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Simulation of a Single-server Model for a Paging Drum Channel System

by

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Abstract

A Single-server model is an abstract mathematical model which can be applied to many systems. This report presents the formulation of a single-server model which represents a Paging Drum Channel System. Simulation has been carried out by Frotran and Simula assuming uniformly distributed inputs.

Simulation of a Single-server Model for a Paging Drum Channel System

1. Introduction

A single-server model is one where there is only one waiting list (queue). Although the model is simple, it can be abstractedly applied to many applications such as computer systems, service stations, input/output channels, paging drum channels, etc. If it models a computer system, then the waiting queue contains jobs to be processed. If it models a service station, then the waiting queue contains cars to be serviced. If it models a paging drum channel PDC, then the waiting queue contains paging requests PR's.

The objective of this simulation, however, is to determeine the following: (a) the average waiting time for each PR arriving at the PDC system and (b) the total PDC system idle time which is essential in deciding whether the number of tasks should be decreased or increased.

2. The waiting queue

The waiting queue is represented by a two-dimensional array with indices K and J. Index K is the pointer to the Kth node in the queue, while index J indicates the field of the node to be taken for computation. Figure 1 shows the format of the $(I-1)^{th}$ node, the I^{th} node, and the $(I+1)^{th}$ node in the waiting queue. Each node represents a paging request entry. However, the user must provide for the I^{th} node the PR arrival time, NODE(I,2), and the PDC system service time, NODE(I,3). For the I^{th} node, K=I and J=1, through 7. Similarly, for the $(I+1)^{th}$ node, K=(I+1) and J=1 through 7. No link is required since the predecessor of NODE(I,J) is NODE(I-1,J) and the successor of NODE(I,J) is NODE(I+1,J), where I>1 and J is the field index. According to this kind of data structure, computation of various statistics is very easily accomplished by using DO loops in Fortran and FOR clauses in Algol and Simula.

