12.41
PWC	-0.39
AF	-1.71
SVF	-1.71
T	1
UJ	0.15
UJI	0.06
UO	-0.93
USS	1.94
UXE	-1.19
UXS	-11.86

The results show that AP, UXS and K are the three most dominant parameters for the cross-over point, and the other parameters that have some significance are USS, AF, SVF, UXE, T and UO.

5.3 Centrex vs Customer-Owned PBX

The two schemes are of equal cost when the following condition is satisfied:

$$0.875*(UL+UE)+0.5*LSS+AP*[(PWC+0.5*LCC)*S+OAC+PVC]/S$$
$$= \{(UT+UTG+UJ)*T+USS*S+AP*[(400+LCC+PWC+UJI)*T+ K*S+OAC+PVC]-AF*SVF*(400*T+K*S)\}/S$$

It can be shown that S can be expressed as

$$S = \frac{T*[UT+UTG+UJ+AP*(400+LCC+PWC+UJI)-AF*SVF*400]}{0.875*(UL+UE)+0.5*LSS+AP*(PWC+0.5*LCC)-USS-(AP-AF*SVF)*K} \tag{75}$$

The weight of each term in (75) is shown below:

T*UT	0.60
T*UTG	0.26
T*UJ	0.02
T*AP*400	0.12
T*AP*LCC	0.00
T*AP*PWC	0.01
T*AP*UJI	0.01
T*AF*SVF*400	-0.02
0.875*UL	3.01
0.875*UE	0.53
0.5*LSS	0.14

AP*PWC	0.08
0.5*AP*LCC	0.02
USS	-0.41
AP*K	-2.72
AF*SVF*K	0.33

The influence factors are

K	2.39
LCC	-0.02
LSS	-0.14
AP	2.76
PWC	-0.07
AF	-0.35
SVF	-0.35
T	1
UE	-0.53
UJ	0.02
UJI	0.01
UL	-3.01
USS	0.41
UT	0.6
UTG	0.26

From the results obtained, the most significant parameters are UL, AP and K. They are followed by T, UT, UE, USS, AF, SVF and UTG. LSS, PWC, LCC, UJ and UJI are of minor significant.

Table 2 summarizes the influence factors at the cross-over point of each pair of schemes.

Table 2 - Influence Factors at the Cross-Over Points

Parameter: Category	Parameter: Symbol	Centrex vs PASS	PASS vs Customer-Owned PBX	Centrex vs Customer-Owned PBX
Monthly recurring charges (tariff)	UL	-3.052		-3.014
	UE	-0.539		-0.532
	UXS	2.292	-11.858	
	UT	0.69		0.596
	UTG	0.297		0.256
	UO	0.197	- 0.932	
	UJ		0.145	0.02
	USS		1.942	0.405
Initial and installation charges (tariff)	UXE	0.268	- 1.194	
	UJI		0.064	0.009
	PWC	0.009	- 0.391	-0.074
	LCC	0.005		-0.018
	OAC			
	PVC			
Gov't monthly charges	LSS	-0.144		-0.142
	UTG			
Others (estimated)	K		11.434	2.386
	SVF		- 1.711	-0.349
	AP	0.258	12.415	2.759
	AF		- 1.711	-0.349
Others (variable)	T	1	1	1

6. CONCLUSION

In this project we have investigated the cost structures of three telecommunications local service schemes available to the Federal Government in the National Capital Region - Government Centrex, Leased PBX (PASS) and Customer-owned PBX. The cost formula of each scheme is developed and expressed in a commun unit - average monthly cost per station. This facilitates cost comparison between types for a given number of users.

Simplified equations have also been developed which allow break-even analysis (or prove-in) for one system versus another and sensitivity analysis within a given system.

It is recognized that currently an interim situation exists concerning the rules and regulations governing the use of Customer-owned PBX's and that recently rate increases have been sought by the carrier for most of the tariffed items. There is also some uncertainty in the actual cost of a purchased PBX system. Readers are therefore cautioned not to take the results found in Appendix II too literally. They may, however, be used to indicate the significance of the various parameters, as outlined below:

- Centrex is cheaper for a small number of stations. This is expected since the Centrex unit cost is based on the total population rather than the individual user group size.

- The cost curves for PASS and Customer-owned PBX is quite similar. It would be presumptuous to make a conclusion based on the test data. However, the following expected observations have been demonstrated using the two costing models.

  a) the prove-in of Customer-owned PBX's is quite dependent on the first cost of the PBX

  b) increasing the amortization interval has a beneficial effect on the prove-in of Customer-owned PBX's

  c) for large users groups some sort of PBX system offers an economic alternative within the current tariff structure.

More quantitative conclusions can be drawn when the various uncertainties have been removed and comparisons have been made with the revised parameter values (Note - a change in the actual cost structure would necessitate revisions to the cost formulae and computer programs).

6.1 Proposed Additional Research

In this research, methodology for cost comparisons on the selection of terminal equipment has been developed. The research does not, however, address to the very important network design problem: How the users should be interconnected?

In general, for a given set of user profiles such as geographical distribution, user requirements, etc., there are a number of ways to interconnect the users to satisfy their communication needs. The users can subscribe to the Centrex Service. Each department can purchase or lease a private branch exchange switching system. Still another possibility is that several departments can share a large exchange switching system. The problem is to design the network which has the lowest cost. The development of the methodology for optimal network design would enable the government to determine the most cost-effective network topology which satisfies the communication need for a given situation.

The proposed research would consist of studying typical user profiles and their telecommunications requirements, developing methodology for communication network optimization, and providing guidelines for local communication network development under various circumstances in the government.

The research would be conducted in three parts:

The first part would be to study telecommunications requirements in the government. The purpose of which would be to identify typical user profiles such as locations and sizes of government departments, and tarffic patterns.

The second part would be to study existing network optimization techniques in the literature, and determine which is most suitable for the design of optimal local communication network topology. After the appropriate method is selected, it would be implemented in the form of computer program and tested with some typical user profile.

In the third part, a generalized computer program would be developed. The program would take user profile information as input parameter and report the optimal network topology. More experiments would be conducted to verify the computer program and to develop some design guidelines.

Appendix I - Derivation of AP and AF

Let P be the initial cost, A be the equivalent monthly installments, paid in advance, and F be the equivalent final value at the end of N years, with annual interest rate R, compounded semiannually. The final value of P at the end of N years is

$$F = P(1 + R/2)^{2N} \tag{A1}$$

The value of 6 monthly installments at the end of the 6 month period, including simple interest, is

$$\begin{aligned} A' &= A(1 + 6R/12) + A(1 + 5R/12) + A(1 + 4R/12) \\ &\quad + \ldots\ldots + A(1 + R/12) \\ &= A(6 + 21R/12) \end{aligned} \tag{A2}$$

The final value of 2N installments of A' at the end of N years is

$$\begin{aligned} F &= A'(1 + R/2)^{2N-1} + A'(1 + R/2)^{2N-2} + \ldots + A' \\ &= A' \left[(1 + R/2)^{2N} - 1 \right] / (R/2) \end{aligned} \tag{A3}$$

Substituting (A2) into (A3)

$$F = A(6 + 21R/12) \left[(1 + R/2)^{2N} - 1 \right] / (R/2)$$

$$AF = \frac{A}{F} = \frac{R}{2(6 + 1.75R) \left[(1 + 0.5R)^{2N} - 1 \right]} \tag{A4}$$

$$AP = \frac{A}{P} = \frac{A}{F} \times \frac{F}{P} \tag{A5}$$

Substituting (A1), (A4) into (A5)

$$AP = \frac{R(1 + 0.5R)^{2N}}{2(6 + 1.75R)\left[(1 + 0.5R)^{2N} - 1\right]} \qquad (A6)$$

Appendix II - Case Studies

In the equivalent monthly cost formulas, most of the parameters are tariff items which are constants at a given time. The only parameters that vary are K, SVF, R and N. The coefficient in the line component of the cost of a PBX system could vary widely. It depends on the vendor, the number of lines, engineering and installation costs at the time of installation. The salvage value factor is an uncertainty. Quotations of a number of PBX systems show that about fifteen percent of the cost is for engineering and installation. Another several percent is installation material cost. This leaves about eighty percent of the cost to the equipment which would have some value at the time of disposal. The salvage value depends on the state of the art of technology, the age of the equipment, among other factors. Since electronic equipment becomes obsolete very quickly, we assume that the salvage value is between ten and twenty percent of its original value. Interest rate fluctuates very widely nowadays. The range between ten and fourteen percent is a reasonable estimate. Length of amortization period depends on the length of time a department stays in the same location which in turn depends on government policy and lease arrangements. In this study, we assume that the amortization period is between three and five years. In summary, we assume that the following range of values are valid for the parameters shown:

$$500 \leq K \leq 1000$$

$$0.1 \leq SVF \leq 0.2$$

$$0.1 \leq R \leq 0.14$$

$$3 \leq N \leq 5$$

For the last three parameters, the following is the best combination for Customer-owned PBX,

$$SVF = 0.2, \ R = 0.1, \ N = 5$$

and the worst combination is

$$SVF = 0.1, \ R = 0.14, \ N = 3$$

In the case studies, the following K values are used:

$$K = 500, 600, 800 \text{ and } 1000$$

For each value of K, the best and worst cases for Customer-owned PBX are studied. The other combinations should yield results which are between the best and worst cases.

The trunk and station (line) combinations included in each case study are

i) $T = 10, \ 10 \leq S \leq 200$

ii) $T = 20, \ 20 \leq S \leq 400$

iii) $T = 40, \ 40 \leq S \leq 500$

iv) $T = 50, \ 50 \leq S \leq 500$

This covers line to trunk ratios between 20 and 1, except for T = 40 and 50. In the latter cases, an upper limit of 500 is chosen because this is close to the limit of PASS.

The values of tariff items are:

UT = 40.75

UTG = 17.5

UO = 1.2

LCC = 13

PWC = 24

UJ = 1.35

USS = 2.5

UJI = 28.5

UL = 21.25

UE = 3.75

LSS = 1.75

OAC = 12

PVC = 6

$$XE = \begin{cases} 2,300 & S \leq 20 \\ 2,700 & 20 < S \leq 40 \\ 3,400 & 40 < S \leq 60 \\ 4,600 & 60 < S \leq 80 \\ 5,900 & 80 < S \leq 100 \\ 7,400 & 100 < S \leq 120 \\ 8,900 & 120 < S \leq 140 \\ 10,700 & 140 < S \leq 160 \\ 12,800 & 160 < S \leq 180 \end{cases}$$

$$XE = \begin{cases} 15{,}000 & 180 < S \le 200 \\ 18{,}800 & 200 < S \le 220 \\ 20{,}400 & 220 < S \le 240 \\ 22{,}000 & 240 < S \le 260 \\ 24{,}400 & 260 < S \le 280 \\ 27{,}400 & 280 < S \le 300 \\ 28{,}800 & 300 < S \le 320 \\ 30{,}400 & 320 < S \le 340 \\ 32{,}300 & 340 < S \le 360 \\ 33{,}500 & 360 < S \le 380 \\ 35{,}100 & 380 < S \le 400 \\ 36{,}700 & 400 < S \le 420 \\ 38{,}200 & 420 < S \le 440 \\ 39{,}600 & 440 < S \le 460 \\ 40{,}800 & 460 < S \le 480 \\ 42{,}300 & 480 < S \le 500 \\ 43{,}900 & 500 < S \le 520 \\ 45{,}800 & 520 < S \le 540 \end{cases}$$

$$XS = \begin{cases} 27.5*S & S \le 30 \\ 825+(S-30)*14 & 30 < S \le 60 \\ 1245+(S-60)*12.1 & 60 < S \le 120 \\ 1971+(S-120)*9.9 & 120 < S \le 200 \\ 2763+(S-200)*10.65 & 200 < S \le 540 \end{cases}$$

The values of EC, EX and EP are plotted against the number of stations. The results are shown in Figures 1 - 8.

