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A Dynamic Programming Algorithm FORTRAN Coded, for Gross Production Scheduling

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A DYNAMIC PROGRAMMING ALGORITHM FORTRAN CODED FOR GROSS PRODUCTION SCHEDULING

DECK KEY

1. Sample Problem 0, 1, 2
   (Refer to Page 17 for Input data listings)
2. Object Deck
3. Source Deck

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Modifications or revisions to this program, as they occur, will be announced in the appropriate Catalog of Programs for IBM Data Processing Systems. When such an announcement occurs, users should order a complete new program from the Program Information Department.

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PROGRAM ABSTRACT

Title: A Dynamic Programming Algorithm FORTRAN Coded, for Gross Production Scheduling.

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Purpose: To solve non-linear production scheduling problems concerning "N" products, each product with up to "M" possible production levels, each level having an associated profit (or cost) figure.

Hardware: 40K, 1620, Card I/O, hardware divide

Procedure: Dynamic programming algorithm, described in the body of the write up.

Execution Time: Heavily dependent on the size and data of the problem. No general rule is possible to give. A typical problem involving 9 products, 7 levels for each took 4 minutes.

Source Language: FORTRAN with FORMAT

Accuracy: Usual 8-digit FORTRAN Accuracy

Limitations: N less than or equal to 199. M less than or equal to 40.

Checkout Status: Checked out completely for N up to 9, M up to 40, Logically for N up to 199.

Comments: This program and its documentation were written by an IBM employee. It was developed for a specific purpose and submitted for general distribution to interested parties in the hope that it might prove helpful to other members of the data processing community. The program and its documentation are essentially in the author's original form. IBM serves as the distribution agency in supplying this program. Questions concerning the use of the program should be directed to the author's attention.

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ABSTRACT

This program has been proven successful in solving production scheduling problems involving N products, each product with up to M possible production levels, each level having associated with it a profit (or cost) figure. There is no mathematical relationship assumed or necessary in any case between production levels and profit (or cost) figures. Said problem being subject to one constraint-that the total of all production units be less than or equal to a pre-set "budget."

A DYNAMIC PROGRAMMING ALGORITHM, FORTRAN CODED, FOR GROSS PRODUCTION SCHEDULING

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I INTRODUCTION - THE PROBLEM

This program is one which has been profitably employed in situations where linear programming techniques would have applied except for the non-linearity of the problem.

As described in this report, the program is shown in the process of determining an optimum productions schedule of N products, each product with M or less feasible production levels, subject to a constraint that the totality of all units produced be less than some "budget." Associated with each production level for each product is some profit (or cost) figure, there being no particular relationship in any case between production level and this figure.

II THE SOLUTION

Source Language:	IBM FORTRAN with FORMAT
Machinery:	Card 40K 1620 with hardware divide
Restrictions:	N less than or equal to 199
	M less than or equal to 40
Execution Time:	See Section V, page 10.

III Description of the Algorithm

While giving a mathematical description of the algorithm, it is convenient to describe it also by example. The form of this example is as follows: (Sample Problem 0)

Consider the manufacture of three products, 1, 2, and 3. We are given data on these products concerning the possible production levels for each and for each level an associated profit. In table form:

Table 1

Prod. 1		Prod. 2		Prod. 3	
X_1	$V_1(X_1)$	X_2	$V_2(X_2)$	X_3	$V_3(X_3)$
0	0.0	10	-1.0	0	0.0
10	1.0	20	0.5	5	0.3
20	2.0	30	0.8	10	0.9
30	2.5	40	1.4	15	1.7
		50	1.8	20	1.8

Where X_j (j = 1, 2, 3) is the feasible levels vector of production for product j, V_j is the associated profit vector. X_{ji} then is the i^{th} level of production of product j, V_{ji} is the associated profit.

If we have no "budget," we can solve the above by inspection for an optimum solution. Produce 30 of 1, 50 of 2, 20 of 3. No problem. Suppose, now, we do have a "budget" and that it is less than 100 units. What we are looking for is an optimum combination of level selection from the table. In such a simple problem, we can still solve the problem by inspection, however, not particularly fast nor easily. The solution table for all budgets from 100 to 10 (in steps of 10) is:

Table 2

Budget	Level of 1	Level of 2	Level of 3	Total
100	30	50	20	100
90	30	40	20	90
80	20	40	20	80
70	30	20	20	70
60	20	20	20	60
50	20	20	10	50
40	20	20	0	40
30	10	20	0	30
20	0	20	0	20
10	0	10	0	10

The solution proceeds as follows: There are 3 products (N=3). We are given X_{ji} and V_{ji} for all products and Budgets of 100, 90, 80. ...,10. We first set up what is called Tableau #3.

Table 3.

	X_{31}	X_{32}	X_{33}	X_{34}	X_{35}	P_3	XB_3
	0	5	10	15	20		
(S_{31} =) 0							
(S_{32} =) 5							
(S_{33} =) 10							
(S_{34} =) 15							
(S_{35} =) 20							

Where the S_{3k} are the amounts of unassigned budget we have left <u>after</u> the assignment of production levels to Products 1 and 2. Since we have no knowledge at this time how much this will be, we must evaluate all possibilities. There are 5 of these, the possibility that 0 will be left (S_{31}), 5 left (S_{32}), 10 left (S_{33}), 15 left (S_{34}), 20 or more left (S_{35}).

Define now the <u>elements</u> of the tableau as Y_{jik}. (The element in the k^{th} row and the i^{th} column of the j^{th} tableau)

A. $\underline{Y_{jik} \text{ does not exist for } i \text{ greater than } k}$, for if we have, say, only 5 left of our budget after assigning products 1 and 2, we cannot consider the possibility of producing 10 of product 3.

B. Define $\underline{P_{n+1} \text{ (any argument)} = 0}$ for an N-Product problem

C. $\underline{Y_{jik} = V_{ji} + P_{j+1}(S_{jk} - X_{ji})}$

That is, in calculating any Y_{jik}, we obtain first of all the corresponding V_{ji} from the input data. This V_{ji} corresponds to some X_{ji}. We next subtract from the S_{jk} of the row we are working on, this X_{ji}, obtaining an argument $S_{j+1,m}$ with which to find a P_{j+1} in the table of P's of the <u>preceding</u> tableau.

In numbers, if we have 40 (=S_{jk}) to assign, we assign 10 (=X_{ji}) we have left 30. Opposite 30 (=$S_{j+1,m}$) in the <u>preceding</u> tableau obtain a P to use in computation.

D. $\underline{P_{jk} = \max(Y_{jik}) \quad (i = 1, 2, \ldots, k)}$

E. $\underline{XB_{jk} = \text{the } X_{ji} \text{ where this maximum is found.}}$

With the above formulae, Tableau #3 is generated (trivial case) as:

Table 4

	X_{31}	X_{32}	X_{33}	X_{34}	X_{35}	P_3	XB_3
$S_{31} = 0$	.0					.0	0
$S_{32} = 5$	.0	.3				.3	5
$S_{33} = 10$	.0	.3	.9			.9	10
$S_{34} = 15$	.0	.3	.9	1.7		1.7	15
$S_{35} = 20$	.0	.3	.9	1.7	1.8	1.8	20

Now, saving the P_3 and XB_3 vectors only, Tableau #2 is generated.

Table 5

	X_{21}	X_{22}	X_{23}	X_{24}	X_{25}	P_2	XB_2
$S_{21} = 10$	-1.0					-1.0	10
$S_{22} = 20$	-0.1	0.5				0.5	20
$S_{23} = 30$	0.8	1.4	0.8			1.4	20
$S_{24} = 40$	0.8	2.3	1.7	1.4		2.3	20

(Table 5 continues on the following page.)

Table 5 (Continued)

	X_{21}	X_{22}	X_{23}	X_{24}	X_{25}	P_2	XB_2
$S_{25} = 50$	0.8	2.3	2.6	2.3	1.8	2.6	30
$S_{26} = 60$	0.8	2.3	2.6	3.2	2.7	3.2	40
$S_{27} = 70$	0.8	2.3	2.6	3.2	3.6	3.6	50

As an aid to following the mathematics, the calculations necessary are included as follows:

$$Y_{211} = V_{21} + P_{31} = -1.0 + .0 = -1.0$$

$$Y_{212} = V_{21} + P_{33} = -1.0 + .9 = -0.1$$
$$Y_{222} = V_{22} + P_{31} = 0.5 + .0 = 0.5$$

$$Y_{213} = V_{21} + P_{35} = -1.0 + 1.8 = 0.8$$
$$Y_{223} = V_{22} + P_{33} = 0.5 + 0.9 = 1.4$$
$$Y_{233} = V_{23} + P_{31} = 0.8 + .0 = 0.8$$

$$Y_{214} = V_{21} + P_{35} = -1.0 + 1.8 = 0.8$$
$$Y_{224} = V_{22} + P_{35} = 0.5 + 1.8 = 2.3$$
$$Y_{234} = V_{23} + P_{33} = 0.8 + .9 = 1.7$$
$$Y_{244} = V_{24} + P_{31} = 1.4 + .0 = 1.4$$

$$Y_{215} = V_{21} + P_{35} = -1.0 + 1.8 = 0.8$$
$$Y_{225} = V_{22} + P_{35} = 0.5 + 1.8 = 2.3$$
$$Y_{235} = V_{23} + P_{35} = 0.8 + 1.8 = 2.6$$
$$Y_{245} = V_{24} + P_{33} = 1.4 + 0.9 = 2.3$$
$$Y_{255} = V_{25} + P_{31} = 1.8 + .0 = 1.8$$

$$Y_{216} = V_{21} + P_{35} = -1.0 + 1.8 = 0.8$$
$$Y_{226} = V_{22} + P_{35} = 0.5 + 1.8 = 2.3$$
$$Y_{236} = V_{23} + P_{35} = 0.8 + 1.8 = 2.6$$
$$Y_{246} = V_{24} + P_{35} = 1.4 + 1.8 = 3.2$$
$$Y_{256} = V_{25} + P_{33} = 1.8 + 0.9 = 2.7$$

$$Y_{217} = V_{21} + P_{35} = -1.0 + 1.8 = 0.8$$
$$Y_{227} = V_{22} + P_{35} = 0.5 + 1.8 = 2.3$$
$$Y_{237} = V_{23} + P_{35} = 0.8 + 1.8 = 2.6$$
$$Y_{247} = V_{24} + P_{35} = 1.4 + 1.8 = 3.2$$
$$Y_{257} = V_{25} + P_{35} = 1.8 + 1.8 = 3.6$$

$P_{21} = \max(-1.0) = -1.0$	$XB_{21} = 10$
$P_{22} = \max(-0.1, 0.5) = 0.5$	$XB_{22} = 20$
$P_{23} = \max(0.8, 1.4, 0.8) = 1.4$	$XB_{23} = 20$
$P_{24} = \max(0.8, 2.3, 1.7, 1.4) = 2.3$	$XB_{24} = 20$
$P_{25} = \max(0.8, 2.3, 2.6, 2.3, 1.8) = 2.6$	$XB_{25} = 30$
$P_{26} = \max(0.8, 2.3, 2.6, 3.2, 2.7) = 3.2$	$XB_{26} = 40$
$P_{27} = \max(0.8, 2.3, 2.6, 3.2, 3.6) = 3.6$	$XB_{27} = 50$

Finally, saving the P_2 and XB_2 vectors only, Tableau #1 is generated. Notice that the S vector is growing steadily.

Table 6

	X_{11}	X_{22}	X_{23}	X_{24}	P_1	XB_1
$S_{11} = 10$	-1.0				-1.0	0
$S_{12} = 20$	0.5	0.0			0.5	0
$S_{13} = 30$	1.4	1.5	1.0		1.5	10

(Table 6 continues on the following page.)

Table 6 continued

	X_{11}	X_{22}	X_{23}	X_{24}	P_1	XB_1
S_{14} = 40	2.3	2.4	2.5	1.5	2.5	20
S_{15} = 50	2.6	3.3	3.4	2.9	3.4	20
S_{16} = 60	3.2	3.6	4.3	3.9	4.3	20
S_{17} = 70	3.6	4.2	4.6	4.8	4.8	30
S_{18} = 80	3.6	4.6	5.2	5.1	5.2	20
S_{19} = 90	3.6	4.6	5.6	5.7	5.7	30
S_{110} = 100	3.6	4.6	5.6	6.1	6.1	30

At this point we are completed with Phase 1 of the problem. The P vectors are forgotten (although P_1 does show the actual profits for each possible "budget" from 10 to 100.) The XB data has been put out on intermediate cards (or tape). Phase 2 of the problem reads this XB data back into the machine to determine the actual schedule..

Collecting the data for Phase 2:

Opposite the "budget" in the S_{1k} vector read XB1k, the optimum number of Product 1 to be scheduled.

Budget = Budget - XB_{1k}

Opposite "budget" in the S_{2k} vector read XB_{2k}, the optimum number of Product 2 to be scheduled.

Budget = Budget - XB_{2k}

Opposite "budget" in the S_{3k} vector read XB_{3k}, the optimum number of Product 3 to be scheduled.

End of Phase 2.

IV. Problem Restrictions

1. As can be seen from the description in Part III, the S_j vector grows with arithmetic rapidity. It goes in each Tableau from some lower bound ($SØ_j$) to some upper bound (SB_j) in steps of A_j where A_j is defined as the incremental step of production level for product j.

   Two bounds can immediately be put on this S_j vector. There is no gain in allowing SB_j to exceed the budget (BUD). Similarly, if Q_j is defined as the lowest feasible production level of product j, then certainly $SØ_j$ need never be considered below:

   $SUMQ = Q_j + Q_{j+1} + \dots + Q_n$. Therefore:

   F. SB_j is less than or equal to BUD for all j

   G.and $SØ_j$ is greater than or equal to SUM (Q_I) (I = N, N-1)...,j.

2. While these formulae help limit the S_j vector, they are not sufficient for most practical sized problems. Consequently, within the program a careful watch is kept on this vector. It is never allowed to exceed 100 entries, regardless of formulae F and G. Whenever it threatens to do so, a calculation is made which locates the center of the S_j vector at a "most likely position" for use in Phase 2, the reverse search. Within the program, this is accomplished by bringing in the input datum $A2_j$ (average of next three month's demand) for each product and keeping a sum (SUMA2) of this data.

When the S_j vector gets out of bounds (more than 100 entries), the statements:

```
127     K = SØMIN/A + (SUMA2/BUD) * (SB-SØ-100.*A) /A
        SØ = K
        SØ = SØ*A
        SB = SØ + 99.*A
```

are used as a (heuristic) method of keeping the S_j vector centered around a "most likely" region. You can see the results of this action in Section IX.

To an extent, this procedure threatens to disturb optimality of the solution, since if we miss the solution point by more than 50.*A_j we will underschedule some product(s) and overschedule others. Experimentally, however, using "live" data, it does not appear that we have any problem at this point.

A second, somewhat more severe restriction has been built into the program. The algorithm, as presented in Section III, calculates all Y_{jik} of the tri-angular array. As programmed, not all of these are computed. As the program proceeds, row by row, each time it finds a maximum row entry, it stores this entry in P_{jk} and the corresponding X_{ji} in XB_{jk}. When starting the next row, it does not start with column 1, but with that column where the maximum was found in the last row. Because of this, admittedly arbitrary, rule, the machine solution to our sample problem 0 (Section X) varies from Table 2 insofar as the budget of 80 is concerned.

Once again, experimentally, it appears that this restriction does not affect the final solution to any significant degree. A third restriction of sorts has been used in this model implicitly all along. This restriction concerns possible values of the parameter A_j. Values of A_j used with this algorithm must be commensurate with one another. They may all be the same; if they differ, the larger A_j must be integer multiples of all smaller A_j.

Typical values of A_j might be:

2, 4, 8, 16, 32, 64, 128, . . .

or 25, 50, 100, 200, 400, ...

In entering data into Phase 1, the products must be sorted in order of increasing A_j.

V. Running Times and Economics

The question is naturally raised "Why the (arbitrary) restrictions on S_j?" The answer to this question lies in the fact that this is not a speedy algorithm. The running times for the three problems described in Section X were observed to be: (exclusive of typing)

Prob 0	phase 1 0.6 min.	phase 2 0.3 min/pass
Prob 1	phase 1 2.8 min.	phase 2 0.8 min/pass
Prob 2	phase 1 36.0 min.	phase 2 0.8 min/pass

Extending these times analytically to a computer with tape I/O in the 705/7070 class, (and on the basis of observations made on "live" problems on this size machine) it is observed that fairly long machine runs (3-10 hours) are required if the number of products exceeds 1000. Limiting S_j to 100 entries instead of 200, say, halves the running time of such a problem. Using restriction 2 in Part IV again halves the running time, and seems to be economically sound.

This program approach requires that profit (or cost) figures be calculated for each product for each feasible production level. This is, of course, no trivial job. Meaningful figures must be found for such items as back order costs, set-up costs, and inventory carrying costs. The cost picture for any product is a complex function of these three items considered along with such factors as:

demand pattern forecast

quantity on hand

quantity in production

facility sharing with other products

and others.