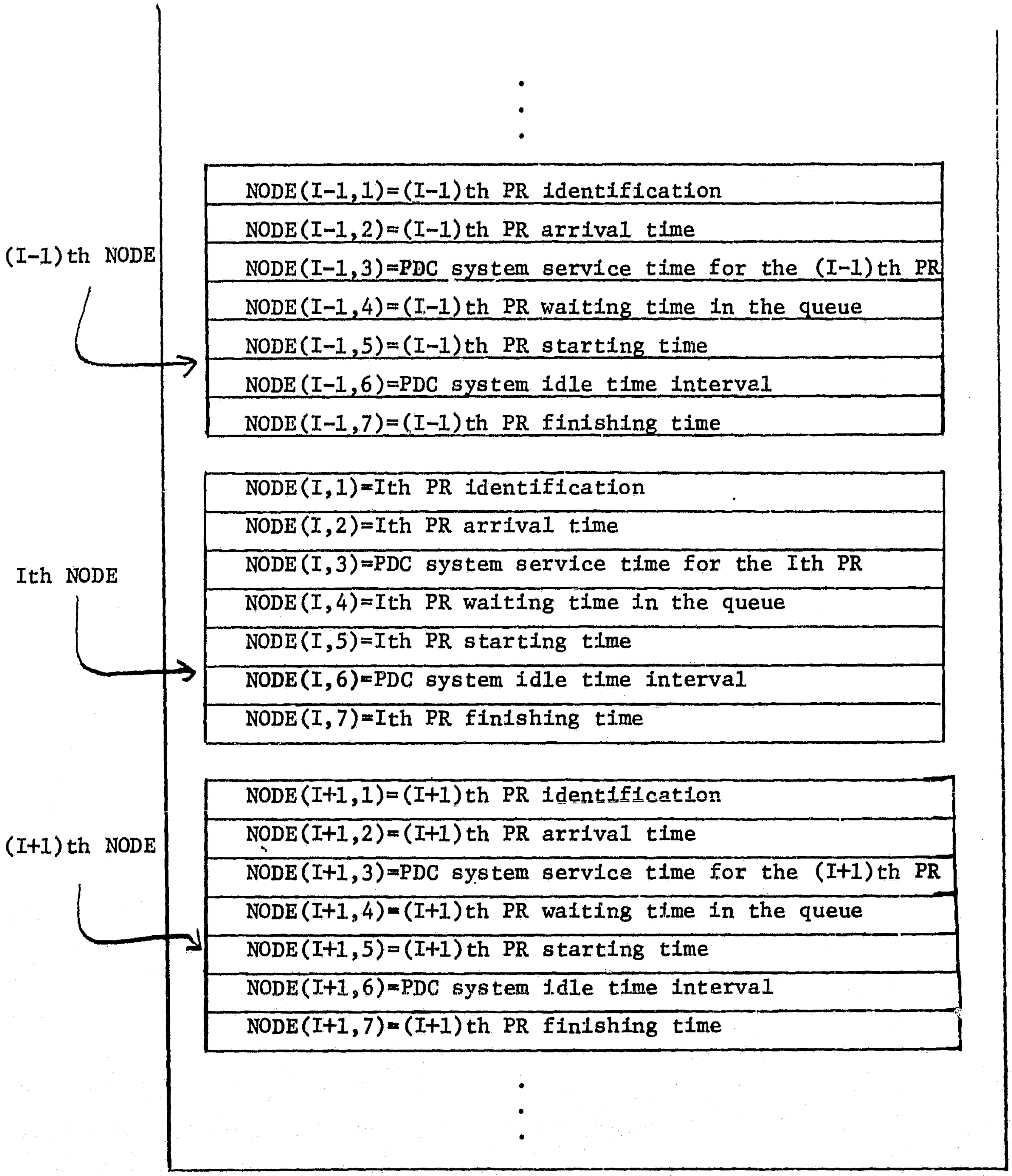

Fig. 1 Format of the (I-1)th node, Ith node, and (I+1)th node in the waiting queue

3. A single-server model

A picture of the single-server model for a paging drum channel is shown in Fig. 2. As a PR arrives at the single-server, it gets the service if there is no other one prior to it, that is, if the single-server is free; otherwise, it enters a paging request queue.

Input parameters are (a) the PR arrival time and (b) the system service time for the PR. Simulation outputs are (a) the average waiting time of the PR in the queue, (b) total system service time, and (c) total system idle time.

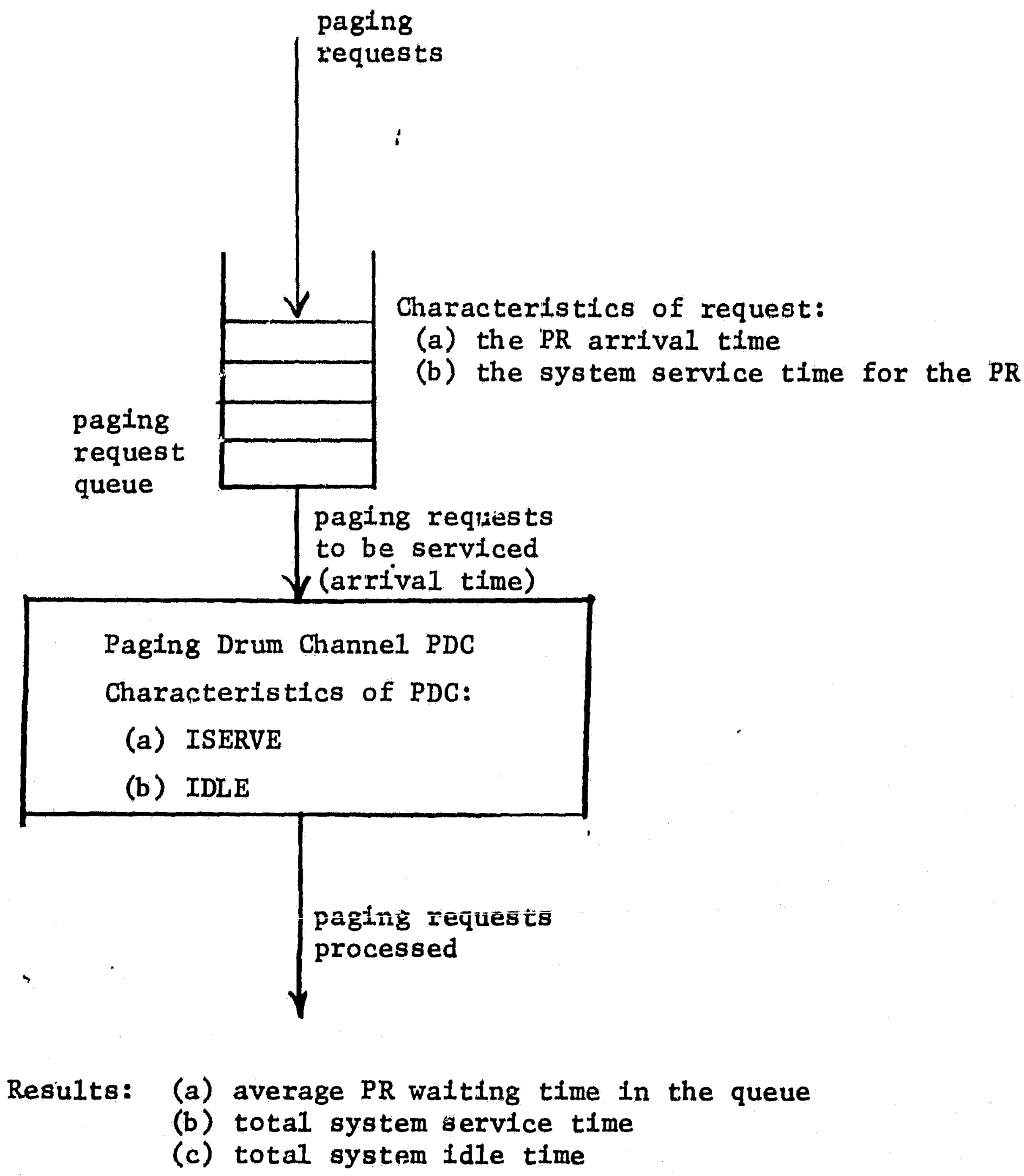

Fig. 2 Block diagram of a single-server model for a paging drum channel

4. Formulation of the model

As shown in Fig. 2, a PR arrives at the PDC system, obtains the service, and leaves the PDC system. Table 1 shows the 13 entities (variables and parameters) in the simulation model, where the entities represent the variable names in the simulation programs. For example, IALL represents the total simulation time while AVG represents the average PR waiting time in the queue.