The following inference can be made from the graphs:

1. The average monthly cost per Centrex station is a constant for $N \geq 3$. This is expected since in the EC formula, the only terms that are not constants are those that contain OAC and PVC, both of which are small numbers, their contributions to EC after amortization being negligible.

2. For small number of stations, the Centrex scheme costs considerably less than both PASS and Customer-owned PBX. In particular, Centrex costs less when the line to trunk ratios in PASS and Customer-owned PBX are less than two. This is an interesting observation because under Centrex, there are two stations per line. In general, Centrex is cost effective in comparison with PASS and Customer-owned PBX except when the PBX line to trunk ratio is very high.

3. In the most favourable SVF, R and N combination, Customer-owned PBX is consistently cheaper than PASS when the price of the system is low (K = 500 or 600). When the price is high, it is better only when the number of trunk is low (T = 10 or 20) and

the line to trunk ratio is small. In the most unfavourable condition in this study, Customer-owned PBX is consistently more expensive than PASS when the price of the system is high (K = 800 or 1000). When the price is low, it is better only when the number of trunks is low (T = 10) and the number of stations is also low. It is difficult to say in general which scheme is better. One point that is quite apparent is that when the price of the PBX system is low, Customer-owned PBX tends to be cheaper.

In summary, Centrex is cheaper when the number of stations is small. For other situations, exact price figure of a PBX system is necessary to determine which scheme is better.