Obtaining meaningful figures of this nature is probably the hardest part of an O. R. man's job if he is to use this or any other similar algorithm for his scheduling.

Nonetheless, the job can be, and has been, done successfully. It appears that, on the basis of many tests with different cost function generators, that as long as all products are computed on the same basis, the final schedules do not show much deviation.

Schedules obtained with this program have been costed out against actual schedules "made by hand." In all cases tested the savings were very considerable.

VI. Operation Notes, Data Description

Input to the program consists of:

1. One problem header card containing according to the Format (I4,F10.0,F10.0,30H),

NUMBR being the No. of products being scheduled

BUD "budget", restriction on total units to be scheduled

DBUD Reduce BUD by DBUD for alternate solutions

30H up to 30 alphanumeric problem identification

2. One product header card per product containing according to the Format (20H I5,I5,F8.0,F8.0,F8.0),

20H up to 20 alphanumeric product identification

IRECD Product identifier (stock number?)

M No. of production levels to be considered

A increment size between production levels

Q minimum production

A2 average demand next 3 months

3. From 1 to 4 product profit (cost) cards, each containing up to 10 numbers. For $1 \leq M \leq 10$, one card will be required, for $11 \leq M \leq 20$, two cards, etc. Format (10F7.0).

Output from the program is in two parts, complete with typed instructions. The output from phase 1 is reverse-sorted on cc 78-80 and used as input to phase 2. Output from phase 2 is on cards and, with proper sense switch settings, on the typewriter as well. Output is identified by column headings and header messages.

Sense switch settings:

1 on to type final answers on typewriter

2 on to obtain alternate solutions, phase 2.

3 on to obtain all messages from the program,off to bypass many of them

4 unused.

Section IX is a typewriter log (sample problem 2) taken with 1 off; 2 on for three passes of phase 2, then off; 3 on.

VII. Key to Abbreviations, Symbols

j is an index, running from 1 to n

n is the number of products

M_j is the number of production levels, j^{th} product

Q_j is the minimum production level

A_j is the increment between levels

$CAPAC_j$ is the maximum level $(=Q_j + A*(M_j-1)\ )$

V_{ji} are the profits (costs) associated with the levels $i = 1,2,\ldots,m$ for each product

X_{ji} are the possible levels themselves.

$$X_{j1} = Q_j$$
$$X_{j2} = Q_j + A_j$$
$$X_{j3} = Q_j + A_j + A_j \qquad \text{etc.}$$

BUD is the "budget" for the total SUM (X_{jl})

S_{jk} are the possible amounts of unassigned BUD left <u>after</u> assigning products 1, 2,...,j-1.

Y_{jik} are the profits(costs) associated with particular S_{jk} and X_{ji}

P_{jk} are the max (Y_{jik}) for $i = 1,2,\ldots.k$

XB_{jk} are the X_{ji} where the maximum is found

$SØ_j$ is the lowest S_{jk} for any j

SB_j is the highest S_{jk} for any j

NR is the number of S_{jk} rows for any j

VIII Miscellaneous, Key to Decks

A. The program is written to accept and use profit data. It is sometimes more convenient to use cost data. This may be done in two ways:

1. Keep the program as is, add to each cost datum before input a fictitious profit, for example, $Y_{jik} = \text{cost} + \$10.00 * X_{ji}$

2. Change the program to scan for a <u>minimum</u> Y_{jik} instead of a maximum.

B. The profit datum associated with the highest production level of a product should be the highest magnitude of that profit series. Conversely for cost data. They need not be in strict ascending magnitude, although frequently they are.

C. Key to Decks:

Deck 1: Fortran Source, Numbered DP-001 through DP-216 in cols. 75-80.

Deck 2: Object Deck. Listing pages 37-43. No card numbers

Deck 3: Sample Data, numbered DP-501 through DP-560 in cols. 75-80.

Type writer log - problem 0

```
DYNAMIC PROG MODEL

 NO.     BUDGET       DBUD
  3       11Ø.         1Ø.          SAMPLE PROB 0


                 NAME IRECD     M   INCRE  MIN QTY    CAPAC   AVG DEM
NO 3 194Ø DESOTO       3        5      5.        .      2Ø.       1Ø.
SØ =          .  SB =        2Ø.  NR =   5
NO 2 1937 CADILLAC     2        5     1Ø.      1Ø.      5Ø.       1Ø.
SØ =        1Ø.  SB =        7Ø.  NR =   7
NØ 1 1948 JAGUAR       1        4     1Ø.        .      3Ø.       1Ø.
SØ =        1Ø.  SB =       1ØØ.  NR =  1Ø


 PHASE 1 COMPLETED   3 ITEMS SCHEDULED

SORT ØUTPUT IN RVERSE SEQUENCE ON CC 78-8Ø
THEN HIT START TO BEGIN PHASE 2

BEGIN PHASE 2, BUDGET =      11Ø.

RERUN INTERMED. CDS. FOR ALT. SOLN.

BEGIN PHASE 2, BUDGET =      1ØØ.

RERUN INTERMED. CDS. FOR ALT. SOLN.

BEGIN PHASE 2, BUDGET =       9Ø.

RERUN INTERMED. CDS. FOR ALT. SOLN.

BEGIN PHASE 2, BUDGET =       8Ø.

RERUN INTERMED. CDS. FOR ALT. SOLN.

BEGIN PHASE 2, BUDGET =       7Ø.

RERUN INTERMED. CDS. FOR ALT. SOLN.

BEGIN PHASE 2, BUDGET =       6Ø.

RERUN INTERMED. CDS. FOR ALT. SOLN.

BEGIN PHASE 2, BUDGET =       5Ø.

 END OF JOB
```

IX typewriter log - problem 1

```
DYNAMIC PROG MODEL

 NO.     BUDGET      DBUD
  9       3000.      200. PROB. NO. 1 FOR D.P.


                 NAME IRECD     M   INCRE  MIN QTY    CAPAC   AVG DEM
PROD 1  WIDGIT          1       5     25.      25.     125.       14.
SO =        25.   SB =        125.  NR =   5
PROD 2  FRAMIS          2       3     25.        .      50.        8.
SO =        25.   SB =        175.  NR =   7
PROD 0 QUOTL BIT        3       7     50.        .     300.       14.
SO =          .   SB =        500.  NR =  11
SO =        50.   SB =        500.  NR =  10
PROD 4  GREEB STALL     4      10     50.        .     450.       35.
SO =        50.   SB =        950.  NR =  19
PROD 5  GRANCH          5      11     50.     100.     600.       35.
SO =       100.   SB =       1550.  NR =  30
SO =       150.   SB =       1550.  NR =  29
PROD 6  GRUNK PITS      6       9    100.     100.     900.       90.
SO =       200.   SB =       2500.  NR =  24
SO =       300.   SB =       2500.  NR =  23
PROD 7  ANBER STEM      7       6    200.        .    1000.       90.
SO =       200.   SB =       3000.  NR =  15
SO =       400.   SB =       3000.  NR =  14
PROD 8  RONTER GUY      8       6    200.     200.    1200.      120.
SO =       400.   SB =       3000.  NR =  14
SO =       600.   SB =       3000.  NR =  13
PROD 9  BINT DUP        9       4    400.        .    1200.      155.
SO =       400.   SB =       3200.  NR =   8
SO =       800.   SB =       3200.  NR =   7


 PHASE 1 COMPLETED   9 ITEMS SCHEDULED

SORT OUTPUT IN RVERSE SEQUENCE ON CC 78-80
THEN HIT START TO BEGIN PHASE 2

BEGIN PHASE 2, BUDGET =     3000.

RERUN INTERMED. CDS. FOR ALT. SOLN.

BEGIN PHASE 2, BUDGET =     2800.

RERUN INTERMED. CDS. FOR ALT. SOLN.

BEGIN PHASE 2, BUDGET =     2600.
BEGIN PHASE 2, BUDGET =     2400.
BEGIN PHASE 2, BUDGET =     2200.
BEGIN PHASE 2, BUDGET =     2000.
BEGIN PHASE 2, BUDGET =     1800.
BEGIN PHASE 2, BUDGET =     1600.
 END OF JOB
```

X typewriter log - Problem 2

```
DYNAMIC PROG MODEL

 NO.     BUDGET       DBUD
  8      8000.        100.   PROBLEM 2 FOR D. P.



                     NAME IRECD     M   INCRE  MIN QTY    CAPAC   AVG DEM
BOLTS U/4 UN NO 3          1    40      50.     100.     2050.     100.
SO =       100.  SB =     2050.   NR =  40
SCREWS NO 18 LONG          2    40      50.        .     1950.     200.
SO =       100.  SB =     4000.   NR =  79
LOCOMOTIVE, STEAM          3    40      50.      50.     2000.        .
SO =       150.  SB =     5100.   NR = 100
SO =       200.  SB =     5150.   NR = 100
LOCOMOTIVE, DEISEL         4    40      50.        .     1950.     100.
SO =       250.  SB =     5200.   NR = 100
EYEGLASS FRAME, BRN        5    10      50.      50.      500.     600.
SO =       300.  SB =     5250.   NR = 100
LAMBSKIN TURBAN            6    10      50.        .      450.     200.
SO =       350.  SB =     5300.   NR = 100
1620 COMPUTER              7    20     100.     300.     2200.     350.
SO =       500.  SB =     7500.   NR =  71
SO =       600.  SB =     7500.   NR =  70
SO =       700.  SB =     7500.   NR =  69
HAIRPIN, NO 6 BLACK        8    40     200.        .     7800.     360.
SO =       600.  SB =     8000.   NR =  38
SO =       800.  SB =     8000.   NR =  37


 PHASE 1 COMPLETED    8 ITEMS SCHEDULED


SORT OUTPUT IN RVERSE SEQUENCE ON CC 78-80
THEN HIT START TO BEGIN PHASE 2

BEGIN PHASE 2, BUDGET =     8000.

BEGIN PHASE 2, BUDGET =     7900.

BEGIN PHASE 2, BUDGET =     7800.

BEGIN PHASE 2, BUDGET =     7700.

BEGIN PHASE 2, BUDGET =     7600.

BEGIN PHASE 2, BUDGET =     7500.

BEGIN PHASE 2, BUDGET =     7400.

BEGIN PHASE 2, BUDGET =     7300.

 END OF JOB

STOP
```

XI Three Sample Problems

Input data Top?

```
   3   110.      10.                      SAMPLE PROB 0                    DP 501
NO 3 1940 DESOTO          3    5 5.      0.       10.                      DP 502
 .     .3      .9     1.7    1.8                                           DP 503
NO 2 1937 CADILLAC        2    5 10.     10.      10.                      DP 504
-1.    .5      .8     1.4    1.8                                           DP 505
NO 1 1948 JAGUAR          1    4 10.     0.       10.                      DP 506
 .     1.      2.     2.5                                                  DP 507
```

Output data

```
BEGIN PHASE 2, BUDGET =        110.

                        PROD. NO. LEVEL  INCRE  MIN QTY   CAPAC  SCHEDULE

NO 1 1948 JAGUAR          1    5      10.       .       30.      30.
NO 2 1937 CADILLAC        2    6      10.      10.      50.      50.
NO 3 1940 DESOTO          3    6       5.       .       20.      20.

                                              TOTAL             100.




BEGIN PHASE 2, BUDGET =        100.

                        PROD. NO. LEVEL  INCRE  MIN QTY   CAPAC  SCHEDULE

NO 1 1948 JAGUAR          1    4      10.       .       30.      30.
NO 2 1937 CADILLAC        2    5      10.      10.      50.      50.
NO 3 1940 DESOTO          3    5       5.       .       20.      20.

                                              TOTAL             100.




BEGIN PHASE 2, BUDGET =         90.

                        PROD. NO. LEVEL  INCRE  MIN QTY   CAPAC  SCHEDULE

NO 1 1948 JAGUAR          1    4      10.       .       30.      30.
NO 2 1937 CADILLAC        2    4      10.      10.      50.      40.
NO 3 1940 DESOTO          3    5       5.       .       20.      20.

                                              TOTAL              90.




BEGIN PHASE 2, BUDGET =         80.

                        PROD. NO. LEVEL  INCRE  MIN QTY   CAPAC  SCHEDULE

NO 1 1948 JAGUAR          1    4      10.       .       30.      30.
NO 2 1937 CADILLAC        2    3      10.      10.      50.      30.
NO 3 1940 DESOTO          3    5       5.       .       20.      20.

                                              TOTAL              80.
```

```
BEGIN PHASE 2, BUDGET =         70.

                        PROD. NO. LEVEL  INCRE  MIN QTY   CAPAC  SCHEDULE

NO 1 1948 JAGUAR          1    4      10.       .       30.      30.
NO 2 1937 CADILLAC        2    2      10.      10.      50.      20.
NO 3 1940 DESOTO          3    5       5.       .       20.      20.

                                              TOTAL              70.
```

Bottom

```
BEGIN PHASE 2, BUDGET =        60.

                        PROD. NO. LEVEL  INCRE  MIN QTY   CAPAC  SCHEDULE

NO 1 1948 JAGUAR              1    3     10.        .     30.      20.
NO 2 1937 CADILLAC            2    2     10.      10.     50.      20.
NO 3 1940 DESOTO              3    5      5.        .     20.      20.

                                               TOTAL               60.




BEGIN PHASE 2, BUDGET =        50.

                        PROD. NO. LEVEL  INCRE  MIN QTY   CAPAC  SCHEDULE

NO 1 1948 JAGUAR              1    3     10.        .     30.      20.
NO 2 1937 CADILLAC            2    2     10.      10.     50.      20.
NO 3 1940 DESOTO              3    3      5.        .     20.      10.

                                               TOTAL               50.
```

```
BEGIN PHASE 2, BUDGET =        40.

                        PROD. NO. LEVEL  INCRE  MIN QTY   CAPAC  SCHEDULE

NO 1 1948 JAGUAR              1    3     10.        .     30.      20.
NO 2 1937 CADILLAC            2    2     10.      10.     50.      20.
NO 3 1940 DESOTO              3    1      5.        .     20.        .

                                               TOTAL               40.




BEGIN PHASE 2, BUDGET =        30.

                        PROD. NO. LEVEL  INCRE  MIN QTY   CAPAC  SCHEDULE

NO 1 1948 JAGUAR              1    2     10.        .     30.      10.
NO 2 1937 CADILLAC            2    2     10.      10.     50.      20.
NO 3 1940 DESOTO              3    1      5.        .     20.        .

                                               TOTAL               30.




BEGIN PHASE 2, BUDGET =        20.

                        PROD. NO. LEVEL  INCRE  MIN QTY   CAPAC  SCHEDULE

NO 1 1948 JAGUAR              1    1     10.        .     30.        .
NO 2 1937 CADILLAC            2    2     10.      10.     50.      20.
NO 3 1940 DESOTO              3    1      5.        .     20.        .

                                               TOTAL               20.
```

```
BEGIN PHASE 2, BUDGET =        10.

                        PROD. NO. LEVEL  INCRE  MIN QTY   CAPAC  SCHEDULE

NO 1 1948 JAGUAR              1    1     10.        .     30.        .
NO 2 1937 CADILLAC            2    1     10.      10.     50.      10.
NO 3 1940 DESOTO              3    1      5.        .     20.        .

                                               TOTAL               10.
```

End sample problem 0.