The activities (functional relationships between variables and parameters) are defined by the following equations where I is the index of page request in the waiting queue:

a. For I=1

The PR waiting time in the queue is 0 for the first PR:

NODE(I,4)=0 (1)

The PDC system idle time is set to the PR arrival time:

NODE(I,6)=NODE(I,2) (2)

The PR starting time is the sum of the PR arrival time and the PR waiting time:

NODE(I,5)=NODE(I,2)+NODE(I,4) (3)

The PR finishing time is the sum of the PR starting time and PDC system service time for the PR:

NODE(I,7)=NODE(I,5)+NODE(I,3) (4)

b. For I>1

The PR waiting time is the difference between the PR arrival time and the previous PR finishing time:

NODE(I,4)=NODE(I-1,7)-NODE(I,2) (5)

The PR starting time is the sum of the PR arrival time and the PR waiting time:

NODE(I,5)=NODE(I,2)+NODE(I,4) (6)

Table 1 Entities of the Simulation Model

Entities	Designation
IALL	total simulation time
NPR	number of PR arriving during the simulation time interval
NODE(I,1)*	PR identification
NODE(I,2)	PR arrival time (input parameter)
NODE(I,3)	PDC system service time for the Ith PR (input parameter)
NODE(I,4)	PR waiting time in the queue
NODE(I,5)	PR starting time
NODE(I,6)	PDC system idle time interval (time interval between the Ith PR starting time and the (I-1)th PR finishing time)
NODE(I,7)	PR finishing time
ISERVE	total PDC system service time
IDLE	total PDC system idle time
WAIT	total PR waiting time in the queue
AVG	average PR waiting time in the queue

*I is the index of paging request.

The PR finishing time is the sum of the PR starting time and the PDC system service time for the PR:

NODE(I,7)=NODE(I,5)+NODE(I,3) (7)

The PDC system idle time interval is the difference between the PR starting time and the previous PR finishing time:

NODE(I,6)=NODE(I,5)-NODE(I-1,7) (8)

c. For $I \geq 1$

Total PDC system service time is the sum of the service time for each PR:

$$ISERVE= \sum_{I=1}^{NPR} NODE(I,3) \quad (9)$$

Total PDC system idle time is the difference between the total simulation time and total service time:

IDLE=IALL-ISERVE (10)

Total paging request waiting time in the queue is the waiting time for each PR:

$$WAIT= \sum_{I=1}^{NPR} NODE(I,4) \quad (11)$$

Average PR waiting time is the total PR waiting time divided by the number of PR's:

AVG=WAIT/NPR (12)

5. Simulation programs

The single-server model for the paging drum channel has been simulated by SIMULA and FORTRAN on the UNIVAC 1108.

5.1 Flow charts

The flow charts of the SIMULA and FORTRAN simulation programs for the single-server model are presented in Figs. 3 and 4. The boxes in the flow chart are numbered and explained below:

Box 1 describes initialization; the number of PR's NPR and the length of the total simulation time interval IALL are read in from card.

Box 2 is for initializing the index for PR(I), total system service time ISERVE, total PR waiting time WAIT.

Box 3 assigns PR identification NODE(I,1), PR arrival time NODE(I,2), and the PDC system service time NODE(I,3). These characteristics are read in from card.

Box 4 and Box 5 checks if the current PR is the first PR or not. If it is the first PR, the PR waiting time is set to 0 since there is no PR prior to it. This is shown in Box 7. If it is not the first PR, go to Box 5 where the PR waiting time NODE(I,4) is computed by subtracting the PR arrival time NODE(I,2) from the previous PR finishing time NODE(I-1,7).

Box 6 checks if NODE(I,4) is negative. If it is negative, NODE(I,4) is set to 0 since in this case the previous PR has left the PDC system when the current PR arrives.

Box 7 In Box 7, the PR waiting time NODE(I,4) is set to 0.

Box 8 In Box 8, the PR starting time NODE(I,5) is computed by adding the PR waiting time NODE(I,4) to the PR arrival time NODE(I,2).

