ESTIMATION OF MANPOWER FORECAST VARIATION
BY GPSS SIMULATION

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INTRODUCTION

Traditionally, manpower estimation has been done on an expected value basis. Such estimates, although providing an estimate of the mean of manpower requirements, provide no indication of the probable spread about the mean. Manpower solution plans, however, often implicitly assume an estimate spread based upon experience gained from previous projects. This paper is concerned with estimation of manpower forecast variations, both in the aggregate and by skill level.

BASIC PROCESS MODEL

Consider the following basic model of a process. Figure I is a flow diagram for the process possessing the following characteristics:

1. There are at least n primarly operations (OPI, OP2, . . . OPn) performed on each unit passing through the process.
2. There are n! possible rework operations (RII, R12, . . . Rnn) on each unit passing through the process.
3. There are n primary yield points (SI, S2, . . . Sn) in the process.

Each primary and secondary operation on a unit represents a demand for manpower with a particular skill. Each yield point represents a possible reduction in "throughput" which affects the manpower requirement as well. Typically, primary operation times, rework times and yield rates are stochastic variables. Therefore, to effectively estimate manpower variation, process simulation must be based on a probabilistic specification of these process elements.

SUBJECTIVE DENSITY FUNCTION SPECIFICATION

Unfortunately, process information rarely is detailed sufficiently to permit direct specification of the density functions of stochastic variables. When such information is available, the developed cumulative distribution function can serve as input to a General Purpose Simulation System (GPSS) model in the form of a tabled function. When such information is not available - and it often is not - subjective estimation can serve as a basis for specification of a density function.

Figure 2 illustrates a family of 8l curves developed by the writer to serve as normalized density functions for specification of stochastic variables. Selection of a particular density function from the family is based on answers to five questions concerning the variable of interest. The individual most familiar with the process is asked to estimate:

1. The modal value (most likely). Point X
2. The lower limit (the value below which only 5 per cent occurrence is expected). Point Y
3. The upper limit (the value above which only 5 per cent occurrence is expected). Point Z
4. The lower limit end point condition (a subjective selection of one of three curves of varying flatness as the curve passes through point Y).
5. The upper limit end point condition [similar to (4) for point Z].

These five questions are in an increasing order of difficulty of obtaining accurate information. The information they extract is believed sufficient, for most applications to allow specification of a density function which approximates the shape of the underlying density function for the variable of interest. The 8l curves represent a family possessing three shapes (i.e., kurtosis levels) at both ends of the density function, at five possible left or right skewness levels. The ratio of XZ to YZ permits selection of the appropriate skewness level. A Fortran program was developed to produce X-Y corrdinates for the 81 cumulative distribution functions in the GPSS specified format.

Figure 3 illustrates the use of the family of density functions.

Assume the most likely (i.e., modal) time required for an operation is estimated at 70 minutes. Fifty minutes is estimated as the lower limit below which operation times occur 5 per cent of the time. Similarly, 100 minutes is estimated to be the 5 per cent upper limit. Since operating times very rarely take less than 47 minutes, a type C curve is selected for the left half of the density function. Because times extend occasionally as high as 125 minutes, a type A curve is chosen for the right half of the density function.

The ratio of XZ to YZ of 30/50 = 0.6 comes closest to a number 2 skewness level which has a ratio of 0.625. Therefore, a CA2 curve is employed. The simulation generates operation times distributed according to density function CA2 employing lower and upper 5 per cent limits of 50 and 100 minutes, respectively. Similar specification of stochastic variables for the other operation times, rework times and per cent transfers to rework or scrap will complete specification of stochastic elements of a model.

SUMMARY

To generate the desired output, which is a distribution of labor requirements by specified skills, a GPSS model is developed for each specific process. Figure 4 is a GPSS model for a process containing three primary and five secondary operations. The model generates operation times, rework times, and transfers to rework and scrap for successive transactions based on the function values produced employing the selected cumulative distribution functions. Data cards for all 81 curves were produced by a FORTRAN program. The data cards for curves AAI and CA3 were merely inserted into the above GPSS program. Figure 5 is a distribution of labor times accumulated for a single run of 100 units through the process. An obvious extension of the model to permit estimation of interference times would be to allow units to queue at process steps as a function of facility restrictions. Such a model would permit estimation of the labor skills required and their variation for a given level of "throughput", including facility restriction effects, for a defined calendar period.