Input   Sample Problem 1.

```
   9 3000.     200.      PROB. NO. 1 FOR D.P.                         DP 508
PROD 1  WIDGIT          1    5  25.    25.       14.                  DP 509
35.     36.    37.     39.     39.5                                   DP 510
PROD 2  FRAMIS          2    3  25.    0.        8.                   DP 511
.62     .75    .88                                                    DP 512
PROD 0 QUOTL BIT        3    7  50.    0.        14.                  DP 513
5.      5.2    5.3     5.6     5.8     5.81    5.9                    DP 514
PROD 4  GREEB STALL     4    10 50.    0.        35.                  DP 515
21.     22.    23.     25.1    25.6    27.2    29.1    30.    31.2    35.7   DP 516
PROD 5  GRANCH          5    11  50.   100.      35.                  DP 517
1.      2.     3.      5.      7.      9.      9.      9.     10.1    10.4   DP 518
11.01                                                                 DP 519
PROD 6  GRUNK PITS      6    9  100.   100.      90.                  DP 520
8.17    8.34   8.8     8.99    9.12    9.76    10.21   12.43  15.     DP 521
PROD 7  ANBER STEM      7    6  200.   0.        90.                  DP 522
11.     13.1   15.17   19.22   26.4    25.8                           DP 523
PROD 8  RONTER GUY      8    6  200.   200.      120.                 DP 524
-18.    18.    18.3    18.33   19.04   29.99                          DP 525
PROD 9  BINT DUP        9    4  400.   0.        155.                 DP 526
28.1    28.    27.     28.5                                           DP 527
```

Output

```
BEGIN PHASE 2, BUDGET =      3000.

                      PROD. NO. LEVEL  INCRE  MIN QTY   CAPAC  SCHEDULE

PROD 9  BINT DUP           9     1     400.      .      1200.      .
PROD 8  RONTER GUY         8     6     200.    200.     1200.   1200.
PROD 7  ANBER STEM         7     5     200.      .      1000.    800.
PROD 6  GRUNK PITS         6     1     100.    100.      900.    100.
PROD 5  GRANCH             5     6      50.    100.      600.    350.
PROD 4  GREEB STALL        4    10      50.      .       450.    450.
PROD 0 QUOTL BIT           3     1      50.      .       300.      .
PROD 2  FRAMIS             2     1      25.      .        50.      .
PROD 1  WIDGIT             1     4      25.     25.      125.    100.

                                          TOTAL          3000.
```

```
BEGIN PHASE 2, BUDGET =      2800.

                      PROD. NO. LEVEL  INCRE  MIN QTY   CAPAC  SCHEDULE

PROD 9  BINT DUP           9     1     400.      .      1200.      .
PROD 8  RONTER GUY         8     6     200.    200.     1200.   1200.
PROD 7  ANBER STEM         7     4     200.      .      1000.    600.
PROD 6  GRUNK PITS         6     1     100.    100.      900.    100.
PROD 5  GRANCH             5     6      50.    100.      600.    350.
PROD 4  GREEB STALL        4    10      50.      .       450.    450.
PROD 0 QUOTL BIT           3     1      50.      .       300.      .
PROD 2  FRAMIS             2     1      25.      .        50.      .
PROD 1  WIDGIT             1     4      25.     25.      125.    100.

                                          TOTAL          2800.
```

```
BEGIN PHASE 2, BUDGET =      2600.

                      PROD. NO. LEVEL  INCRE  MIN QTY   CAPAC  SCHEDULE

PROD 9  BINT DUP           9     1     400.      .      1200.      .
PROD 8  RONTER GUY         8     2     200.    200.     1200.    400.
PROD 7  ANBER STEM         7     5     200.      .      1000.    800.
PROD 6  GRUNK PITS         6     1     100.    100.      900.    100.
PROD 5  GRANCH             5    11      50.    100.      600.    600.
PROD 4  GREEB STALL        4    10      50.      .       450.    450.
PROD 0 QUOTL BIT           3     2      50.      .       300.     50.
PROD 2  FRAMIS             2     4      25.      .        50.     50.
PROD 1  WIDGIT             1     6      25.     25.      125.    125.

                                          TOTAL          2575.
```

```
BEGIN PHASE 2, BUDGET =      2400.

                     PROD. NO. LEVEL   INCRE  MIN QTY   CAPAC  SCHEDULE

PROD 9   BINT DUP          9     1     400.        .    1200.        .
PROD 8   RONTER GUY        8     2     200.     200.    1200.     400.
PROD 7   ANBER STEM        7     5     200.        .    1000.     800.
PROD 6   GRUNK PITS        6     1     100.     100.     900.     100.
PROD 5   GRANCH            5     9      50.     100.     600.     500.
PROD 4   GREEB STALL       4    10      50.        .     450.     450.
PROD 0  QUOTL BIT          3     1      50.        .     300.        .
PROD 2   FRAMIS            2     2      25.        .      50.      25.
PROD 1   WIDGIT            1     5      25.      25.     125.     125.

                                             TOTAL             2400.
```

24

```
BEGIN PHASE 2, BUDGET =      2200.

                     PROD. NO. LEVEL   INCRE  MIN QTY   CAPAC  SCHEDULE

PROD 9   BINT DUP          9     1     400.        .    1200.        .
PROD 8   RONTER GUY        8     2     200.     200.    1200.     400.
PROD 7   ANBER STEM        7     5     200.        .    1000.     800.
PROD 6   GRUNK PITS        6     1     100.     100.     900.     100.
PROD 5   GRANCH            5     6      50.     100.     600.     350.
PROD 4   GREEB STALL       4    10      50.        .     450.     450.
PROD 0  QUOTL BIT          3     1      50.        .     300.        .
PROD 2   FRAMIS            2     1      25.        .      50.        .
PROD 1   WIDGIT            1     4      25.      25.     125.     100.

                                             TOTAL             2200.
```

```
BEGIN PHASE 2, BUDGET =      2000.

                     PROD. NO. LEVEL   INCRE  MIN QTY   CAPAC  SCHEDULE

PROD 9   BINT DUP          9     1     400.        .    1200.        .
PROD 8   RONTER GUY        8     2     200.     200.    1200.     400.
PROD 7   ANBER STEM        7     4     200.        .    1000.     600.
PROD 6   GRUNK PITS        6     1     100.     100.     900.     100.
PROD 5   GRANCH            5     6      50.     100.     600.     350.
PROD 4   GREEB STALL       4    10      50.        .     450.     450.
PROD 0  QUOTL BIT          3     1      50.        .     300.        .
PROD 2   FRAMIS            2     1      25.        .      50.        .
PROD 1   WIDGIT            1     4      25.      25.     125.     100.

                                             TOTAL             2000.
```

25

```
BEGIN PHASE 2, BUDGET =      1800.

                     PROD. NO. LEVEL   INCRE  MIN QTY   CAPAC  SCHEDULE

PROD 9   BINT DUP          9     1     400.        .    1200.        .
PROD 8   RONTER GUY        8     2     200.     200.    1200.     400.
PROD 7   ANBER STEM        7     3     200.        .    1000.     400.
PROD 6   GRUNK PITS        6     1     100.     100.     900.     100.
PROD 5   GRANCH            5     6      50.     100.     600.     350.
PROD 4   GREEB STALL       4    10      50.        .     450.     450.
PROD 0  QUOTL BIT          3     1      50.        .     300.        .
PROD 2   FRAMIS            2     1      25.        .      50.        .
PROD 1   WIDGIT            1     4      25.      25.     125.     100.

                                             TOTAL             1800.
```

```
BEGIN PHASE 2, BUDGET =      1600.

               PROD. NO. LEVEL  INCRE  MIN QTY   CAPAC  SCHEDULE

PROD 9  BINT DUP        9    1    400.       .  1200.          .
PROD 8  RONTER GUY      8    2    200.    200.  1200.       400.
PROD 7  ANBER STEM      7    2    200.       .  1000.       200.
PROD 6  GRUNK PITS      6    1    100.    100.   900.       100.
PROD 5  GRANCH          5    6     50.    100.   600.       350.
PROD 4  GREEB STALL     4   10     50.       .   450.       450.
PROD 0 QUOTL BIT        3    1     50.       .   300.          .
PROD 2  FRAMIS          2    1     25.       .    50.          .
PROD 1  WIDGIT          1    4     25.     25.   125.       100.

                                          TOTAL          1600.
```

End Sample Problem 1.

Sample Problem 2.

Input.

```
   8   8000.    100.      PROBLEM 2 FOR D. P.                            DP 528
BOLTS U/4 UN NO 3       1   40    50. 100.    100.                       DP 529
1.     2.     3.     4.     5.     6.     7.     8.     9.     10.       DP 5301
11.    12.    13.    14.    15.    .6     17.    18.    19.    20.       DP 5311
21.    22.    23.    24.    25.    26.    27.    28.    29.    30.       DP 5321
31.    32.    33.    34.    35.    37.    38.    39.    40.    41.       DP 5331
SCREWS NO 18 LONG       2   40    50.         200.                       DP 534
20.5   21.    21.5   22.    22.5   23.    23.5   24.    24.5   25.       DP 5352
25.5   26.    26.5   27.    27.5   28.    28.5   29.    29.5   30.       DP 5362
30.5   31.    31.5   32.    32.5   33.    33.4   34.    34.5   35.       DP 5372
35.5   36.    36.5   37.    37.5   8.     38.    38.5   39.    40.       DP 5382
LOCOMOTIVE, STEAM       3   40    50.    50. 300.                        DP 539
30.    30.1   30.2   30.3   30.4   30.5   30.6   30.7   30.8   30.9      DP 5403
31.    32.    32.1   32.3   32.3   32.4   32.5   32.6   32.7   32.8      DP 5413
33.    33.1   33.2   33.3   33.4   33.4   33.5   33.7   33.8   33.9      DP 5423
34.    35.    36.    37.    37.1   37.2   37.4   37.6   37.66  37.77     DP 5433
LOCOMOTIVE, DEISEL      4   40  50.           100.                       DP 544
       20.    20.1   22.    22.22  22.23  22.25  22.56  22.75  22.78     DP 5454
22.88  22.89  22.9   22.91  22.92  22.95  22.99  23.    23.    23.5      DP 5464
24.    24.    24.4   24.5   24.8   24.9   25.    25.11  25.22  25.33     DP 5474
25.44  25.55  25.66  25.77  25.88  25.99  26.1   26.2   26.3   26.9      DP 5484
EYEGLASS FRAME, BRN     5   10    50.  50.    600.                       DP 549
15.1   15.3   15.6   15.8   16.    16.2   16.2   16.3   .88    16.55     DP 5505
LAMBSKIN TURBAN         6   10    50.         200.                       DP 551
30.12  30.44  30.45  30.456 30.458 30.88  31.    32.556 33.    34.235    DP 5526
1620 COMPUTER           7   20  100.    300.  350.                       DP 553
11.56  11.57  11.66  11.77  11.88  11.89  11.9   11.91  11.92  11.93     DP 5547
11.94  11.98  12.    12.    15.    17.    17.5   18.    18.4   18.5      DP 5557
HAIRPIN, NO 6 BLACK     8   40  200.          360.                       DP 556
1.     1.1    1.12   1.123  1.123  1.22   1.235  1.55   1.6    1.88      DP 5578
2.     2.5    2.55   2.56   2.58   2.9    3.     3.2    3.25   3.66      DP 5588
3.9    4.     4.22   4.33   4.43   4.53   4.64   4.76   4.87   4.87      DP 5598
5.     5.21   5.31   5.42   5.53   5.64   5.85   5.94   6.     7.258     DP-5608
```

Output

```
BEGIN PHASE 2, BUDGET =      8000.

                        PROD. NO. LEVEL  INCRE  MIN QTY   CAPAC  SCHEDULE

HAIRPIN, NO 6 BLACK        8     3     200.        .     7800.    400.
1620 COMPUTER              7    21     100.     300.     2200.   2200.
LAMBSKIN TURBAN            6    11      50.        .      450.    450.
EYEGLASS FRAME, BRN        5    10      50.      50.      500.    500.
LOCOMOTIVE, DEISEL         4    40      50.        .     1950.   1950.
LOCOMOTIVE, STEAM          3     1      50.      50.     2000.     50.
SCREWS NO 18 LONG          2    34      50.        .     1950.   1650.
BOLTS U/4 UN NO 3          1    15      50.     100.     2050.    800.

                                                TOTAL             8000.
```

```
BEGIN PHASE 2, BUDGET =      7900.

                        PROD. NO. LEVEL  INCRE  MIN QTY   CAPAC  SCHEDULE

HAIRPIN, NO 6 BLACK        8     3     200.        .     7800.    400.
1620 COMPUTER              7    20     100.     300.     2200.   2200.
LAMBSKIN TURBAN            6    10      50.        .      450.    450.
EYEGLASS FRAME, BRN        5    10      50.      50.      500.    500.
LOCOMOTIVE, DEISEL         4    37      50.        .     1950.   1800.
LOCOMOTIVE, STEAM          3     1      50.      50.     2000.     50.
SCREWS NO 18 LONG          2    35      50.        .     1950.   1700.
BOLTS U/4 UN NO 3          1    15      50.     100.     2050.    800.

                                                TOTAL             7900.
```

```
BEGIN PHASE 2, BUDGET =      7800.

                        PROD. NO. LEVEL  INCRE  MIN QTY   CAPAC  SCHEDULE

HAIRPIN, NO 6 BLACK        8     2     200.        .     7800.    200.
1620 COMPUTER              7    21     100.     300.     2200.   2200.
LAMBSKIN TURBAN            6    11      50.        .      450.    450.
EYEGLASS FRAME, BRN        5    10      50.      50.      500.    500.
LOCOMOTIVE, DEISEL         4    40      50.        .     1950.   1950.
LOCOMOTIVE, STEAM          3     1      50.      50.     2000.     50.
SCREWS NO 18 LONG          2    34      50.        .     1950.   1650.
BOLTS U/4 UN NO 3          1    15      50.     100.     2050.    800.

                                                TOTAL             7800.
```

```
BEGIN PHASE 2, BUDGET =      7700.

                        PROD. NO. LEVEL  INCRE  MIN QTY   CAPAC  SCHEDULE

HAIRPIN, NO 6 BLACK        8     2     200.        .     7800.    200.
1620 COMPUTER              7    20     100.     300.     2200.   2200.
LAMBSKIN TURBAN            6    10      50.        .      450.    450.
EYEGLASS FRAME, BRN        5    10      50.      50.      500.    500.
LOCOMOTIVE, DEISEL         4    37      50.        .     1950.   1800.
LOCOMOTIVE, STEAM          3     1      50.      50.     2000.     50.
SCREWS NO 18 LONG          2    35      50.        .     1950.   1700.
BOLTS U/4 UN NO 3          1    15      50.     100.     2050.    800.

                                                TOTAL             7700.
```

```
BEGIN PHASE 2, BUDGET =      7600.

               PROD. NO. LEVEL  INCRE  MIN QTY   CAPAC  SCHEDULE

HAIRPIN, NO 6 BLACK      8    1   200.        .   7800.       .
1620 COMPUTER            7   21   100.     300.   2200.   2200.
LAMBSKIN TURBAN          6   11    50.        .    450.    450.
EYEGLASS FRAME, BRN      5   10    50.      50.    500.    500.
LOCOMOTIVE, DEISEL       4   40    50.        .   1950.   1950.
LOCOMOTIVE, STEAM        3    1    50.      50.   2000.     50.
SCREWS NO 18 LONG        2   34    50.        .   1950.   1650.
BOLTS U/4 UN NO 3        1   15    50.     100.   2050.    800.

                                        TOTAL            7600.




BEGIN PHASE 2, BUDGET =      7500.

               PROD. NO. LEVEL  INCRE  MIN QTY   CAPAC  SCHEDULE

HAIRPIN, NO 6 BLACK      8    1   200.        .   7800.       .
1620 COMPUTER            7   20   100.     300.   2200.   2200.
LAMBSKIN TURBAN          6   10    50.        .    450.    450.
EYEGLASS FRAME, BRN      5   10    50.      50.    500.    500.
LOCOMOTIVE, DEISEL       4   37    50.        .   1950.   1800.
LOCOMOTIVE, STEAM        3    1    50.      50.   2000.     50.
SCREWS NO 18 LONG        2   35    50.        .   1950.   1700.
BOLTS U/4 UN NO 3        1   15    50.     100.   2050.    800.

                                        TOTAL            7500.




BEGIN PHASE 2, BUDGET =      7400.

               PROD. NO. LEVEL  INCRE  MIN QTY   CAPAC  SCHEDULE

HAIRPIN, NO 6 BLACK      8    1   200.        .   7800.       .
1620 COMPUTER            7   20   100.     300.   2200.   2200.
LAMBSKIN TURBAN          6   10    50.        .    450.    450.
EYEGLASS FRAME, BRN      5   10    50.      50.    500.    500.
LOCOMOTIVE, DEISEL       4   35    50.        .   1950.   1700.
LOCOMOTIVE, STEAM        3    1    50.      50.   2000.     50.
SCREWS NO 18 LONG        2   35    50.        .   1950.   1700.
BOLTS U/4 UN NO 3        1   15    50.     100.   2050.    800.

                                        TOTAL            7400.




BEGIN PHASE 2, BUDGET =      7300.

               PROD. NO. LEVEL  INCRE  MIN QTY   CAPAC  SCHEDULE

HAIRPIN, NO 6 BLACK      8    1   200.        .   7800.       .
1620 COMPUTER            7   20   100.     300.   2200.   2200.
LAMBSKIN TURBAN          6   10    50.        .    450.    450.
EYEGLASS FRAME, BRN      5   10    50.      50.    500.    500.
LOCOMOTIVE, DEISEL       4   33    50.        .   1950.   1600.
LOCOMOTIVE, STEAM        3    1    50.      50.   2000.     50.
SCREWS NO 18 LONG        2   35    50.        .   1950.   1700.
BOLTS U/4 UN NO 3        1   15    50.     100.   2050.    800.

                                        TOTAL            7300.
```

