THE STUDY OF A MODIFICATION TO IBM PROGRAM 496

By

RICHARD HAYS GIBBS

Bachelor of Science

Pennsylvania State University

University Park, Pennsylvania

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Dean of the Graduate School

PREFACE

The main purpose of this study is to clarify some ideas on a possible modification to the IBM Program for solving the Transportation Problem by the IBM 650 Computor. The Transportation Problem is a special case of the Linear Programming technique. The Transportation Problem is used to solve problems in which it is desired to minimize the cost of transporting homogeneous goods from several sources to a group of different destinations. Since the method of solution of the Problem is lengthy, high-speed computors are utilized for most applications. Programs have been developed to instruct the computors to accomplish the calculations to solve this type of problem. In this study, we are interested in the IBM Program 496 and the IBM 650 Computor.

James Hetrick of the Continental Oil Company brought to my attention a possible modification of the IBM program that might result in reduced machine computation time. Since the IBM program for the Transportation Problem is so widely used, I decided that it was worth while to see if the program could be improved. With the aid of Mr. Hetrick's advice and assistance, this study was formulated and carried out.

I am deeply indebted to Stanley Poley, the author of the IBM Program 496, for permitting the enclosure of his program in this study. The completeness and lucidity of his work has greatly decreased my need to describe the details of his program.

Indebtedness is also acknowledged to Dr. John W. Hamblin, for placing the facilities of the Computing Center at my disposal; and to Dr.

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CHAPTER I

INTRODUCTION

The main purpose of this study is to determine which of two computor programs solves the Transportation Problem in the least amount of time on the IBM 650 Computor. The study was conducted empirically. Both programs were tested for various size problems to determine which of the programs takes the least computation time.

So that the reader may understand the analysis of the study to follow, it is deemed necessary to discuss (1) the nature of the Transportation Problem, (2) the method of obtaining the solution of the Transportation Problem, and (3) the structure of the two programs to be studied.

A. The Nature of the Transportation Problem

The Transportation Problem is a special case in Linear Programming.[1] The formulation and solution of this type of problem were first applied to the problem of supplying goods from sources of supply to a number of points of demand. However, the Transportation Problem can be constructed for varied applications. The only limitations imposed upon the application, other than those required of a general Linear Programming

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[1]For a complete explanation of the theory and application of Linear Programming in general, it is suggested that the following references be utilized.

A. Charnes, W. W. Cooper, and A. Henderson, An Introduction to Linear Programming (New York, 1953).

C. W. Churchman, R. L. Ackoff, E. L. Arnoff, Introduction to Operations Research (New York, 1957), pp. 279-342.

problem, are that

(1) the coefficients of the variables must be equal to either one or zero;

(2) the sum of the goods at the sources must equal the sum of the goods required at the destinations; and,

(3) the quantities at supply and demand points must be expressed in homogeneous units.

The solution of the Transportation Problem yields an optimum solution consistent with any imposed restrictions inherent in the application. All alternate solutions of the same value as the optimum are also indicated. This technique then permits fast and accurate analysis of possible courses of action to be taken to solve the specific problem.

B. The Method of Solving the Transportation Problem

To avoid the need of a technical discussion of the theory of Linear Programming, the method of solving the Transportation Problem will be shown by the use of a specific example. The example is simplified to permit understanding of the basic techniques. The problem can be stated thus: The Ajax Co., which produces a homogeneous product at three plants located in different locations, wishes to ship this product to five different demand points or destinations at minimum cost. Freight and storage rates are given between each plant and each destination. The problem is to determine the amount of the product that will be shipped from each plant to each destination, so that the overall shipping cost will be minimized.

The necessary information can be assembled on the two matrices shown in Tables I-1 and I-2. The plants are designated as S_1, S_2, S_3

TABLE I-1. Physical Requirements of Problem

Destinations / Plants	D_1	D_2	D_3	D_4	D_5	Production
S_1	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	6
S_2	X_{21}	X_{22}	X_{23}	X_{24}	X_{25}	8
S_3	X_{31}	X_{32}	X_{33}	X_{34}	X_{35}	9
Demand	3	2	8	4	6	23

TABLE I-2. Unit Shipping Costs

Destinations / Plants	D_1	D_2	D_3	D_4	D_5
S_1	C_{11} 4	C_{12} 6	C_{13} 10	C_{14} 2	C_{15} 8
S_2	C_{21} 2	C_{22} 8	C_{23} 15	C_{24} 7	C_{25} 10
S_3	C_{31} 8	C_{32} 4	C_{33} 12	C_{34} 3	C_{35} 7

and the destinations are designated D_1, D_2, D_3, D_4, D_5. Table I-1 shows the physical requirements of the problem. These requirements are that S_1, S_2, and S_3 can produce 6, 8, and 9 units of product respectively, while destinations D_1, D_2, D_3, D_4, and D_5 require, to supply their customers, 3, 2, 8, 4, and 6 units of product respectively. The X values contained in the table designate the number of units of product to be shipped from S_i to D_j, where i equals 1, 2, or 3 and j equals 1, 2, 3, 4, or 5. The purpose of the problem is to determine these X_{ij} values. Although not necessary, it has been assumed, for simplicity, that the amount of production equals the amount of demand.

Table I-2 shows the unit shipping cost, C_{ij}, of shipping one unit of product from S_i to D_j. Therefore, the problem is to obtain values for each X_{ij} in Table I-1 such that they satisfy the given movement requirements and minimize the total cost.

The process involved in finding the minimum cost and the proper X values is to first find a feasible solution. A feasible solution is one which satisfies the movement requirements of the problem. After an initial feasible solution is obtained, the solution is inspected to determine if the solution produces a minimum cost. If it does, the problem is solved: a minimum cost is stated; and, the X values are determined from the feasible solution. If the solution does not produce a minimum cost, the cost matrix is inspected to determine what X values, when entered in the solution, will reduce the cost. The entrance into the solution of the X value that reduces the cost the greatest amount is then accomplished, and a new feasible solution results. Again this solution is inspected to see if the cost is minimum. The process is repeated until a minimum cost is obtained.

1. Selection of an Initial Feasible Solution

The first requirement in utilizing the transportation technique is to find an initial feasible solution. Several methods have been developed to find this solution. The one most widely used, and shown below, finds the solution by attempting to sub-optimize, with respect to cost, the various combinations of supply and demand. The minimum element, C_{ij}, in the first row of the cost matrix is found, and the corresponding X_{ij} is set equal to S_i or D_j, whichever is smaller. If the S_i is all utilized, the procedure is repeated in the next row. If there is some S_i remaining, the next minimum C_{ij} in the same row is found and the corresponding X_{ij} is set equal to D_j or what remains to be shipped from S_i, whichever is smaller. This procedure is continued in this manner, row by row, until the last row is completed.

In the example, the minimum element in the first row of the unit cost matrix is seen to be C_{14}. The corresponding X value, X_{14}, is set equal to S_1 or D_4, whichever is smaller. In this case X_{14} would be set equal to 4, the total demand at D_4. Since there are still units of product available at S_1(6-4=2), the next lowest unit cost is selected, that is C_{11}. Since S_1 is now smaller than D_1, X_{11} is set equal to S_1. Since all of the units of product produced at S_1 have now been shipped, the second row is scanned for the minimum C_{ij}. This procedure is followed through all the rows of the cost matrix. The initial feasible solution for the example appears in Table I-3, which shows the units of product that would be shipped from each plant to each destination. All blocks which are blank signify that no units would be shipped. The corresponding total cost of this solution can be found by multiplying each X_{ij} in Table I-3 by the corresponding C_{ij} in Table I-2 and summing the products.

TABLE I-3. Initial Feasible Solution

Destinations / Plants	D_1	D_2	D_3	D_4	D_5	Production
S_1	X_{11} 2			X_{14} 4		6
S_2	X_{21} 1	X_{22} 2			X_{25} 5	8
S_3			X_{33} 8		X_{35} 1	9
Demand	3	2	8	4	6	23

TABLE I-4. Unit Cost Matrix of Initial Feasible Solution and V and V Tables

Destinations / Plants	D_1	D_2	D_3	D_4	D_5	Row Values Ui
S_1	4			2		0
S_2	2	8			10	- 2
S_3			12		7	- 5
Column Values Vj	4	10	17	2	12	

The total cost of the initial feasible solution is 187.

2. Inspection for Minimum Cost

To determine if the cost obtained from a solution is minimum, it is necessary to inspect each X_{ij} and corresponding C_{ij} not included in the feasible solution. In this way the costs associated with not using the blocks which are blank can be determined. If none of these costs can reduce the total cost of the feasible solution, the cost obtained from the solution is the minimum. On the other hand, if any of the costs associated with the blank blocks can reduce the total cost of the feasible solution, it is then necessary to compute a new feasible solution.