Figure 1: Equivalent Monthly Costs

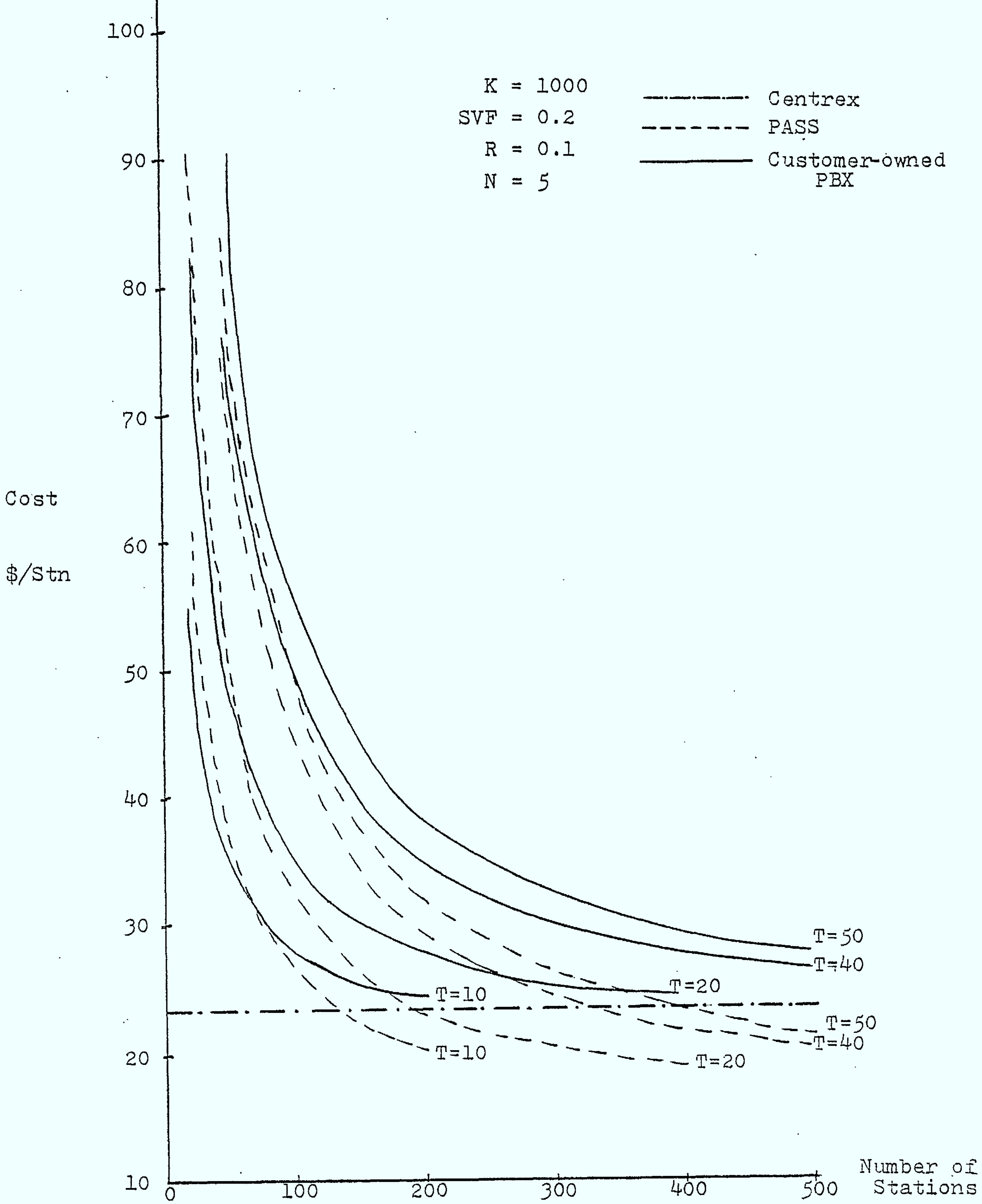


Figure 2: Equivalent Monthly Costs

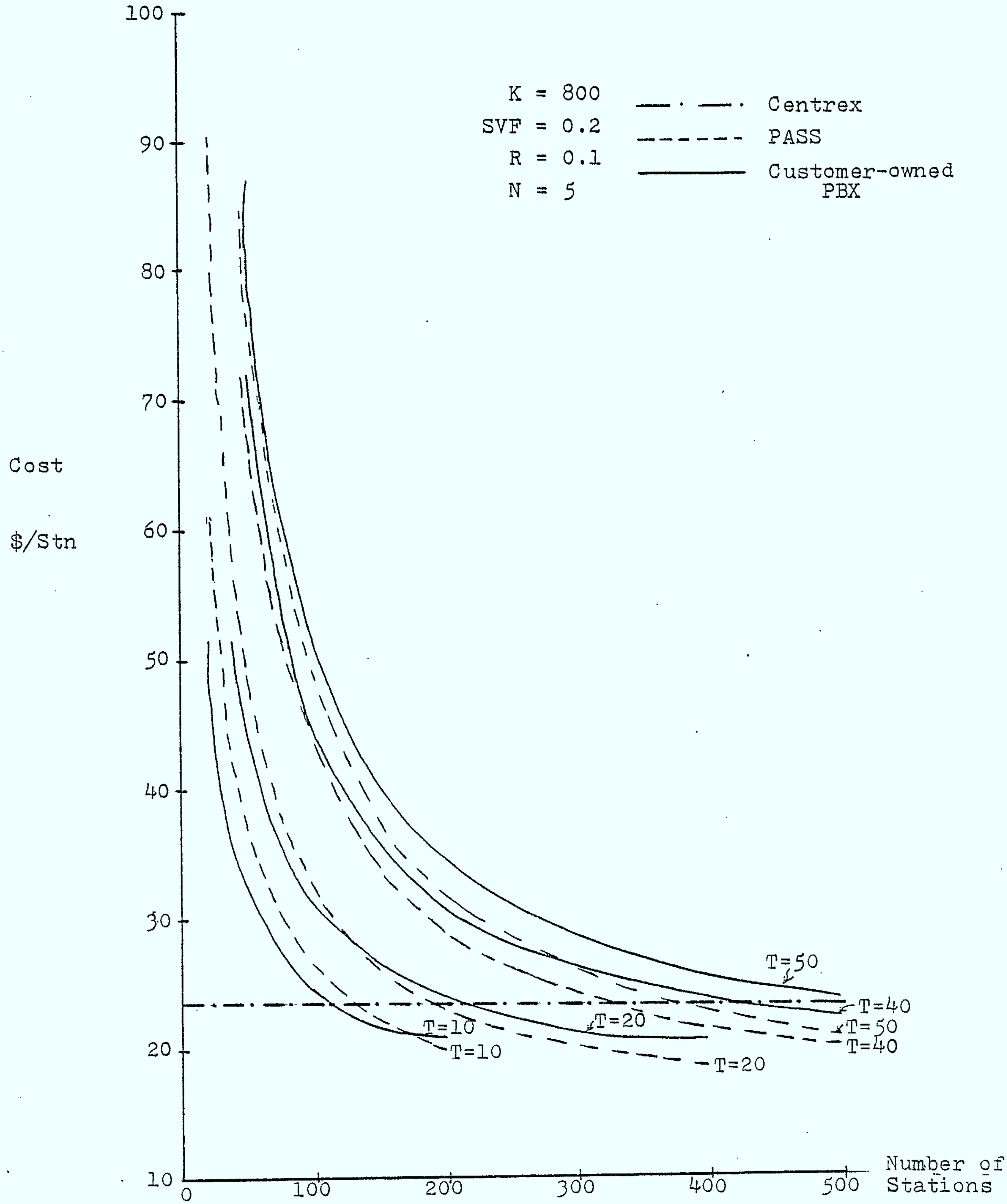


Figure 3: Equivalent Monthly Costs

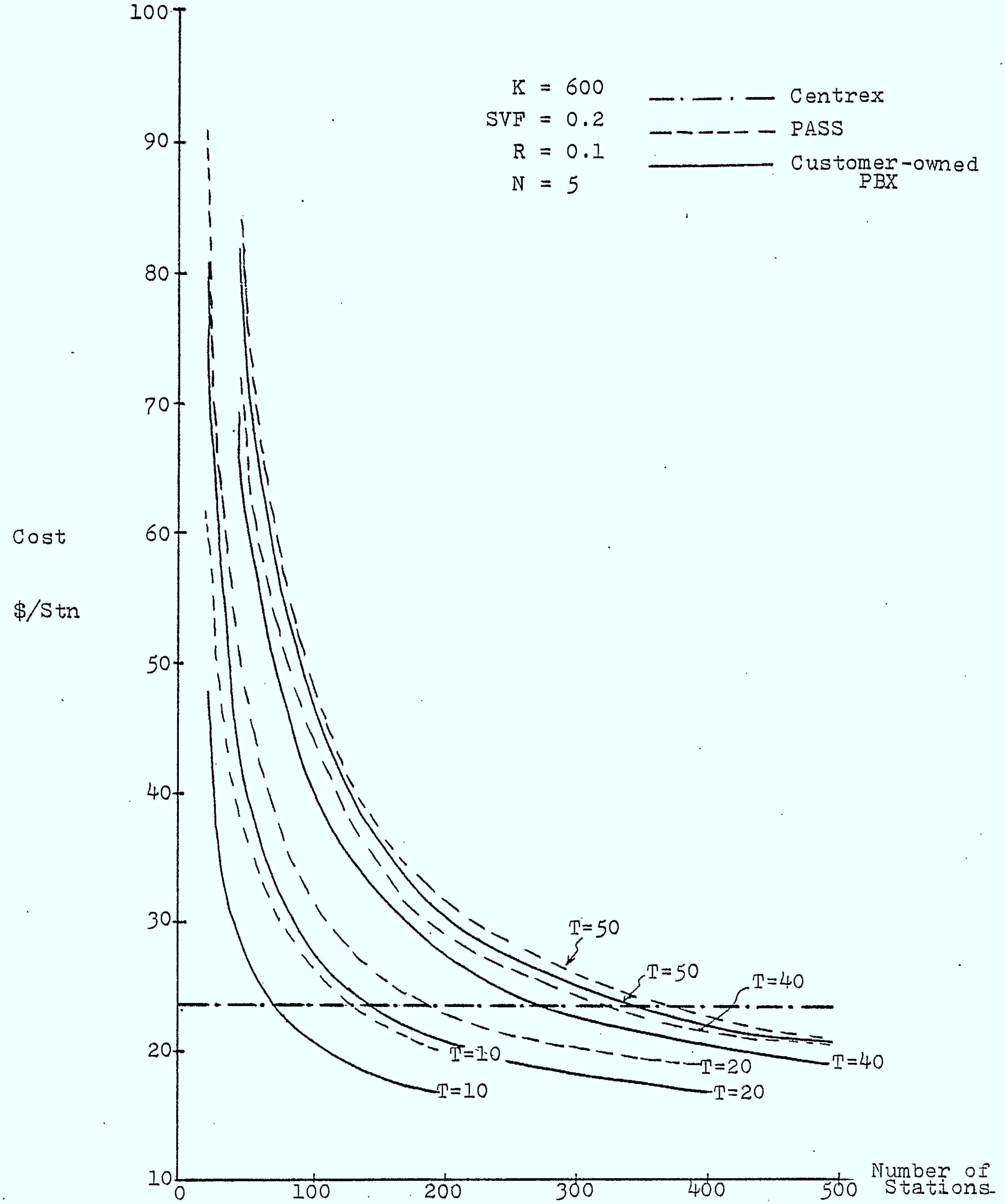


Figure 4: Equivalent Monthly Costs

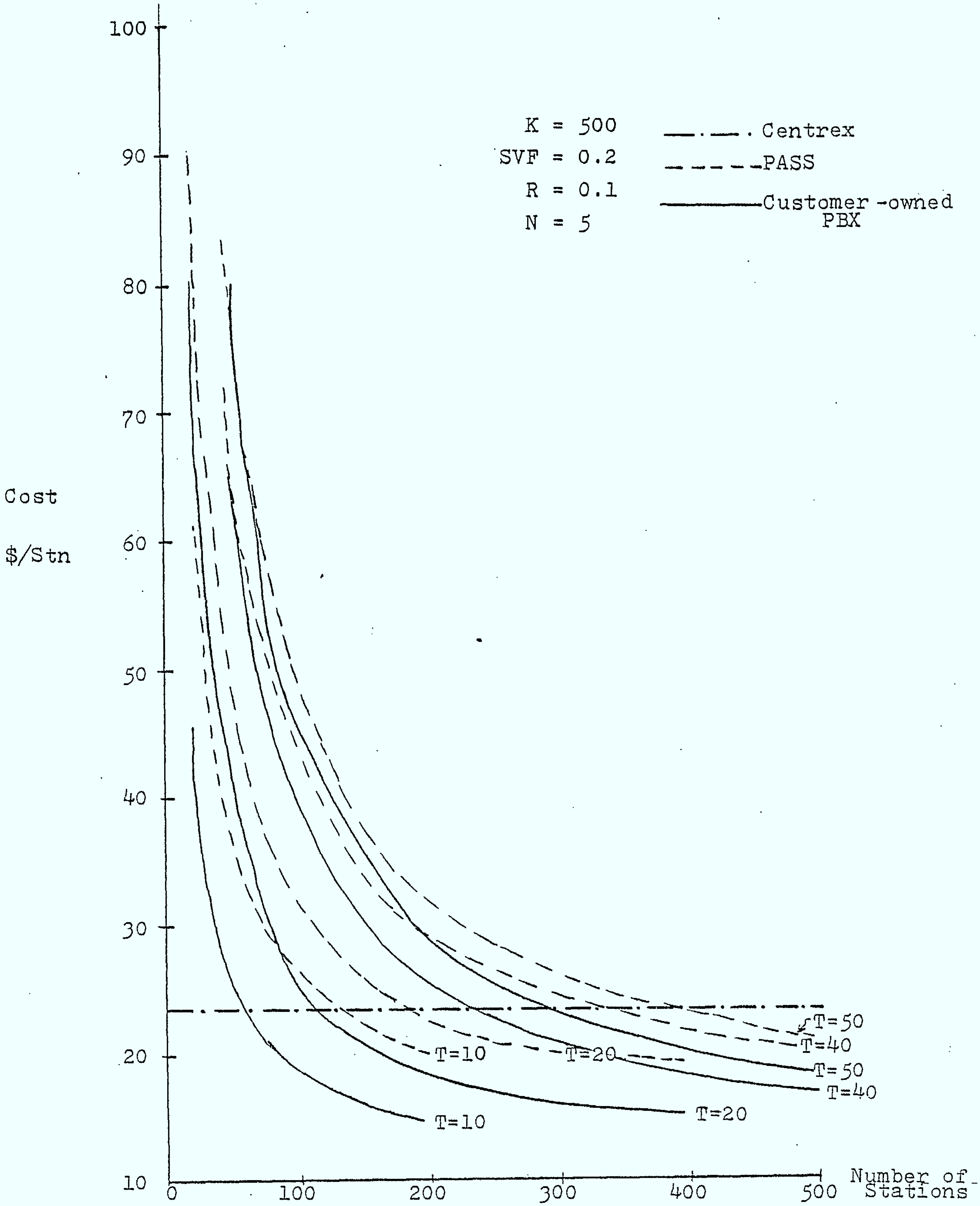


Figure 5: Equivalent Monthly Costs

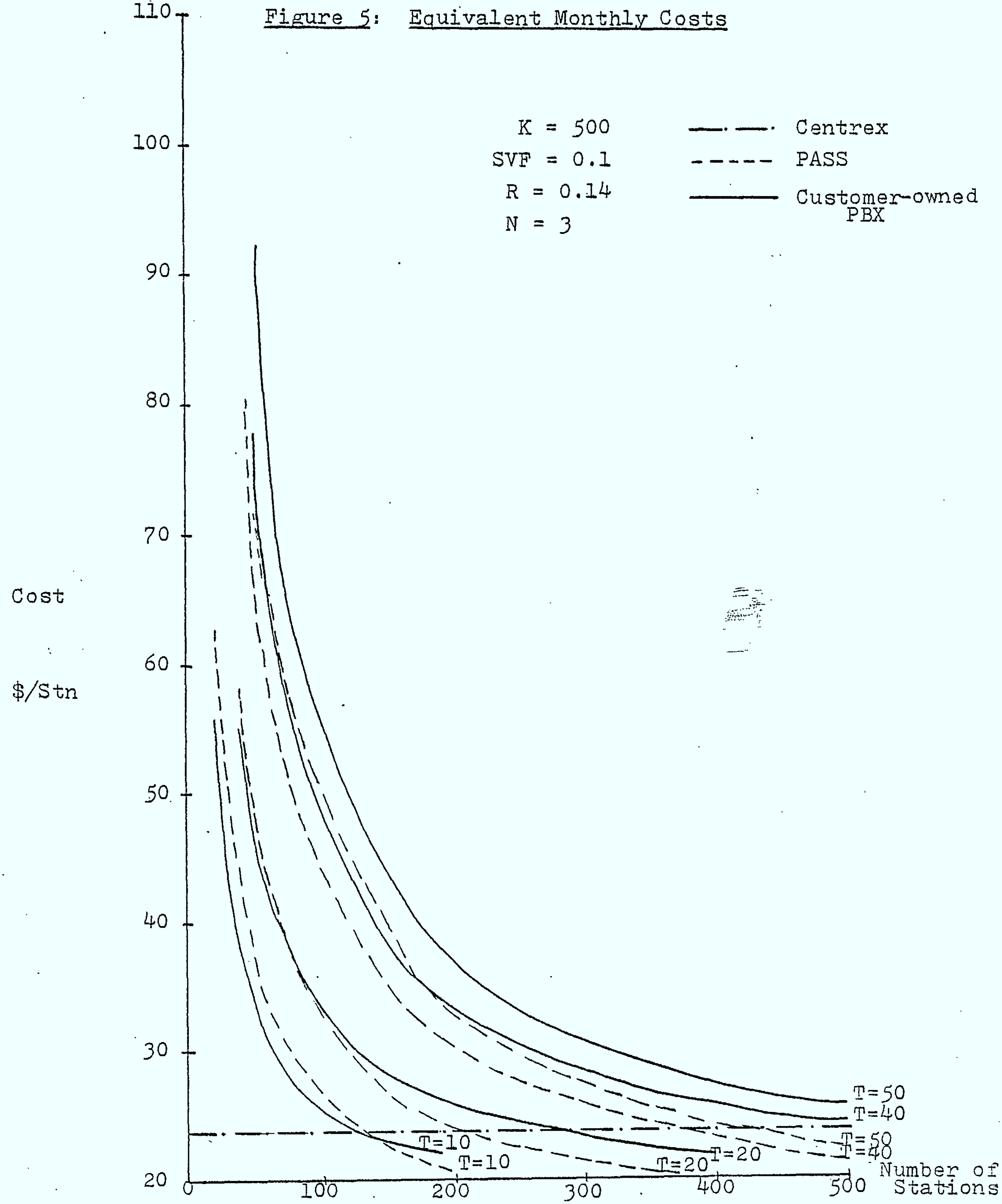


Figure 6: Equivalent Monthly Costs

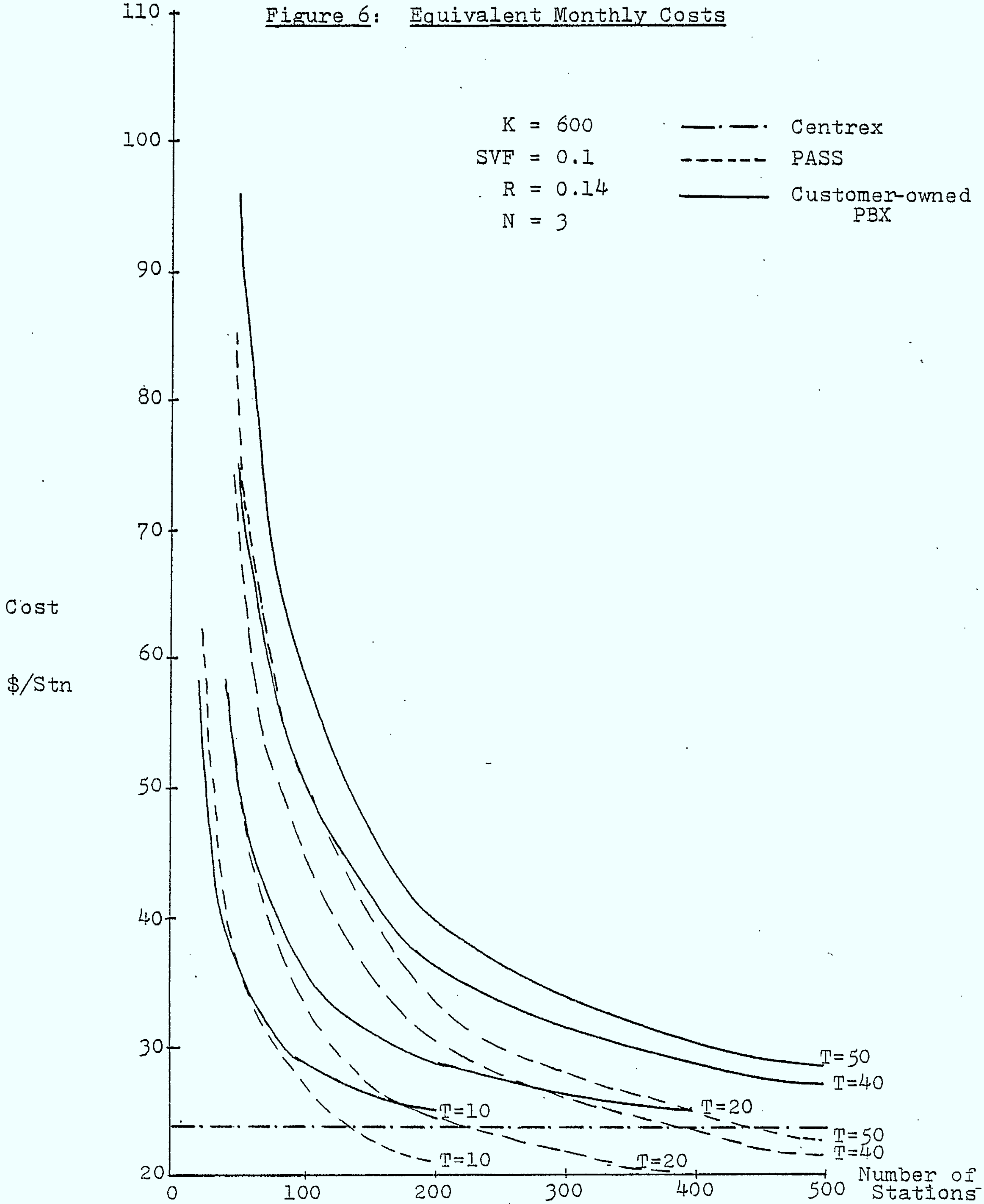


Figure 7: Equivalent Monthly Costs

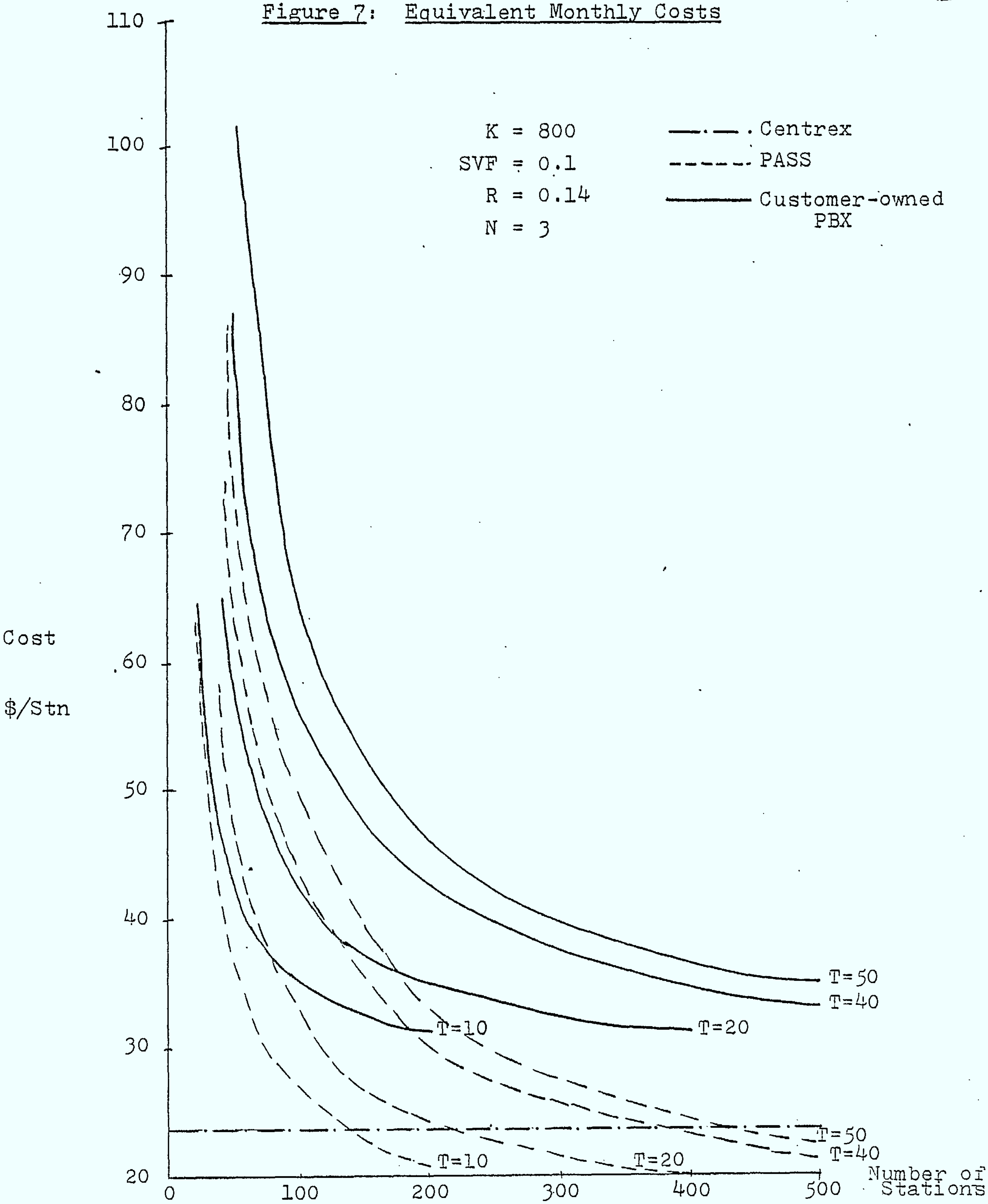
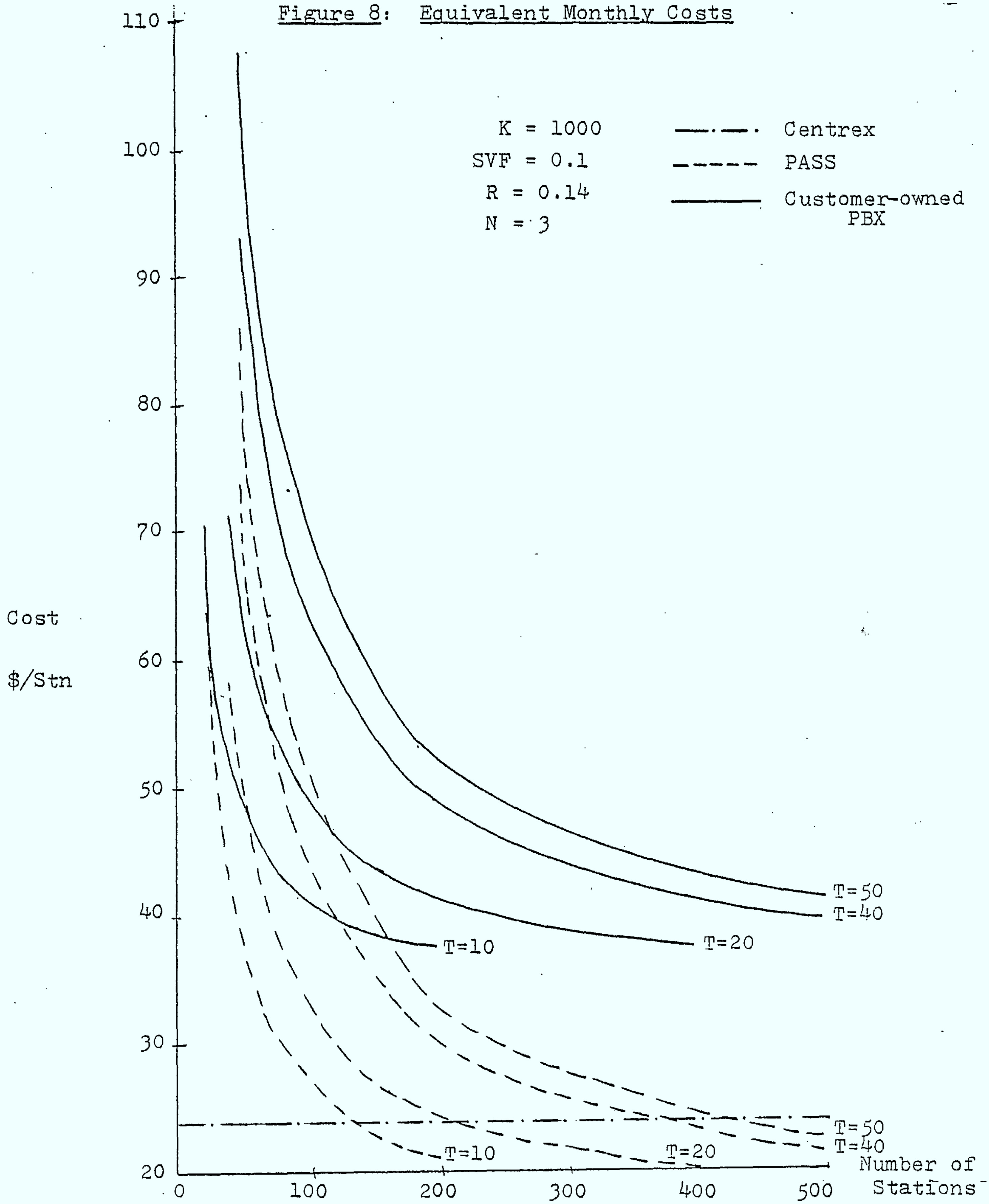


Figure 8: Equivalent Monthly Costs



Appendix III - Computer Programs

Each of the two programs, COMPUTE and PLOT, generates a report on the equivalent monthly costs incurred in employing a Centrex, PASS or Customer-owned PBX system. The input requirements are essentially the same except as noted. Program COMPUTE prints the costs according to the station and trunk count combinations specified by the user while program PLOT prints the costs at the station counts selected by the program for the number of trunks specified by the user. In addition, program PLOT plots the equivalent costs on a Calcomp plotter.