XII Listing of the FORTRAN Source Deck.

```
C     NON-LINEAR PROGRAMMING. A MODEL DESIGNED FOR PRODUCTION SCHEDULING DP-001
C     JOHN W. BURGESON, APPLIED SCIENCE REP. I B M AKRON                 DP 002
C     CHANGE LEVEL 3/5/62                                                DP 003
C     THIS PROG CAN HANDLE A MAX OF 199 PRODUCTS.                        DP 004
C     THE LIMIT IS CAUSED BY THE 3 DIGIT SEQUENCE                        DP 005
C     NUMBER PUT IN CC 78-80 BY THE FORTRAN PUNCH SUBROUTINE.            DP 006
C     THE PROG HAS 2 PHASES. OUTPUT FROM 1 IS 5 CARDS PER PRODUCT. THIS  DP 007
C     INTERMEDIATE DECK MUST BE SORTED IN REVERSE ORDER FOR INPUT TO     DP 008
C     PHASE 2. PHASE 2 MAY BE RUN MANY TIMES WITH THIS DECK, EACH PASS   DP 009
C     DEVELOPING A NEW SCHEDULE WITH A (REDUCED) NEW BUDGET.             DP 010
      DIMENSION S(40), V(40), PRECP(100), CURRP(100)                     DP 011
 1102 FORMAT (///1H )                                                    DP 012
 1103 FORMAT (///18H PHASE 1 COMPLETEDI4,16H ITEMS SCHEDULED)            DP 013
 1104 FORMAT (/11H END OF JOB/)                                          DP 014
 1118 FORMAT (//18HDYNAMIC PROG MODEL///24H NO.    BUDGET      DBUD)     DP 015
 2222 FORMAT(/15X,49HPROD. NO. LEVEL  INCRE  MIN QTY   CAPAC  SCHEDULE/) DP 016
 7776 FORMAT (I4,F10.0,F10.0,30H                              )          DP 017
 7777 FORMAT (20H                    I5,I5,F8.0,F8.0,F8.0,F8.0,I6)       DP 018
 7778 FORMAT (//42HSORT OUTPUT IN RVERSE SEQUENCE ON CC 78-80)           DP 019
 7779 FORMAT (/23HBEGIN PHASE 2, BUDGET =F10.0/)                         DP 020
 7780 FORMAT (31HTHEN HIT START TO BEGIN PHASE 2)                        DP 021
 7781 FORMAT (/35HRERUN INTERMED. CDS. FOR ALT. SOLN.)                   DP 022
 7782 FORMAT (/15X,48HNAME IRECD    M  INCRE  MIN QTY   CAPAC  AVG DEM)  DP 023
 7783 FORMAT (4HSO =F10.0,6H  SB =F10.0,6H  NR =I4)                      DP 024
 7784 FORMAT (/42X,5HTOTALF15.0)                                         DP 025
   77 FORMAT (F7.0,F7.0,F7.0,F7.0,F7.0,F7.0,F7.0,F7.0,F7.0,F7.0)         DP 026
      NUMB = 0                                                           DP 027
      TYPE 1118                                                          DP 028
      READ 7776,NUMBR,BUD,DBUD                                           DP 029
C     NUMBR IS THE TOTAL NUMBER OF PRODUCTS TO BE PROCESSED              DP 030
C     BUD IS THE BUDGET EXPRESSED IN TOTAL NO. OF UNITS                  DP 031
C     DBUD IS AN AMOUNT (OPTIONAL) BY WHICH BUD MAY BE REDUCED IN        DP 032
C     PHASE 2 TO OBTAIN ALTERNATE SOLUTIONS WITH REDUCED BUDGETS.        DP 033
      TYPE 7776,NUMBR,BUD,DBUD                                           DP 034
      PLACE = BUD                                                        DP 035
      SUMQ=0.                                                            DP 036
      SUMA2=0.                                                           DP 037
      OLDSO=0.                                                           DP 038
      OLDSB=0.                                                           DP 039
      TYPE 1102                                                          DP 040
      PRECP(1)=0.                                                        DP 041
      OLDA=0.                                                            DP 042
      NROLD=1                                                            DP 043
C     SENS E SWITCH 3 ON PERMITS THIS ADDITIONAL TYPED INFO              DP 044
      IF(SENSE SWITCH 3) 79,80                                           DP 045
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   79 TYPE 7782                                                          DP 046
   80 READ 7777, IRECD,M,A,Q,A2                                          DP 047
C     IRECD IS PROD IDENTIFIER (STOCK NO) NOT USED BY PROG               DP 048
C     M IS NO OF PROD LEVELS CONSIDERED. MUST BE BETWEEN 1 AND 40        DP 049
C     A IS INCREMENT SIZE FROM LEVEL TO LEVEL, MUST BE 25,50,100,ETC     DP 050
C     Q IS MINIMUM QUANTITY TO BE MADE. MUST BE MULTIPLE OF A            DP 051
C     A2 IS AVERAGE DEMAND OVER NEXT 3 MONTHS                            DP 052
      IF(M-40) 85,85,999                                                 DP 053
   85 EM=M-1                                                             DP 054
C     NOW CALCULATE CAPAC FOR THIS PRODUCT                               DP-055
      CAPAC = Q + A*EM                                                   DP 056
C     CAPAC IS THE MAX PROD LEVEL                                        DP 057
C     THUS IF X IS A PROD LEVEL WE CAN SAY -                             DP 058
C     X = Q, Q+A, Q+2.*A, . . . , CAPAC                                  DP 059
      DO 81 I=1,M,10                                                     DP 060
      I2=I+1                                                             DP 061
      I3=I+2                                                             DP 062
      I4=I+3                                                             DP 063
      I5=I+4                                                             DP 064
      I6=I+5                                                             DP 065
      I7=I+6                                                             DP 066
      I8=I+7                                                             DP 067
      I9=I+8                                                             DP 068
      I0=I+9                                                             DP 069
   81 READ 77,V(I),V(I2),V(I3),V(I4),V(I5),V(I6),V(I7),V(I8),V(I9),V(I0) DP 070
C     V(I) IS THE PROFIT ASSOCIATED WITH PROD LEVEL I                    DP 071
C     SENSE SWITCH 3 ON PERMITS THIS ADDITIONAL TYPED INFO               DP 072
      IF(SENSE SWITCH 3) 82,83                                           DP 073
   82 TYPE 7777, IRECD,M,A,Q,CAPAC,A2                                    DP 074
   83 NUMB=NUMB+1                                                        DP 075
      SUMQ=SUMQ+Q                                                        DP 076
      SUMA2=SUMA2+A2                                                     DP 077
      SUMC=OLDSB+CAPAC                                                   DP 078
      SOMIN=OLDSO                                                        DP 079
      IF(OLDSO-SUMQ) 114,115,115                                         DP 080
  114 SOMIN=SUMQ                                                         DP 081
  115 SBMAX=SUMC                                                         DP 082
      IF(SUMC-BUD) 118,118,117                                           DP 083
  117 SBMAX =BUD                                                         DP 084
  118 K=SOMIN/A                                                          DP 085
      SO=K                                                               DP 086
      K=SBMAX/A+.9999                                                    DP 087
      SB=K                                                               DP 088
      SO=SO*A                                                            DP 089
      SB=SB*A                                                            DP 090
      NR=(SB-SO)/A+1.                                                   DP 091
      IF(NR-100) 135,135,127                                            DP 092
  127 K=SOMIN/A+(SUMA2/BUD)*(SB-SO-100.*A)/A                            DP 093
      SO=K                                                              DP 094
      SO=SO*A                                                           DP 095
      SB=SO+99.*A                                                       DP 096
      NR=100                                                            DP 097
  135 DO 136 J = 1,40                                                   DP 098
  136 S(J) = SO                                                         DP 099
  137 QQ=Q                                                              DP 100
      IF(SENSE SWITCH 3) 138,139                                        DP 101
C     SENSE SWITCH 3 ON PERMITS THIS ADDITIONAL TYPED INFO              DP 102
  138 TYPE 7783,SO,SB,NR                                                DP 103
  139 IGAG=1                                                            DP 104
      SS=SO                                                             DP 105
      INDEX=1                                                           DP 106
  150 P=-1000000.                                                       DP 107
      X=QQ                                                              DP 108
      IDEX1=IGAG                                                        DP 109
      XB=QQ                                                             DP 110
      CALC OF Y. S WILL CONTAIN FOR EACH X THE HIGHEST S FOUND          DP 111
  171 ARG=SS-X                                                          DP 112
      IF(ARG-OLDSB) 185,180,180                                         DP 113
  180 Y=V(IDEX1) + PRECP(NROLD)                                         DP 114
      GO TO 300                                                         DP 115
  185 T4=ARG-OLDSO                                                      DP 116
      IF(T4) 320,190,190                                                DP 117
  190 IDEX2 = (ARG-OLDSO)/OLDA + 1.5                                    DP 118
      Y=V(IDEX1)+PRECP(IDEX2)                                           DP 119
  300 IF(Y-P) 320,310,310                                               DP 120
  310 P=Y                                                               DP 121
      XB=X                                                              DP 122
      QQ = X                                                            DP 123
      IGAG=IDEX1                                                        DP 124
  320 X=X+A                                                             DP 125
      IDEX1=IDEX1+1                                                     DP 126
      IF(X-SS) 335,335,340                                              DP 127
  335 IF (X-CAPAC) 171,171,340                                          DP 128
  340 IF(P+1000000.) 341,600,341                                        DP 129
  600 SO=SO+A                                                           DP 130
      IF (NR-100) 601,602,601                                           DP 131
  601 NR=NR-1                                                           DP 132
      GO TO 137                                                         DP 133
  602 SB=SB+A                                                           DP 134
      GO TO 137                                                         DP 135
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  341 CURRP(INDEX)=P                                                    DP 136
      IDEXB=(XB-Q)/A +1.5                                               DP 137
      S(IDEXB)=SS                                                       DP 138
      SS=SS+A                                                           DP 139
      INDEX = INDEX + 1                                                 DP 140
      IF(SS-SB)150,150,370                                              DP 141
  370 DO 372 JK=1,NR                                                    DP 142
  372 PRECP(JK)=CURRP(JK)                                               DP 143
      OLDSB=SB                                                          DP 144
      OLDSO=SO                                                          DP 145
      OLDA=A                                                            DP 146
      NROLD=NR                                                          DP 147
      DO 378 I=1,40,10                                                  DP 148
      I2=I+1                                                            DP 149
      I3=I+2                                                            DP 150
      I4=I+3                                                            DP 151
      I5=I+4                                                            DP 152
      I6=I+5                                                            DP 153
      I7=I+6                                                            DP 154
      I8=I+7                                                            DP 155
      I9=I+8                                                            DP 156
      I0=I+9                                                            DP 157
  378 PUNCH77,S(I),S(I2),S(I3),S(I4),S(I5),S(I6),S(I7),S(I8),S(I9),S(I0) DP 158
      PUNCH 7777, IRECD,M,A,Q,CAPAC,SO,NUMB                             DP 159
      IF(NUMB-NUMBR) 80,400,999                                         DP 160
  400 TYPE 1103,NUMB                                                    DP 161
      TYPE 7778                                                         DP 162
      TYPE 7780                                                         DP 163
      PAUSE                                                             DP 164
    9 TYPE 7779,PLACE                                                   DP 165
      PUNCH 7779, PLACE                                                 DP 166
      IF(SENSE SWITCH 1) 3333,3334                                      DP 167
 3333 TYPE 2222                                                         DP 168
 3334 PUNCH 2222                                                        DP 169
C     BEGIN INPUT TO PHASE 2                                            DP-170
   10 READ  7777, IRECD,M,A,Q,CAPAC,SO,NUMB                             DP 171
      I=41                                                              DP 172
      DO 11 K=1,40,10                                                   DP 173
      I=I-10                                                            DP 174
      I2=I+1                                                            DP 175
      I3=I+2                                                            DP 176
      I4=I+3                                                            DP 177
      I5=I+4                                                            DP 178
      I6=I+5                                                            DP 179
      I7=I+6                                                            DP 180
      I8=I+7                                                            DP 181
      I9=I+8                                                            DP 182
      I0=I+9                                                            DP 183
   11 READ 77,S(I),S(I2),S(I3),S(I4),S(I5),S(I6),S(I7),S(I8),S(I9),S(I0) DP 184
      X = 0.                                                            DP 185
   17 IF(PLACE) 41,41,18                                                DP 186
   18 DO 20 I = 1,M                                                     DP 187
      IF(PLACE-S(I)) 22,22,20                                           DP 188
   20 CONTINUE                                                          DP 189
      X=CAPAC                                                           DP 190
      GO TO 23                                                          DP 191
   22 EM = I-1                                                          DP 192
      X = Q + A*EM                                                      DP 193
   23 PLACE = PLACE - X                                                 DP 194
   41 PUNCH 7777, IRECD,I,A,Q,CAPAC,X                                   DP 195
C     X WILL BE THE OPTIMUM NO. OF UNITS TO PRODUCE                     DP 196
      IF(SENSE SWITCH 1) 42,43                                          DP 197
C     SENSE SWITCH 1 ON TO TYPE ANSWERS AS WELL AS PUNCH THEM           DP 198
   42 TYPE  7777, IRECD,I,A,Q,CAPAC,X                                   DP 199
   43 IF(NUMB-1) 999,48,10                                              DP 200
C                   END OF JOB PROCEDURE                                DP 201
   48 TOTAL = BUD - PLACE                                               DP 202
      PUNCH 7784, TOTAL                                                 DP 203
      IF(SENSE SWITCH 1) 49,51                                          DP 204
   49 TYPE 7784, TOTAL                                                  DP 205
   51 BUD = BUD - DBUD                                                  DP 206
      PLACE = BUD                                                       DP 207
C     SENSE SWITCH 2 ON TO REDUCE BUD BY DBUD AND OBTAIN ALT. SOLN.     DP 208
      PUNCH 1102                                                        DP 209
      IF(SENSE SWITCH 2)  55,6999                                       DP 210
   55 IF(SENSE SWITCH 3) 52,9                                           DP 211
   52 TYPE 7781                                                         DP 212
      GO TO 9                                                           DP 213
 6999 TYPE 1104                                                         DP 214
  999 STOP                                                              DP 215
      END                                                               DP 216
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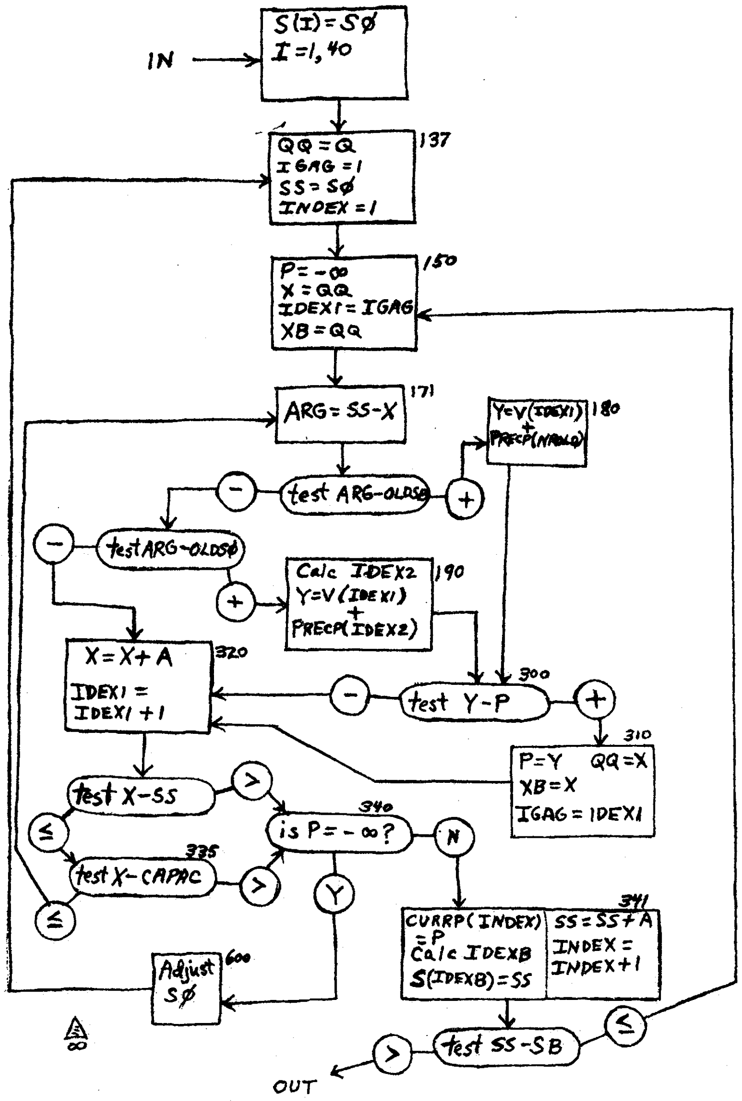
Flow Chart of the Algorithm



XIV Listing of the Object Deck

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Loader

Program

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} Post-loader

note: maintain card order in the loader and post-loader. Otherwise card order is immaterial. This object produced by program "SQUEEZ" 1.3.005.

J. W. Burgeson

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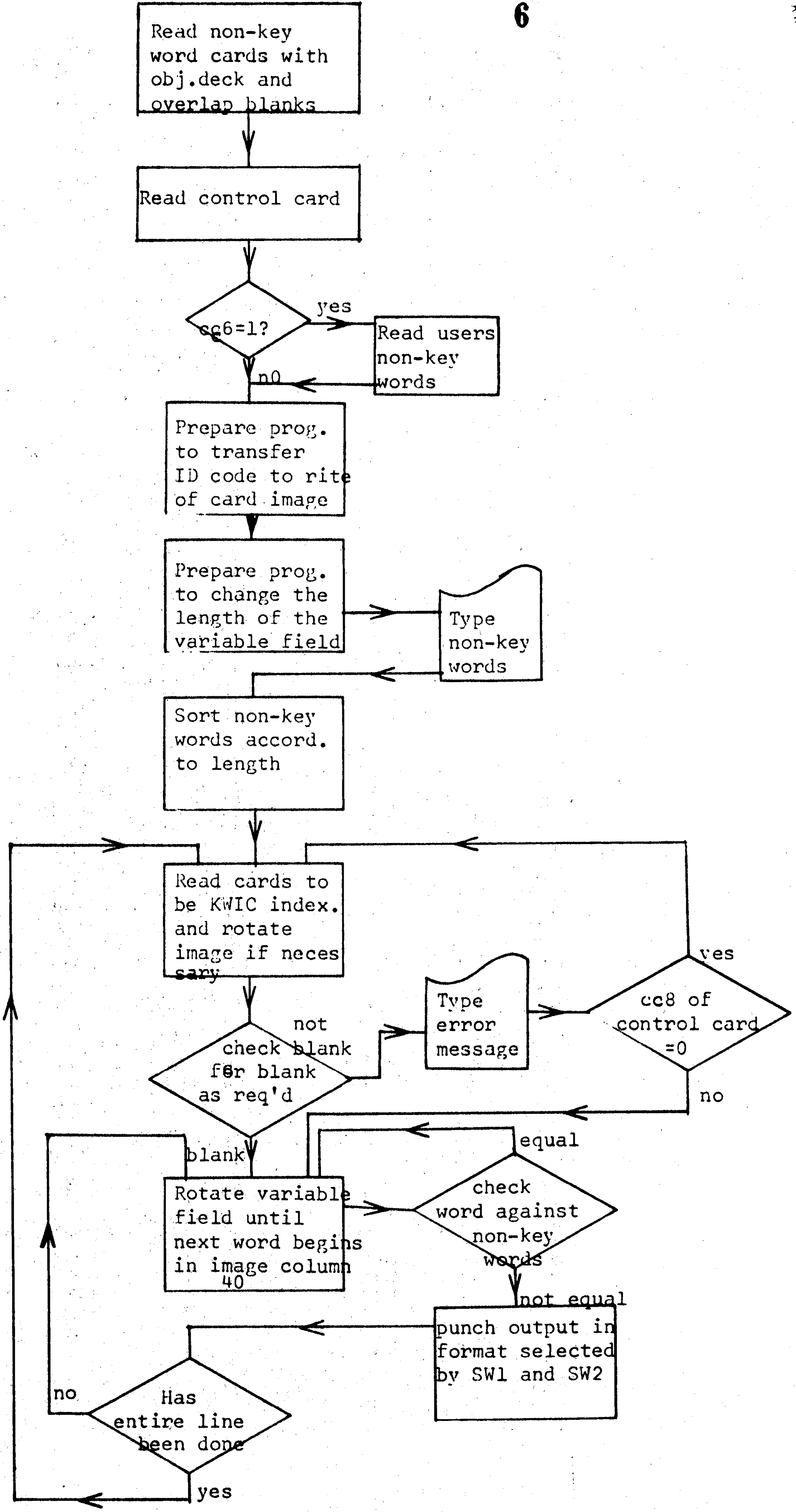
Read non-key word cards with obj.deck and overlap blanks
Read control card
cc6=1?
yes
Read users non-key words
n0
Prepare prog. to transfer ID code to rite of card image
Prepare prog. to change the length of the variable field
Type non-key words
Sort non-key words accord. to length
Read cards to be KWIC index. and rotate image if necessary
check for blank as req'd
not blank
Type error message
cc8 of control card =0
yes
no
blank
Rotate variable field until next word begins in image column 40
check word against non-key words
equal
not equal
punch output in format selected by SW1 and SW2
Has entire line been done
no
yes

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RNCD   RNCD   CØNTR                           02414 36 10609 00500
       SF     CØNTR                           02426 32 10609 00000
       SF     CØNTR+2                         02438 32 10611 00000
       BD     *+24,CØNTR+5                    02450 43 02474 10614
       B      B                               02462 49 02858 00000
       TD     BUFFA-2,400                     02474 25 09607 00400
       TR     INPUT-1,ØRDRD-1                 02486 31 06008 07808
       BT     RACD-12,RACD-13                 02498 27 02522 02521
       B      B,,7                            02510 49 02858 -0000
       SF     INPUT+1                         02522 32 06010 00000
RACD   RACD   INPUT+2                         02534 37 06011 00500
*    READ NØN-KEY WØRD CARDS
       TFM    INDXA,INPUT-1                   02546 16 05806 -6008
       TFM    INDXB,INPUT                     02558 16 05811 -6009
       CF     INDXA                           02570 33 05806 00000
       CF     INDXB                           02582 33 05811 00000
       AM     INDXA,2                         02594 11 05806 -0002
       AM     INDXB,2                         02606 11 05811 -0002
       BD     *-48,INDXA,11                   02618 43 02570 0580Ø
       BD     *-60,INDXB,11                   02630 43 02570 0581J
       AM     INDXA,2                         02642 11 05806 -0002
       AM     INDXB,2                         02654 11 05811 -0002
       SF     INDXA,,6                        02666 32 0580Ø 00000
       CF     INDXA                           02678 33 05806 00000
       BD     RACD+36,INDXA,11                02690 43 02570 0580Ø
       BD     RACD+36,INDXB,11                02702 43 02570 0581J
       CF     INDXA                           02714 33 05806 00000
       CF     INDXB                           02726 33 05811 00000
       TF     INDXC,INDXB                     02738 26 05816 05811
       AM     INDXC,2                         02750 11 05816 -0002
       BD     *+48,INDXC,11                   02762 43 02810 0581Ø
       RACD   INDXB,,6                        02774 37 0581J 00500
       CF     INDXC                           02786 33 05816 00000
       B      RACD+36                         02798 49 02570 00000
       TFM    INDXC,0,610                     02810 16 0581Ø 000-0
       TD     INDXC,400,6                     02822 25 0581Ø 00400
       RCTY                                   02834 34 00000 00102
       BB                                     02846 42 00000 00000
B      TFM    TRAN-1,BUFFT+2                  02858 16 03025 J0211
```

```
       TDM    GØ+13,1                         02870 15 04167 00001
       BD     IF,CØNTR                        02882 43 02918 10609
       BD     IF,CØNTR+1                      02894 43 02918 10610
       B      *+36                            02906 49 02942 00000
IF     TF     TRAN+23,CØNTR+1                 02918 26 03049 10610
       B      *+48                            02930 49 02978 00000
       TDM    GØ+13,9                         02942 15 04167 00009
       TFM    GØ+6,BUFF+2                     02954 16 04160 -5841
       B      START                           02966 49 03146 00000
       SM     TRAN-1,2                        02978 12 03025 -0002
STAR   NØP                                    02990 41 00000 00000
       SF     TRAN+22                         03002 32 03048 00000
       SF     BUFFT-1                         03014 32 10208 00000
TRAN   TFM    LØØP-1,80,10                    03026 16 04961 00000
       SM     LØØP-1,*-*                      03038 12 04961 -0000
       SM     TRAN-1,1                        03050 12 03025 -0001
       A      TRAN-1,TRAN+23                  03062 21 03025 03049
       A      TRAN-1,TRAN+23                  03074 21 03025 03049
       TFM    TRAN-13,BUFF+162                03086 16 03013 -6001
       S      TRAN-13,TRAN+23                 03098 22 03013 03049
       S      TRAN-13,TRAN+23                 03110 22 03013 03049
       AM     TRAN-13,1                       03122 11 03013 -0001
       B      START                           03134 49 03146 00000
*           CHANGING LENGTH ØF VARIABLE FIELDS
START  BD     *+36,CØNTR+2                    03146 43 03182 10611
       BD     *+24,CØNTR+3                    03158 43 03182 10612
       B      FLØØP-24                        03170 49 03746 00000
       TF     LØØP-1,CØNTR+3                  03182 26 04961 10612
       SF     LØØP-2                          03194 32 04960 00000
       TFM    ABØUT-1,0                       03206 16 04585 -0000
       A      ABØUT-1,LØØP-1                  03218 21 04585 04961
       A      ABØUT-1,LØØP-1                  03230 21 04585 04961
       AM     ABØUT-1,ERRØR                   03242 11 04585 -4611
       TFM    ABØUT-1,65,610                  03254 16 0458N 00Ø05
       AM     ABØUT-1,2                       03266 11 04585 -0002
       TD     ABØUT-1,400 ,6                  03278 25 0458N 00400
*    CHANGING LENGTH ØF VARIABLE FIELDS
*    CLEAR FIELDS AND ADD LENGTHS
*    CLEAR AND ADD 2*LENGTH ØF FIELD TØ REGISTERS FØR CHANGING LENGTH
*    VARIABLE FIELDS---THIS THEN ALLØWS THE CØRRECT RØTATIØN AND ØUTP
*       G ØF THIS SUB
*       TRANSMIT CØRRECTED LENGTHS TØ EQUATIØNS INCLUDING BUFF
          TFM    RØTATE-1,0                                      03290 16 05465 -0000
          A      RØTATE-1,LØØP-1                                 03302 21 05465 04961
          A      RØTATE-1,LØØP-1                                 03314 21 05465 04961
          TFM    ERR-1,0                                         03326 16 04381 -0000
          A      ERR-1,RØTATE-1                                  03338 21 04381 05465
          AM     ERR-1,BUFF                                      03350 11 04381 -5839
          TFM    RACD-1,0                                        03362 16 02533 -0000
          A      RACD-1,RØTATE-1                                 03374 21 02533 05465
          AM     RACD-1,BUFFB                                    03386 11 02533 -9809
          TFM    GØ-1,0                                          03398 16 04153 -0000
          A      GØ-1,RØTATE-1                                   03410 21 04153 05465
          AM     GØ-1,BUFFA                                      03422 11 04153 -9609
*       FØR BUFF
          TF     RØTATE+11,ERR-1                                 03434 26 05477 04381
          TF     RØTATE+18,ERR-1                                 03446 26 05484 04381
          TF     RØTATE+66,ERR-1                                 03458 26 05532 04381
          SM     ERR-1,1                                         03470 12 04381 -0001
          TF     RØTATE+78,ERR-1                                 03482 26 05544 04381
          SM     ERR-1,1                                         03494 12 04381 -0001
          TF     RØTATE+42,ERR-1                                 03506 26 05508 04381
          AM     ERR-1,1                                         03518 11 04381 -0001
          TF     SUB2+71,ERR-1                                   03530 26 05645 04381
*       FØR BUFFA
          AM     GØ-1,1                                          03542 11 04153 -0001
          TF     SUB40+30,GØ-1                                   03554 26 05736 04153
          AM     GØ-1,2                                          03566 11 04153 -0002
          TF     SUB40+35,GØ-1                                   03578 26 05741 04153
          AM     GØ-1,28                                         03590 11 04153 -0028
          TF     SUB40+6,GØ-1                                    03602 26 05712 04153
*       FØR BUFFB
          AM     RACD-1,1                                        03614 11 02533 -0001
          TF     SUB2+42,RACD-1                                  03626 26 05616 02533
          TF     SUB2+107,RACD-1                                 03638 26 05681 02533
          SM     RACD-1,2                                        03650 12 02533 -0002
          TF     SUB2+102,RACD-1                                 03662 26 05676 02533
          AM     RACD-1,78                                       03674 11 02533 -0078
          TF     SUB2+66,RACD-1                                  03686 26 05640 02533
          AM     RACD-1,4                                        03698 11 02533 -0004
```

```
  GØ      RACD   BUFFI+2                                         04154 37 10211 00500
          NØP    ERMES                                           04166 41 04274 00000
          TD     BUFFI+164,400                                   04178 25 10373 00400
          TR     BUFF+1,TRAN-1,11                                04190 31 05840 0302N
          SM     TRAN-1,1                                        04202 12 03025 -0001
          CM     TRAN+11,0,10                                    04214 14 03037 000-0
          BE     *+24                                            04226 46 04250 01200
          TF     BUFF+162,TRAN-1,11                              04238 26 06001 0302N
          AM     TRAN-1,1                                        04250 11 03025 -0001
          CF     TRAN-13,,6                                      04262 33 0301L 00000
*       READ IN CARDS TØ BE KEY WØRD INDEXED
*       BEGIN CHECKING FØR ERRØRS(NØN-BLANKS IN CØLUMNS LL+LM ØR IN THIS
*DESIRED BY THE USE ØF SW4
 ERMES    TFM    ERR-1,0                                         04274 16 04381 -0000
          TD     BUFF+164,400                                    04286 25 06003 00400
          A      ERR-1,LØØP-1                                    04298 21 04381 04961
          A      ERR-1,LØØP-1                                    04310 21 04381 04961
          AM     ERR-1,BUFF+1                                    04322 11 04381 -5840
          BD     ERR,ERR-1,11                                    04334 43 04382 0438J
          AM     ERR-1,1                                         04346 11 04381 -0001
          BD     ERR,ERR-1,11                                    04358 43 04382 0438J
          B      ABØUT                                           04370 49 04586 00000
 ERR      RCTY   ...RETURN CARRIAGE                              04382 34 00000 00102
          TFM    ERRØR-2,0                                       04394 16 04609 -0000
          A      ERRØR-2,LØØP-1                                  04406 21 04609 04961
          AM     ERRØR-2,1                                       04418 11 04609 -0001
          SF     ERRØR-3                                         04430 32 04608 00000
          TF     ERRØR+15,ERRØR-2                                04442 26 04626 04609
          TF     ERRØR+16,ERRØR-2                                04454 26 04627 04609
          TDM    ERRØR+13,7                                      04466 15 04624 00007
          TDM    ERRØR+15,7                                      04478 15 04626 00007
          WATY   ERRØR                                           04490 39 04611 00100
*       WRITE ERRØR MESSAGE
```

```
         TF      SUB2+54,RACD-1                                   03710 26 05628 02533
         SM      RACD-1,3                                         03722 12 02533 -0003
         TF      SUB2+90,RACD-1                                   03734 26 05664 02533
         WATY    INPUT+2                                          03746 39 06011 00100
         TFM     INDXC,ØRDRD+2                                    03758 16 05816 -7811
*       BEGIN REARRANGING NØN-KEY WØRDS BY LENGTH
FLØØP    TFM     CØMP1+9,0,10                                     03770 16 03791 000-0
CØMP1    AM      *+9,1,10,LENGTH ØF WØRD FØR THIS PASS            03782 11 03791 000-1
         MM      CØMP1+9,2,10                                     03794 13 03791 000-2
         TFM     INDXA,INPUT-1                                    03806 16 05806 -6008
         TFM     INDXB,INPUT                                      03818 16 05811 -6009
         SM      INDXB,2,10                                       03830 12 05811 000-2
         SM      INDXA,2,10                                       03842 12 05806 000-2
SLØØP    TFM     *+21,0,10                                        03854 16 03875 000-0
         AM      *+9,1,10,LENGTH ØF THE WØRD BEING WØRKED ØN
                                                                  03866 11 03875 000-1
         AM      INDXA,2                                          03878 11 05806 -0002
         AM      INDXB,2                                          03890 11 05811 -0002
         BD      SLØØP+12,INDXA,11                                03902 43 03866 0580Ø
         BD      SLØØP+12,INDXB,11                                03914 43 03866 0581J
         C       CØMP1+9,SLØØP+21                                 03926 24 03791 03875
         BNE     SKIP                                             03938 47 03998 01200
TRANS    TF      T1+11,99                                         03950 26 03973 00099
T1       AM      INDXC                                            03962 11 05816 -0000
         TF      INDXC,INDXB,611                                  03974 26 0581Ø 0581J
         AM      INDXC,2                                          03986 11 05816 -0002
SKIP     AM      INDXA,2                                          03998 11 05806 -0002
         AM      INDXB,2                                          04010 11 05811 -0002
         BD      SLØØP,INDXA,11                                   04022 43 03854 0580Ø
         BNR     *+24,INDXB,11                                    04034 45 04058 0581J
         B       *+24                                             04046 49 04070 00000
         BD      SLØØP,INDXB,11                                   04058 43 03854 0581J
         TD      INDXC,400,6                                      04070 25 0581Ø 00400
         AM      INDXC,2                                          04082 11 05816 -0002
         CM      CØMP1+9,20,10                                    04094 14 03791 000K0
         BNE     CØMP1                                            04106 47 03782 01200
         TD      ØRDRD+4,400                                      04118 25 07813 00400
         TD      INDXC,400,6                                      04130 25 0581Ø 00400
*       FINISH ØRDERING ØF NØN-KEY WØRDS
         SF      BUFFT-1                                          04142 32 10208 00000
```