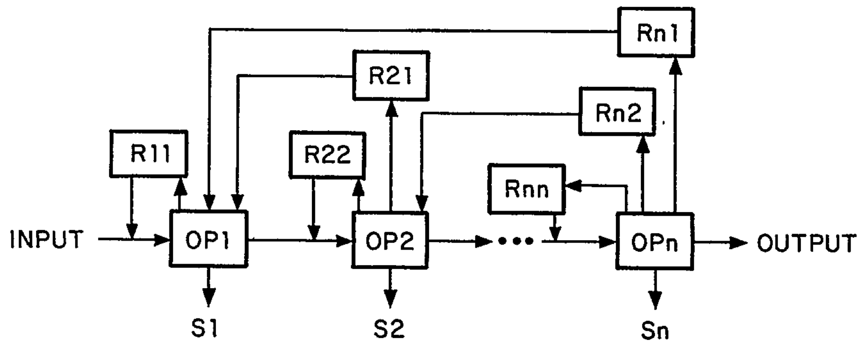

Figure 1. Basic Process Model

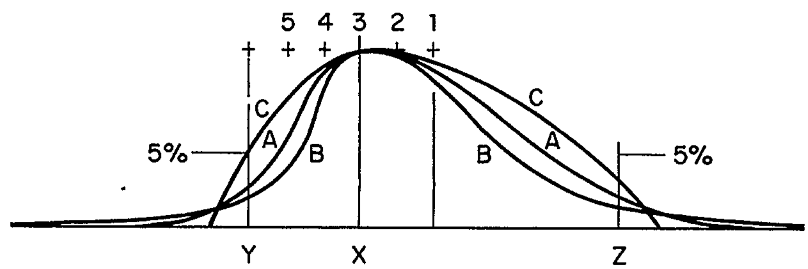

Figure 2. A Family of Density Functions

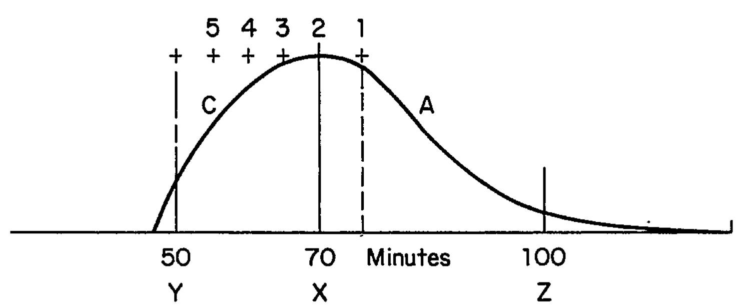

Figure 3. Distribution of Operation Times

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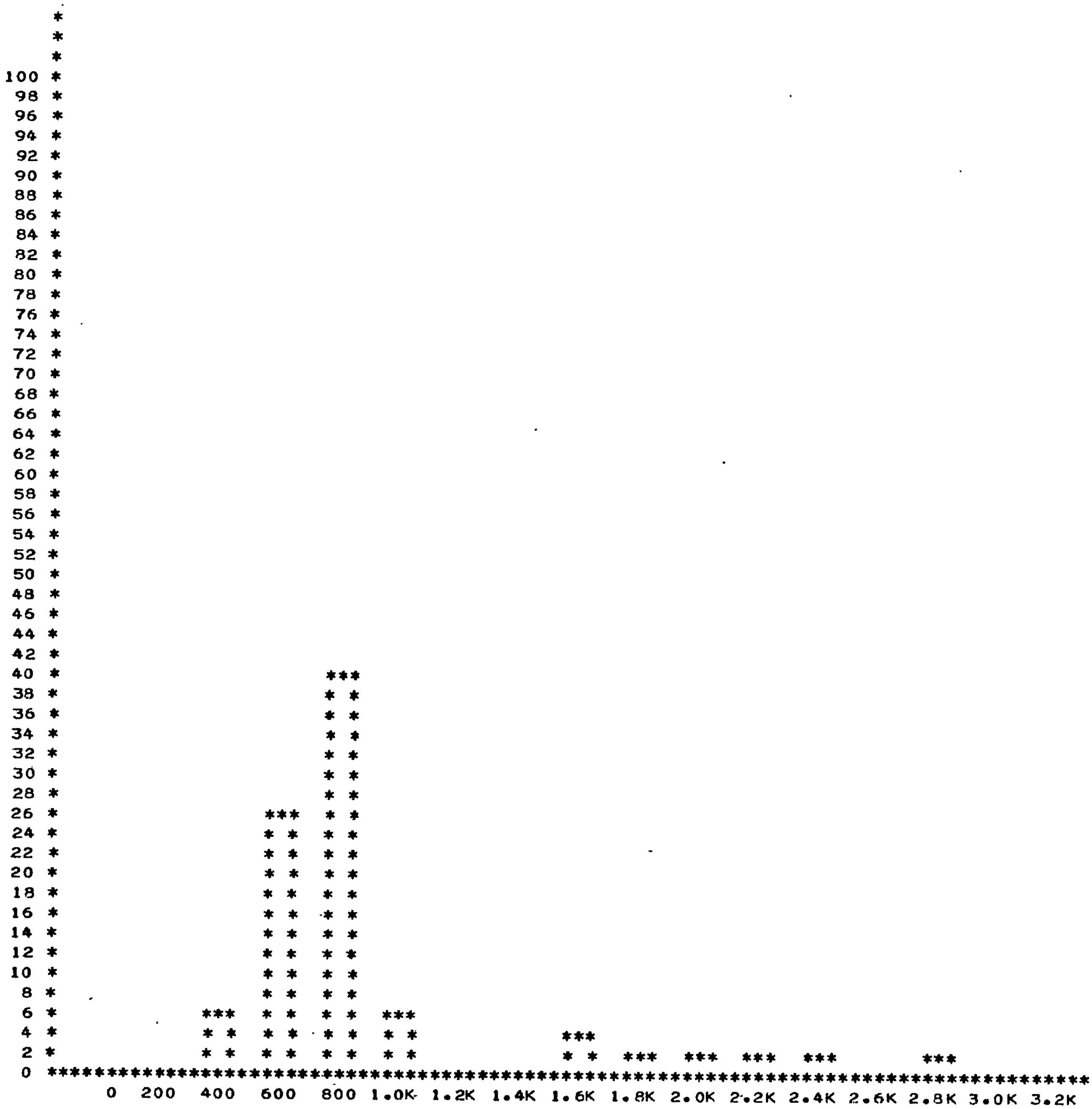
BLOCK
NUMBER  *LCC   OPFRATION  A,B,C,D,E,F,G              COMMENTS
        *
        *       STOCHASTIC MANPOWER FSTIMATOR 2
                SIMULATE
        *
        *   FUNCTION DEFINITIONS
         1      FUNCTION   RN1,C17        (AA1)
        0.000 -50.0 0.002 -37.5 0.007 -25.0 0.020 -12.5 0.051 0.000 0.111 12.5
        0.207 25.0  0.338 37.5  0.495 50.0  0.653 62.5  0.786 75.0  0.884 87.5
        0.944 100.0 0.976 112.5 0.991 125.0 0.998 137.5 1.000 150.0
         2      FUNCTION   RN2,C17       (CA3)
        0.000 -50.0 0.001 -37.5 0.002 -25.0 0.003 -12.5 0.051 0.000 0.222 12.5
        0.391 25.0  0.542 37.5  0.669 50.0  0.772 62.5  0.849 75.0  0.906 87.5
        0.947 100.0 0.974 112.5 0.990 125.0 0.998 137.5 1.000 150.0
        *
1               GENERATE   1,,,100,,20
2        ENT10  ENTER      10
3               ADVANCE    V1
4               ASSIGN     1,V1
5               ASSIGN     18+,P1
6               TABULATE   10
7               LEAVE      10
8               ASSIGN     2,V10
9               TRANSFER   ,*2,SCP1,TRF11
10       SCP1   TABULATE   1
11              TABULATE   2
12              TABULATE   3
13              TERMINATE  1
14       TRF11  ASSIGN     3,V11
15              TRANSFER   ,*3,ENT11,ENT20
16       ENT11  ENTER      11
17              ADVANCE    V12
18              ASSIGN     11,V12
19              ASSIGN     18+,P11
20              TABULATE   11
21              LEAVE      11
22              TRANSFER   ,ENT10
23       ENT20  ENTER      20
24              ADVANCE    V2
25              ASSIGN     12,V2
26              ASSIGN     19+,P12
27              TABULATE   20
28              LEAVE      20
29              ASSIGN     4,V20
30              TRANSFER   ,*4,SCP2,TRF21
31       SCP2   TABULATE   1