Box 9	In Box 9, the PR finishing time is computed by adding the PDC system service time NODE(I,3) to the PR starting time NODE(I,5) which is the time when the current PR is serviced.
Box 10	Checks if the current PR is the first PR arriving at the PDC system.
Box 11	If the current PR is not the first PR, the current system idle time NODE(I,6) is computed by subtracting the previous PR finishing time NODE(I-1,7) from the current PR starting time NODE(I,5).
Box 12	Checks if the computed PDC system idle time NODE(I,6) is negative.
Box 13	If it is negative, NODE(I,6) is set to 0 and the current PR waits until the previous PR leaves the PDC system.
Box 14	If it is the first PR, the PDC system idle time interval NODE(I,6) is equal to the first PR arrival time NODE(I,2) since so far no PR has been serviced.
Box 15	In box 15, the attributes or the contents of the entities which are variables in the SIMULA program of the mathematical model are printed out.
Box 16 and Box 17	In box 16 and box 17, the total PDC system service time ISERVE and the total PR waiting time WAIT are accumulated.
Box 18	Checks if all the PR's have been serviced.
Box 19	If there are more PR's coming, index I is incremented, and control is then returned to box 3.
Box 20 and Box 21	In box 20 and 21, the average PR waiting time AVG is computed.
Box 22	In box 22, the total simulated time IALL in seconds is printed.
Box 23	In box 23, the total PDC idle time IDLE is computed by subtracting the total PDC service time ISERVE from IALL.

Box 24, Box 25, and Box 26	In these three boxes, total PDC system idle time IDLE, total PDC system service time ISERVE, and average PR waiting time AVG are printed.

5.2 Listings

The SIMULA simulation program is in Appendix A and the FORTRAN simulation program is in Appendix B.

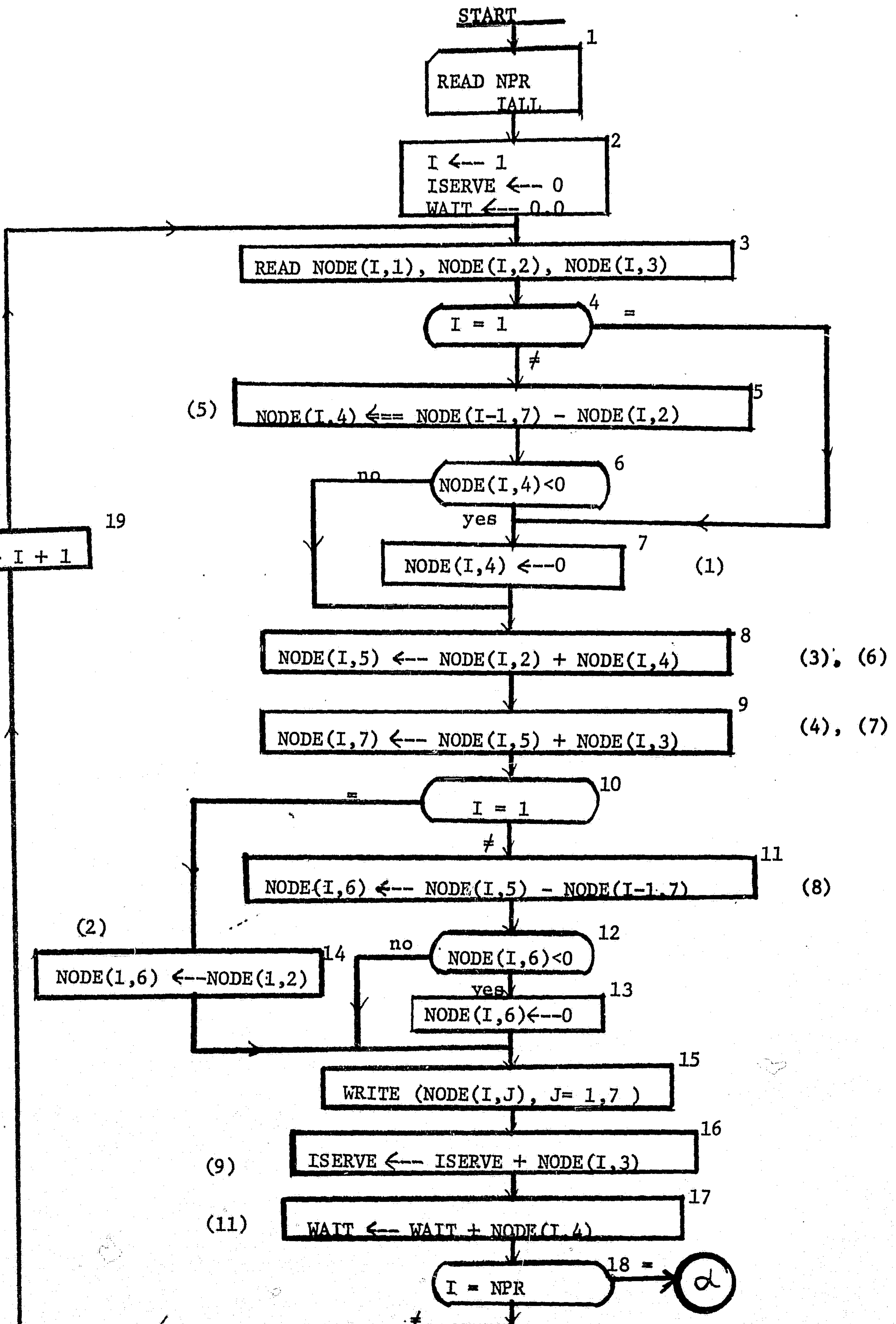

Fig. 3 Flow chart for the simulation programs (Page 1)