The following procedure is used to evaluate the costs associated with not using the blank blocks in the feasible solution. This procedure will determine whether the solution is minimal or whether it is necessary to find a new solution. This procedure was developed by Dantzig.[2]

First, column value and row value tables are constructed. The column values are designated V_j and the row values, U_i. These tables are constructed in such a manner that

$$U_i + V_j = C_{ij} .$$

The U_i associated with the first block of the feasible solution in which an X_{ij} value appears is arbitrarily assigned the value of zero. Passing through the rest of the solution matrix, the remaining U_i and V_j values are calculated. This procedure may require more than one pass through

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[2] G. B. Dantzig, Chapter XXI, *Activity Analysis of Production and Allocation*, ed. T. C. Koopmans, Cowles Commission Monograph #13, John Wiley and Sons (New York, 1951).

the solution matrix to complete the U and V tables.

Upon completion of the U and V tables, the quantity W_{ij} is computed for each and every element of the cost matrix. The W_{ij} value is computed by the equation,

$$W_{ij} = U_i + V_j - C_{ij}$$

The W_{ij} value is equivalent to the cost associated with not utilizing a particular X_{ij} in the feasible solution. If the W_{ij} value for any element is negative, the introduction of that element into the solution matrix would increase the total cost by the amount (W_{ij}) (Θ) where Θ is equal to the number of units to be shipped from S_i to D_j. However, if the W_{ij} value is greater than zero, the introduction of that element into the solution matrix would decrease the total cost by the amount (W_{ij}) (Θ). Therefore if the W_{ij} value is greater than zero for any element in the matrix, the feasible solution is not minimal. Conversely, if all the W_{ij} values are zero or negative, the solution is minimal and the problem is solved.

The U and V tables for the initial feasible solution of the example appear in Table I-4. U_1 is arbitrarily set equal to zero. Therefore, V_1 and V_4 are equal to 4 and 2 respectively. Passing to the next element, C_{21}, in the cost matrix, it is seen that U_2 can be calculated since U_2 is equal to $C_{21} - V_1$, both known values. Proceeding in this manner the U and V tables are calculated in two passes through the solution matrix.

The W_{ij} values are then computed for each and every element of the cost matrix. For example, W_{12} is equal to $U_1 + V_2 - C_{12}$ or 4. The W_{ij} values for all elements are shown in Table I-5. From the nature of the calculations, the W_{ij} values associated with the elements in the

TABLE I-5. Element Evaluation-Wij Values for Initial Solution

Destinations / Plants	D_1	D_2	D_3	D_4	D_5
S_1	0	4	7	0	4
S_2	0	0	0	-7	0
S_3	-9	1	0	-6	0

TABLE I-6. Stepping Stone Route

Destinations / Plants	D_1	D_2	D_3	D_4	D_5	Production
S_1	X_{11} (2)		X_{13} ( )	X_{14} 4		6
S_2	X_{21} (1)	X_{22} 2			X_{25} (5)	8
S_3			X_{33} (8)		X_{35} (1)	9
Demand	3	2	8	4	6	23

solution matrix are zero. A zero for any other W_{ij} value, such as W_{23}, signifies that there is an alternate solution with the same total cost. If all the W_{ij} values had been zero or negative, the initial feasible solution would have been minimal. However, since there is at least one non-zero, positive value, namely W_{13}, in Table I-5, the solution is not minimal.

3. Iterative Procedure to Find the Minimal Solution

Having determined that the last feasible solution is not minimal through inspection of the W_{ij} values, it is now necessary to find a new feasible solution. The new feasible solution is found by entering the corresponding X_{ij} value of a W_{ij} value which is greater than zero. Since the solution matrix can only contain the number of elements equal to the sum of the sources and destinations minus one, some X_{ij} value already in the solution will be eliminated. In this way the total cost is reduced. The total amount of cost reduction depends upon the number of units of product that can be assigned the X_{ij} that is entering the solution.

When the new feasible solution has been found, it is inspected, as explained above, to see if the solution is minimal. If the solution is not the minimum, then another feasible solution must be found. This process is repeated until a feasible solution with the minimum total cost is obtained. The process of repeatedly finding feasible solutions is an iterative procedure. That is, each time the process is repeated, the same procedures are utilized. The computation of each feasible solution has therefore been called an "iteration".

The following procedure is used to obtain a new feasible solution and reduction in total cost. To facilitate the understanding of this discussion, let the X_{ij} element that is to enter the feasible solution be designated by X_{IJ}. First, a X_{IJ} is found that corresponds to a non-zero, positive W_{IJ} value from the previous solution. Then, using the feasible solution table, this X_{IJ} element is entered into the solution through a technique which has been called "the Stepping Stone Method".[3] Commencing at the X_{IJ} element a closed path is constructed, utilizing some of the X_{ij} elements in the solution matrix as stepping stones. The route of the path must be either along a row or up or down a column.

To determine which X_{ij} elements can be used as stepping stones, the following procedure is used. Consider the X_{IJ} element to be part of the solution matrix. Then eliminate all X_{ij} elements of the solution matrix which are in a row or column that does not contain any other X_{ij} element of the solution matrix. Repeat this process until there are not any X_{ij} elements standing alone in either a row or column of the solution matrix. Then the remaining X_{ij} elements of the solution matrix are stepping stones and a closed path can be constructed, including each of them.

Having established the closed path, it is now possible to determine how many units of product can be assigned to the X_{IJ} element. The number of units of product that can be assigned to the X_{IJ} element is designated θ. To find θ, it is necessary to remember that the units of product assigned to any X_{ij} element in the solution matrix cannot be less than zero; and the total units of product available at any source or required at any destination is constant. Remembering this, the

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[3] A. Charnes and W. W. Cooper: "The Stepping Stone Method of Explaining Linear Programming Calculations in Transportation Problems", Management Science, 1, no. 1, Appendix, October 1954.

maximum value of Θ is equal to the smallest X_{ij} value contained in elements that are odd stepping stones, as counted over the closed path from the X_{IJ} element.

After Θ has been obtained, the solution matrix is altered, and a new feasible solution obtained. The value Θ is placed in the X_{IJ} element and each stepping stone element is increased or decreased by Θ units of product, so that the supply and demand requirements of the problem are maintained. The value of each element in the solution that is not a stepping stone remains constant in the altered solution matrix. The decrease in cost is equal to (W_{IJ}) (Θ) and is subtracted from the total cost to determine the new total transportation cost. The new feasible solution is then inspected to determine if the minimal solution has been reached. If not, another iteration through the cycle is accomplished.

In the example, it was determined that the minimal solution was not obtained by the initial feasible solution since W_{12}, W_{13}, and W_{15} are equal to positive, non-zero values, as shown in Table I-5. Since there are several W_{ij} values greater than zero, any one of the corresponding X_{ij} elements could be selected to enter the solution. In the example, the X_{13} element is selected to enter the solution matrix.

Utilizing the last feasible solution, in this case contained in Table I-3, a closed path consisting of stepping stones can be constructed to permit the entry of X_{13} into the solution matrix. By eliminating from consideration all elements that stand alone in a row or column, the stepping stones can be determined. In Table I-3, the elements X_{22} and X_{14} are eliminated since they stand alone in Columns 2 and 4 respectively. However X_{11} is not eliminated since X_{13}, the element to enter the solution matrix, is considered part of the solution matrix. The remain- six elements are designated stepping stones. A path constructed by "rook's" moves will result in a closed path as shown in Table I-6.

From inspection of the path and the stepping stones, the maximum number of units, θ, that can be transferred to X_{13} can be determined. Elements X_{11}, X_{25}, and X_{33} are the odd elements in the path, as counted from X_{13}. The minimum value contained in these three elements is then equal to θ. Since X_{11} contains the minimum value, θ, is equal to two.

The value of θ is entered in X_{13}, signifying that a better solution is obtained if two units of product are shipped from S_1 to D_3. To maintain the requirements of the problem, the values of the remaining stepping stone elements must be altered. In Row 1 of Table I-6, two units of product must be subtracted from X_{11} to maintain the overall supply of six units of product. Similarly, since X_{11} has been reduced by two, X_{21} must be increased by two, X_{25} decreased by two, X_{35} increased by two, and X_{33} decreased by two. The problem is again in balance. The altered solution matrix appears in Table I-7.

To compute the new total cost the value (W_{IJ}) (θ) is subtracted from the total cost of the previous feasible solution. The decrease in cost of this solution is 7×2 or 14. By subtracting this value from the previous cost, which was 187, a new total cost of 173 is obtained. The new total cost can be verified by multiplying each X_{ij} value in the solution matrix by the corresponding C_{ij} value in the cost matrix of Table I-2, and summing the products.

