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DECISION SUPPORT FOR DETERMINING STEADY STATE PRODUCTION RATES AS A FUNCTION OF REPAIR POLICY

by

Lydia Anne Chastain

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May 10, 1984
Date

Professor in Charge

Chairman of Department

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ABSTRACT

General studies of decision making and studies of specific decisions have indicated the potential benefits of computer support for decision making. The name Decision Support System (DSS) emphasizes the role which computer-based support plays with respect to users. DSS can be defined as systems applicable to problems which are at least partially, but not completely, structurable. DSS provide high level operations for retrieving data, generating alternative solutions, and evaluating these alternatives.

The purpose of this research is to develop a decision support framework that can be used to aid the designer in predicting operating characteristics of a system. The procedure proposed is based on an analytical model to obtain the steady state production rate of the Primer Insert Submodule used in small caliber ammunition. A continuous Markov process was used to model the system. The methodology and techniques presented in this study involve 1) taking information currently available on existing systems, 2) projecting these parameters into the future time frame in which the system will become operable, and 3) using these projected parameters and the proposed methodology for decision support to determine the early prediction of system operating characteristics. Applications of these

techniques will provide a rational basis for investigating steady state capabilities and evaluating policies for allowed failures. The final results from the application of the methodology presented is a model for specifying possible courses of action and a program which will achieve an optimum balance between maintenance and logistics on one hand and equipment performance on the other for a given state of operational readiness. It is still up to the user, however, to select each specific alternative to be assessed.

CHAPTER I

INTRODUCTION

General studies of decision making and studies of specific decisions have indicated the potential benefits of computer support for decision making. The name Decision Support System (DSS) emphasizes the role which computer-based support plays with respect to users. DSS provides high level operations for retrieving data, generating alternative solutions, and evaluating these alternatives. They are designed to help decision makers cope with partially structured decision tasks. If a problem is partially structured, it is possible to bring some structure to the problem if the decision maker is willing to accept a certain data set or certain processing routines as relevant to the problem solution. DSS are better defined as systems applicable to problems which are at least partially, but not completely, structurable. A good DSS brings as much structure to the problem as possible. A decision maker is faced with a problem in which 1) relevant information for decision making is unavailable, 2) alternatives are unknown, or 3) appropriate values for making a choice are unknown. The purpose of DSS is to facilitate the judgment process as one attempts to contend with these unknowns.

The purpose of this research is to develop a decision support framework that can be used to aid the designer in predicting operating characteristics of a system. The procedure proposed is based on an analytical model to obtain the steady state production rate of the Primer Insert Submodule used in small caliber ammunition. A continuous Markov process was used to model the system. The methodology and techniques presented in this study involve 1) taking information currently available on existing systems, 2) projecting these parameters into the future time frame in which the system will become operable, and 3) using these projected parameters and the proposed methodology for decision support to determine the early prediction of system operating characteristics. If the designer had this computer-based support available, he could then estimate the reliability, availability, maintainability, and sparing procedures of the system in order to evaluate competing designs.

In this study, a general application is presented and the techniques for applying decision support capabilities to the Markov process are demonstrated to predict the expected steady state production rate as a function of repair policy. Applications of these techniques will provide a rational basis for investigating steady state capabilities and evaluating policies for allowed failures. The final results from the application of the methodology presented will be a model for specifying possible courses of action and a program which will achieve an optimum balance between maintenance and logistics on one hand and equipment performance on the other for a given state of operational readiness. It is still up to the user, however, to select each specific alternative to be assessed.

This study is divided into five sections including the introduction. Chapter II describes the Markov process as it is related to the Primer Insert Submodule. The approach is discussed and structured in order to evaluate the production of the Submodule.

Chapter III depicts the physical configuration of the Primer Insert Submodule. The Markov process described in Chapter II is then modeled for the process flowchart of the Submodule. Several sets of data are described which are necessary input for the model's calculation. The results of the calculations are then tabulated.

Chapter IV concludes the study and suggests recommendations. The Appendices follow this chapter and include a deck setup, a program listing, and a sample output for the application language used.

CHAPTER II

MATHEMATICAL MODEL

This chapter develops an analytical model to obtain the steady state production rate of a turret type submodule for Primer Insert. A decision was made to approach the problem by enumerating the states in which the system will exist. The basic configuration of the system, a series of turrets with 24 stations per turret, led to the concept of treating the system as a collection of 24 equal independent parallel elements and a number of series elements.