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         RCTY                                                     04502 34 00000 00102
         TD      BUFF+164,400                                     04514 25 06003 00400
         WATY    BUFF+2                                           04526 39 05841 00100
*       WRITE ERRØRA CARD
         TFM     ERR+1,41,10                                      04538 16 04383 000M1
         TFM     ERR+97,41,10                                     04550 16 04479 000M1
         BD      ABØUT,CØNTR+7                                    04562 43 04586 10616
         B       GØ                                               04574 49 04154 00000
ABØUT    TFM     INDXA,INPUT-1                                    04586 16 05806 -6008
         B       LØØP-12                                          04598 49 04950 00000
ERRØR    DAC     50,CØLUMN 67 IS NØT BLANK AS REQUIRED.                     .
                                                                  04611 00100
         DAC     31,                                    '         04711 00062
ER1      DAC     45,TO CONTINUE WITH THE NEXT CARD, PRESS START.'
                                                                  04773 00090
RESET    DAC     44,RESET SW4, TYPE NEW VARIABLE CØLUMN LENGTH.'
                                                                  04863 00088
         TFM     *+21,66,10                                       04950 16 04971 000Ø6
LØØP     SM      *+9,1,10                                         04962 12 04971 000-1
         BL      GØ                                               04974 47 04154 01300
         BD      RØTATE,BUFF+78                                   04986 43 05466 05917
         BD      RØTATE,BUFF+77                                   04998 43 05466 05916
         BD      *+36,BUFF+80                                     05010 43 05046 05919
         BD      *+24,BUFF+79                                     05022 43 05046 05918
         B       RØTATE                                           05034 49 05466 00000
         SF      BUFF+79                                          05046 32 05918 00000
         TFM     INDXA,BUFF+79                                    05058 16 05806 -5918
         TFM     INDXB,BUFF+80                                    05070 16 05811 -5919
         TFM     INDXC,0                                          05082 16 05816 -0000
         AM      INDXA,2                                          05094 11 05806 -0002
         AM      INDXB,2                                          05106 11 05811 -0002
         AM      INDXC,1                                          05118 11 05816 -0001
         BD      *-36,INDXA,11                                    05130 43 05094 0580Ø
         BD      *-48,INDXB,11                                    05142 43 05094 0581J
         SM      INDXB,2                                          05154 12 05811 -0002
         TF      INDXC1,INDXC                                     05166 26 05831 05816
         A       INDXC1,INDXC1,,LENGTH ØF WØRD                    05178 21 05831 05831
         TF      INDXC2,INDXC                                     05190 26 05836 05816
         TFM     INDXB1,ØRDRD                                     05202 16 05826 -7809
         AM      INDXB1,2                                         05214 11 05826 -0002
         BNR    *-12,INDXB1,11                            05226 45 05214 05820
         SM     INDXC2,1                                  05238 12 05836 -0001
         BH     *-36,INDXC2,11                            05250 46 05214 01130
         NØP    ,,,WE HAVE RECØRD MARKE BEFØRE FIRST CHARACTER ØF CØRRECT
                                                          05262 41 00000 00000
NXTWD    AM     INDXB1,2                                  05274 11 05826 -0002
         BNR    *+24,INDXB1,11                            05286 45 05310 05822
         B      INDC                                      05298 49 05382 00000
         SM     INDXB1,2                                  05310 12 05826 -0002
         A      INDXB1,INDXC1                             05322 21 05826 05831
         C      INDXB1,INDXB,611                          05334 24 05820 0581J
         BE     RØTATE                                    05346 46 05466 01200
         AM     INDXB1,2                                  05358 11 05826 -0002
         B      NXTWD                                     05370 49 05274 00000
INDC     BC1    CØL40                                     05382 46 05442 00100
*     SELECT METHØDS ØF PUNCHING
*     SW1 UP FØR KEY WØRDS ØNLY ØN CØLUMN J/
*     SW2 UP FØR KEY WØRDS ØNLY IN CØLUMN 1
*     SW1+SW2 ØFF FØR BØTH TYPES ØF ØUTPUT
         BC2    CØL2                                      05394 46 05418 00200
         BTM    SUB40                                     05406 17 05706 -0000
CØL2     BTM    SUB2                                      05418 17 05574 -0000
         B      RØTATE                                    05430 49 05466 00000
CØL40    BTM    SUB40                                     05442 17 05706 -0000
         B      RØTATE                                    05454 49 05466 00000
RØTATE   TD     *+47,BUFF+132                             05466 25 05513 05971
         TD     BUFF+132,400                              05478 25 05971 00400
         TR     BUFF-1,BUFF+1                             05490 31 05838 05840
         TDM    BUFF+130                                  05502 15 05969 00000
         SF     BUFF-1                                    05514 32 05838 00000
         TF     BUFF+132,BUFF                             05526 26 05971 05839
         CF     BUFF+131                                  05538 33 05970 00000
         CF     BUFF+77                                   05550 33 05916 00000
         B      LØØP                                      05562 49 04962 00000
*     NEW SUB2 RØUTINE
SUB2     TD     BUFF+163,400                              05574 25 06002 00400
*     SUBR TØ ØUTPUT IN CØLUMN 1
         TR     BUFFB-1,BUFF+1                            05586 31 09808 05840
         TD     BUFFB+76,400                              05598 25 09885 00400
         TR     BUFFB+133,BUFFB-1                         05610 31 09942 09808
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         TR     BUFFB+213,BUFF+1                          05622 31 10022 05840
         TR     BUFFB+211,BUFF+133                        05634 31 10020 05972
         TDM    BUFFB+76,0                                05646 15 09885 00000
         TFM    BUFFB+210,0,10                            05658 16 10019 000-0
         TR     BUFFB+131,BUFFB+133                       05670 31 09940 09942
         WACD   BUFFB+78                                  05682 39 09887 00400
         BB                                               05694 42 00000 00000
SUB40    TD     BUFF+163,400                              05706 25 06002 00400
*     SUBR TØ ØUTPUT IN CØLUMN 40
         TR     BUFFA+1,BUFF+1                            05718 31 09610 05840
         TR     BUFFA+133,BUFFA+135                       05730 31 09742 09744
         TD     BUFFA+77,400                              05742 25 09686 00400
         TR     BUFFA-1,BUFFA+1                           05754 31 09608 09610
         TFM    BUFFA+78,0,8                              05766 16 09687 0-000
         WACD   BUFFA                                     05778 39 09609 00400
         BB                                               05790 42 00000 00000
INDXA    DS     5                                         05806 00005
INDXB    DS     5                                         05811 00005
INDXC    DS     5                                         05816 00005
INDXA1   DS     5                                         05821 00005
INDXB1   DS     5                                         05826 00005
INDXC1   DS     5                                         05831 00005
INDXC2   DS     5                                         05836 00005
BUFF     DAC    50,                                                   ,
                                                          05839 00100
         DSC    50,0                                      05938 00050
         DSC      20,0                                    05988 00020
INPUT    DAS    900                                       06009 01800
ØRDRD    DAS    900                                       07809 01800
BUFFA    DAS    100                                       09609 00200
BUFFB    DAS    200                                       09809 00400
BUFFI    DAS    200                                       10209 00400
CØNTR    DAS    80                                        10609 00160
         DEND   RCDSB                                     02402
```

PART IV - NOTES ON THIS PROGRAM

A. Node Numbering

In many previous programs of this sort the jobs had to be numbered so that the head of an arrow (J) was always greater than the tail (I) of that arrow. In addition input cards had to be in J sequence within I sequence with no missing I values. These restrictions allowed checking arrow diagram logic by a sequence check of I values and a test of I against J. In this program another method is used for checking logic that removes these restrictions.

As long as none of the restrictions of Part II are violated, I and J may be any three digit numbers. However, the restrictions on maximum project size are in terms of the highest numbered node and not in terms of the total number of nodes, so it is sometimes necessary to use the smallest numbers available for I and J. There is also a slight speed advantage in putting the jobs in approximately the same order as the previous restriction required.

B. Program Capacity

For a 20,000 digit core memory machine, the sum of the number of the highest numbered node and the number of jobs must be 1672 or less. For 40,000 digits of storage this restriction is 3672 and for 60,000 digits it is 5672. The highest possible numbered node is 999. For 20,000 digits the maximum number of jobs may be less than 1400 for the reason stated in Part VI - C.

C. Machine Requirements

1620 Data Processing System

1622 Card Read Punch

No other special features

1623 Additional Core Memory is optional.

PART V - INPUT

The input to this program contains three types of data cards. Type 1 and 2 cards may be arranged in any desired order. See Appendix A for sample problem input.

Type 1 - Heading or description cards

These are identified by some character in column 1, other than a blank or numeric digit. The remainder of the card may be punched with any information desired. The identifying character in column 1 may be different for each type 1 card.

Type 2 - Job description cards

There is one of these for every job in the project. Blanks in numeric fields are taken as zeros, except that a zero I field must be punched zero in the units position (column 3).

Columns	
1 - 3	Tail of the job arrow - I
4 - 6	Head of the job arrow - J
7 - 10	Time duration of the job - D (I,J)
11 - 15	Cost of the job
16 - 50	Description of the job and miscellaneous data
51 - 80	Not used - may contain anything

Type 3 - End of the project

This is the last card in the input deck and should be blank.

PART VI - OPERATING INSTRUCTIONS

A. Program Deck

The SPS listing of this program is in Appendix C. The condensed program deck (listing in Appendix D) consists of 70 cards numbered 00 through 69 in columns 79-80. Column 1 of card number 62 contains a digit signifying the core memory size of the computer being used.

$\bar{2}$	20,000 Positions
$\bar{4}$	40,000 Positions
$\bar{6}$	60,000 Positions

B. Procedure

PARITY	Switch	-	STOP
O FLOW	Switch	-	STOP
I/O	Switch	-	STOP
Program	Switches	-	not used

Load Program Deck - Depress RESET, place program deck in read hopper, depress LOAD. To read final program card, depress READER START. Computer then halts when program is loaded.

Data Pass I - Place data deck in read hopper, press READER START and computer START. To read the final data card, depress READER START. Computer does error analysis and either halts or prints an error message.

Data Pass II - If no errors were discovered, place data deck in read hopper and blank cards in punch hopper. Press READER START, PUNCH START, and computer START. To read the final data card, depress READER START.

C. Error Messages and Actions

Error 1 - Available storage has been exceeded. The number of the highest numbered arrow plus the number of jobs is greater than 1672 (for 20,000 positions of storage). Typewriter prints I,J,D, COST for

the last job and halts. To work the next project press START.

Error 2 - More than one "last" node (a node which is not the tail of some arrow) has been found. Typewriter prints the numbers of all but the first "last" node found and halts. To find the first "last" node type out locations 3247-49. To work the next project INSERT 16 01095 00$\bar{1}$6 49 00402, RELEASE, START.

Error 3 - More than one "first" node (a node which is not the head of some arrow) has been found. Typewriter prints the numbers of all but the first "first" node found and halts. To find the first "first" node type out location 3244-46. To work the next project INSERT 16 01095 00$\bar{1}$6 49 00402, RELEASE, START.

Error 4 - A loop has been found in the arrow diagram. For example a series of jobs (1,2), (2,3), and (3,1) would be a loop. Typewriter prints I,J,D, COST for the first job where the error may be detected. (i.e. The earliest start for this job exceeds the sum of all job times.) This job need not be on the loop itself, but may be on a chain of jobs which passes through one of the nodes on the loop. To work the next project press START.

There is a very remote possibility that a type 1 error could go undetected as such. During data pass I a temporary table is set up in locations 4000 - 6001 to be used to find "first" and "last" nodes. If 1400 jobs or more are read, this table may be destroyed. This will cause several type 2 and 3 error messager however.

PART VII - OUTPUT

A deck of cards similar to the pass II data deck is produced. The type 1 output cards are unchanged. The type 2 output cards are identical to input in columns 1 - 50, and contain the following calculated quantities in columns 51 - 80.

Columns	
51 - 55	Earliest start date
56 - 60	Earliest finish date
61 - 65	Latest start date
66 - 70	Latest finish date
71 - 75	Total float time
76 - 80	Free float time
75	Contains * if this is a critical job

There are no type 3 cards in the output deck. The last output card is a type 1 card containing project cost and completion date. By letting the first column of the output cards be a printer format control, any desired listing may be developed.

PART VIII - SUGGESTIONS

A Additional or Special Output

The second pass of data controls the amount of output. For example if you do not wish to include dummy jobs in the printed report, omit them from the data deck in the second data pass. If you wish to prepare several reports on one project, it is possible to make several second passes. Prepare a transfer card with 49 01798 0000 in columns 1 - 12, and place it on top of the pass 2 deck. Press RESET and LOAD to execute another second pass.

B Least Cost Estimating

Repeated applications of this program will give an idea of how project completion time varies with cost. First schedule the project with normal job time and normal costs, then compress the schedule along the critical path, which shortens the over-all project time at the expense of increasing some job costs. Running the schedule again will show the new project time and cost and the new critical path. If the assumption is made that cost of a job varies linearly with completion time between the limits of normal job time and crash time, this estimating may be done automatically by means of a specialized parametric linear programming algorithm. In either case a series of project durations are obtained as a function of direct job costs. By combining these with the indirect costs for overhead, penalties, etc., the least cost may be estimated.

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PART X - APPENDIX A

APPENDIX A - SAMPLE PROBLEM INPUT

SAMPLE PROBLEM - FIGURE 1

SCHEDULE REPLACEMENT OF A PIPE LINE

I	J	D	COST	DESCRIPTION OF JOBS	ES	EF	LS	LF	TF	FF
1	2	10		LEAD TIME						
1	5	28		TIME AVAILABLE						
2	3	2	300	MEASURE AND SKETCH						
2	20	1	25	MAKE ASSIGNMENTS						
20	3									
3	4	1	100	DEVELOP MATERIAL LIST						
4	5									
4	6	2	300	ERECT SCAFFOLD						
4	7	30	850	PROCURE PIPE						
4	8	45	300	PROCURE VALVES						
5	6	1	100	DEACTIVATE LINE						
6	8									
6	9	6	400	REMOVE OLD PIPE						
7	9	5	1200	PREFAB SECTIONS						
8	11	1	100	PLACE VALVES						
9	10	6	800	PLACE NEW PIPE						
10	11	2	100	WELD PIPE						
11	12	1	100	FIT UP						
11	13	4	300	INSULATE						
12	13									
12	14	1	50	PRESSURE TEST						
13	14	1	100	REMOVE SCAFFOLD						
14	15	1	100	CLEAN UP						
1	15	60		PROMISED COMPLETION						

TEST PROBLEM - SEE FIGURE 2

I	J	D	COST	DESCRIPTION OF JOBS	ES	EF	LS	LF	TF	FF
1	2	3								
1	3	9								
2	3	4								
2	5	7								
3	4	5								
4	5	6								

APPENDIX 3 - SAMPLE PROBLEM OUTPUT