The second feasible solution is inspected to determine if the solution is minimal. As indicated earlier, this is done by constructing the U and V tables and calculating W_{ij} values. These values are inspected

TABLE I-7. Second Feasible Solution

Destinations / Plants	D_1	D_2	D_3	D_4	D_5	Production
S_1			X_{13} 2	X_{14} 4		6
S_2	X_{21} 3	X_{22} 2			X_{25} 3	8
S_3			X_{33} 6		X_{35} 3	9
Demand	3	2	8	4	6	23

TABLE I-8. Third Feasible Solution

Destinations / Plants	D_1	D_2	D_3	D_4	D_5	Production
S_1			X_{13} 2	X_{14} 4		6
S_2	X_{21} 3				X_{25} 5	8
S_3		X_{32} 2	X_{33} 6		X_{35} 1	9
Demand	3	2	8	4	6	23

TABLE I-9. Element Evaluation - W_{ij} Values for Third Solution

Destinations / Plants	D_1	D_2	D_3	D_4	D_5
S	- 7	- 4	0	0	- 3
S	0	- 1	0	0	0
S	- 9	0	0	- 1	0

for any non-zero, positive values. If none are found, the solution is minimal. However, in the example, the second feasible solution is not minimal. Therefore, another iteration must be accomplished to find a new feasible solution.

The third feasible solution appears in Table I-8. Upon inspection of Table I-9, the W_{ij} values of this solution, it is found that all values are negative or zero. The minimal solution is then determined for this problem. The total transportation cost is 171, and the products are to be shipped as indicated in Table I-8. A W_{ij} value of zero which does not correspond to X_{ij} elements in the solution matrix, indicates that there is an alternate solution that results in the same total cost. Such a case arises for W_{23} and W_{24}. These alternate solutions should be determined so that the company may select the solution that suits their operations the best.

C. The Two Programs to be Studied

Although the foregoing example was quite simple to solve by hand, most actual applications of the Transportation Problem are quite lengthy. A high speed computor is generally employed to solve these problems. The machine must be given instructions so that it can perform the necessary operations. The aggregate of the instructions is called a computor program. In this study it is desired to determine which of two programs of the Transportation Problem will result in the minimum machine computation time.

The two programs to be studied are quite similar. They both employ the same general procedure for solving the problem as outlined in Section B. Of course, the machine cannot scan a table visually. However, through logical choice procedures, the machine can accomplish the same results.

The first program was written by Stanley Poley of IBM and is designated IBM Program 496. This program will be referred to as Poley's program throughout the remaining discussion. The explanation of this program, including the machine instructions, can be found in Appendix A of this study.

Poley's program is divided into three sections. In section 1, the initital feasible solution is obtained in the same manner as previously described. In section 2 the iteration procedure is programmed. Poley has divided the iteration program into 6 phases. In phases 1 and 2, he constructs the U and V tables and calculates the W_{ij} values. In Phase 2, he selects the maximum, non-zero, positive W_{ij} to designate the X_{ij} element that will enter the solution matrix. In Phases 3 and 4, the stepping stones are determined and the θ value found. In Phase 5, the solution matrix is altered; and, in Phase 6, the new total cost is calculated. The third section of Poley's program evaluates any alternate minimal solutions.

The second program being studied is a modification of Poley's program. It is identical to Poley's program except in Phase 2 of the iteration program. Instead of selecting the maximum, non-zero, positive W_{ij} value, the modified program uses the first non-zero, positive W_{ij} value that the machine finds to designate the X_{ij} element to enter the solution matrix. In this way the time that is required to find the maximum W_{ij} in Poley's program is reduced. The instructions that will modify Poley's program to accomplish this change are located in Appendix B of this study.

CHAPTER II

ANALYSIS OF THE PROBLEM

There are various users of this program who feel that the Poley's Program can be improved. It has been stated that instead of searching for the maximum, non-negative W_{ij}, the program should use the first calculated non-negative W_{ij} as designating the X_{ij} element to be included in the solution matrix. It is claimed that this change would decrease the time of each iteration. However, it is also conceded that, since the maximum, non-negative W_{ij} is neglected, the solution will not converge upon the optimum as quickly and will therefore require more passes through the program or iterations.

It is the purpose of this thesis to determine the economy of this change in Poley's Program in regard to machine time. As a by-product of this study the author also desires to determine a criteria from which machine time can be predicted for different size problems.

Several restrictions on this study must be acknowledged. First, this study only applies to the computation of the Transportation Problem on the IBM 650 Computor. Second, this study is restricted to problems in which all the data can be stored internally by the IBM 650. Therefore, the size of the problems is limited to that case considered "small" by Poley. Poley has defined a small problem on page 1/9 of Appendix A.

Since it is considered impractical to attack this study from a theoretical aspect due to the random nature of the matrices, the only feasible method is to compare actual machine times for the two different programs being compared. The phases of the study are (1) preparation of the programs, (2) selection of the samples, (3) collection of the data, and (4) analysis of the data.

A. Preparation of the Programs

With the aid of James Hetrick and his associates at the Continental Oil Company, Poley's program was modified to permit the first, non-negative W_{ij} found to designate the element to be included in the solution matrix. The actual program revision appears in Appendix B. Poley's flow chart and program commence on page 8/46 of Appendix A.

B. Selection of the Samples

To assure representative samples, all input data was randomized. This included all values for units required at each destination and available at each source. Also randomized were the costs associated with each element, C_{ij}. The test problems appear in Table II-1. The size matrix is equal to the product of the destinations and sources.

TABLE II-1 Test Problems

SIZE MATRIX (mn)	NUMBER OF SAMPLES
40	15
140	20
280	6
560	4
876	3

Also included as test problems are fifteen sample problems that had been computed previously by the Continental Oil Company in accordance with Poley's program. The data involved in these problems is not random, but is characteristic of actual applications. The size of these fifteen problems is 73×12. It was felt necessary, for the accuracy of the study, to include problems involving large matrices. However, the machine time was too extensive to permit samples of this size to be computed by the author.

C. Collection of the Data

For samples of size 40 thru 560 the procedure for collecting data is outlined below. The initial distribution of each sample was determined from Program I of Poley's program. Then each sample was optimized by both Poley's Program II and the modified program. Stop watch readings were taken for the total time of Program II.

For the purposes of the study, Program II was broken into three parts; program loading time, computation time, and solution punch time. The program loading time is the time required by the machine to read the program into the memory of the 650 Computor. The punch time is the time required by the machine to punch out the minimal solution on the cards. The loading and punch operations occur once for each problem. The computation time is the time required by the machine, once the program is stored in the memory, to compute the minimal solution. The loading and punch times were constant for each size matrix, and therefore, are not referred to in the body of the data to follow.

By dividing the computation time by the number of iterations, the average time per iteration was calculated. From spot checking in the process of computing it was found that the time per iteration is generally constant, not being greater or less than about 25% of the average value.

The data for matrix sizes 40 thru 560 is shown in Tables II-2 thru II-5. All watch readings are expressed in hundredths of a minute. The difference in total time between the two methods of programming is calculated for each sample. Every value that appears in this column with a plus sign is equivalent to the amount of time by which Poley's program is faster than the modified program. Also calculated is the percent difference between the two methods using Poley's program as the base.

Three samples (A,B,&C) of matrix size 73×12 or 876 were used to obtain an average time per iteration for Poley's and the modified programs. Each sample was permitted to go through about twenty iterations. The total time of each sample, minus the load time, was then divided by the number of iterations to obtain the time per iteration. These quantities were then averaged and a mean time per iteration obtained for both programs. This value for Poley's program was then multiplied by the number of iterations from each of the fifteen samples obtained from the Continental Oil Company. The resulting data is, therefore, an approximation of the true computing time for these fifteen samples. This data is shown in Tables II-6 and II-7.

The average values of the variables for each size matrix are shown in Table II-8.

D. Analysis of the Data

In this section the data shall be analyzed to establish the two results of this project. They are (1) the determination of the superior program and (2) an equation to express the time required in utilizing this superior program.