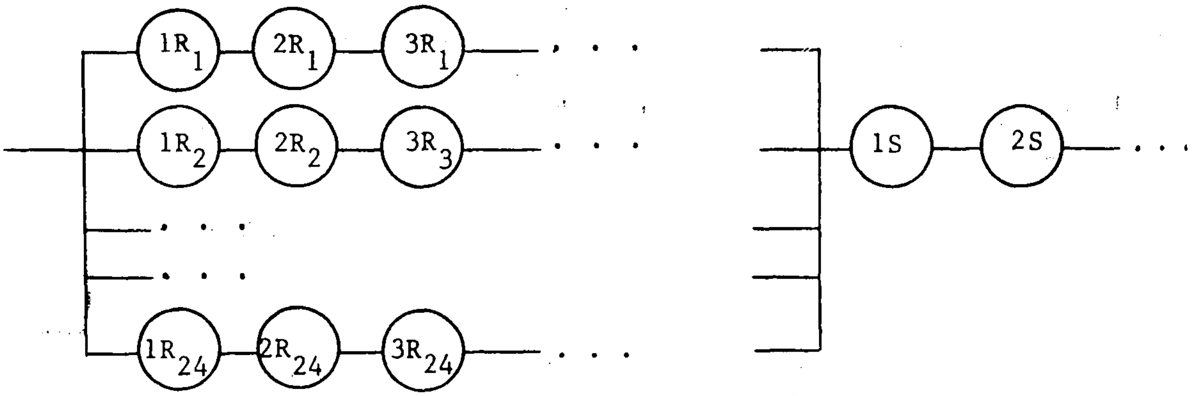

Figure 1. Basic Configuration.

The kth parallel element represents the composite of all equipment associated with station k on all turrets, the failure of which will cause failure of line k and hence cause a reduction of 1/24 in the production rate, but would not force the entire submodule to be shut down. The series element mathematically represents all failures in the submodule which would cause mandatory shutdown of the entire submodule for repair.

By carefully cataloging all elements in the submodule into one of these failure classes and obtaining reasonable estimates on mean failure and repair times, one can, through statistical analysis, obtain composite MTBFs and MTTRs for each parallel and series element, and hence the failure and repair rates.

A continuous Markov process was used to model the system. The basic assumption of a Markov process is that the state of the system at future times depends only on the present state and not on past states. The states of the system are given as follows:

State	System Condition
0	Zero failures present, system operating
1	One parallel line failed, system operating
2	Two parallel lines failed, system operating
.	.
.	.
n-1	n-1 parallel lines failed, system operating
n	n parallel lines failed, shutdown for repair
n+1	A series element has failed, shutdown for repair
n+2	Series plus one parallel line failed, shutdown for repair
n+3	Series plus two parallel lines failed, shutdown for repair
.	.
.	.
2n	Series plus (n-1) parallel lines failed, shutdown for repair.

The value of n is varied from 1 to 10 to obtain the best management policy for the rates given.

Further assumptions made for the model are:

(1) The probability density functions for all failures and repairs are exponential

(2) The probability of multiple failures in (t,t+dt) is negligible, i.e., transitions from state 0 to state 2 directly are impossible)

(3) No failures may occur in a repair state.

The following state diagram, Figure 2, was developed to aid in analyzing the structure of the model.

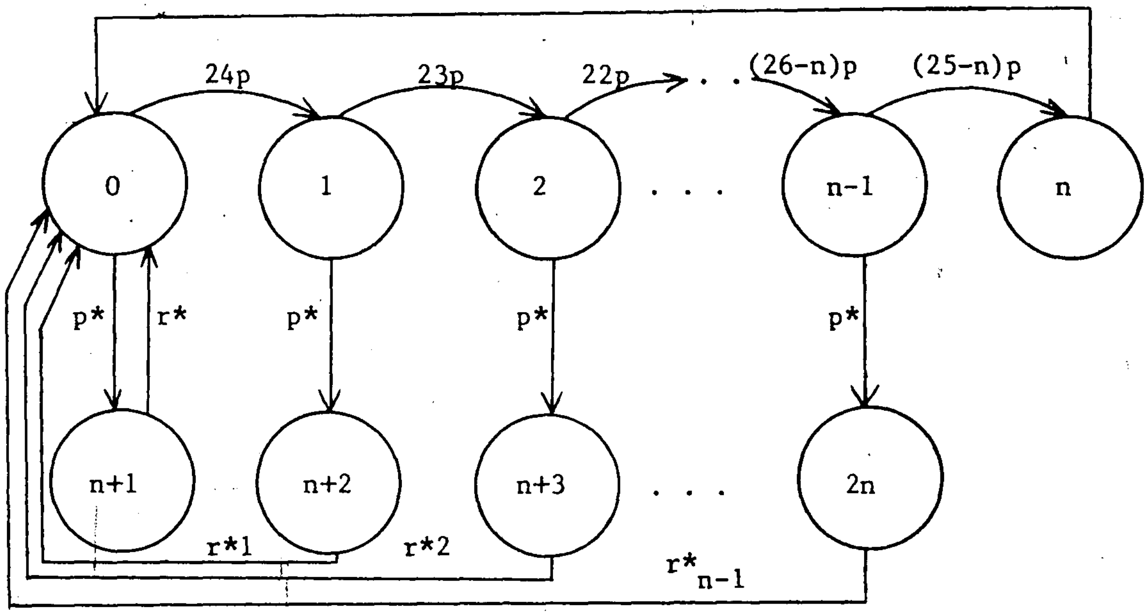

Figure 2. State Diagram.

The numbered circles represent the states previously described. The expressions on the connecting arrows represent the conditional transition rates for communicating between states, that is:

p = the failure rate of one parallel line
p^* = the failure rate for a series failure
r_n = the repair rate for n failed rotary tools
r^* = the repair rate for a series failure
r^*k = the repair rate for a series plus k failed rotary tools.