32              TABULATE   2
33              TABULATE   3
34              TERMINATE  1
35       TRF21  ASSIGN     5,V21
36              TRANSFER   ,*5,ENT21,TRF22
37       ENT21  ENTER      21
38              ADVANCE    V24
39              ASSIGN     19+,P13
40              ASSIGN     13,V24
41              TABULATF   21
42              LEAVE      21
43              TRANSFER   ,ENT10
44       TRF22  ASSIGN     6,V22
45              TRANSFER   ,*6,ENT22,ENT30
46       ENT22  ENTER      22
47              ADVANCE    V23
48              ASSIGN     19+,P14
49              ASSIGN     14,V23
50              TABULATE   22
51              LEAVE      22
52              TRANSFER   ,ENT20
53       ENT30  ENTER      30
54              ADVANCE    V3
55              ASSIGN     15;V3
56              ASSIGN     20+,P15
57              TABULATE   30
58              LEAVE      30
59              ASSIGN     7,V30
60              TRANSFER   ,*7,SCP3,TRF32
61       SCP3   TABULATE   1
62              TABULATE   2
63              TABULATE   3
64              TERMINATE  1
65       TRF32  ASSIGN     9,V32
66              TRANSFER   ,*9,ENT32,TRF33
67       ENT32  ENTER      32
68              ADVANCE    V34
69              ASSIGN     16,V34
70              ASSIGN     20+,P16
71              TABULATE   32
72              LEAVE      32
73              TRANSFER   ,ENT20
74       TRF33  ASSIGN     10,V33
75              TRANSFER   ,*10,ENT33,FTERM
76       ENT33  ENTER      33
77              ADVANCE    V35
78              ASSIGN     17,V35
79              ASSIGN     20+,P17
80              TABULATE   33
81              LEAVE      33
82              TRANSFER   ,ENT30
83       FTERM  TABULATE   1
84              TABULATE   2
85              TABULATE   3
86              TERMINATE  1
        *
        *
        *   STORAGE  CAPACITITIFS
         10     STORAGE    2000
         11     STORAGE    2000
         20     STORAGE    2000
         21     STORAGE    2000
         22     STORAGE    2000
         30     STORAGE    2000
         32     STORAGE    2000
         33     STORAGE    2000
        *