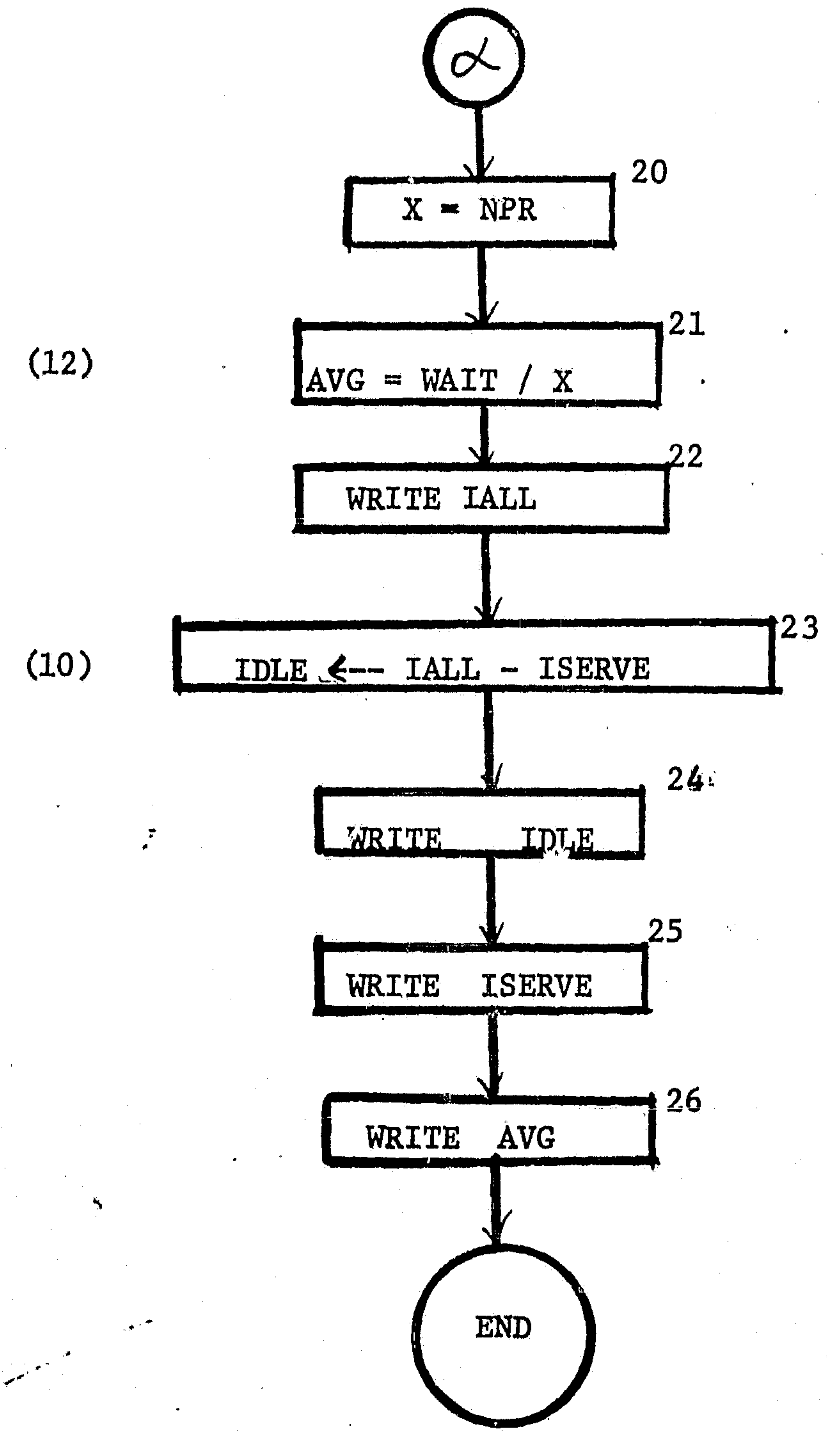

Fig. 4 Flow chart for the simulation programs (Page 2)

6. Simulation examples

Three examples are presented in this section to illustrate the simulation of the given PDC system with different input parameters. The paging requests are assumed to arrive according to Uniform Distribution in the following examples.

6.1 Example 1

The input data for example 1 is shown in Table 2. In this example, the PR arrival rate (80 second interval) is higher than the PDC system service rate (100 seconds/PR). The computer print-out is shown in Fig. 5. The first PR arrives at time 80, waits no time, gets service at time 80, and leaves the system at time 180. The last PR arrives at time 800, waits 180 units of time, gets service at time 980, and leaves the system at time 1080. Thus, the PR's are queued up as they arrive at the system. The average PR waiting time is 90 time units, while the total PDC system idle time is 80 time units. Thus, the number of tasks should be decreased.

6.2 Example 2

The input data for example 2 is shown in Table 3. In this example the PR's require various system service time ranging from 60 to 90 time units. The computer print out is shown in Fig. 6. The first PR arrives at time 80, waits no time, gets service get time 80 and leaves the system at time 170. The last PR arrives at time 800, waits 10 units of time, gets service at time 810, and leaves the system at time 910. Thus, some PR's must wait in the queue and some do not have to wait. The computed average PR waiting time is 4 time units while the total PDC system idle time is 180 time units.