Define $P_i(t)$ as the probability of being in state i as a function of time, $i = 0, 1, \ldots, 2n$. It is now possible, using the state diagram, to write a set of equations expressed in matrix form as:

$$\frac{d\bar{P}}{dt} = \underset{\sim}{A}\bar{P}$$

Specifically:

$$\frac{dP_o}{dt} = -(24p+p^*)P_o+r_nP_n+r^*P_{n+1}+r^*_1P_{n+2}+\ldots+r^*_{n-1}P_{2n}$$

$$\frac{dP_i}{dt} = (25-i)pP_{i-1}-[(24-i)p+p^*]P_i$$

$$,i=1,2,\ldots n-1$$

$$\frac{dP_n}{dt} = (25-n)pP_{n-1}-r_nP$$

$$\frac{dP_k}{dt} = p^*P_{k-n-1} -r^*_{k-n-1}P_k$$

$$,k = n+1,n+2,\ldots,2n$$

Since the system must exist in one of the states specified, we have the additional equation

$$P_o + P_1 + \ldots + P_{2n} = 1$$

It was decided that steady-state probabilities were sufficient for the purpose of this study. Hence, setting all time derivatives equal to zero in the above equations one obtains

$$P_1 = 24p/(23p+p^*) \cdot P_o$$

$$P_i = (25-i)p/[(24-i)p+p^*] \cdot P_{i-1}$$

$$, i = 2,3,\ldots n-1$$

$$P_n = (25-n)p/r_n \cdot P_{n-1}$$

$$P_k = p^*/r^*_{k-n-1} \cdot P_{k-n-1}$$

$$, k = n+1,\ldots 2n$$

It is observable that in the above equations all probabilities P_i, $i=1,\ldots 2n$, are defined in terms of a lower numbered probability. For example,

$$P_2 = 23p/(22p+p^*) \cdot P_1$$

One may thus avoid using matrix inversion techniques in solving these equations.

The approach taken in the enclosed FORTRAN program was to solve all $P_i, i=1,2,\ldots,2n$, in terms of P_o.

By substituting into the equation $\sum_{k=0}^{2n} P_k = 1$, one may solve explicitly for P_o and use this value to directly solve for all remaining P_k. Given the estimates of failure and repair parameters, the program varies n, the number of turret stations allowed to fail before shutdown for repair. The output printed is the steady state production rate, PROD, and the probability of being in a repair state, DOWN, as a function of n, where

$$\mathrm{PROD} = \sum_{k=0}^{n-1} P_k \cdot (24-k)/24 \cdot \mathrm{PMAX},$$

$$\mathrm{PMAX} = \text{Maximum production rate}$$

and

$$\mathrm{DOWN} = P_n + P_{n+1} + \ldots + P_{2n}$$

CHAPTER III

PRIMER INSERT SUBMODULE

Description of Submodule

The primer insert submodule's function is to insert primers into bullet cases. Six rotary turrets and other driving, inspecting, and feeding devices make up this submodule. The process flow is as follows:

1. Bullet cases are loaded onto a carrying chain by the Chain Loading Turret. A case is not loaded into a chain loading position if a corresponding downstream tool station is down.

2. Primers are placed into primer cups of the cases by the Primer Insert Turret.

3. Primers are permanently fastened into the cases by the Primer Crimp Turret.

4. The primer's position in the bullet cases is checked by the Primer Inspect Turret. If a defect is detected, the case will be ejected by the Reject and Unload Turret further downstream.

5. The primers are then sealed in the cases with a lacquer and the inside mouth of the case is coated with a varnish. These operations are done by the Sealant Application Turret. Two optical inspection stations check the process.

6. Defective cases are ejected by the Reject and Unload Turret. Cases not rejected are sent on to the Load and Assemble Submodule.

For the purpose of modeling, repair actions connected with the Primer Insert Submodule were broken into two distinct classifications, 1) those concerned with the failures of the rotary turrets tools (parallel failures), and 2) those concerned with failures that cause the entire submodule to shut down (serial failures). The types of parallel failures considered by the model are chain loading turret tool failures, primer insert tool failures, crimp turret tool failures, primer inspect turret tool failures, sealant application turret tool failures, and reject and unload turret tool failures.

The types of serial failures considered are primer feed tray failure, which is the detonation of primers in the feed tray or the improper feeding of primers; jam failure, which is when a bullet case jams in one of the rotary turrets or elsewhere in the submodule; electrical failures, which are the power failures or the failure of an inspection station; turret series failure, which is the failure of the turret driving mechanism; and chain failures, in which the chain breaks, derails, or fails in some other manner.

A failure of a single tool on one of the six turrets (each containing 24 tools) decreases the production rate of the Primer Insert Submodule by fifty rounds per minute. Each subsequent failure of a rotary tool decreases the production rate by another fifty rounds per minute. Repair of a rotary tool may or may not be initiated when the tool fails, depending on the repair policy. The submodule must be shut down to effect a repair of a rotary tool. A serial failure causes the submodule to immediately stop production and repair must be completed before production can resume.