*   VARIABLE DEFINITIONS
 1      FVARIABLE  300+(FN1/100)600
 10     FVARIABLE  (95/100-FN2*45/10000)*1000
 11     FVARIABLF  (95/100-FN2*45/10000)*1000
 12     FVARIABLE  240+(FN1/100)120
 2      FVARIABLE  600+(FN1/100)240
 20     FVARIABLE  (80/100-FN2*20/10000)*1000
 21     FVARIABLE  (90/100-FN1*10/10000)*1000
 22     FVARIABLE  (90/100-FN2*40/10000)*1000
 23     FVARIABLE  150+(FN2/100)50
 24     FVARIABLE  80+(FN2/100)40
 3      FVARIABLE  1200+(FN2/100)1200
 30     FVARIABLE  (90/100-FN1*10/10000)*1000
 32     FVARIABLE  (90/100-FN2*20/10000)*1000
 33     FVARIABLE  (90/100-FN2*30/10000)*1000
 34     FVARIABLE  300+(FN1/100)300
 35     FVARIABLE  150+(FN1/100)50
*
*   TABLE DEFINITIONS
 1      TABLE      P18,0,200,22
 2      TABLE      P19,0,200,22
 3      TABLE      P20,0,500,18
*
 10     TABLE      P1,0,50,26
 11     TABLE      P11,100,20,22
 20     TABLE      P12,460,20,33
 21     TABLE      P13,50,5,24
 22     TABLE      P14,100,10,17
 30     TABLE      P15,500,200,17
 32     TABLE      P16,100,50,20
 33     TABLE      P17,100,10,17
*
        START      100
        CLEAR
        START      100
        CLEAR
        START      100
        CLFAR
        START      100
        CLEAR
        START      100
        CLEAR
        START      100
        CLEAR
        START      100
        CLFAR
        START      100
        CLEAR
        START      100
        CLEAR
        START      100
        REPORT
        OUTPUT
 TAB    TITLE      ,TOTAL TIME ACCUMULATED BY SKILL OR OPERATION
 TAB    INCLUDE    T1- 33/1,5
        EJECT
        GRAPH      TF,1
        ORIGIN     55,5
        X          ,3,2,0,,22
        Y          0,2,50,1
 30     STATEMENT  58,42,SKILL 1 MANPOWER DENSITY FUNCTION ESTIMATE
        ENDGRAPH
        EJECT
*
        GRAPH      TF,2
        ORIGIN     55,5
        X          ,3,2,0,,22
        Y          0,2,50,1
 30     STATEMENT  58,42,SKILL 2 MANPOWER DENSITY FUNCTION ESTIMATE
        ENDGRAPH
        EJECT
*
        GRAPH      TF,3
        ORIGIN     55,5
        X          ,3,2,0,,18
        Y          0,2,50,1
 30     STATEMENT  58,42,SKILL 3 MANPOWER DENSITY FUNCTION ESTIMATE
        ENOGRAPH
        EJECT
*
        GRAPH      TD,1
        ORIGIN     55,5
        X          ,,4,0,,22
        Y          0,2,50,1
 30     STATEMENT  58,40,SKILL 1 MANPOWER CUMULATIVE DISTRIBUTION
        ENDGRAPH
        EJECT
*
        GRAPH      TD,2
        ORIGIN     55,5
        X          ,,4,0,,22
        Y          0,2,50,1
 30     STATEMENT  58,40,SKILL 2 MANPOWER CUMULATIVE DISTRIBUTION
        ENDGRAPH
        EJECT
*
        GRAPH      TD,3
        ORIGIN     55,5
        X          ,,4,0,,18
        Y          0,2,50,1
 30     STATEMENT  58,40,SKILL 3 MANPOWER CUMULATIVE DISTRIBUTION
        ENDGRAPH
        END
```

Fig. 4



SKILL 1 MANPOWER DENSITY FUNCTION ESTIMATE

Fig. 5