To generate this report a number of variables have to be read in by the user. These variables have a direct influence on the monthly costs and may vary from time to time. Following is a description of each input card.

Card 1:

The first input card contains the variables pertaining to various monthly charges. The format of the card is as follows:

Columns	Description
1 - 5	Trunk charge per trunk per month (UT)
6 - 10	Gov't overhead charge per trunk per month (UTG)
11 - 15	Options cost per station per month (UO)
16 - 20	Line connection charge (LCC)
21 - 25	Premises work charge (PWC)

Columns	Description
26 - 30	Jack charge per trunk per month (UJ)
31 - 35	Maintenance cost per station per month (USS)
36 - 40	Jack installation charge per month (UJI)
41 - 45	Unit line cost/month/station for Centrex (UL)
46 - 50	Unit extension cost/month for Centrex (UE)
51 - 55	Unit line local shared service cost (LSS)
56 - 60	Administrative charges (OAC)
61 - 65	Premises visit charge (PVC)

Format for each field is F5.2.

Card 2:

The second input card reads in coefficients and rates. The format of the card is as follows:

Columns	Description
1 - 5	Coefficient of number of lines in EPI (K)
6 - 10	Salvage value of Customer-owned PBX (SFV)
11 - 15	Interest rate expressed as decimal value (R)
16 - 20	Amortization period in years (N)

Format is I5 for K and N, and is F5.2 for SVF and R.

Card 3 (and subsequent cards if desired):

These cards will read in the number of trunks and corresponding range of stations. Each card will also read in an increment value which is to be used as the stepping factor between line values in the specified range. The format of these cards is as follows:

Columns	Description
1 - 5	Number of trunks
6 - 10	Lower limit of range of stations
11 - 15	Upper limit of range of stations
16 - 20	Increment value

Format for each field is I5.

NOTE: If using program PLOT the increment value is not specified. Also, there may be a limitation to plot no more than 60 inches at a given time. This may vary according to the installation.

The source listing of COMPUTE and PLOT are shown in order in the following pages.