Process Flowchart

Figure 3 shows the process flowchart for the Primer Insert Submodule. The series elements in the flowchart do not correspond exactly to the serial elements described in the submodule description. The primer feed and inspect correspond to the primer feed tray of the submodule description. However, the primer inspect and mouth varnish inspect are included in the electrical serial failures.

Input Data

Table 1 contains the best estimates available of the failure and repair data for the parallel and serial elements described in the submodule description. To avoid proprietary disclosure, the data used for the purposes of demonstration were ficticious.

Output and Results

The program described in Appendix I was used to investigate ten tool repair policies for the primer insert submodule. These repair policies ranged from repair after the first rotary tool failure to repair after the tenth rotary tool failure. Table 2 shows the expected steady

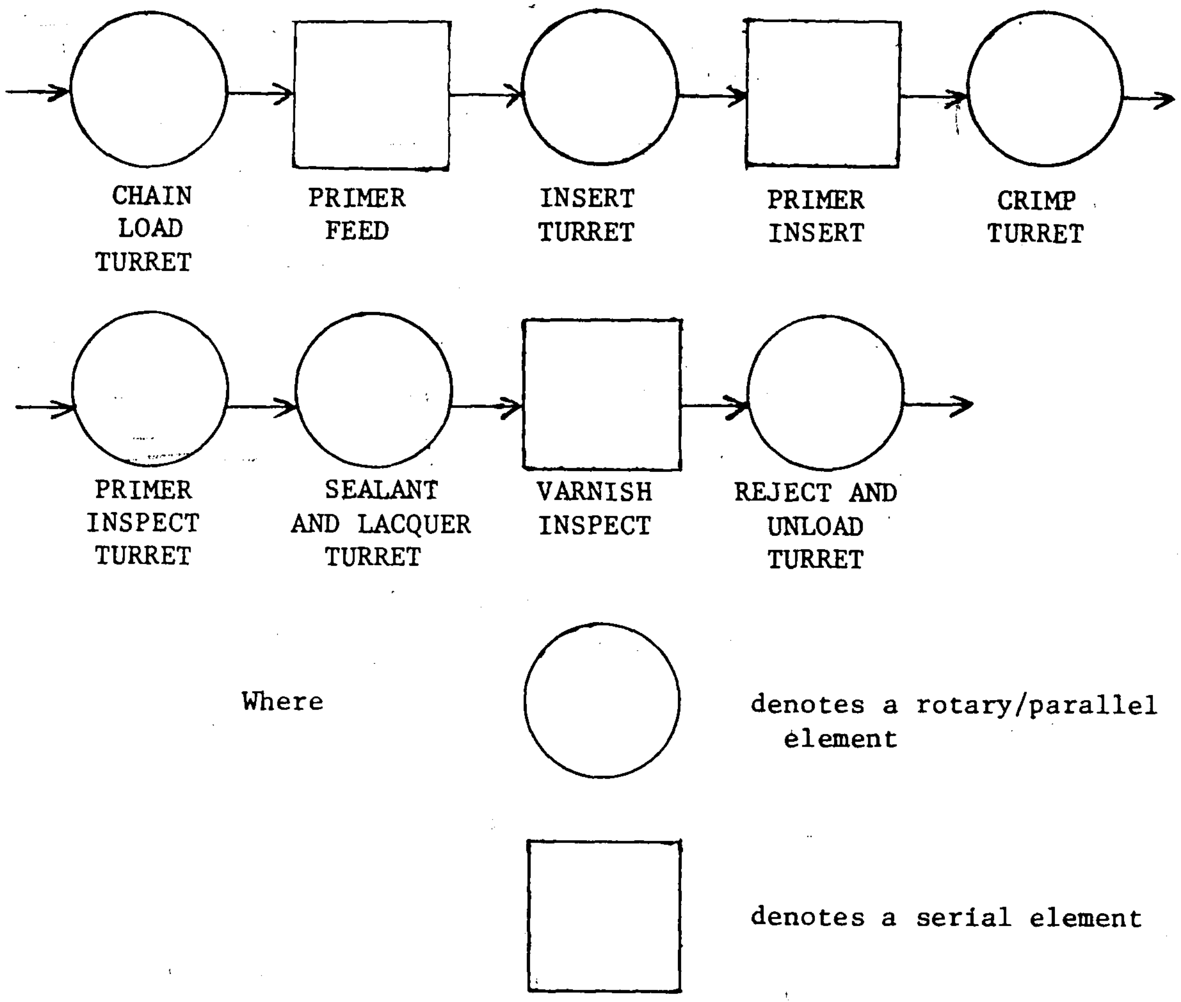

Figure 3. Primer-Insert Submodule Process Flowchart.