```
                    SAMPLE PROBLEM - FIGURE 1

-            SCHEDULE REPLACEMENT OF A PIPE LINE
-
-I   J   D  COST  DESCRIPTION OF JOBS                ES    EF    LS    LF    TF    FF
-
  1  2  10        LEAD TIME                                10          10     *
  1  5  28        TIME AVAILABLE                           28    16    44    16
  2  3   2   300  MEASURE AND SKETCH                 10    12    10    12     *
  2 20   1    25  MAKE ASSIGNMENTS                   10    11    11    12     1
 20  3                                               11    11    12    12     1     1
  3  4   1   100  DEVELOP MATERIAL LIST              12    13    12    13     *
  4  5                                               13    13    44    44    31    15
  4  6   2   300  ERECT SCAFFOLD                     13    15    43    45    30    14
  4  7  30   850  PROCURE PIPE                       13    43    16    46     3
  4  8  45   300  PROCURE VALVES                     13    58    13    58     *
  5  6   1   100  DEACTIVATE LINE                    28    29    44    45    16
  6  8                                               29    29    58    58    29    29
  6  9   6   400  REMOVE OLD PIPE                    29    35    45    51    16    13
  7  9   5  1200  PREFAB SECTIONS                    43    48    46    51     3
  8 11   1   100  PLACE VALVES                       58    59    58    59     *
  9 10   6   800  PLACE NEW PIPE                     48    54    51    57     3
 10 11   2   100  WELD PIPE                          54    56    57    59     3     3
 11 12   1   100  FIT UP                             59    60    62    63     3
 11 13   4   300  INSULATE                           59    63    59    63     *
 12 13                                               60    60    63    63     3     3
 12 14   1    50  PRESSURE TEST                      60    61    63    64     3     3
 13 14   1   100  REMOVE SCAFFOLD                    63    64    63    64     *
 14 15   1   100  CLEAN UP                           64    65    64    65     *
  1 15  60        PROMISED COMPLETION                      60     5    65     5     5
-  PROJECT COST        5225            PROJECT COMPLETION        65




                  TEST PROBLEM - SEE FIGURE 2
-
-I   J   D  COST  DESCRIPTION OF JOBS                ES    EF    LS    LF    TF    FF
-
  1  2   3                                                  3     2     5     2
  1  3   9                                                  9           9     *
  2  3   4                                            3     7     5     9     2     2
  2  5   7                                            3    10    13    20    10    10
  3  4   5                                            9    14     9    14     *
  4  5   6                                           14    20    14    20     *
-  PROJECT COST                        PROJECT COMPLETION        20
```