Program COMPUTE

```
      INTEGER T
      REAL JC,JI,LSS,OAC,LCC
      DIMENSION T(10),S(10,100),CNTRX(10,100),PASS(10,100),PBX(10,100)
C-----------------------------------------------------------------------C
C                                                                       C
C     READ IN AND PRINT VARIOUS COSTS AND CHARGES.                      C
C                                                                       C
C-----------------------------------------------------------------------C
      READ 44,UT,UTG,UO,LCC,PWC,UJ,USS,UJI,UL,UE,LSS,OAC,PVC
   44 FORMAT(13F5.2)
      READ73,K,SVF,R,N
   73 FORMAT(I5,2F5.2,I5)
      PRINT 701
  701 FORMAT('1',30X,'*** LIST OF VARIABLES READ IN ***',//)
      PRINT 702,UT
  702 FORMAT('0',25X,'TRUNK CHARGE PER TRUNK PER MONTH            $',F7.2)
      PRINT 703,UTG
  703 FORMAT('0',25X,'GOVT OVERHEAD CHARGE PER TRUNK PER MONTH    $',F7.2)
      PRINT 704,UO
  704 FORMAT('0',25X,'OPTIONS COST PER STATION PER MONTH          $',F7.2)
      PRINT 706,LCC
  706 FORMAT('0',25X,'LINE CONNECTION CHARGE                      $',F7.2)
      PRINT 707,PWC
  707 FORMAT('0',25X,'PREMISES WORK CHARGE                        $',F7.2)
      PRINT 710,UJ
  710 FORMAT('0',25X,'JACK CHARGE PER TRUNK PER MONTH             $',F7.2)
      PRINT 711,USS
  711 FORMAT('0',25X,'MAINTENANCE COST PER STATION PER MONTH      $',F7.2)
      PRINT 713,UJI
  713 FORMAT('0',25X,'JACK INSTALLATION CHARGE PER MONTH          $',F7.2)
      PRINT 715,UL
  715 FORMAT('0',25X,'UNIT LINE COST/MONTH/STATION FOR CENTREX    $',F7.2)
      PRINT 716,UE
  716 FORMAT('0',25X,'UNIT EXTENSION COST/MONTH FOR CENTREX       $',F7.2)
      PRINT 717,LSS
  717 FORMAT('0',25X,'UNIT LINE LOCAL SHARED SERVICE COST         $',F7.2)
      PRINT 718,OAC
  718 FORMAT('0',25X,'ADMINISTRATIVE CHARGES                      $',F7.2)
      PRINT 705,PVC
  705 FORMAT('0',25X,'PREMISES VISIT CHARGE                       $',F7.2)
      PRINT 720,K
  720 FORMAT('0',25X,'COEFFICIENT OF # OF LINES IN EPI             ',I7)
      PRINT 721,SVF
  721 FORMAT('0',25X,'SALVAGE VALUE OF CUSTOMER PBX                ',F7.2)
      PRINT 722,R
  722 FORMAT('0',25X,'INTEREST RATE                                ',F7.2)
      PRINT 723,N
  723 FORMAT('0',25X,'AMORTIZATION PERIOD IN YEARS                 ',I7)
C-----------------------------------------------------------------------C
C                                                                       C
C     CALL SUBROUTINE 'CONFAC' TO CALCULATE THE CONVERSION FACTORS,     C
C     AND SUBROUTINE 'LINES' TO READ IN THE # OF TRUNKS AND THE         C
C     CORRESPONDING RANGE OF LINES AND STEPPING FACTOR.                 C
C                                                                       C
C-----------------------------------------------------------------------C
      CALL CONFAC(AP,AF,R,N)
      CALL LINES(T,S,NUMT)
```

```
C-----------------------------------------------------------------------C
C                                                                       C
C     PASS WHICH IS THE EQUIVALENT MONTHLY COST/STATION FOR PASS IS     C
C     CALCULATED USING THE VALUES WHICH WERE READ IN FOR THE # OF       C
C     TRUNKS AND THE # OF LINES.                                        C
C                                                                       C
C-----------------------------------------------------------------------C
      DO 18 I=1,NUMT
         TC=UT*T(I)
         TCG=UTG*T(I)
         TLC=LCC*T(I)
         TPW=PWC*T(I)
         DO 19 J=1,50,1
            IF(S(I,J).EQ.0) GO TO 991
            OC=UO*S(I,J)
            XM=XS(S(I,J))+TC+TCG+OC
            LPW=PWC*S(I,J)
            XI=XE(S(I,J))+TLC+TPW+LPW+OAC+PVC
            PASS(I,J)=(XM+XI*AP)/S(I,J)
C           PRINT77,I,J,PASS(I,J)
C 77        FORMAT('0','PASS(',I2,',',I2,')=',F12.2)
  19     CONTINUE
 991     PASS(I,J)=0
  18  CONTINUE
C-----------------------------------------------------------------------C
C                                                                       C
C     AS ABOVE, PBX THE EQUIVALENT MONTHLY COST/STATION FOR CUSTOMER-   C
C     OWNED PBX IS CALCULATED.                                          C
C                                                                       C
C-----------------------------------------------------------------------C
      DO 21 I=1,NUMT,1
         TC=UT*T(I)
         TCG=UTG*T(I)
         JC=UJ*T(I)
         TLC=LCC*T(I)
         TPW=PWC*T(I)
         JI=UJI*T(I)
         DO 22 J=1,50,1
            IF(S(I,J).EQ.0) GO TO 992
            SC=USS*S(I,J)
            PM=TC+TCG+JC+SC
            EPII=EPI(T(I),S(I,J),K)
            PI=EPII+TLC+TPW+JI+OAC+PVC
            VX=SVF*EPII
            PBX(I,J)=(PM+PI*AP-VX*AF)/S(I,J)
C           PRINT176,I,J,PBX(I,J)
C 176       FORMAT('0','PBX(',I2,',',I2,')=',F12.2)
  22     CONTINUE
 992     PBX(I,J)=0
  21  CONTINUE
C-----------------------------------------------------------------------C
C                                                                       C
C     AS ABOVE, CNTRX THE EQUIVALENT MONTHLY COST/STATION FOR CENTREX   C
C     IS CALCULATED.                                                    C
C                                                                       C
C-----------------------------------------------------------------------C
      DO 850 I=1,NUMT,1
         DO 851 J=1,50,1
            IF(S(I,J).EQ.0) GO TO 993
            CM=(0.875*(UL+UE)+0.5*LSS)*S(I,J)
```

```
          CI=(PWC+0.5*LCC)*S(I,J)+OAC+PVC
          CNTRX(I,J)=(CM+AP*CI)/S(I,J)
C         PRINT 177,I,J,PBX(I,J)
C177      FORMAT('0','CNTRX(',I2,',',I2,')=',F12.2)
 851    CONTINUE
 993    CNTRX(I,J)=0
 850  CONTINUE
C-----------------------------------------------------------------------C
C                                                                       C
C     GENERATE A REPORT OF THE MONTHLY COSTS FOR CNTRX, PASS, AND       C
C     PBX.                                                              C
C                                                                       C
C-----------------------------------------------------------------------C
      PRINT 509
 509  FORMAT('1',17X,'..................................................
     *.............')
      PRINT 510
 510  FORMAT(' ',17X,'.',36X,'MONTHLY COSTS FOR',5X,'    .')
      PRINT 501
 501  FORMAT(' ',17X,'.',1X,'# OF TRUNKS',4X,'# OF STATIONS',2X,
     *'CENTREX',5X,'PASS',6X,'PBX','      .')
      DO 502 I=1,NUMT,1
        PRINT 503,T(I)
 503    FORMAT(' ',17X,'.',61X,'.',/,18X,'.',5X,I2,54X,'.')
        IS=S(I,1)
        PRINT 508,IS,CNTRX(I,1),PASS(I,1),PBX(I,1)
 508    FORMAT('+',17X,'. ',19X,I4,7X,'$',F6.2,3X,'$',F6.2,3X,'$',F6.
     *2,'    .')
        DO 506 J=2,100,1
          IF(CNTRX(I,J).EQ.0) GO TO 502
          IS=S(I,J)
          PRINT 507,IS,CNTRX(I,J),PASS(I,J),PBX(I,J)
 507      FORMAT(' ',17X,'. ',19X,I4,7X,'$',F6.2,3X,'$',F6.2,3X,'$',
     *F6.2,'    .')
 506    CONTINUE
 502  CONTINUE
      PRINT 511
 511  FORMAT(' ',17X,'..................................................
     *.............')
      PRINT 512
 512  FORMAT('1',' ')
      STOP
      END
C-----------------------------------------------------------------------C
C                                                                       C
C     SUBROUTINE TO CALCULATE AP, THE CONVERSION FACTOR FROM INITIAL    C
C     COST TO MONTHLY COST, AND ALSO AF, THE CONVERSION FACTOR FROM     C
C     SALVAGE VALUE TO MONTHLY VALUE.                                   C
C                                                                       C
C-----------------------------------------------------------------------C
      SUBROUTINE CONFAC(AP,AF,R,N)
      PR=2*N
      COM=(1+0.5*R)**PR
      APN=R*COM
      DNA=COM-1
      DNB=2*(6+1.75*R)
      DEN=DNA*DNB
      AP=APN/DEN
      AF=R/DEN
      RETURN
```

```
      END
C-------------------------------------------------------------------C
C                                                                   C
C     SUBROUTINE TO READ IN UP TO 10 DIFFERENT TRUNK VALUES AND     C
C     CORRESPONDING RANGE OF LINES AND STEPPING FACTOR(IE. DISTANCE C
C     BETWEEN DESIRED LINE VALUES).                                 C
C                                                                   C
C-------------------------------------------------------------------C
      SUBROUTINE LINES(T,S,NUMT)
      DIMENSION S(10,100)
      INTEGER UP,LOW,T(10),STEP
      NUMT=1
 10   READ (5,370,END=11)T(NUMT),LOW,UP,STEP
 370  FORMAT(4I5)
      L=0
      DO 5 J=LOW,UP,STEP
        L=L+1
        S(NUMT,L)=J
  5   CONTINUE
      IF(S(NUMT,L).EQ.UP) GO TO 988
      S(NUMT,L+1)=UP
      S(NUMT,L+2)=0
      GO TO 983
 988  S(NUMT,L+1)=0
 983  NUMT=NUMT+1
      GO TO 10
 11   NUMT=NUMT-1
      RETURN
      END
C-------------------------------------------------------------------C
C                                                                   C
C     FUNCTION TO CALCULATE XS WHICH IS THE PBX RENTAL COST PER     C
C     MONTH.                                                        C
C                                                                   C
C-------------------------------------------------------------------C
      FUNCTION XS(IVAL)
      REAL IVAL
      XS=0
      IF(IVAL.LE.30) XS=27.5*IVAL
      IF(IVAL.GT.30.AND.IVAL.LE.60) XS=825+(IVAL-30)*14
      IF(IVAL.GT.60.AND.IVAL.LE.120) XS=1245+(IVAL-60)*12.1
      IF(IVAL.GT.120.AND.IVAL.LE.200) XS=1971+(IVAL-120)*9.9
      IF(IVAL.GT.200.AND.IVAL.LE.540) XS=2763+(IVAL-200)*10.65
      IF(IVAL.GT.540) PRINT 27,IVAL
   27 FORMAT('0','TOO MANY LINES FOR XS: ',F7.2)
      RETURN
      END
C-------------------------------------------------------------------C
C                                                                   C
C     FUNCTION TO CALCULATE XE WHICH IS THE INSTALLATION CHARGE     C
C     FOR PASS EQUIPMENT.                                           C
C                                                                   C
C-------------------------------------------------------------------C
      FUNCTION XE(IVAL)
      REAL IVAL
      XE=0
      IF(IVAL.LE.20) XE=2300
      IF(IVAL.GT.20.AND.IVAL.LE.40) XE=2700
      IF(IVAL.GT.40.AND.IVAL.LE.60) XE=3400
      IF(IVAL.GT.60.AND.IVAL.LE.80) XE=4600
```

```
      IF(IVAL.GT.80.AND.IVAL.LE.100) XE=5900
      IF(IVAL.GT.100.AND.IVAL.LE.120) XE=7400
      IF(IVAL.GT.120.AND.IVAL.LE.140) XE=8900
      IF(IVAL.GT.140.AND.IVAL.LE.160) XE=10700
      IF(IVAL.GT.160.AND.IVAL.LE.180) XE=12800
      IF(IVAL.GT.180.AND.IVAL.LE.200) XE=15000
      IF(IVAL.GT.200.AND.IVAL.LE.220) XE=18800
      IF(IVAL.GT.220.AND.IVAL.LE.240) XE=20400
      IF(IVAL.GT.240.AND.IVAL.LE.260) XE=22000
      IF(IVAL.GT.260.AND.IVAL.LE.280) XE=24400
      IF(IVAL.GT.280.AND.IVAL.LE.300) XE=27400
      IF(IVAL.GT.300.AND.IVAL.LE.320) XE=28800
      IF(IVAL.GT.320.AND.IVAL.LE.340) XE=30400
      IF(IVAL.GT.340.AND.IVAL.LE.360) XE=32300
      IF(IVAL.GT.360.AND.IVAL.LE.380) XE=33500
      IF(IVAL.GT.380.AND.IVAL.LE.400) XE=35100
      IF(IVAL.GT.400.AND.IVAL.LE.420) XE=36700
      IF(IVAL.GT.420.AND.IVAL.LE.440) XE=38200
      IF(IVAL.GT.440.AND.IVAL.LE.460) XE=39600
      IF(IVAL.GT.460.AND.IVAL.LE.480) XE=40800
      IF(IVAL.GT.480.AND.IVAL.LE.500) XE=42300
      IF(IVAL.GT.500.AND.IVAL.LE.520) XE=43900
      IF(IVAL.GT.520.AND.IVAL.LE.540) XE=45800
      IF(IVAL.GT.540) PRINT 37,IVAL
   37 FORMAT('0','TOO MANY LINES FOR XE: ',F7.2)
      RETURN
      END