Table 1

PRIMER-INSERT FAILURE AND REPAIR ESTIMATES*

ELEMENT	PARALLEL		SERIAL	
	MTBF	MTTR	MTBF	MTTR
Chain Loading Turret	4800	15		
Insert Turret	4800	15		
Crimp Turret	9600	15		
Primer Inspect Turret	2400	15		
Sealant and Lacquer Turret	9600	5		
Unload and Reject Turret	14400	15		
Primer Feed Tray			960	15
Jam			100	2
Electrical			960	10
Turret Series Failure			24160	30
Chain Breakage			6000	30

*Estimates expressed in minutes per tool.

The process time estimates used were:

Time to Stop = 30 Seconds
Time to Jog = 2 Seconds
Time to Start = 60 Seconds

Table 2

REPAIR POLICIES

No. of Tools Failed Before Shutdown	Expected Steady State Production Rate	Probability of Being Down for Repair
1	817.8	.3185
2	828.7	.2973
3	826.5	.2885
4	821.9	.2833
5	817.2	.2798
6	813.0	.2774
7	809.6	.2756
8	807.0	.2744
9	805.1	.2735
10	803.7	.2729

state production rate and the probability of being down for repair for each of the ten repair policies. The maximum expected steady state production rate occurred when the policy was repair after the second rotary tool failure.

At this point, the decision maker can select alternatives to be assessed based on other factors such as the value of lost production, number of maintenance crewmen available, sparing of equipment, etc. Various combinations of rotary MTBF and MTTR were made for the purpose of demonstration representing the following combinations:

1. MTBF (best estimate), MTTR (best estimate)
2. 1/2 MTBF, MTTR
3. MTBF, 2MTTR
4. 1/2 MTBF, 2 MTTR
5. 2 MTBF, 2 MTTR
6. MTBF, 1/2 MTTR
7. 2 MTBF, 1/2 MTTR.

These combinations can be read into the program interactively. The results of this sensitivity analysis are shown in Table 3.

Table 3

SENSITIVITY ANALYSIS

Run No.	Rotary MTBF (Min)	Rotary MTTR (Min)	Optimum Policy Allowed Failures (Tools)	Average Prod. Rate per Shift (Rds/Min)
1	900.000	14.063	2.	828.747
2	450.000	14.063	3.	651.027
3	900.000	28.125	2.	658.267
4	450.000	28.125	3.	462.741
5	1800.000	14.063	2.	959.840
6	900.000	7.031	2.	952.026
7	1800.000	7.031	2.	1037.651

CHAPTER IV

CONCLUSIONS AND RECOMMENDATIONS

The maximum expected steady state production rate for the primer insert submodule was 828.7 rounds per minute. This optimum policy occurred when the rotary tool repair was initiated after the second rotary failure. The data indicated that the most frequent failures would occur in the primer inspect turret and primer feed or by electrical failure or jam. Detonation was a major cause of failure.

The serial failures contribute to downtime more than the rotary failures. The serial Mean Time Between Failure (MTBF) (81.4 minutes) is significantly less than the rotary Mean Time Between Failure (MTBF) (900 minutes).

The model is fairly insensitive to different tool repair policies. That is, there is no great change in expected steady state production rate in a small range about the optimum tool repair policy. However, the model is sensitive to variations in the parallel MTBF and MTTR estimates. As shown in Table 3, overestimating or underestimating the failure and repair times has a great effect on the expected steady state production rate. The tool policy, however, remains at repair after either two or three tool failures for all seven time combinations. Decisions relating to preventative and corrective maintenance, repair crew scheduling, redundancy, and the value of lost production could greatly affect the failure and repair times. It is the purpose of this computer-based support to eliminate as many unknowns as possible and to add structure to the problem so that the decision maker can make a satisfactory decision based on other decisions.

It is recommended that the most recent data available be used in determining the tool policies. This data would replace the data in Table 1 and would produce different results.

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APPENDIX I

APPENDIX I

A. Deck Setup

The computer program is written in FORTRAN 77. The values for MTBF and MTTR can be entered interactively to aid in decision support. These variables may be changed for program operation on a different computer.

The data cards follow the following format:

NP corresponds to number of parallel elements
NS corresponds to number of series elements.

CARD	COLUMN	DESCRIPTION
1	21-25	Number of parallel elements
2 to NP + 1	1-28	Name of turret
	30-39	Mean time between failures $X10^3$ in minutes
	40-49	Mean time to repair in minutes
NP + 2	21-25	Number of series elements
NP + 3 to NP + NS + 2	1-28	Name of series element
	30-39	Mean time between failures $X10^3$ in minutes
	40-49	Mean time to repair in minutes
NP + NS + 3	10-19	Combined starting and stopping time in minutes
	20-29	Jog time in minutes
	30-39	Maximum production rate per minute