TABLE II-2

DATA FOR MATRIX SIZE 40

Constants	Poley's Program	Modified Program
Load Time (min)	0.99	1.04
Punch Time (min)	0.04	0.04

7/10	9/10	12/10	11/10	9/10	12/10	11/10	12/10	8/10
	Poley's Program (P)			Modified Program (M)				
Sample Number	Total Compute Time (min)	Number of Iterations	Average Time per Iteration (min)	Total Compute Time (min)	Number of Iterations	Average Time Per Iteration (min)	Difference in Total Time (M-P) (min)	% Difference (M-P)/P (%)
1.	0.23	2.0	0.115	0.38	3.0	0.127	+ 0.15	65.22
2.	0.75	5.0	0.150	1.39	10.0	0.139	+ 0.64	85.33
3.	1.65	10.0	0.165	2.77	18.0	0.154	+ 1.12	67.88
4.	0.63	4.0	0.158	0.63	5.0	0.126	0	0
5.	1.28	8.0	0.160	1.72	11.0	0.156	+ 0.44	34.38
6.	1.04	6.0	0.173	1.48	9.0	0.164	+ 0.44	42.31
7.	0.65	4.0	0.163	1.10	7.0	0.157	+ 0.45	69.23
8.	0.85	5.0	0.170	1.71	11.0	0.155	+ 0.86	101.18
9.	1.12	7.0	0.160	1.46	10.0	0.146	+ 0.34	30.36

TABLE II-2 (Continued)

	Poley's Program (P)			Modified Program (M)				
Sample Number	Total Compute Time (min)	Number of Iterations	Average Time per Iteration (min)	Total Compute Time (min)	Number of Iterations	Average Time per Iteration (min)	Difference in Total Time (M-P) (min)	% Difference (M-P)/P (%)
10.	0.64	4.0	0.160	0.58	4.0	0.145	- 0.06	- 9.38
11.	0.38	3.0	0.127	0.63	5.0	0.126	+ 0.25	65.79
12.	0.82	5.0	0.164	0.76	5.0	0.152	- 0.06	- 7.32
13.	0.46	3.0	0.153	0.88	6.0	0.147	+ 0.42	91.30
14.	1.59	9.0	0.177	2.16	14.0	0.154	+ 0.57	35.85
15.	0.58	4.0	0.145	0.66	5.0	0.132	+ 0.08	13.79

TABLE II-3

DATA FOR MATRIX SIZE 140

Constants	Poley's Program	Modified Program
Load Time (min)	1.04	1.09
Punch Time (min)	0.07	0.07

	Poley's Program (P)			Modified Program (M)				
Sample Number	Total Compute Time (min)	Number of Iterations	Average Time per Iteration (min)	Total Compute Time (min)	Number of Iterations	Average Time per Iteration (min)	Difference in Total Time (M-P) (min)	% Difference (M-P)/P (%)
16.	5.59	13.0	0.430	6.99	21.0	0.333	+ 1.40	25.04
17.	6.46	14.0	0.461	15.74	46.0	0.342	+ 9.28	143.65
18.	5.02	12.0	0.418	15.01	43.0	0.349	+ 9.99	199.00
19.	4.57	11.0	0.415	9.17	27.0	0.340	+ 4.60	100.66
20.	5.58	12.0	0.465	4.99	14.0	0.356	- 0.59	- 10.57
21.	4.09	10.0	0.409	8.63	26.0	0.332	+ 4.54	111.00
22.	5.59	13.0	0.430	13.06	38.0	0.344	+ 7.47	133.63
23.	7.04	15.0	0.469	10.74	29.0	0.370	+ 3.70	52.56
24.	8.57	19.0	0.451	13.68	38.0	0.360	+ 5.11	59.63
25.	3.46	8.0	0.432	9.63	29.0	0.332	+ 6.17	178.32

TABLE II-3 (Continued)

Sample Number	Poley's Program (P) Total Compute Time (min)	Poley's Program (P) Number of Iterations	Poley's Program (P) Average Time per Iteration (min)	Modified Program (M) Total Compute Time (min)	Modified Program (M) Number of Iterations	Modified Program (M) Average Time per Iteration (min)	Difference in Total Time (M-P) (min)	% Difference (M-P)/P (%)
26.	10.87	23.0	0.473	17.57	52.0	0.338	+ 6.70	61.64
27.	5.16	11.0	0.469	10.30	29.0	0.355	+ 5.14	99.61
28.	3.50	8.0	0.438	4.81	14.0	0.344	+ 1.31	37.43
29.	4.93	11.0	0.448	6.79	19.0	0.357	+ 1.86	37.73
30.	5.05	11.0	0.459	5.33	14.0	0.381	+ 0.28	5.54
31.	5.94	13.0	0.457	7.83	23.0	0.340	+ 1.89	31.82
32.	7.20	17.0	0.424	18.65	54.0	0.345	+11.45	159.03
33.	9.21	19.0	0.485	14.86	45.0	0.330	5.65	61.35
34.	8.37	19.0	0.441	8.69	25.0	0.348	+ 0.32	3.82
35.	6.95	15.0	0.463	11.08	29.0	0.382	+ 4.13	59.42

TABLE II-4

DATA FOR MATRIX SIZE 280

Constants	Poley's Program	Modified Program
Load Time (min)	1.11	1.16
Punch Time (min)	0.10	0.10

	Poley's Program (P)			Modified Program (M)				
Sample Number	Total Compute Time (min)	Number of Iterations	Average Time per Iteration (min)	Total Compute Time (min)	Number of Iterations	Average Time per Iteration (min)	Difference in Total Time (M-P) (min)	% Difference (M-P)/P (%)
36.	16.97	20.0	0.849	31.99	49.0	0.653	+ 15.02	88.51
37.	17.46	22.0	0.794	50.30	83.0	0.606	+ 32.84	188.09
38.	21.39	26.0	0.823	44.54	71.0	0.627	+ 23.15	108.23
39.	20.40	23.0	0.887	40.70	63.0	0.646	+ 20.30	99.51
40.	12.89	15.0	0.859	27.86	43.0	0.648	+ 14.97	116.14
41.	24.20	28.0	0.864	41.74	70.0	0.596	+ 17.54	72.48

TABLE II-5

DATA FOR MATRIX SIZE 560

Constants	Poley's Program	Modified Program
Load Time (min)	1.21	1.26
Punch Time (min)	0.12	0.12

	Poley's Program (P)			Modified Program (M)				
Sample Number	Total Compute Time (min)	Number of Iterations	Average Time per Iteration (min)	Total Compute Time (min)	Number of Iterations	Average Time per Iteration (min)	Difference in Total Time (M-P) (min)	% Difference (M-P)/P (%)
42.	47.68	35.0	1.362	78.17	86.0	0.909	+ 30.49	63.95
43.	47.41	35.0	1.355	100.30	111.0	0.904	+ 52.86	111.56
44.	52.27	36.0	1.452	90.58	99.0	0.915	+ 38.31	73.29
45.	42.96	33.0	1.302	130.33	142.0	0.918	+ 87.37	203.38

TABLE II-6

COMPUTATION OF MEAN TIME PER ITERATION

MATRIX SIZE 876

9/10	14/10	11/10	13/10	13/10
Sample Number*	Number of Iterations	Compute Time (min)	Time per Iteration (min)	Mean Time per Iteration (min)
A-P	19.0	38.69	2.036	
B-P	17.0	33.01	1.942	
C-P	19.0	35.88	1.888	1.955
A-M	16.0	21.69	1.356	
B-M	23.0	29.31	1.274	
C-M	22.0	28.64	1.302	1.311

*The notation such as (A-P) refers to Sample A computed by Poley's Program.

TABLE II-7

DATA FOR MATRIX SIZE 876

Poley's Program

15/10 15/10 15/10 15/10

Sample Number	Number of Iterations	Mean Time per Iteration (min)	Total Computation Time (min)
46.	65.0	1.955	127.075
47.	72.0	1.955	140.760
48.	45.0	1.955	87.975
49.	63.0	1.955	123.165
50.	48.0	1.955	93.840
51.	65.0	1.955	127.075
52.	41.0	1.955	80.155
53.	54.0	1.955	105.570
54.	36.0	1.955	70.380
55.	39.0	1.955	76.245
56.	49.0	1.955	95.795
57.	49.0	1.955	95.795
58.	39.0	1.955	76.245
59.	55.0	1.955	107.525
60.	93.0	1.955	181.815

TABLE II-8

AVERAGE VALUE OF VARIABLES

Size Of Matrix	Poley's Program (P)			Modified Program (M)				
	Total Compute Time (min)	Number of Iterations	Mean Time per Iteration (min)	Total Compute Time (min)	Number of Iterations	Mean Time per Iteration (min)	Difference in Total Time (M-P) (min)	% Difference (M-P)/P (%)
40	0.845	5.3	0.156	1.22	8.20	0.145	+ 0.375	44.38
140	6.158	13.7	0.447	10.678	30.75	0.349	+ 4.520	73.40
280	18.885	22.3	0.846	39.522	63.17	0.629	+ 20.637	109.28
560	47.580	34.8	1.368	99.845	109.50	0.912	+ 52.265	109.85
876	105.961	54.2	1.955			1.311		

1. Determination of the Superior Program

Of initial interest in this phase of the study would be a distribution of the time differences between the two programs. However, because of the different size matrices which generate different average computation times, this criteria is useless. By using the percentage difference between Poley's and the modified programs, though, the data falls into its right perspective. This distribution is graphed in Figure 1.