```
                          10 *          CRITICAL PATH SCHEDULING FOR PROJECTSZ
                          20 *          PLANNED BY THE ARROW DIAGRAMMING TECHNIQUEZ
                          30 *           Z
                          40 *          RAY N. SAUER      IBM SYSTEMS RESEARCH INSTITUTEZ
                          50 *                            JULY 16, 1962Z
                          60 *           Z
                          70 *          INPUT DATA - ANY NUMBER OF TYPE 1 AND TYPE 2 CARDS. WHICHZ
                          80 *                           MAY BE INTERSPERSED AND IN ANY ORDER.  THESEZ
                          90 *                           ARE FOLLOWED BY A TYPE 3 CARD.Z
                         100 *            1.  HEADING CARDS - THE CHARACTER IN COLUMN 1 MUST NOTZ
                         110 *                                     BE BLANK OR NUMERIC.  THE REMAINDERZ
                         120 *                                     OF THE CARD MAY CONTAIN ANYTHING.Z
                         130 *            2.  JOB DESCRIPTORS - ONE FOR EVERY JOB IN THE PROJECT.Z
                         140 *                      COLUMNS          LEADING ZEROS ARE NOT NECESSARY.Z
                         150 *                        1-3      TAIL OF THE JOB ARROW - IZ
                         160 *                        4-6      HEAD OF THE JOB ARROW - JZ
                         170 *                        7-10     TIME DURATION OF THE JOB - DZ
                         180 *                       11-15     COST OF THE JOBZ
                         190 *                       16-50     DESCRIPTION OF THE JOB + MISC DATAZ
                         200 *                       51-80     NOT USED - MAY CONTAIN ANYTHINGZ
                         210 *                                   - I MAY BE GREATER OR LESS THAN JZ
                         220 *            3.  END OF PROJECT - COLUMNS 1-3 ARE BLANK.Z
                         230 *           Z
                         240 *          OUTPUT CARDS - SAME AS INPUT WITH THE CALCULATED SCHEDULEZ
                         250 *                         IN COLUMNS 51-60 OF TYPE 2 CARDS.  A TYPE 1Z
                         260 *                         CARD IS PUNCHED WITH PROJECT TIME AND COST.Z
                         270 *                         THE TYPE 3 CARD IS NOT PUNCHED.Z
                        1010 *           Z
                        1020 *          READ AND STORE JOB INFORMATIONZ
                        1030 *          FIND HIGHEST NUMBERED NODEZ
                        1040 *           Z
00402                   1050       DORG 402Z
00402 16 00432 -3999    1130 JOBS  TFM  *+30.3999..      INITIALIZATIONZ
00414 11 00432 000-1    1140       AM   *+18.1.10Z
00426 33 00000 00000    1150       CF    Z
00438 14 00432 -6001    1160       CM   *-6.6001Z
00450 47 00414 01200    1170       BNE  JOBS+12Z
00462 22 03232 03232    1180       S    TCOST.TCOSTZ
00474 22 03240 03240    1190       S    MOST.MOSTZ
00486 16 03243 00-00    1200       TFM  BIG.0.9Z
00498 16 03253 0-000    1210       TFM  K.0.8Z
00510 32 00100 00000    1220       SF   RECORD-1Z
                        1240 *           Z
00522 17 02850 000-0    2010 READ1 BTM  READ.0.10.       READ AND STORE IJD(K)Z
00534 44 00794 02848    2020       BNF  AVAIL.READ-2.. FLAG I AND J NODESZ
00546 11 03253 0-001    2030       AM   K.1.8Z
00558 17 02550 000-0    2040       BTM  TNS.0.10Z
00570 26 00600 03270    2050       TF   *+30.SIZEZ
00582 22 00599 03253    2060       S    *+17.KZ
00594 26 00000 03173    2070       TF   .DZ
00606 32 03167 00000    2080       SF   J-2Z
00618 32 03170 00000    2090       SF   D-3Z
00630 32 03174 00000    2100       SF   COST-4Z
```

```
00642 21 03252 03178  2110         A     [illegible] I.05IZ
00654 21 03240 03173  2120         A     ..S..
00666 26 00696 03166  2130         TF    FLAGIO+6.IZ
00678 26 00708 03169  2140         TF    FLAGIO-18.JZ
00690 32 04000 00000  2150 FLAGIO  SF    4000Z
00702 32 05000 00000  2160         SF    5000Z
                      2170 *              Z
00714 24 03166 03243  2180         C     I.BIG..          FIND HIGHEST NODE A..
00726 47 00750 01100  2190         BNH   *+24...          DETERMINE STORAGE AVAILABILITYZ
00738 26 03243 03166  2200         TF    BIG.IZ
00750 24 03169 03243  2210         C     J.BIGZ
00762 47 00786 01100  2220         BNH   *+24Z
00774 26 03243 03169  2230         TF    BIG.JZ
00786 49 00522 00000  2240         B     READIZ
00794                 2250         DORG  *-3Z
00794 16 03263 -3285  3010 AVAIL   TFM   TEST.TJZ
00806 21 03262 03243  3020         A     TEST-1.BIGZ
00818 21 03262 03253  3030         A     TEST-1.KZ
00830 24 03263 03270  3040         C     TEST.SIZEZ
00842 46 02318 01100  3050         BH    ERROR1Z
                      3060 *              Z
                      3070 *             FIND STARTING AND ENDING NODESZ
                      3080 *             CHECK FOR MORE THAN ONE OF EACHZ
                      3090 *              Z
00854 26 03258 03253  3095         TF    KLAST.KZ
00866 16 03246 00-00  3100         TFM   FIRST.0.9Z
00878 16 03249 00-00  3110         TFM   LAST.0.9Z
00890 26 03253 03243  3120         TF    K.BIGZ
00902 26 01049 03253  3130         TF    OMEGA+11.KZ
00914 26 00961 03253  3140.        TF    CKFLAG+23,KZ
00926 26 00949 03253  3150         TF    CKFLAG+11.KZ
00938 44 01038 04000  3160 CKFLAG  BNF   OMEGA.4000Z
00950 44 00994 05000  3170         BNF   ALPHA.5000Z
00962 12 03253 00-01  3180 OUT     SM    K.1.9Z
00974 46 01094 01200  3190         BZ    TICALCZ
00986 49 00902 00000  3200         B     CKFLAG-36Z
00994                 3210         DORG  *-3Z
00994 14 03246 00-00  3220 ALPHA   CM    FIRST.0.9Z
01006 47 02358 01200  3230         BNE   ERROR3Z
01018 26 03246 03253  3240         TF    FIRST.KZ
01030 49 00962 00000  3250         B     OUTZ
01038                 3260         DORG  *-3Z
01038 44 00962 05000  4010 OMEGA   BNF   OUT.5000Z
01050 14 03249 00-00  4020         CM    LAST.0.9Z
01062 47 02338 01200  4030         BNE   ERROR2Z
01074 26 03249 03253  4040         TF    LAST.KZ
01086 49 00962 00000  4050         B     OUTZ
01094                 4060         DORG  *-3Z
                      4070 *              Z
                      4080 *             COMPUTE EARLIEST STARTING TIMES - TI(I)Z
                      4090 *             CHECK FOR A LOOP IN THE ARROW DIAGRAMZ
                      4100 *              Z
01094 16 01124 -3280  4110 TICALC  TFM   *+30.TIZ
01106 16 01148 -3285  4120         TFM   *+42.TJZ
```

19.

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01118 16 03103 -0000   4130          TFM  ,0Z
01130 11 01124 00000   4140          AM   *-6,10,10Z
01142 16 00000 R9999   4150          TFM  ,99999Z
01154 11 01148 00000   4160          AM   *-6,10,10Z
01166 12 03243 00-01   4170          SM   BIG,1,9Z
01178 46 01118 01300   4180          BNN  TICALC+24Z
01190 16 03253 0-000   4190 TILOOP   TFM  K,0,8Z
01202 33 03264 00000   4200          CF   FLAGZ
01214 11 03253 0-001   4210          AM   K,1,8Z
01226 17 02484 000-0   4220          BTM  GETIJD,0,10Z
01238 16 01273 -3280   4230          TFM  *+35,TIZ
01250 21 01272 03166   4240          A    *+22,IZ
01262 26 03263 00000   4250          TF   TESTZ
01274 21 03263 03173   4260          A    TEST,DZ
01286 16 01321 -3280   5010          TFM  *+35,TIZ
01298 21 01320 03169   5020          A    *+22,JZ
01310 26 03219 00000   5030          TF   TIJZ
01322 24 03219 03263   5040          C    TIJ,TESTZ
01334 47 01390 01300   5050          BL   ONIZ
01346 24 03253 03258   5060 BACKI    C    K,KLASTZ
01358 47 01214 01200   5070          BNE  TILOOP+24Z
01370 44 01470 03264   5080          BNF  TJCALC,FLAGZ
01382 49 01190 00000   5090          B    TILOOPZ
01390                  5100          DORG *-3Z
01390 24 03263 03240   5110 ONI      C    TEST,MOSTZ
01402 46 02426 01100   5120          BH   ERROR4Z
01414 16 01444 -3280   5130          TFM  *+30,TIZ
01426 21 01443 03169   5140          A    *+17,JZ
01438 26 00000 03263   5150          TF   ,TESTZ
01450 32 03264 00000   5160          SF   FLAGZ
01462 49 01346 00000   5170          B    BACKIZ
01470                  5185          DORG *-3Z
                       5180 *             Z
                       5190 *             COMPUTE LATEST STARTING TIMES - TJ(J)Z
                       5200 *             Z
01470 16 01506 -3280   5210 TJCALC   TFM  *+35,TIZ
01482 21 01504 03249   5220          A    *+22,LASTZ
01494 26 03184 00000   5230          TF   LAMDAZ
01506 16 01536 -3285   5240          TFM  *+30,TJZ
01518 21 01535 03249   5250          A    *+17,LASTZ
01530 26 00000 03184   5260          TF   ,LAMDAZ
01542 26 03253 03258   6010 TJLOOP   TF   K,KLASTZ
01554 33 03264 00000   6020          CF   FLAGZ
01566 17 02484 000-0   6030          BTM  GETIJD,0,10Z
01578 16 01613 -3285   6040          TFM  *+35,TJZ
01590 21 01612 03169   6050          A    *+22,JZ
01602 26 03263 00000   6060          TF   TESTZ
01614 22 03263 03173   6070          S    TEST,DZ
01626 16 01661 -3285   6080          TFM  *+35,TJZ
01638 21 01660 03166   6090          A    *+22,IZ
01650 26 03224 00000   6100          TF   TJIZ
01662 24 03224 03263   6110          C    TJI,TESTZ
01674 46 01730 01100   6120          BH   ONJZ
01686 12 03253 0-001   6130 BACKJ    SM   K,1,8Z
```

```
01698 47 01566 01200 6140        BNZ  TOLOOP+24Z
01710 44 01786 03264 6150        BNF  OUTPUT,FLAGZ
01722 49 01542 00000 6160        B    TOLOOPZ
01730                6170        DORG *-3Z
01730 16 01760 -3265 6180 UNJ    TFM  *+30,TJZ
01742 21 01759 03166 6190        A    *+17,IZ
01754 26 00000 03263 6200        TF   ,TESTZ
01766 32 03264 00000 6205        SF   FLAGZ
01778 49 01686 00000 6210        B    BACKJZ
01786                6220        DORG *-3Z
                     6230 *            Z
                     6240 *           CALCULATE AND PUNCH START, FINISH, AND FLOAT TIMESZ
                     6250 *            Z
01786 48 00000 00000 7010 OUTPUT H     Z
01798 17 02850 000-J 7020 READ2  BTM  READ,-1,10Z
01810 44 02226 02848 7030        BNF  EOJ,READ-2Z
01822 33 03265 00000 7125        CF   CRITZ
01834 17 02550 000-0 7130        BTM  TNS,0,10Z
01846 32 03187 00000 7140        SF   J-2Z
01858 32 03170 00000 7150        SF   D-3Z
01870 16 01905 -3280 7160        TFM  *+35,TIZ
01882 21 01904 03166 7170        A    *+22,IZ
01894 26 03189 00000 7180        TF   TIIZ
01906 16 01941 -3280 7190        TFM  *+35,TIZ
01918 21 01940 03189 7200        A    *+22,JZ
01930 26 03219 00000 7210        TF   TIJZ
01942 16 01977 -3285 7220        TFM  *+35,TJZ
01954 21 01976 031[illegible] 7230        A    *+22,JZ
01966 26 03204 00000 7240        TF   TJJZ
01978 26 03194 03189 7250        TF   EF,TIIZ
01990 21 03194 03173 7260        A    EF,DZ
02002 26 03199 03204 8010        TF   LS,TJJZ
02014 22 03199 03173 8020        S    LS,DZ
02026 26 03209 03199 8030        TF   TF,LSZ
02038 22 03209 03189 8040        S    TF,TIIZ
02050 47 02074 01200 8050        BNZ  *+24Z
02062 32 03265 00000 8060        SF   CRITZ
02074 26 03214 03219 8070        TF   FF,TIJZ
02086 22 03214 03194 8080        S    FF,EFZ
02098 16 03275 -0201 8090        TFM  STRIP,RECORD+100Z
02110 17 02656 -3185 8100        BTM  EDIT,TII-4Z
02122 17 02656 -3190 8110        BTM  EDIT,EF-4Z
02134 17 02656 -3195 8120        BTM  EDIT,LS-4Z
02146 17 02656 -3200 8130        BTM  EDIT,TJJ-4Z
02158 17 02656 -3205 8140        BTM  EDIT,TF-4Z
02170 17 02656 -3210 8150        BTM  EDIT,FF-4Z
02182 44 02206 03265 8160        BNF  *+24,CRITZ
02194 16 00249 000J4 8170        TFM  RECORD+148,14,10Z
02206 39 00101 00400 8180        WACD RECORDZ
02218 49 01798 00000 8190        B    READ2Z
02226                8200        DORG *-3Z
                     9010 *            Z
                     9020 *           PUNCH TOTAL COST AND COMPLETION TIMEZ
                     9030 *            Z
```