B. Program Listing

```




c                 dictionary of variables
c
c      nturet          number of turrets, right justified integer
c      turret          name of turret
c      tmtbf           mtbf for turret, 10**-3 min, floating pt.
c      tmttr           mttr for turret, floating pt.
c      tss             combined starting and stopping time for the
c                      submodule, minutes, floating pt.
c      jogtm           jog time, minutes, floating pt.
c      pmax            max. production rate of submodule, 1/min.,
c                      floating pt.
c      ttr             mean time to repair derived by averaging the
c                      repair time excluding the stop, start, and
c                      jog times, minutes, floating pt.
c      rtmtbf          reciprocal of tmtbf, 10**-3 min., floating pt.
c      slm             mttr/mtbf, 10**-3 min., floating pt.
c      srmtbf          summation of 1/mtbf for given data
c      sslm            summation of mttr/mtbf, 10**-3 min.
c      ttf             mean time between failures, 1000/srmtbf
c      ttr             mean time to repair derived by averageing the
c                      repair times excluding stop, start, and jog
c                      times, minutes, floating pt.
c      ps              1/ttf
c      rs1             1/ttr
c      n               number of tools failed before shutdown
c      prod            expected steady state production, rounds/min.
c      down            probability of being down for repair
c      ii              number of variations for sensitivity analysis
c      xhld            array containing rotary mtbf,rotary mttr,
c                      optimum allowed failures(tools), and average
```

```
c                    dictionary of variables
c
c      nturet        number of turrets, right justified integer
c      turret        name of turret
c      tmtbf         mtbf for turret, 10**-3 min.,floating pt.
c      tmttr         mttr for turret, floating pt.
c      tss           combined starting and stopping time for the
c                    submodule, minutes, floating pt.
c      jogtm         jog time, minutes, floating pt.
c      pmax          max. production rate of submodule, 1/min.,
c                    floating pt.
c      ttr           mean time to repair derived by averaging the
c                    repair time excluding the stop, start, and
c                    jog times, minutes, floating pt.
c      rtmtbf        reciprocal of tmtbf, 10**-3 min., floating pt.
c      slm           mttr/mtbf, 10**-3 min., floating pt.
c      srmtbf        summation of 1/mtbf for given data
c      sslm          summation of mttr/mtbf, 10**-3 min.
c      ttf           mean time between failures, 1000/srmtbf
c      ttr           mean time to repair derived by averageing the
c                    repair times excluding stop, start, and jog
c                    times, minutes, floating pt.
c      ps            1/ttf
c      rsl           1/ttr
c      n             number of tools failed before shutdown
c      prod          expected steady state production, rounds/min.
c      down          probability of being down for repair
c      ii            number of variations for sensitivity analysis
c      xhld          array containing rotary mtbf,rotary mttr,
c                    optimum allowed failures(tools), and average
```

```
c                             production per shift
c
c


           dimension p(20), r(10), rsp(10)
           dimension xhld(25,4)
           dimension turret(14)

           real jostm

           nanal=0

c                     assignment of input/output numbers

           open(unit=2,device='dsk',file='test.dat')
           open(unit=6,device='tty')

           in=2
           io=6
           iflag=0

c***** read in data on turrets in parallel, then in series
c       (turret name, mtbf,mttr)

1000       continue

           do 251 ij= 1,2
           read(in,201) nturet
201        format(20x,i5)
           if(nturet) 1000,1000,1020
1020       continue

c***** write headings for entered data

```

```
           write(io,699)
           write(io,290)
290        format(t16,'name',t38,'mtbf',t46,'1/mtbf',t56,'mttr',
     +     t63,'mttr/mtbf',/,t37,'(10**3',t46,'(10**-3)',t55,
     +     '(mins.)',t64,'(10**-3)',/,t37,'mins.)'///)

           srmtbf=0.0
           sslm=0.0

c***** calculate

           do 250 jt=1,nturret
           read(in,202) turret,tmtbf,tmttr
202        format(14a2,1x,2f10.2)
           rtmtbf=1.0/tmtbf
           srmtbf=srmtbf+rtmtbf
           slm=rtmtbf*tmttr
           sslm=sslm+slm
           write(io,291) turret,tmtbf,rtmtbf,tmttr,slm
291        format(4x,14a2,t34,4f9.2)
250        continue

c***** write summations

           write(io,292) srmtbf,sslm
292        format(t45,'--------',t63,'--------',/,t/,'summation',
     +     t43,f9.2,t61,f9.2)
           ttf=1000./srmtbf

c***** mtbf and mttr derived by averaging

           write(io,293) ttf
293        format(//,8x,'mtbf = mean time between failures',//,
     +     8x,'mtbf = ',f9.3,' mins.')
           ttr=sslm/srmtbf
```

```
            go to (210,211), ij

      210   tr1=ttr
            ttf1=ttf
      211   write(io,294) ttr
      294   format(///,8x,'mttr = mean time to repair derived by ',
     +      'averaging the repair',/,16x,'times excluding stop,',
     +      ' jog, and start times',//,8x,'mttr = ',f9.3,' mins.')
            go to (251,220), ij
      220   ps=1.0/ttf
            rs1=1.0/ttr
      251   continue

c***** read and write time to start and stop, jogtime, and
c      maximum production rate

            read(in,203) tss,jogtm,pmax
      203   format(9x,3f10.4)
            write(io,699)
            write(io,692) tss
            write(io,693) jogtm
            write(io,696) pmax

c***** read data interactively

      205   write(6,100)
      100   format(//,1x,'enter mtbf and mttr you wish to use',
     +      ' for analysis in the following form',/,2x,
     +      'xxxx.xx xxx.xxxx',/)
            read(6,102) ttf,tr
      102   format(1X,F8.2,1x,f8.4)
            nanal=nanal+1

            if(iflag.eq.1) go to 104