Although the samples for matrix sizes 280 and 560 are limited, it is apparent that, as the matrix size increases, the probability that Poley's program is faster also increases. This point is shown clearly in Figures 2 and 3. Figure 2 is a plot of the time per iteration for each size matrix. Included in this plot are the figures for matrix size 876. The plot is based on the relatively large samples of matrix sizes 40 and 140. However, it can be seen that the other points deviate very little from the curves. Figure 3 is a plot of the number of iterations for each size matrix. These curves are also based on the samples of matrix size 40 and 140.

From these figures it is obvious that the difference in the number of iterations is increasing faster than the difference in the time per iteration. Although the modified program takes less time per iteration, it requires far more iterations. For example, at matrix size 95 (Figure 3, Point A), the number of iterations of the modified program is twice the number of Poley's program. However, the time per iteration of the modified program does not reach one-half the value for Poley's program in the effective range of the curves.

Figure 4 is a plot of the total computation time for each program. From this plot it is evident that, as the matrix size increases, the

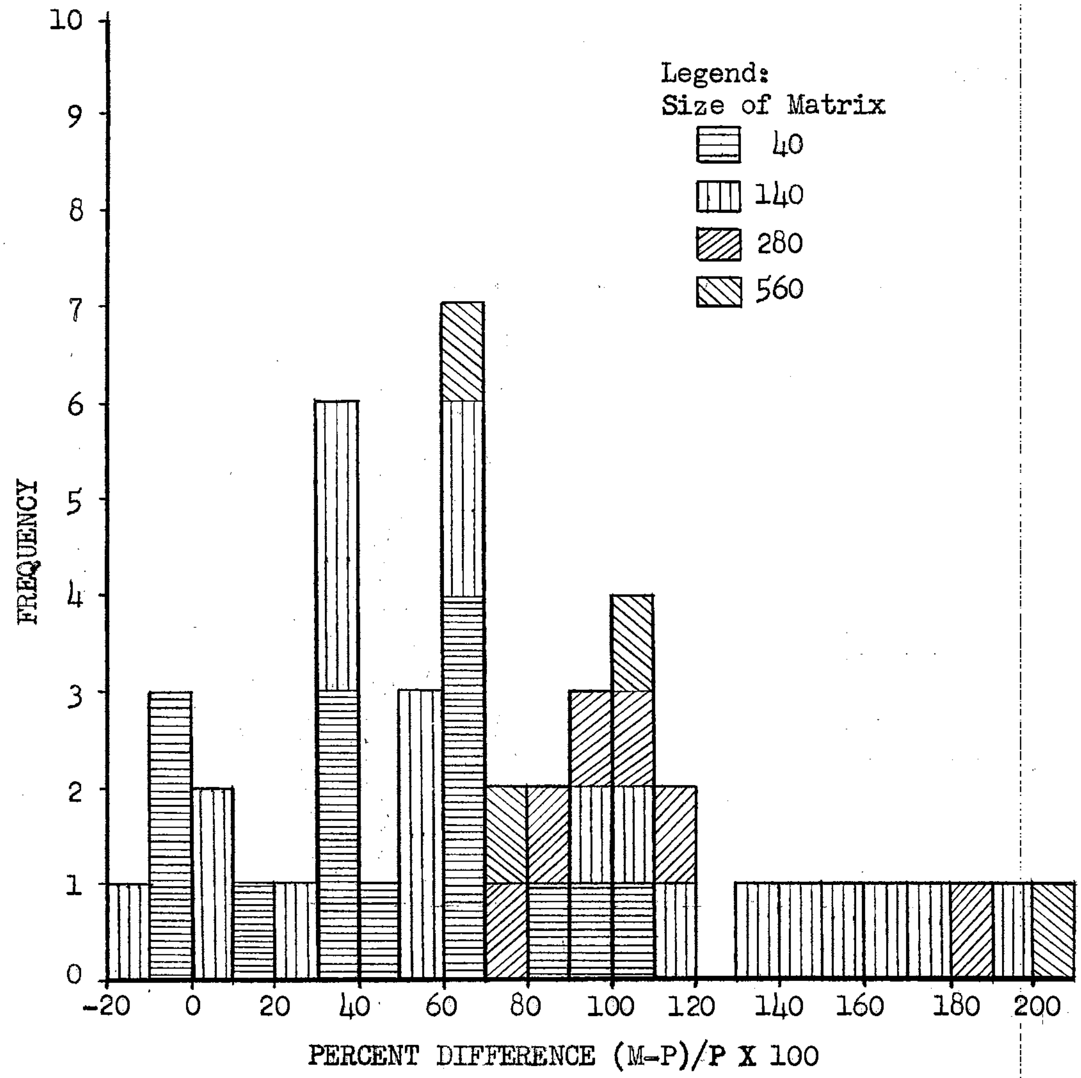

Figure 1 FREQUENCY DISTRIBUTION, SAMPLES 1 THROUGH 45

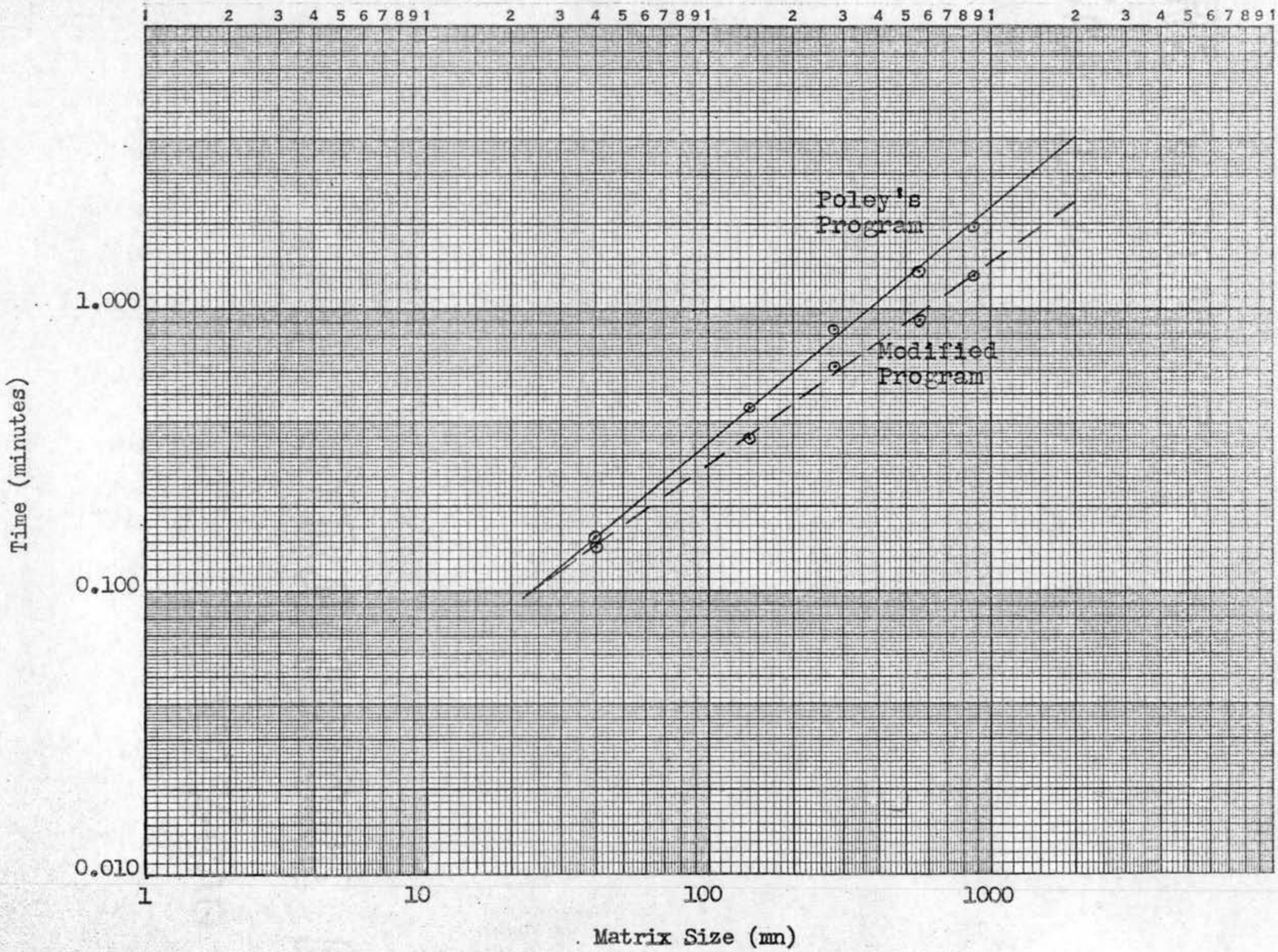

Figure 2. Average Time Per Iteration

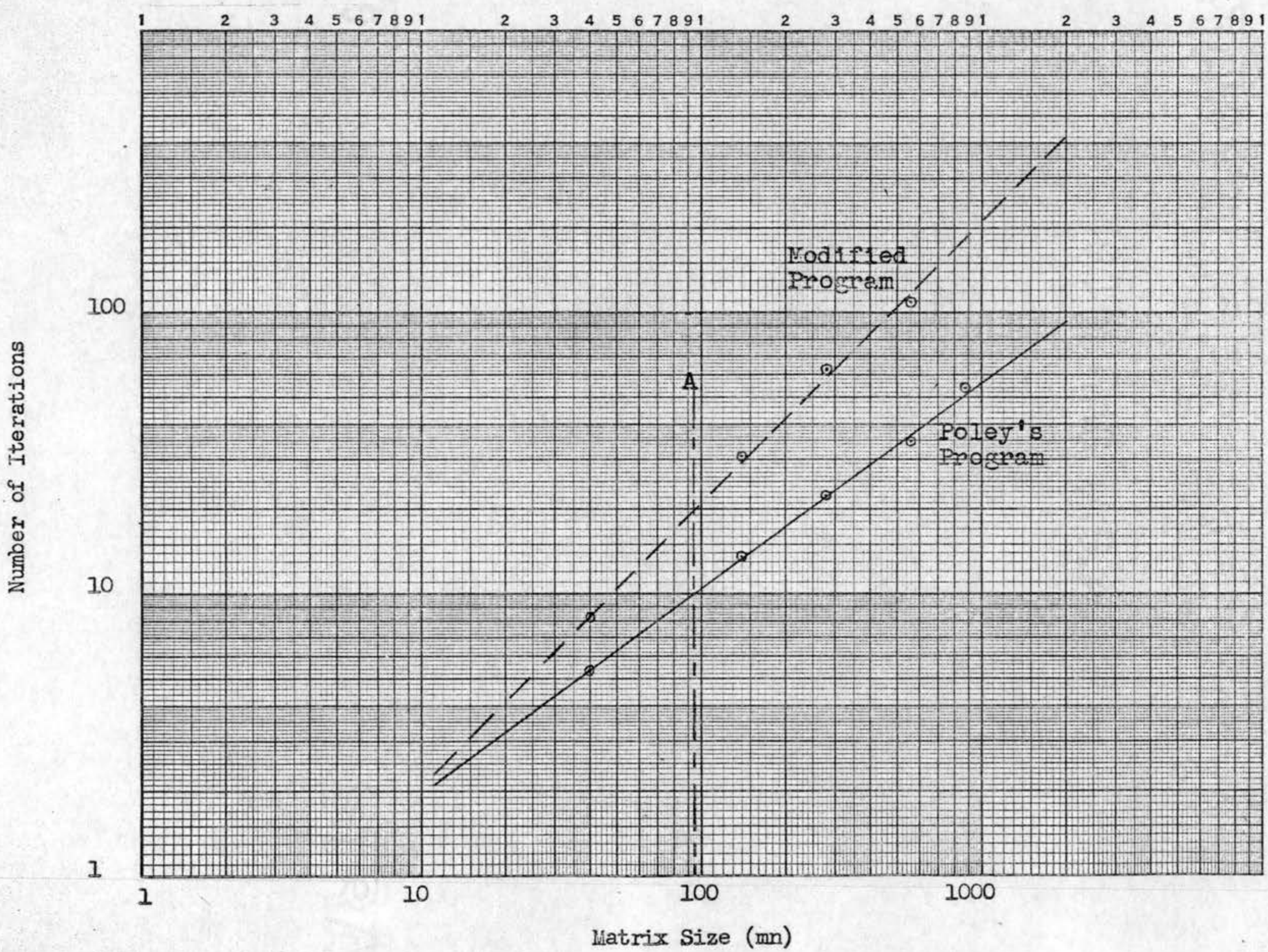

Figure 3. Average Number of Iterations

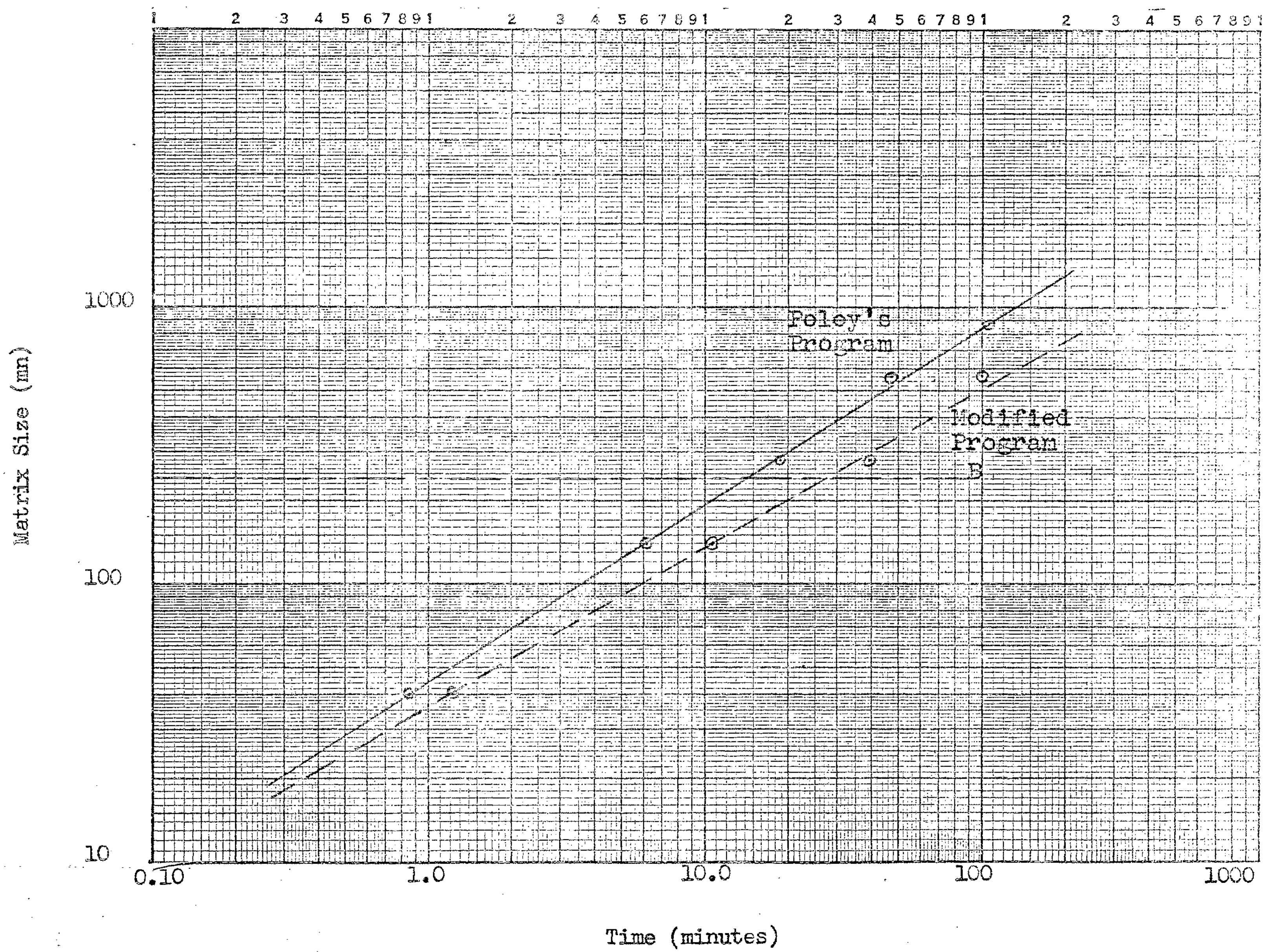

Figure 4. Average Total Computation Time

computation time for the modified program is increasing at a faster rate than the computation time for Poley's program. Of course, these results are to be expected from the foregoing discussion. At matrix size 240 (Figure 3, Point B) the average computation time for the modified program is twice that of Poley's program. From this discussion it is evident that the program developed by Poley is to be preferred.