21.

```
02226 31 00100 02982  9040 EOJ     TR   RECORD-1,TITLE-1Z
02238 16 03275 -0137  9050         TFM  STRIP,RECORD+36Z
02250 17 02656 -3225  9060         BTM  EDIT,TCOST-7Z
02262 16 03275 -0227  9070         TFM  STRIP,RECORD+126Z
02274 17 02656 -3180  9100         BTM  EDIT,LAMDA-4Z
02286 39 00101 00400  9110         WACD RECORDZ
02298 48 00000 00000  9120 GOBACK  H     Z
02310 49 00402 00000  9130         B    JOBSZ
02318                 9140         DORG *-3Z
                      9150 *             Z
                      9160 *            ERROR ROUTINESZ
                      9170 *             Z
02318 15 03157 00001  9180 ERROR1  TDM  ER+12,1Z
02330 49 02438 00000  9190         B    ER14Z
02338                 9200         DORG *-3Z
02338 15 03157 00002  9210 ERROR2  TDM  ER+12,2Z
02350 49 02370 00000  9220         B    ER23Z
02358                 9230         DORG *-3Z
02358 15 03157 00003  9240 ERROR3  TDM  ER+12,3Z
02370 16 01095 000M8  9250 ER23    TFM  TICALC+1,48,10Z
02382 34 00000 00102  9251         RCTY  Z
02394 39 03145 00100  9252         WATY ERZ
02406 38 03250 00100  9253         WNTY K-3Z
02418 49 00962 00000  9254         B    OUTZ
02426                 9260         DORG *-3Z
02426 15 03157 00004 10010 ERROR4  TDM  ER+12,4Z
02438 34 00000 00102 10020 ER14    RCTY  Z
02450 39 03145 00100 10030         WATY ERZ
02462 38 03164 00100 10032         WNTY I-2Z
02474 49 02298 00000 10040         B    GOBACKZ
02482                10050         DORG *-3Z
                     11010 *             Z
                     11020 *            SUBROUTINE TO GET IJK(K) FROM STORAGEZ
                     11030 *             Z
02483           2 00000 11040      DS   2Z
02484 26 02519 03270 11050 GETIJD  TF   *+35,SIZEZ
02496 22 02518 03253 11060         S    *+22,KZ
02508 26 03173 00000 11070         TF   DZ
02520 32 03167 00000 11080         SF   J-2Z
02532 32 03170 00000 11090         SF   D-3Z
02544 42 00000 00000 11100         BB    Z
02548                11110         DORG *-7Z
                     11120 *             Z
                     11130 *            SUBROUTINE TO TRANSFER NUMERIC STRIPZ
                     11040 *            FOR INPUT FIELDS I, J, D, AND COSTZ
                     11150 *             Z
02549           2 00000 11160      DS   2Z
02550 16 02580 -3164 11170 TNS     TFM  *+30,I-2Z
02562 16 02585 -0101 11180         TFM  *+23,RECORDZ
02574 25 00000 00000 11190         TD    Z
02586 11 02585 000-2 11200         AM   *-1,2,10Z
02598 11 02580 000-1 11210         AM   *-18,1,10Z
02610 14 02580 -3179 11220         CM   *-30,COST+1Z
02622 47 02574 01200 11230         BNE  *-48Z
```

```
02634 32 03164 00000 11240          SF   1-2Z
02646 42 00000 00000 11250          BB    Z
02650                11260          DORG *-7Z
                     12010 *          Z
                     12020 *         SUBROUTINE TO TRANS FR NUMERIC FIELZ
                     12030 *         AND ELIMINATE LEADING ZEROSZ
                     12040 *         HIGH ORDER ADDRESS OF NUMERIC IS IN EDIT-1Z
                     12050 *         HIGH ORDER ADDRESS OF ALPHAMERIC IS IN STRIPZ
                     12060 *          Z
02654        5 00000 12070          DS   5Z
02656 32 03264 00000 12080 EDIT     SF   FLAGZ
02668 26 02739 02655 12090          TF   ZERO-1,EDIT-1Z
02680 26 02746 03275 12100          TF   ZERO+6,STRIPZ
02692 26 02783 02655 12110          TF   DIGIT+23,EDIT-1Z
02704 26 02790 03275 12120          TF   DIGIT+30,STRIPZ
02716 44 02760 03264 12130          BNF  DIGIT,FLAGZ
02728 43 02760 00000 12140          BD   DIGITZ
02740 16 00000 000-0 12150 ZERO     TFM  0,0,10Z
02752 49 02796 00000 12160          B    DIGIT+36Z
02760                12170          DORG *-3Z
02760 33 03264 00000 12180 DIGIT    CF   FLAGZ
02772 25 02795 00000 12190          TD   *+23Z
02784 16 00000 000P0 12200          TFM  0,70,10Z
02796 11 02655 000-1 12210          AM   EDIT-1,1,10Z
02808 11 03275 000-2 12220          AM   STRIP,2,10Z
02820 26 02843 02655 12230          TF   *+23,EDIT-1Z
02832 44 02668 00000 12240          BNF  EDIT+12Z
02844 42 00000 00000 12250          BB    Z
02848                12260          DORG *-7Z
                     12310 *          Z
                     12311 *         READ ROOTINE.  TITLE CARDS MAY BE INTERSPERSED WITH JOBSZ
                     12320 *          Z
02849        2 00000 12330          DS   2Z
02850 37 00101 00500 12340 READ     RACD RECORDZ
02862 14 00101 000P0 12370          CM   RECORD,70,10Z
02874 46 02978 01300 12380          BNL  END+12Z
02886 14 00104 -0000 12390          CM   RECORD+3Z
02898 46 02966 01200 12400          BE   ENDZ
02910 14 00101 000-0 12401          CM   RECORD,0,10Z
02922 46 02978 01200 12402          BE   END+12Z
02934 44 02850 02849 12410          BNF  READ,READ-1Z
02946 39 00101 00400 12450          WACD RECORDZ
02958 49 02850 00000 12460          B    READZ
02966                12470          DORG *-3Z
02966 33 02848 00000 12480 END      CF   READ-2Z
02978 42 00000 00000 12490          BB    Z
02982                12500          DORG *-7Z
                     13010 *          Z
                     13020 *         AREA AND STORAGE DEFINITIONSZ
                     13030 *          Z
00101       80 00000 13040 RECORD   DAS  80,101Z
02983       40 00000 13050 TITLE    DAC  40,-  PROJECT COST                              ,,Z
03063       41 00000 13060          DAC  41, PROJECT COMPLETION                          -,,Z
03145       10 00000 13070 ER       DAC  10,ERROR 0  -,,Z
```

```
03166      3 00000 13080 I          DS    3Z
03169      3 00000 13090 J          DS    3Z
03173      4 00000 13100 D          DS    4Z
03178      5 00000 13110 COST       DS    5Z
03179      1 00000 13111            DC    1.-..Z
03184      5 00000 13112 LAMDA      DS    5Z
03189      5 00000 13120 TII        DS    5Z
03194      5 00000 13130 EF         DS    5Z
03199      5 00000 13140 LS         DS    5Z
03204      5 00000 13150 TJJ        DS    5Z
03209      5 00000 13160 IF         DS    5Z
03214      5 00000 13170 FF         DS    5Z
03219      5 00000 13180 TIJ        DS    5Z
03224      5 00000 13190 TJI        DS    5Z
03232      8 00000 13200 TCOST      DC    8.0Z
03240      8 00000 13210 MOST       DC    8.0Z
03243      3 00000 13220 BIG        DS    3Z
03246      3 00000 13230 FIRST      DS    3Z
03249      3 00000 13240 LAST       DS    3Z
03253      4 00000 13250 K          DS    4Z
03254      1 00000 13251            DC    1.-..Z
03258      4 00000 13260 KLAST      DS    4Z
03263      5 00000 14010 TEST       DS    5Z
03264      1 00000 14020 FLAG       DS    1Z
03265      1 00000 14030 CRIT       DS    1Z
03270      5 00000 14040 SIZE       DC    5.20009..       CHANGE THIS FOR 40 OR 60KZ
03275      5 00000 14046 STRIP      DS    5Z
03280      5 00000 14050 TI         DS    5Z
03285      5 00000 14060 TJ         DS    5Z
                   14070 *                Z
00402              14080            DEND  JOBSZ
```

APPENDIX D - PROGRAM LISTING - CONDENSED DECK

```
36000720050036002010050044000120027526000590027425000110000026000900026900000000
2600095002643100000000200260011400274250000000011490001200000000            -   1
160043203999110043200001330000000000140043206001470041401200Z0010040200462000002
220323203232220324003240160324300000160325300000320010000000Z0010046200522000003
170285000000440079402848110325300001170255000000260060003270Z0010052200582000004
220059903253260000003173320316700000320317000000320317400000Z0010058200642000005
210323203178210324003173260069603166260070803169320400000000Z0010064200702000006
320500000000240316603243470075001100260324303166240316903243Z0010070200762000007
470078601100260324303169490052200000Z0000000000             -10076200798000008
160326303285210326203243210326203253240326303270460231801100Z0010079400854000009
260325803253160324600000160324900000260325303243260104903253Z0010085400914000010
260096103253260094903253440103804000440099405000120325300001Z0010091400974000011
460109401200490090200000Z0000000000                         -10097400998000012
140324600000470235801200260324603253490096200000Z000000000000 -10099401042000013
440096205000140324900000470233801200260324903253490096200000Z0010103801098000014
1601124032801601148032851600000000001101124000J01600000R9999Z0010109401154000015
1101148000J0120324300001460111801300160325300000330326400000Z0010115401214000016
110325300001170248400000160127303280210127203166260326300000Z0010121401274000017
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240326303240460242601100160144403280210144303169260000003263Z0010139001450000020
320326400000490134600000Z000000000000*                      -10145001474000021
160150503280210150403249260318400000160153603285210153503249Z0010147001530000022
260000003184260325303258330326400000170248400000160161303285Z0010153001590000023
210161203169260326300000220326303173160166103285210166003166Z0010159001650000024
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440178603264490154200000Z000000000000*                      -10171001734000026
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48000000000017028500000J440222602848330326500000170255000000Z0010178601846000028
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260320903199220320903189470207401200320326500000260321403219Z0010202602086000032
220321403194160327500201170265603185170265603190170265603195Z0010208602146000033
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390010100400490179800000Z000000000000                       -10220602230000035
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390010100400480000000000490040200000Z0000000000             -10228602322000037
150315700001490243800000Z00000000000                        -10231802342000038
150315700002490237000000Z000000000000*                      -10233802362000039
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420000000000Z000000000                                      -10254402556000044
160258003164160258500101250000000000110258500002110258000001Z0010255002610000045
14025800317947025740120032031640000042000000000000Z00000000000 -10261002658000046
320326400000260273902655260274603275260278302655260279003275Z0010265602716000047
4402760032644302760000001600000000000490279600000Z00000000000 -10271602764000048
```

25.

```
33032644000002502795000001600000000000P0110265500001110327500002400102760028200000049
2602843026554402668000000420000000000000Z000000000**              -10282002856000050
3700101005001400101000P0460297801300140010400000460296601200Z0010285002910000051
140010100000460297801200440285002849390010100400490285000000Z0010291002970000052
33028480000042000000000000Z00000000000                            -10296602990000053
K00000575956514543630043566263000000000000          Z000000000001010298203032000054
                          Z0000000000                           1010303203062000055
  575956514543630043565457534563495655000000000000000Z000000000001010306203112000056
                           Z0000000000 *                        1010311203144000057
M55959565900700000000Z0000000000                                1010314403164000058
Z0000000000                                                     1010317903180000059
           Z0000000000                                          1010322503241000060
Z0000000000                                                     1010325403255000061
K0009Z0000000000                                                1010326603271000062
L6000000005004900000Z0000000*0                                   -10009600115000063
36001000005003600172005003600244005003600316005003600000000500000000 *    -     64
        102030400020406080003060902100408021610050015102006021814200Z0000065
70411282008061472300908172630000000000005060708090012141618151811242720242Z0000066
82236352035304540363248445532494653604846546275445362718012345678912345 6Z0000067
7890234567890J34567890JK4567890JKL567890JKLM67890JKLMN7890JKLMNO890JKLMNZ0000068
M80000000000049004020P90JKLMNOPQZ0000L10038800019M900000000000M90003600000000000000069
```

73

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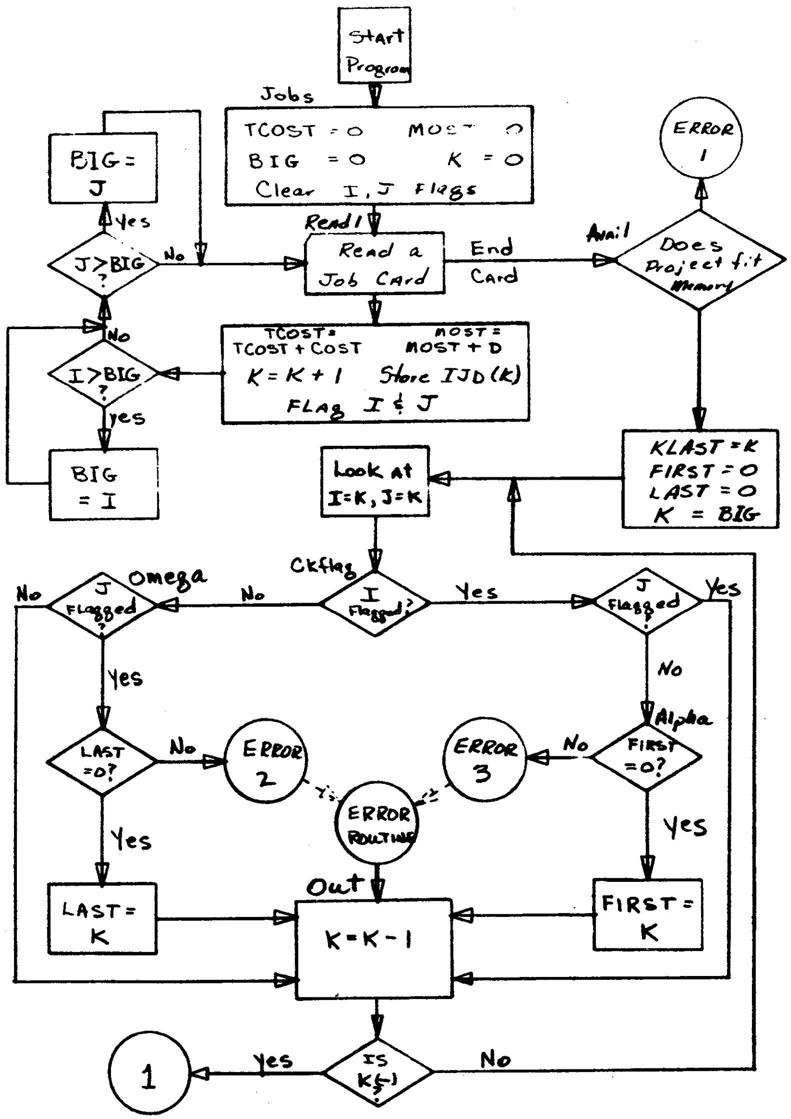
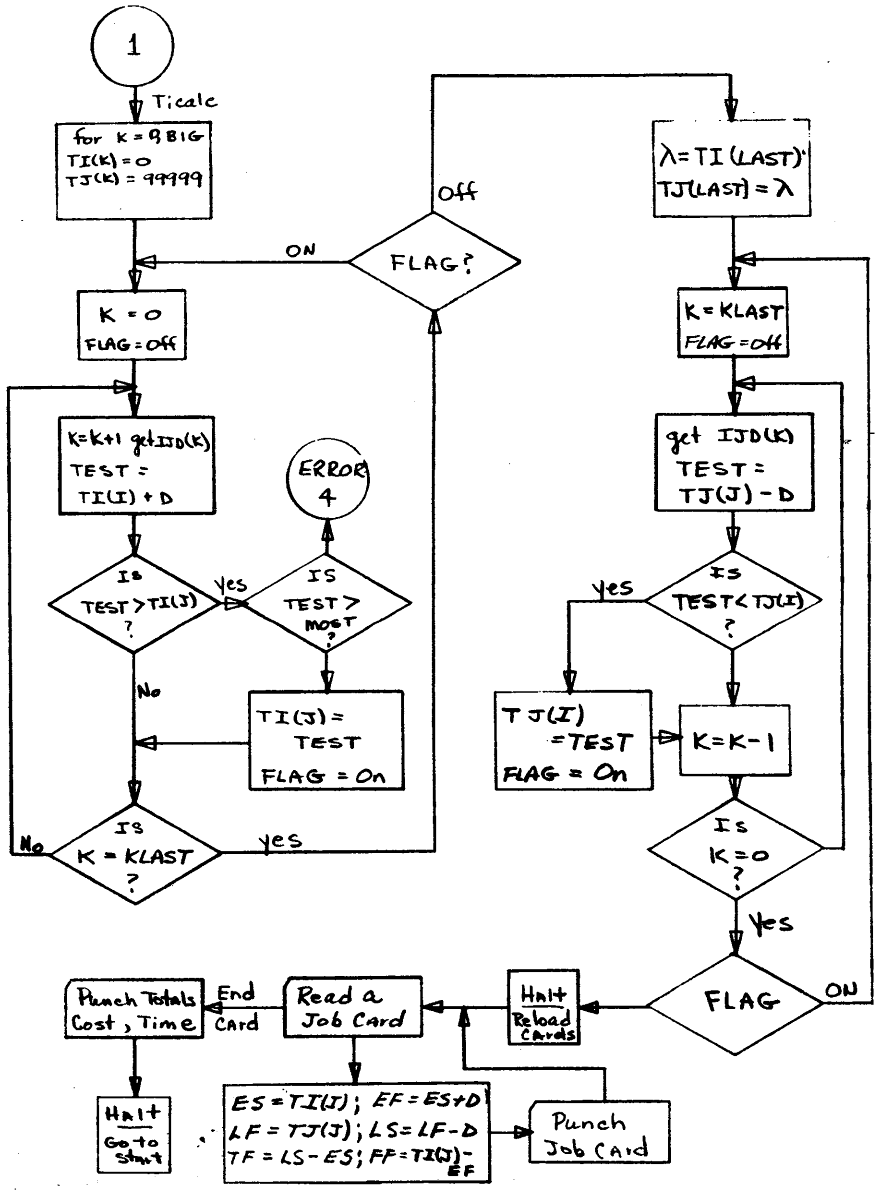
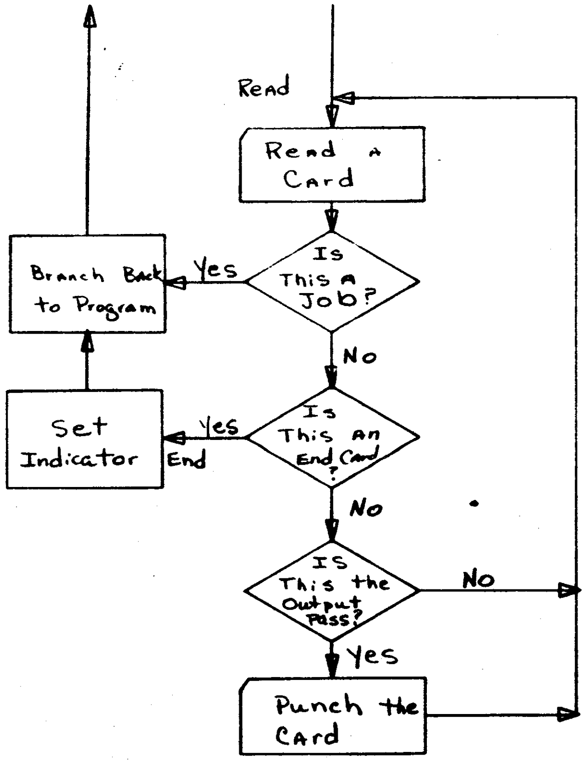
E Program Flowcharts







Read Routine