```

```
c***** write headers for analysis

            write(io,700)
            write(io,701)
            write(io,702)
            write(io,703)

            iflag=1

c***** begin sensitivity analysis

104         do 310 ii=1,nanal
            xprod=0.0
            rs=rs1
            pr=1.0/ttf

            do 60 n=1,10
            nn=n-1

            do 11 k=1,n
            fk=k
            r(k)=1./(tss+(fk-1.)*jostm+fk*tr)
            if(rs-r(k))5,5,4
4           rsp(k)=r(k)
            go to 11
5           rsp(k)=rs
11          continue


            po=1.0
            p(1)=24.*pr/r(1)*po
            p(n+1)=ps/rs*po
            if(n-1) 17,17,6
6           p(1)=24.*pr/(23.*pr+ps)*po
```

```
      do 10 j=2,nn
      fj=j
10    p(j)=(25.-fj)*pr/((24.-fj)*pr+ps)*p(j-1)
      fn=n

      do 15 k=2,n
      kk=k+n
15    p(kk)=ps/rsp(k-1)*p(k-1)
      p(n)=(25.-fn)*pr/r(n)*p(n-1)
17    n2=n*2
      sum=po

      do 20 k=1,n2
20    sum=sum+p(k)
      po=po/sum

      do 30 k=1,n2
30    p(k)=p(k)/sum
      prod=po*pmax
      l=n-1
      if(n-1) 50,50,45

45    do 50 j=1,l
      prod=prod + p(j) * (float(24-j) / 24.) * pmax
50    continue
      down =0.0

      do 51 j=n,n2
      down=down + p(j)
51    continue


      if(xprod-prod) 302,303,303
302   xhld(nanal,1)=ttf
      xhld(nanal,2)=tr
```

```
        xhld(nanal,3)=float(n)
        xhld(nanal,4)=prod
        xprod=prod

303     if(nanal-1) 301,301,60
301     write(io,704) n,prod,down
60      continue
310     continue

c***** end analysis


c***** formats for write statements

699     format(//,t35,'submodule',/)
692     format(20x,'timo to start and stop',t50,
     +  f10.4,'min.')
693     format(20x,'time to jog',t50,f10.4,' min.')
696     format(20x,'maximum production rate',t50,f10.2,
     +  'rounds',////)
700     format(///,20x,'no. of tools',5x,'expected',11x,
     +  'probability of')
701     format(20x,'failed before',4x,'steady state',
     +  7x,'being down')
702     format(20x,'shut down',8x,'production rate',4x,
     +  'for repair')
703     format(20x,'*****************************************',
     +  '********')
704     format(24x,i3,10x,f10.1,10x,f6.4)

        write(6,299) xhld(nanal,4)
299     format(/,1x,'production rate is ',f10.2,' rounds/min.',/)

331     write(6,332)
332     format(1x,'do you wish to continue?',/,1x,
```

```
     +  'type y for yes or n for no!')
        read(6,333) answer
333     format(A1)
        if(answer.eq.'y') go to 205
        if(answer.eq.'n') go to 335
        write(6,707)
707     format(1x,'error message - you did not type the',
     +  ' correct response',/)
        go to 331

c***** write headings for sensitivity analysis

335     write(io,320) nanal
320     format(///,t30,'sensitivity analysis',//t18,'note ',
     +  'run no. 1 is best estimate while',/t24'2 thru ',i2,
     +  ' are answers obtained by varying',/t24,'mtbf and ',
     +  ',mttr',//t12,'run',t17,'rotary mtbf',t30,'rotary ',
     +   'mttr't44,'optimum policy',t60,'average prod.',/,
     +  t12,'no.',t20,'(min)',t33,'(min)',t43,'allowed ',
     +  'failures',t60,'rate per shift',/t48,'(tools)',t62,
     +  '(rds/min)',/)


c***** write values for analysis

        do 325 ii=1,nanal
325     write(io,330) ii,(xhld(ii,jj),jj=1,4)
330     format(t11,i3,t18,f10.3,t31,f10.3,t49,f4.0,t62,f10.3)

        write(6,400)
400     format(///////////)


c***** end of program

        call exit
        end
```