2. Average Time Equation

Now that the superior program has been determined, it is felt that there is sufficient data available to develop an equation to relate the time required by Program II of Poley's program to the matrix size. From the curve representing the average computation time for Poley's program (Figure 4), it is possible to derive this equation empirically. It is

$$T = 0.00274S^{1.55} \qquad 10 < S < 2000$$

where T is the average computation time and S is the matrix size.

This equation is an approximation of the average computation time. Due to the disparity in the number of iterations in any particular size problem, the true computation time can vary up to 100% of the average time. Due to the low degree of accuracy there is very little need to add a constant value for the load and punch portions of the program, except for a matrix of small size. The total of these two values would be from 1 to 2 minutes, depending upon the size of the matrix.

CHAPTER III

SUMMARY OF RESULTS

The purpose of the study was to determine the economics as to IBM 650 machine time of modifying Poley's program to compute the solution of the Transportation Problem. This modification was to find the initial non-negative W_{ij} in Phase 2 of Poley's program; and, using that value, proceed to alter the solution matrix and calculate the decrease in cost.

It was found that this modification increased the time of computation for all size matrices. In fact, for matrix sizes 240 and above, the modified program required over twice as much time as Poley's program. From this study it is quite evident that Poley's program is superior to the modified program.

From data collected in the pursuit of this study, it was evident that an equation could be developed to express the computation time of Program II of Poley's program. This was done and the equation can be found on Page 36 of this study.

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APPENDIX A

IBM PROGRAM 496

The Transportation Problem

By Stanley Poley

This report is made up of three parts:

1. Introduction - Pages 1/9 thru 9/9
2. Program Analysis - Pages 1/46 thru 46/46
3. Machine Operating Notes - Pages 1/5 thru 5/5

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The Transportation Problem

S. Poley

›ose:

This program has been designed to solve the transportation problem which is essentially a special type linear programming problem. Given certain specified requirements at various destinations and amounts available at specified origins, an allocation of a homogeneous product over all possible routes is desired such that the total cost of transporting the goods is minimized. In order to solve such a problem, the following information is required.

a) Amount available at each origin (S_j)

b) Amount required at each destination (D_i)

c) Unit cost of shipment from any origin j to any destination i (C_{ij}).

Given the above information, the program will determine the desired minimal mode of transportation. It is also possible to obtain alternate optional solutions, i.e., one or more additional solutions which yield the same minimum total cost.

rictions:

Let $\frac{A}{B} = Q + \frac{R}{B}$

where Q is an integer and R the remainder. We define

$$\left(\frac{A}{B}\right)^* = \begin{cases} Q \text{ if } R = 0 \\ (Q+1) \text{ if } R \neq 0 \end{cases}$$

Let m = number of destinations
n = number of origins

We will call a problem "small" if m, n satisfy the following inequalities:

$$\left.\begin{array}{r} 2(m+n) + \left(\frac{mn}{2}\right)^* + \left(\frac{m+n-1}{2}\right)^* + \left(\frac{m+n-1}{10}\right)^* < 1200 \\ n < 100 \end{array}\right\} (1)$$

Similarly, a problem will be characterised as being "big" if m, n satisfy the inequalities:

$$\left.\begin{array}{r} 2(m+n) + \left(\frac{n}{2}\right)^* + \left(\frac{m+n-1}{2}\right)^* + \left(\frac{m+n-1}{10}\right)^* < 1200 \\ n < 100 \end{array}\right\} (2)$$

The present program will solve a transportation problem for which m, n satisfies either the "small or big" inequalities.

In the case of a "small" problem, the entire cost matrix (C_{ij}) is stored on the drum. Only a single row of the cost matrix is stored on the drum in a "big" problem and the cost matrix must be continually circulated thru the read feed of the 533. It is therefore advantageous to process a given problem as a small problem whenever possible as this eliminates the C_{ij} card reading time inherent in the big problem.

The elements C_{ij} of the cost matrix must all be positive. If a given cost matrix contains negative elements the problem may be solved in the following manner:

Let C be the magnitude of the most negative C_{ij}. Construct a new cost matrix C'_{ij} related to the given one by the relation

$$C'_{ij} = C_{ij} + C$$

Clearly $C'_{ij} \geqslant 0$ for all i, j. If we now solve the transportation problem using the C'_{ij} cost matrix, the total cost for the given problem may be found by the relation

$$\sum C_{ij} \quad X_{ij} = \sum (C'_{ij} - C) \ X_{ij}$$
$$= \sum C'_{ij} \ X_{ij} - C \sum X_{ij}$$

The curves given in Figure 1 will be helpful in determining approximately whether a problem is big, small, or impossible (with this program). In doubtful situations, formulas (1) and (2) will yield an explicit answer.

All input data (S_j, D_j, C_{ij}) are restricted to a maximum size of five digits.

ethod:

The iterative method employed is essentially the same as the "stepping stone" method proposed by A. Charnes and W. W. Cooper. (1) All operations are performed using fixed point arithmetic.

It is impossible to give reliable time estimates until some experience with the program has been obtained. Typical running times will be distributed as soon as they are available.

(1) A. Charnes and W. W. Cooper: "The Stepping Stone Method of Explaining Linear Programming Calculations in Transportation Problems" - Management Science, October, 1954

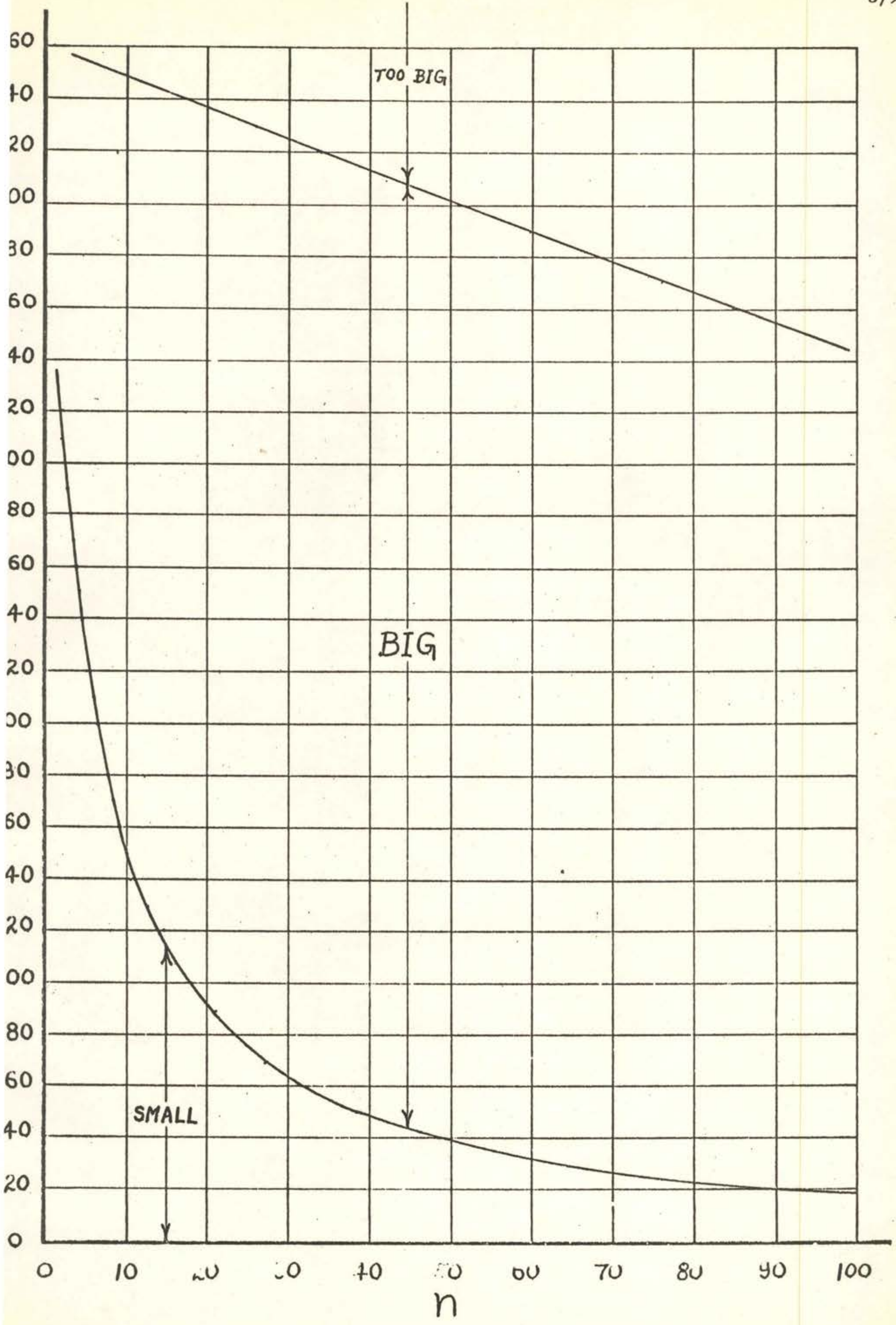

FIGURE 1: PROBLEM SIZE CURVES

ıage:

The following three independent programs together comprise the transportation program:

(I) Initial Distribution
(II) Iteration
(III) Alternate Optima

The use of these programs will be described separately in what follows.