Thus, the number of tasks may be increased.

6.3 Example 3

The input data for example 3 is shown in Table 4. In this example, PR arrival rate (λ) is set equals to PR service rate (μ) at the PDC system. The drum utilization factor of the PDC system is $\rho = \lambda/\mu = 1$. The computer print out is shown in Fig. 7. The first PR arrives at time 80, waits no time, gets service at time 80, and leaves the system at time 160. The last PR arrives at time 800, waits no time, gets service at time 800, and leaves the system at time 880. Thus, no PR has to wait while the total PDC system idle time is minimized. Therefore, the average PR waiting time is 0 time unit and the total PDC system idle time is 80 time units. Consequently, the number of tasks may be increased.

Table 2 Input data for example 1

Paging Request Identification	Paging Request Arrival Time	System Service Time for the Paging Request
1	80	100
2	160	100
3	240	100
4	320	100
5	400	100
6	480	100
7	560	100
8	640	100
9	720	100
10	800	100

Total Simulation Time = 1200

Total Number of PR = 10.

EXAMPLE 1

Fig .5. Example 1. SIMULATION OF A CHANNEL (constant system service time of 100)

PR ID	ARRIVAL TIME	SYSTEM SERVICE TIME	PR WAITING TIME	PR STRATING TIME	SYSTEM IDLE TIME	FINISHING TIME
1	80	100	0	80	80	180
2	160	100	20	180	0	280
3	240	100	40	280	0	380
4	320	100	60	380	0	480
5	400	100	80	480	0	580
6	480	100	100	580	0	680
7	560	100	120	680	0	780
8	640	100	140	780	0	880
9	720	100	160	880	0	980
10	800	100	180	980	0	1080

TOTAL SIMULATED TIME = 1200 SECONDS

TOTAL SYSTEM IDLE TIME = 200

TOTAL SYSTEM SERVICE TIME = 1000

AVERAGE WAITING TIME IN THE QUEUE = 90.0000 SECONDS

Table 3 Input data for example 2

Paging Request Identification	Paging Request Arrival Time	System Service Time for the Paging Request
1	80	90
2	160	90
3	240	50
4	320	50
5	400	60
6	480	60
7	560	70
8	640	70
9	720	90
10	800	90

Total Simulation Time = 1200

Total Number of PR = 10.

Fig.6.Example 2:SIMULATION OF A CHANNEL (variable system service time from 60 to 90)

PR ID	ARRIVAL TIME	SYSTEM SERVICE TIME	PR WAITING TIME	PR STRATING TIME	SYSTEM IDLE TIME	FINISHING TIME
1	80	90	0	80	80	170
2	160	90	10	170	0	260
3	240	50	20	260	0	310
4	320	50	0	320	10	370
5	400	60	0	400	30	460
6	480	60	0	480	20	540
7	560	70	0	560	20	630
8	640	70	0	640	10	710
9	720	90	0	720	10	810
10	800	90	10	810	0	900

TOTAL SIMULATED TIME = 1200 SECONDS

TOTAL SYSTEM IDLE TIME = 480

TOTAL SYSTEM SERVICE TIME = 720

AVERAGE WAITING TIME IN THE QUEUE = 4.0000 SECONDS

Table 4 Input data for example 3

Paging Request Identification	Paging Request Arrival Time	System Service Time for the Paging Request
1	80	80
2	160	80
3	240	80
4	320	80
5	400	80
6	480	80
7	560	80
8	640	80
9	720	80
10	800	80

Total Simulation Time = 1200

Total Number of PR = 10.

Fig.7. Example3: SIMULATION OF A CHANNEL (arrival time is a multiple of constant system service time)

PR ID	ARRIVAL TIME	SYSTEM SERVICE TIME	PR WAITING TIME	PR STRATING TIME	SYSTEM IDLE TIME	FINISHING TIME
1	80	80	0	80	80	160
2	160	80	0	160	0	240
3	240	80	0	240	0	320
4	320	80	0	320	0	400
5	400	80	0	400	0	480
6	480	80	0	480	0	560
7	560	80	0	560	0	640
8	640	80	0	640	0	720
9	720	80	0	720	0	800
10	800	80	0	800	0	880