C. Sample Output

```
                                        submodule

            name                        mtbf     1/mtbf     mttr    mttr/mtbf
                                       (10**3   (10**-3)  (mins.)   (10**-3)
                                       mins.)


chain loading turret                    4.80      0.21     15.00       3.12
insert turret                           4.80      0.21     15.00       3.12
crimp turret                            9.60      0.10     15.00       1.56
primer inspect turret                   2.40      0.42     15.00       6.25
sealant and lacquer turret              9.60      0.10      5.00       0.52
unload and reject turret               14.40      0.07     15.00       1.04
                                                 -------             -------
  summation                                       1.11                15.62


   mtbf = mean time between failures

   mtbf =    900.000 mins.


   mttr = mean time to repair derived by averaging the repair
               times excluding stop, jog, and start times

   mttr =     14.063 mins.
```

```
                                  submodule

                   name                        mtbf      1/mtbf     mttr    mttr/mtbf
                                             (10**3    (10**-3)  (mins.)   (10** 3)
                                             mins.)



chain loading turret                          4.80       0.21     15.00       3.12
insert turret                                 4.80       0.21     15.00       3.12
crimp turret                                  9.60       0.10     15.00       1.56
primer inspect turret                         2.40       0.42     15.00       6.25
sealant and lacquer turret                    9.60       0.10      5.00       0.52
unload and reject turret                     14.40       0.07     15.00       1.04
                                                       --------            --------
  summation                                              1.11                15.62


    mtbf = mean time between failures

    mtbf =    900.000 mins.


    mttr = mean time to repair derived by averaging the repair
                times excluding stop, jog, and start times

    mttr =     14.063 mins.
```

```
                              submodule

              name                    mtbf     1/mtbf    mttr   mttr/mtbf
                                    (10**3   (10**-3) (mins.)  (10**-3)
                                    mins.)


   primer feed tray                   0.96      1.04     15.00     15.63
   jam                                0.10     10.00      2.00     20.00
   electrical                         0.96      1.04     10.00     10.42
   turret series failure             24.16      0.04     30.00      1.24
   chain breakage                     6.00      0.17     30.00      5.00
                                            --------            --------
     summation                                 12.29               52.28


     mtbf = mean time between failures

     mtbf =    81.358 mins.


     mttr = mean time to repair derived by averaging the repair
                  times excluding stop, jog, and start times

     mttr =      4.254 mins.


                              submodule

                 time to start and stop             1.5000min.
                 time to jog                        0.0333 min.
                 maximum production rate          1200.00rounds
```

```
enter mtbf and mttr you wish to use for analysis in the following form
 xxxx.xx xxx.xxxx

  900.00  14.063


                      no. of tools     expected            probability of
                      failed before    steady state        being down
                      shut down        production rate     for repair
                      ****************************************************
                             1                817.8             .3185
                             2                828.7             .2973
                             3                826.5             .2885
                             4                821.9             .2833
                             5                817.2             .2798
                             6                813.0             .2774
                             7                809.6             .2756
                             8                807.0             .2744
                             9                805.1             .2735
                            10                803.7             .2729

production rate is      828.74 rounds/min.


do you wish to continue?
type y for yes or n for no?
y


enter mtbf and mttr you wish to use for analysis in the following form
 xxxx.xx xxx.xxxx

  450.00  14.063

production rate is      651.02 rounds/min.
```

```
do you wish to continue?
type y for yes or n for no:
y


enter mtbf and mttr you wish to use for analysis in the following form
 xxxx.xx xxx.xxxx


  900.00  28.125

production rate is      658.27 rounds/min.

do you wish to continue?
type y for yes or n for no:
y


enter mtbf and mttr you wish to use for analysis in the following form
 xxxx.xx xxx.xxxx

  450.00  28.125

production rate is      462.74 rounds/min.

do you wish to continue?
type y for yes or n for no:
y


enter mtbf and mttr you wish to use for analysis in the following form
 xxxx.xx xxx.xxxx

 1800.00  14.063
```

```
production rate is      959.84 rounds/min.

do you wish to continue?
type y for yes or n for no:
y


enter mtbf and mttr you wish to use for analysis in the following form
 xxxx.xx xxx.xxxx

  900.00   7.031

production rate is      952.03 rounds/min.

do you wish to continue?
type y for yes or n for no:
y


enter mtbf and mttr you wish to use for analysis in the following form
 xxxx.xx xxx.xxxx

 1800.00   7.031

production rate is     1037.65 rounds/min.

do you wish to continue?
type y for yes or n for no:
n
```

C

```
                    sensitivity analysis

          note run no. 1 is best estimate while
                2 thru  7 are answers obtained by varying
                mtbf and mttr

run   rotary mtbf   rotary mttr   optimum policy   average prod.
no.      (min)         (min)     allowed failures  rate per shift
                                      (tools)        (rds/min)

 1       900.000       14.063          2.              828.739
 2       450.000       14.063          3.              651.018
 3       900.000       28.125          2.              658.267
 4       450.000       28.125          3.              462.741
 5      1800.000       14.063          2.              959.835
 6       900.000        7.031          2.              952.031
 7      1800.000        7.031          2.             1037.654
```

VITA

Lydia Anne Chastain is the daughter of Dr. and Mrs. Herchel Eugene Lynch of New Boston, Texas. She graduated from New Boston High School as valedictorian in 1976. She attended the University of Arkansas and received a Bachelor of Science in Industrial Engineering in 1980. During her undergraduate years, she was a member of Kappa Kappa Gamma Sorority, the Engineering Council for Students, and the American Institute of Industrial Engineering. She also served as editor of the Arkansas Engineer for two years.

Since graduation, Anne has worked for Owens Corning Fiberglas, AT&T Technologies, and Lehigh University.

Anne currently lives in Breinigsville, Pennsylvania with her husband, Michael and their infant son, Matthew Evans.