C-----------------------------------------------------------------------C
C                                                                       C
C     FUNCTION TO CALCULATE EPI WHICH IS THE EQUIPMENT PURCHASE         C
C     AND INSTALLATION COST FOR CUSTOMER-OWNED PBX.                     C
C                                                                       C
C-----------------------------------------------------------------------C
      FUNCTION EPI(TR,LN,K)
      REAL LN
      INTEGER TR
      EPI=K*LN+400*TR
      RETURN
      END
```

```
      INTEGER T
      REAL JC,JI,L,LSS,OAC,LCC
      DIMENSION T(10),S(10,50),XAXIS(12),CNTRX(10,50),PASS(10,50),
     *PBX(10,50),YAXIS(12)
C-----------------------------------------------------------------------C
C                                                                       C
C     READ IN AND PRINT VARIOUS COSTS AND CHARGES.                      C
C                                                                       C
C-----------------------------------------------------------------------C
      READ 44,UT,UTG,UO,LCC,PWC,UJ,USS,UJI,UL,UE,LSS,OAC,PVC
 44   FORMAT(13F5.2)
      READ73,K,SVF,R,N
 73   FORMAT(I5,2F5.2,I5)
      PRINT 701
 701  FORMAT('1',30X,'*** LIST OF VARIABLES READ IN ***',//)
      PRINT 702,UT
 702  FORMAT('0',25X,'TRUNK CHARGE PER TRUNK PER MONTH              $',F7.2)
      PRINT 703,UTG
 703  FORMAT('0',25X,'GOVT OVERHEAD CHARGE PER TRUNK PER MONTH      $',F7.2)
      PRINT 704,UO
 704  FORMAT('0',25X,'OPTIONS COST PER STATION PER MONTH            $',F7.2)
      PRINT 706,LCC
 706  FORMAT('0',25X,'LINE CONNECTION CHARGE                        $',F7.2)
      PRINT 707,PWC
 707  FORMAT('0',25X,'PREMISES WORK CHARGE                          $',F7.2)
      PRINT 710,UJ
 710  FORMAT('0',25X,'JACK CHARGE PER TRUNK PER MONTH               $',F7.2)
      PRINT 711,USS
 711  FORMAT('0',25X,'MAINTENANCE COST PER STATION PER MONTH        $',F7.2)
      PRINT 713,UJI
 713  FORMAT('0',25X,'JACK INSTALLATION CHARGE PER MONTH            $',F7.2)
      PRINT 715,UL
 715  FORMAT('0',25X,'UNIT LINE COST/MONTH/STATION FOR CENTREX      $',F7.2)
      PRINT 716,UE
 716  FORMAT('0',25X,'UNIT EXTENSION COST/MONTH FOR CENTREX         $',F7.2)
      PRINT 717,LSS
 717  FORMAT('0',25X,'UNIT LINE LOCAL SHARED SERVICE COST           $',F7.2)
      PRINT 718,OAC
 718  FORMAT('0',25X,'ADMINISTRATIVE CHARGES                        $',F7.2)
      PRINT 705,PVC
 705  FORMAT('0',25X,'PREMISES VISIT CHARGE                         $',F7.2)
      PRINT 720,K
 720  FORMAT('0',25X,'COEFFICIENT OF # OF LINES IN EPI               ',I7)
      PRINT 721,SVF
 721  FORMAT('0',25X,'SALVAGE VALUE OF CUSTOMER PBX                  ',F7.2)
      PRINT 722,R
 722  FORMAT('0',25X,'INTEREST RATE                                  ',F7.2)
      PRINT 723,N
 723  FORMAT('0',25X,'AMORTIZATION PERIOD IN YEARS                   ',I7)
C-----------------------------------------------------------------------C
C                                                                       C
C     CALL SUBROUTINE 'LINES' TO READ IN THE # OF TRUNKS AND THE        C
C     CORRESPONDING RANGE OF LINES.  RETURNS WITH APPROPRIATE ARRAYS    C
C     AND MAX AND MIN VALUES OF LINES WHICH ARE PASSED TO SUBROUTINE    C
C     'SCALER',WHICH SCALES THE X-AXIS.                                 C
C                                                                       C
C-----------------------------------------------------------------------C
```

```
      CALL CONFAC(AP,AF,R,N)
      CALL LINES(T,S,NUMT,MXL,MNL)
      CALL SCALER(MXL,MNL,XAXIS)
C     PRINT 252
C252  FORMAT('-','THE XAXIS IS SCALED AS FOLLOWS:')
C     DO 253 I=1,10,1
C         PRINT 254,I,XAXIS(I)
C254      FORMAT(' ','XAXIS(',I2,')=',F8.2)
C253  CONTINUE
C-----------------------------------------------------------------------C
C                                                                       C
C     PASS WHICH IS THE EQUIVALENT MONTHLY COST/STATION FOR PASS IS     C
C     CALCULATED USING THE VALUES WHICH WERE READ IN FOR THE # OF       C
C     TRUNKS AND THE # OF LINES.                                        C
C                                                                       C
C-----------------------------------------------------------------------C
      DO 18 I=1,NUMT
         TC=UT*T(I)
         TCG=UTG*T(I)
         TLC=LCC*T(I)
         TPW=PWC*T(I)
         DO 19 J=1,50,1
            OC=UO*S(I,J)
            XM=XS(S(I,J))+TC+TCG+OC
            LPW=PWC*S(I,J)
            XI=XE(S(I,J))+TLC+TPW+LPW+OAC+PVC
            PASS(I,J)=(XM+XI*AP)/S(I,J)
C           PRINT77,I,J,PASS(I,J)
C 77        FORMAT('0','PASS(',I2,',',I2,')=',F12.2)
  19     CONTINUE
  18  CONTINUE
C-----------------------------------------------------------------------C
C                                                                       C
C     AS ABOVE, PBX THE EQUIVALENT MONTHLY COST/STATION FOR PURCHASED   C
C     PBX IS CALCULATED.                                                C
C                                                                       C
C-----------------------------------------------------------------------C
      DO 21 I=1,NUMT,1
         TC=UT*T(I)
         TCG=UTG*T(I)
         JC=UJ*T(I)
         TLC=LCC*T(I)
         TPW=PWC*T(I)
         JI=UJI*T(I)
         DO 22 J=1,50,1
            SC=USS*S(I,J)
            PM=TC+TCG+JC+SC
            EPII=EPI(T(I),S(I,J),K)
            PI=EPII+TLC+TPW+JI+OAC+PVC
            VX=SVF*EPII
            PBX(I,J)=(PM+PI*AP-VX*AF)/S(I,J)
C           PRINT176,I,J,PBX(I,J)
C 176       FORMAT('0','PBX(',I2,',',I2,')=',F12.2)
  22     CONTINUE
  21  CONTINUE
C-----------------------------------------------------------------------C
C                                                                       C
C     AS ABOVE, CNTRX THE EQUIVALENT MONTHLY COST/STATION FOR CENTREX   C
C     IS CALCULATED.                                                    C
C                                                                       C
```

```
C-----------------------------------------------------------------------C
      DO 850 I=1,NUMT,1
         DO 851 J=1,50,1
            CM=(0.875*(JL+UE)+0.5*LSS)*S(I,J)
            CI=(PWC+0.5*LCC)*S(I,J)+OAC+PVC
            CNTRX(I,J)=(CM+AP*CI)/S(I,J)
 851     CONTINUE
 850  CONTINUE
C-----------------------------------------------------------------------C
C                                                                       C
C     THE MAX AND MIN VALUES FOR CNTRX, PASS AND PBX  ARE DETERMINED.   C
C                                                                       C
C-----------------------------------------------------------------------C
      PASMAX=EMAX(PASS,NUMT)
      PASMIN=EMIN(PASS,NUMT)
      PBXMAX=EMAX(PBX,NUMT)
      PBXMIN=EMIN(PBX,NUMT)
      CTXMAX=EMAX(CNTRX,NUMT)
      CTXMIN=EMIN(CNTRX,NUMT)
C-----------------------------------------------------------------------C
C                                                                       C
C     ESTABLISH THE MAX AND MIN VALUES FOR THE Y-AXIS.                  C
C                                                                       C
C-----------------------------------------------------------------------C
      IF(PASMAX.GT.PBXMAX) YMAX=PASMAX
      IF(PBXMAX.GT.PASMAX) YMAX=PBXMAX
      IF(CTXMAX.GT.YMAX) YMAX=CTXMAX
      IF(PASMIN.LT.PBXMIN) YMIN=PASMIN
      IF(PBXMIN.LT.PASMIN) YMIN=PBXMIN
      IF(CTXMIN.LT.YMIN) YMIN=CTXMIN
C     PRINT 255,YMAX,YMIN
C255  FORMAT('0','YMAX=',F8.2,/,' YMIN=',F8.2)
C-----------------------------------------------------------------------C
C                                                                       C
C     USE THE ABOVE MAX AND MIN VALUES TO SCALE THE Y-AXIS.  GENERATE   C
C     A REPORT OF THE MONTHLY COSTS FOR CNTRX, PASS AND PBX.  CALL THE  C
C     SUBROUTINE 'PLOTTS' TO PLOT THE VALUES WHICH WERE CALCULATED      C
C     FOR CNTRX, PASS, AND PBX.                                         C
C                                                                       C
C-----------------------------------------------------------------------C
      CALL ESCALR(YMAX,YMIN,YAXIS)
C     PRINT 256
C256  FORMAT('-','THE YAXIS IS SCALED AS FOLLOWS:')
C     DO 257 I=1,10,1
C        PRINT 258,I,YAXIS(I)
C258      FORMAT(' ','YAXIS(',I2,')=',F8.2)
C257  CONTINUE
      PRINT 509
 509  FORMAT('1',17X,'..............................................
     *.............')
      PRINT 510
 510  FORMAT(' ',17X,'.',36X,'MONTHLY COSTS FOR',5X,'    .')
      PRINT 501
 501  FORMAT(' ',17X,'.',1X,'# OF TRUNKS',4X,'# OF STATIONS',2X,
     *'CENTREX',5X,'PASS',6X,'PBX','      .')
      DO 502 I=1,NUMT,1
         PRINT 503,T(I)
 503     FORMAT(' ',17X,'.',61X,'.',/,18X,'.',5X,I2,54X,'.')
         IS=S(I,1)
         PRINT 508,IS,CNTRX(I,1),PASS(I,1),PBX(I,1)
```

```
 508      FORMAT('+',17X,'. ',19X,I4,7X,'$',F6.2,3X,'$',F6.2,3X,'$',F6.-
     *2,'    .')
          DO 506 J=5,50,5
             IS=S(I,J)
             PRINT 507,IS,CNTRX(I,J),PASS(I,J),PBX(I,J)
 507         FORMAT(' ',17X,'. ',19X,I4,7X,'$',F6.2,3X,'$',F6.2,3X,'$',
     *F6.2,'    .')
 506      CONTINUE
 502   CONTINUE
       PRINT 511
 511   FORMAT(' ',17X,'..............................................
     *.............')
       PRINT 512
 512   FORMAT('1',' ')
       CALL PLOTTS(XAXIS,YAXIS,CNTRX,PASS,PBX,NUMT,S)
C
C
       STOP
       END
C----------------------------------------------------------------------C
C                                                                      C
C      SUBROUTINE TO PLOT THE VALUES WHICH WERE CALCULATED FOR CNTRX,  C
C      PASS AND PBX USING THE PLOTTING ROUTINES OF THE CALCOMP PLOTTER. C
C                                                                      C
C----------------------------------------------------------------------C
       SUBROUTINE PLOTTS(XAXIS,YAXIS,CNTRX,PASS,PBX,NUMT,S)
       DIMENSION XAXIS(12),YAXIS(12),CNTRX(10,50),PASS(10,50),PBX(10,50)
       DIMENSION S(10,50),IBUF(1000),XAX(52),YAX(52)
C----------------------------------------------------------------------C
C                                                                      C
C      ESTABLISH IDENTIFICATION AND THE ORIGIN, SCALE THE X-AXIS AND   C
C      THE Y-AXIS, DRAW BOTH AXES AND PRINT THE TITLE.                 C
C                                                                      C
C----------------------------------------------------------------------C
       CALL PLOTID('ACMPLOT','U15466P68D')
       CALL PLOT(1.0,0.5,-3)
       DO 38 I=1,NUMT,1
       CALL SCALE(XAXIS,10.0,10,1)
       CALL SCALE(YAXIS,10.0,10,1)
       DO 671 II=1,5,1
       CALL AXIS(0.0,0.0,'# OF STATIONS',-13,10.0,0.0,XAXIS(11),
     *XAXIS(12))
       CALL AXIS(0.0,0.0,'COST IN $/STN',13,10.0,90.0,YAXIS(11),
     *YAXIS(12))
       CALL SYMBOL(2.0,10.0,.21,'EQUIVALENT MONTHLY COSTS',0.0,24)
       CALL SYMBOL(7.0,3.5,.14,'PBX       Y',0.0,10)
       CALL SYMBOL(7.0,8.0,.14,'PASS      +',0.0,10)
       CALL SYMBOL(7.0,7.5,.14,'CENTREX  Z',0.0,10)
       CALL SYMBOL(7.0,7.0,.14,'TRUNKS   ',0.0,8)
       ENUM=S(I,1)
       CALL NUMBER(999.,999.,.14,ENUM,0.0,-1)
 671   CONTINUE
C----------------------------------------------------------------------C
C                                                                      C
C      PLOT THE ACTUAL POINTS.                                         C
C                                                                      C
C----------------------------------------------------------------------C