TOTAL SIMULATED TIME = 1200 SECONDS

TOTAL SYSTEM IDLE TIME = 400

TOTAL SYSTEM SERVICE TIME = 800

AVERAGE WAITING TIME IN THE QUEUE = .0000 SECONDS

7. Acknowledgement

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8. References

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APPENDIX A. LISTING OF THE SIMULA SIMULATION PROGRAM

```
'RUN AA,001-11-768,KWOK
'ALG,CIS        IOCS,IOCS
  SIMULA BEGIN
COMMENT SIMULATION OF A MATHEMATICAL MODEL OF A PDC UNDER IOCS***$
COMMENT PAGING REQUESTS ARE STORED IN A HARDWARE QUEUE $
COMMENT TOTAL PDC SYSTEM SERVICE TIME $
  INTEGER ISERVE$
COMMENT TOTAL SIMULATION TIME $
  INTEGER IALL$
COMMENT NUMBER OF PAGING REQUESTS IN THE QUEUE $
  INTEGER NPR$
COMMENT INDEX FOR THE PAGING REQUEST $
  INTEGER I $
COMMENT TOTAL PDC SYSTEM IDLE TIME $
  INTEGER IDLE$
  REAL WAIT$
  REAL AVG$
  REAL X$
  INTEGER ARRAY NODE(1..10, 1..7)$
  FORMAT F1 (A,I4,I4)$
  FORMAT F2(A, I3,I3,I3) $
COMMENT PR MEANS PAGING-IN OR PAGING-OUT REQUEST $
COMMENT NODE(I,1) IS PR ID
        NODE(I,2) IS PR ARRIVAL TIME
        NODE(I,3) IS PDC SYSTEM SERVICE TIME FOR THE PR
        NODE(I,4) IS THE PR WAITING TIME IN THE QUEUE
        NODE(I,5) IS THE PR STARTING TIME
        NODE(I,6) IS THE PDC SYSTEM IDLE TIME
        NODE(I,7) IS THE PR FINISHING TIME $
COMMENT PRINT TITLES
  WRITE('   SIMULATION OF A PDC SYSTEM PROCESSING PAGING REQUESTS')$
  ISERVE= 0$
  WAIT = 0.0$
COMMENT INPUT REQUEST CHARACTERISTICS $
  READ(IALL,NPR, F1) $
COMMENT GENERATING 10 NODES FOR THE 10 PR'S $
  FOR I = 1 STEP 1 UNTIL NPR DO BEGIN
COMMENT INPUT PR-ID, ARRIVAL TIME,SYSTEM SERVICE TIMES
  READ(NODE(I,1),NODE(I,2),NODE(I,3), F2)$
COMMENT COMPUTE WAITING TIME $
  IF I NEQ 1 THEN GO TO L11 $
  NODE(I,4) = 0 $
  GO TO L13$
L11 .. NODE(I,4) = NODE(I-1,7) - NODE(I,2) $
COMMENT NO WAITING IF THE DIFFERENCE IS NEGATIVE $
  IF NODE(I,4) LSS 0 THEN NODE(I,4) = 0 $
COMMENT PR STARTING TIME $
L13 .. NODE(I,5) = NODE(I,2) + NODE(I,4)$
COMMENT PR FINISHING TIME $
  NODE(I,7) = NODE(I,5) + NODE(I,3) $
  IF I NEQ 1 THEN GO TO L14 $
COMMENT COMPUTE INITIAL SYSTEM IDLE TIME $
  NODE(1,6) = NODE(1,2) $
```

```
   GO TO L15 $
 COMMENT SYSTEM IDLE TIME WHEN THE JOB ARRIVES (ACCUMULATED TIME)$
 L14 .. NODE(I,6) = NODE(I,5) - NODE(I-1,7) $
 COMMENT NO ADDED SYSTEM IDLE TIME IF THE DIFFERENCE IS NEGATIVE$
   IF NODE(I,6) LSS 0 THEN NODE(I,6) = 0 $
 COMMENT PRINT INTERMEDIATE RESULT $
 L15 .. WRITE( 'PR-ID = ', NODE(I,1))$
        WRITE(' PR ARRIVAL TIME = ',NODE(I,2))$
        WRITE(' PDC SYSTEM SERVICE TIME = ',NODE(I,3))$
        WRITE(' PR WAITING TIME = ', NODE(I,4))$
        WRITE(' PR STARTING TIME = ',NODE(I,5))$
        WRITE(' PDC SYSTEM IDLE TIME = ',NODE(I,6))$
        WRITE(' PR FINISHING TIME = ', NODE(I,7))$
   WRITE(' *************************************************************') $
 COMMENT STATISTICS GATHERING $
 COMMENT TOTAL PDC SYSTEM SERVICE TIME $
   ISERVE = ISERVE + NODE(I,3) $
 COMMENT COMPUTE TOTAL PR WAITING TIME $
   WAIT = WAIT + NODE(I,4) $
   END $
 COMMENT COMPUTE AVERAGE PR WAITING TIME $
   X = NPR $
   AVG = WAIT /X $
   WRITE( ' TOTAL SIMULATED TIME IS ', IALL, ' SECONDS')$
 COMMENT TOTAL PDC SYSTEM IDLE TIME $
   IDLE = IALL - ISERVE $
   WRITE( ' TOTAL PDC SYSTEM IDLE TIME IS ', IDLE) $
   WRITE(' TOTAL PDC SYSTEM SERVICE TIME IS ',ISERVE) $
   WRITE( ' AVERAGE PR WAITING TIME IN THE QUEUE = ',AVG,' SECONDS')$
   END$
 !MAP
 !XQT
 12000010
   1080100                                             FIRST JOB
   2160100
   3240100
   4320100
   5400100
   6480100
   7560100
   8640100
   9720100
  10800100                                             LAST JOB
 !XQT
 12000010
   1080090
   2160090
   3240050
   4320050
   5400060
   6480060
   7560070
   8640070
   9720090
  10800090
 !XQT
 12000010
   1080080
   2160080
   3240080
   4320080
```

```
  5400080
  6480080
  7560080
  8640080
  9720080
 10800080
'FIN
```

APPENDIX B. LISTING OF THE FORTRAN SIMULATION PROGRAM

```
!RUN CS230,001-11-768,KWOK,1,20
!FOR,IS          CH1,CH2
      DIMENSION NODE(10,7)
C     PR IS PAGING REQUEST SERVICED BY THE PDC
C     NODE(I,1) IS  PR ID
C     NODE(I,2) IS  PR-ARRIVAL TIME
C     NODE(I,3) IS SYSTEM SERVICE TIME FOR THE PR
C     NODE(I,4) IS THE  PR WAITING TIME IN THE WAITING QUEUE
C     NODE(I,5) IS THE PR  STARTING TIME
C     NODE(I,6) IS THE SYSTEM IDLE TIME
C     NODE(I,7) IS THE PR  FINISHING TIME
C     PRINT TITLE
      WRITE(6,1)
    1 FORMAT( 1H1, 30X,'SIMULATION OF A CHANNEL',//)
      WRITE( 6,2)
    2 FORMAT(1H0,'  PR ID  ARRIVAL TIME  SYSTEM SERVICE TIME   PR WAITIN
     1G TIME   PR STRATING TIME  SYSTEM IDLE TIME  FINISHING TIME',/)
      ISERVE = 0
      WAIT = 0.0
C     INPUT
C     TOTAL NUMBER OF PR'S
C     TOTAL SIMULATION TIME IN SECONDS
      READ( 5,101) TALL, NPR
  101 FORMAT( I4,I4)
C     GENERATING 10 NODES FOR THE 10 PR'S
C     ASSIGN CHARACTERISTICS TO EACH PR
      DO 10 I= 1,NPR
C     INPUT PR  ID, ARRIVAL TIME, SYSTEM SERVICE TIME
      READ(5,100)( NODE(I,J),J= 1,3)
  100 FORMAT( I3,I3,I3)
C     WAITING TIME
      IF( I .NE. 1) GO TO 11
      NODE(1,4) = 0
      GO TO 13
   11 NODE(I,4) = NODE(I-1,7) - NODE(I,2)
C     NO WAITING IS NECESSARY IF THE DIFFERENCE IS NEGATIVE
      IF( NODE(I,4).LT. 0) NODE(I,4) = 0
C      PR STARTING TIME
   13 NODE(I,5) = NODE(I,2) + NODE( I,4)
C      PR FINISHING TIME
      NODE(I,7) = NODE(I,5) + NODE(I,3)
      IF( I .NE. 1) GO TO 14
C     COMPUTE INITIAL SYSTEM IDLE TIME
      NODE(1,6) = NODE(1,2)
      GO TO 15
C     SYSTEM IDLE TIME WHEN THE PR  ARRIVES
   14 NODE(I,6) = NODE(I,5) - NODE( I-1,7)
C     NO SYSTEM IDLE TIME IF THE DIFFERENCE IS NEGATIVE
      IF( NODE(I,6).LT. 0) NODE(I,6) = 0
C     PRINT INTERMEDIATE RESULTS
   15 WRITE( 6,3)(NODE(I,J) ,J=1,7)
    3 FORMAT(1H0,2X,I2,10X,I5,10X,I5,10X,I5,20X,I5,10X,I5,10X,I5)
      WRITE(6,9)
```

```
C       STATISTIC GATHERING
C       COMPUTE TOTAL SYSTEM SERVICE TIME
        ISERVE = ISERVE + NODE(I,3)
C       COMPUTE TOTAL WAITING TIME
        WAIT = WAIT + NODE(I,4)
   10   CONTINUE
C       COMPUTE AVERAGE WAITING TIME
        X = NPR
        AVG = WAIT /X
        WRITE(6,5) IALL
    5   FORMAT( 1H0,5X,'TOTAL SIMULATED TIME = ', I5,' SECONDS')
C       COMPUTE TOTAL SYSTEM IDLE TIME
        IDLE = IALL- ISERVE
        WRITE(6,6) IDLE
    6   FORMAT(1H0,5X,'TOTAL SYSTEM IDLE TIME = ',I5)
        WRITE(6,7) ISERVE
    7   FORMAT(1H0,5X,'TOTAL SYSTEM SERVICE TIME = ',I5)
        WRITE(6,8) AVG
    8   FORMAT(1H0,5X,'AVERAGE WAITING TIME IN THE QUEUE = ',F14.4, ' SECO
       1NDS')
    9   FORMAT(1H0, 110('*'))
        END
'MAP
'XQT
12000010
  1080100                                         FIRST PR
  2160100
  3240100
  4320100
  5400100
  6480100
  7560100
  8640100
  9720100
 10800100                                         LAST PR
'XQT
12000010
  1080090
  2160090
  3240050
  4320050
  5400050
  6480060
  7560070
  8640070
  9720090
 10800090
'XQT
12000010
  1080080
  2160080
  3240080
  4320080
  5400080
  6480080
  7560080
  8640080
  9720080
 10800080
'FIN
```