          NPTS=50
          DO 39 J=1,50,1
             XAX(J)=S(I,J)
```

```
   39      CONTINUE
   40      XAX(NPTS+1)=XAXIS(11)
           XAX(NPTS+2)=XAXIS(12)
C          PRINT 259,NPTS
C259       FORMAT('0','NPTS=',I2)
           K=NPTS+2
C          DO 401 II=1,K,1
C             PRINT 402,II,XAX(II)
C402          FORMAT('0','XAX(',I2,')=',F8.2)
C401       CONTINUE
           DO 41 J=1,NPTS,1
              YAX(J)=PBX(I,J)
   41      CONTINUE
           YAX(NPTS+1)=YAXIS(11)
           YAX(NPTS+2)=YAXIS(12)
           K=NPTS+2
C          DO 403 II=1,K,1
C             PRINT 404,II,YAX(II)
C404          FORMAT('0','YAX(',I2,')=',F8.2)
C403       CONTINUE
           CALL LINE(XAX,YAX,NPTS,1,1,9)
           DO 42 J=1,NPTS,1
              YAX(J)=PASS(I,J)
   42      CONTINUE
           YAX(NPTS+1)=YAXIS(11)
           YAX(NPTS+2)=YAXIS(12)
           K=NPTS+2
C          DO 405 II=1,K,1
C             PRINT 406,II,YAX(II)
C406          FORMAT('0','YAX(',I2,')=',F8.2)
C405       CONTINUE
           CALL LINE(XAX,YAX,NPTS,1,1,3)
           DO 43 J=1,NPTS,1
              YAX(J)=CNTRX(I,J)
   43      CONTINUE
           YAX(NPTS+1)=YAXIS(11)
           YAX(NPTS+2)=YAXIS(12)
           K=NPTS+2
C          DO 407 II=1,K,1
C             PRINT 408,II,YAX(II)
C408          FORMAT('0','YAX(',I2,')=',F8.2)
C407       CONTINUE
           CALL LINE(XAX,YAX,NPTS,1,1,8)
           CALL PLOT(11.0,0.0,-3)
   38   CONTINUE
        CALL PLOT(0.0,0.0,999)
        RETURN
        END
C---------------------------------------------------------------------C
C                                                                     C
C       SUBROUTINE TO CALCULATE AP, THE CONVERSION FACTOR FROM INITIAL C
C       COST TO MONTHLY COST, AND ALSO AF, THE CONVERSION FACTOR FROM C
C       SALVAGE VALUE TO MONTHLY VALUE.                               C
C                                                                     C
C---------------------------------------------------------------------C
        SUBROUTINE CONFAC(AP,AF,R,N)
        PR=2*N
        COM=(1+0.5*R)**PR
        APN=R*COM
        DNA=COM-1
```

```
      DNB=2*(6+1.75*R)
      DEN=DNA*DNB
      AP=APN/DEN
      AF=R/DEN
      RETURN
      END
C-----------------------------------------------------------------------C
C                                                                       C
C     SUBROUTINE TO READ IN UP TO 10 DIFFERENT TRUNK VALUES AND         C
C     CORRESPONDING RANGE OF LINES.  CALL SUBROUTINE 'XPANDR' TO        C
C     EXPAND THIS RANGE INTO 50 VALUES TO BE USED IN CALCULATIONS       C
C     AND PLOTTING.  USE FUNCTIONS 'MIN' AND 'MAX' TO DETERMINE         C
C     THE MAX AND MIN NUMBER OF LINES.                                  C
C                                                                       C
C-----------------------------------------------------------------------C
      SUBROUTINE LINES(T,S,NUMT,MXL,MNL)
      DIMENSION S(10,50)
      REAL L
      INTEGER UP,LOW,T(10)
      NUMT=1
      I=0
 10      READ (5,370,END=11)T(NUMT),LOW,UP
 370     FORMAT(3I5)
         I=I+1
         S(I,1)=LOW
         S(I,50)=UP
         CALL XPANDR(I,S)
         NUMT=NUMT+1
C        DO 5 J=1,50,1
C           PRINT 250,I,J,S(I,J)
C250        FORMAT(' ','S(',I2,',',I2,')=',F7.2)
C   5    CONTINUE
      GO TO 10
 11   NUMT=NUMT-1
      MXL=MAX(S,NUMT)
      MNL=MIN(S,NUMT)
C     PRINT 251,MXL,MNL
C251  FORMAT('0','MXL=',I4,/,' MNL=',I4)
      RETURN
      END
C-----------------------------------------------------------------------C
C                                                                       C
C     SUBROUTINE TO SCALE THE AXIS WHERE THE MAX AND MIN VALUES ARE     C
C     INTEGERS.                                                         C
C                                                                       C
C-----------------------------------------------------------------------C
      SUBROUTINE SCALER(MX,MN,AXIS)
      DIMENSION AXIS(12)
      DIFF=MX-MN
      DELTA=DIFF/9
      DO 17 I=1,10,1
         AXIS(I)=(MN-DELTA)+I*DELTA
   17 CONTINUE
      RETURN
      END
C-----------------------------------------------------------------------C
C                                                                       C
C     SUBROUTINE TO SCALE THE AXIS WHERE THE MAX AND MIN VALUES ARE     C
C     REAL.                                                             C
C                                                                       C
```

```
C--------------------------------------------------------------------------C
      SUBROUTINE ESCALR(EMX,EMN,AXIS)
      DIMENSION AXIS(12)
      DIFF=EMX-EMN
      DELTA=DIFF/9
      DO 17 I=1,10,1
         AXIS(I)=(EMN-DELTA)+I*DELTA
   17 CONTINUE
      RETURN
      END
C--------------------------------------------------------------------------C
C                                                                          C
C     FUNCTION TO DETERMINE THE INTEGER MAX VALUE OF A TWO-DIMENSIONAL     C
C     ARRAY OF REALS.                                                      C
C                                                                          C
C--------------------------------------------------------------------------C
      FUNCTION MAX(S,NUM)
      REAL S(10,50)
      MAX=0
      J=50
      DO 13 I=1,NUM,1
            IF(S(I,J).GT.MAX) MAX=S(I,J)
   13 CONTINUE
      RETURN
      END
C--------------------------------------------------------------------------C
C                                                                          C
C     FUNCTION TO DETERMINE THE REAL MAX VALUE OF A TWO-DIMENSIONAL        C
C     ARRAY OF REALS.                                                      C
C                                                                          C
C--------------------------------------------------------------------------C
      FUNCTION EMAX(E,NUM)
      DIMENSION E(10,50)
      EMAX=0.0
      DO 313 I=1,NUM,1
         DO 314 J=1,50,1
            IF(E(I,J).GT.EMAX) EMAX=E(I,J)
  314    CONTINUE
  313 CONTINUE
      RETURN
      END
C--------------------------------------------------------------------------C
C                                                                          C
C     FUNCTION TO DETERMINE THE INTEGER MIN VALUE OF A TWO-DIMENSIONAL     C
C     ARRAY OF REALS.                                                      C
C                                                                          C
C--------------------------------------------------------------------------C
      FUNCTION MIN(S,NUM)
      REAL S(10,50)
      MIN=99999
      DO 16 I=1,NUM,1
         IF (S(I,1).LT.MIN) MIN=S(I,1)
   16 CONTINUE
      RETURN
      END
C--------------------------------------------------------------------------C
C                                                                          C
C     FUNCTION TO DETERMINE THE REAL MIN VALUE OF A TWO-DIMENSIONAL        C
C     ARRAY OF REALS.                                                      C
C                                                                          C
```

```
C---------------------------------------------------------------------C
      FUNCTION EMIN(E,NUM)
      DIMENSION E(10,50)
      EMIN=9999.99
      DO 413 I=1,NUM,1
         DO 414 J=1,50,1
            IF (E(I,J).LT.EMIN) EMIN=E(I,J)
  414    CONTINUE
  413 CONTINUE
      RETURN
      END
C---------------------------------------------------------------------C
C                                                                     C
C     FUNCTION TO CALCULATE XS WHICH IS THE PBX RENTAL COST PER       C
C     MONTH.                                                          C
C                                                                     C
C---------------------------------------------------------------------C
      FUNCTION XS(IVAL)
      REAL IVAL
      XS=0
      IF(IVAL.LE.30) XS=27.5*IVAL
      IF(IVAL.GT.30.AND.IVAL.LE.60) XS=825+(IVAL-30)*14
      IF(IVAL.GT.60.AND.IVAL.LE.120) XS=1245+(IVAL-60)*12.1
      IF(IVAL.GT.120.AND.IVAL.LE.200) XS=1971+(IVAL-120)*9.9
      IF(IVAL.GT.200.AND.IVAL.LE.540) XS=2763+(IVAL-200)*10.65
      IF(IVAL.GT.540) PRINT 27,IVAL
   27 FORMAT('0','TOO MANY LINES FOR XS: ',F7.2)
C  28 PRINT 102,IVAL,XS
C 102 FORMAT('0','FOR IVAL= ',F7.2,' XS= ',F8.2)
      RETURN
      END
C---------------------------------------------------------------------C
C                                                                     C
C     FUNCTION TO CALCULATE XE WHICH IS THE INSTALLATION CHARGE       C
C     FOR PASS EQUIPMENT.                                             C
C                                                                     C
C---------------------------------------------------------------------C
      FUNCTION XE(IVAL)
      REAL IVAL
      XE=0
      IF(IVAL.LE.20) XE=2300
      IF(IVAL.GT.20.AND.IVAL.LE.40) XE=2700
      IF(IVAL.GT.40.AND.IVAL.LE.60) XE=3400
      IF(IVAL.GT.60.AND.IVAL.LE.80) XE=4600
      IF(IVAL.GT.80.AND.IVAL.LE.100) XE=5900
      IF(IVAL.GT.100.AND.IVAL.LE.120) XE=7400
      IF(IVAL.GT.120.AND.IVAL.LE.140) XE=8900
      IF(IVAL.GT.140.AND.IVAL.LE.160) XE=10700
      IF(IVAL.GT.160.AND.IVAL.LE.180) XE=12800
      IF(IVAL.GT.180.AND.IVAL.LE.200) XE=15000
      IF(IVAL.GT.200.AND.IVAL.LE.220) XE=18800
      IF(IVAL.GT.220.AND.IVAL.LE.240) XE=20400
      IF(IVAL.GT.240.AND.IVAL.LE.260) XE=22000
      IF(IVAL.GT.260.AND.IVAL.LE.280) XE=24400
      IF(IVAL.GT.280.AND.IVAL.LE.300) XE=27400
      IF(IVAL.GT.300.AND.IVAL.LE.320) XE=28800
      IF(IVAL.GT.320.AND.IVAL.LE.340) XE=30400
      IF(IVAL.GT.340.AND.IVAL.LE.360) XE=32300
      IF(IVAL.GT.360.AND.IVAL.LE.380) XE=33500
      IF(IVAL.GT.380.AND.IVAL.LE.400) XE=35100
```

```
      IF(IVAL.GT.400.AND.IVAL.LE.420) XE=36700
      IF(IVAL.GT.420.AND.IVAL.LE.440) XE=38200
      IF(IVAL.GT.440.AND.IVAL.LE.460) XE=39600
      IF(IVAL.GT.460.AND.IVAL.LE.480) XE=40800
      IF(IVAL.GT.480.AND.IVAL.LE.500) XE=42300
      IF(IVAL.GT.500.AND.IVAL.LE.520) XE=43900
      IF(IVAL.GT.520.AND.IVAL.LE.540) XE=45800
      IF(IVAL.GT.540) PRINT 37,IVAL
   37 FORMAT('0','TOO MANY LINES FOR XE: ',F7.2)
C 35  PRINT 181,IVAL,XE
C181  FORMAT('0','FOR IVAL= ',F7.2,' XE= ',F8.2)
      RETURN
      END
C--------------------------------------------------------------------C
C                                                                    C
C     FUNCTION TO CALCULATE EPI WHICH IS THE EQUIPMENT PURCHASE      C
C     AND INSTALLATION COST FOR PURCHASED PBX.                       C
C                                                                    C
C--------------------------------------------------------------------C
      FUNCTION EPI(TR,LN,K)
      REAL LN
      INTEGER TR
      EPI=K*LN+400*TR
      RETURN
      END
C--------------------------------------------------------------------C
C                                                                    C
C     SUBROUTINE TO EXPAND THE RANGE OF LINES INTO 50 VALUES TO      C
C     BE USED IN CALCULATIONS AND PLOTTING.                          C
C                                                                    C
C--------------------------------------------------------------------C
      SUBROUTINE XPANDR(IROW,STN)
      REAL STN(10,50)
      DIFF=STN(IROW,50)-STN(IROW,1)
      DELTA=DIFF/49
      DO 450 I=2,49,1
         STN(IROW,I)=(STN(IROW,1)-DELTA) + I*DELTA
 450  CONTINUE
      DO 451 I=5,45,5
         ITEMP=STN(IROW,I)
         STN(IROW,I)=ITEMP
 451  CONTINUE
      RETURN
      END
```