It should be noted that <u>all input data must be punched on seven word load cards.</u> For convenience, the seven-word-per-card format is here given:

Col. 1-10: Control word (overpunch 12 in col's. 1 and 10)

Col. 11-20: Word 1 (overpunch 12 in col. 20)

'
'
'

Col. 71-80: Word 7 (overpunch 12 in col. 80)

The control word has the form (00,xxxx,000n) where xxxx is the location of word 1 and n is the number of words to be loaded ($1 \leq n \leq 7$). Unused 10 digit fields may be left blank.

The 533 and 407 utility control panels will suffice for the entire problem.

<u>ogram I: Initial Distribution:</u>

This program may be employed to calculate an initial shipping pattern to be used as input to the iteration program in the event that an initial distribution is either not available of if it develops that a given initial distribution is degenerate. (2)

The necessary input is as follows:

Ibid.

Availibilities: S_j

Requirements: D_i	S_1	S_2		S_n
D_1	C_{11}	C_{12}	- - -	C_{1n}
D_2	C_{21}	C_{22}	- - -	C_{2n}
⋮	⋮	⋮	- - -	⋮
D_m	C_{m1}	C_{m2}	- - -	C_{mn}

$(\sum D_i = \sum S_j)$

Cost Matrix: C_{ij}

The following input cards are required:

a) Master Data Card I:

Control word:	00, 1928, 0003	
Word 1:	000, m, 0000	(m = xxx.)
" 2:	0000, n, 0000	(n = xx.)
" 3:	00000, R, E, F, G	

ıere:

R = xx. = number of cards per C_{ij} row for big problem only (punch 00 if small)

E = { 9 if master data card is to be punched each iteration
8 if master data cards not desired each iteration

F = { 9 if big problem
8 if small problem

G = { 9 if alternate optima are desired
8 if alternate optima not desired

Requirements: D_i

The D_i 's must be packed two per word and read into a solid block of words beginning at 1200, in sequence on increasing i. Thus

(D_1) (D_2) → 1200 $(D_i$ = xxxxx)

(D_3) (D_4) → 1201, etc.

If m is odd, the unused right half of the last word must be punched with zeros.

c) Availabilities: S_j

The S_j's must be packed two per word and read into a solid block of words beginning at 1500, in sequence on increasing j. Thus

(S_1) (S_2) → 1500 (S_j = xxxxx)

(S_3) (S_4) → 1501, etc.

If n is odd, the unused right half of the last word must be punched with zeros.

d) Cost Matrix: C_{ij}

1) Small: The C_{ij}'s must be packed two per word and read into a solid block of words beginning at 0000, in sequence on increasing i, and increasing j within each row. Thus, if n = 3

(C_{11}) (C_{12}) → 0000 (C_{ij} = xxxxx)

(C_{13}) (C_{21}) → 0001

(C_{22}) (C_{23}) → 0002, etc

If n and m are both odd, the unused right half of the last word must be punched with zeros.

2) Big: The C_{ij}'s must be packed two per word and each row read into a solid block of words beginning at 0000, in ascending sequence on j. The separate rows should be in ascending sequence on i. Each row must begin on a new card, not containing elements of a preceeding or following row. Thus if n = 35 and 14 C_{ij}'s are punched per card, there will be three cards (R = 03) per row, as follows:

Card	Control Word	Contents
# 1	00,0000,0007	C_{p1} . . . . . C_{p14} ($1 \leq p \leq m$)
# 2	00,0007,0007	C_{p15} . . . . C_{p28}
# 3	00,0014,0004	C_{p29} . . . . C_{p35}

Output Description:

The output of program I is immediately usable as input to program II. It is described fully in the following section on program II. Suffice it to say that a new master data card is punched along with (i) (j) (C_{ij}) (X_{ij}) tables giving the initial distribution.

The iteration program carries out the modified stepping stone procedure with a given initial distribution as the first approximation to a minimal solution.

A given initial distribution consists of (m + n-1) basis elements. Each basis element contains the following information:

$$i \;\; j \;\; C_{ij} \;\; X_{ij}$$

where X_{ij} is the number of units of the homogeneous goods shipped from origin j to destination i at unit cost C_{ij}. Thus the total initial transportation cost is

$$\sum C_{ij} \; X_{ij}$$

where the summation is carried out for the (m + n - 1) basis elements.

The X_{ij}'s are subject to the "balancing" restrictions,

$$D_i = \sum_j X_{ij} \qquad i = 1, - - -, m$$

$$S_j = \sum_i X_{ij} \qquad j = 1, \ldots\ldots, n$$

It should be noted that having (m + n-1) basis elements satisfying the balancing relations is not sufficient to guarantee a non-degenerate distribution. The iteration program will quickly detect and reject a degenerate initial distribution

The necessary input cards are as follows: (note that the following represents the entire output of Program I and need not be prepared if said program has been used).

a) Master Data Card II

Control Word:	00, 1928, 0006	
Word 1:	000, m, 0000	(m = xxx.)
" 2:	0000, n, 0000	(n = xx.)
" 3:	00000, R, E, F, G	
" 4:	$\sum S_j$	(units digit in col. 50)
" 5: }	- - - - - - - - $\sum C_{ij} \; X_{ij}$	(units digit in col. 70)
" 6: }		

where R, E, F, G are as defined on page 5.

b) Basis Elements

The basis elements are loaded in essentially two parts; the (ij C_{ij}) table and the (X_{ij}) table:

The (ij C_{ij}) Table:

This table is loaded into a solid block of $(m+n-1)$ words starting at location $B_1 = \left(\frac{mn}{2}\right)^*$

if the problem is small, and $B_1 = \left(\frac{n}{2}\right)^*$ if the problem is big. Each word has the form

(xxx) (xx) (xxxxx)
i j C_{ij}

The order of this table is immaterial.

X_{ij} Table:

The X_{ij}'s must be packed two per word and loaded into a solid block beginning at location $(B_1 + m + n)$. If the number of basis elements is odd, the right hand part of the last word must be punched with zeros. The order of the X_{ij}'s must correspond to the order of the (ijC) table, e.g., consider the following distribution:

i \ j	1	2	3
1		X_{12}	
2			X_{23}
3		X_{32}	X_{33}
4	X_{41}		X_{43}

The (ij C_{ij}) and (X_{ij}) tables might be as follows:

ij Cij Table (C_{ij} = xxxxx)	X_{ij} Table (X_{ij} = xxxxx)
001, 02, C_{12}	(X_{12}) (X_{23})
002, 03, C_{23}	(X_{32}) (X_{33})
003, 02, C_{32}	(X_{41}) (X_{43})
003, 03, C_{33}	
004, 01, C_{41}	
004, 03, C_{43}	

Cost Matrix: C_{ij}

The form of the cost matrix is described under Program1, page 6. If the problem is big, circulating several reproductions of the cost matrix in the read feed of the 533 will considerably reduce card handling.

ut Description:

When the minimal solution has been found, a master data card (III), containing the minimal total cost and an iteration count, is punched along with (ij C_{ij}) and (X_{ij}) tables giving the minimal distribution in exactly the same form as the initial distribution. The iteration count is in the data address part of Word 7 on the master data card.

If alternate optimal solutions have been requested, one card indicating each alternate solution is punched. These cards, along with the minimal solution may be used immediately as input for Program III.

If "E" has been punched 9 on the input master data card, a current master data card will be punched after every iteration. These cards inform the machine operator as to the progress of the problem by giving him the current total cost and iteration count.

gram III: Alternate Optimal Solutions:

If it is indicated that alternate optima are desired, Program II punches a single load card containing i, j, C_{ij} for non-basis $W_{ij} = 0$*. These cards have the following form

Word 1:	000 (i) 0000	i = xxx.
" 2:	0000 (j) 0000	j = xx.
" 3:	00000 (Cij)	C_{ij} = xxxxx

They are loaded back into the 650 along with the optimal solution given by Program II. Program III punches an alternate optimal distribution for each (i, j, C_{ij}) card in exactly the same form as the input optimal solution.

ut Description:

For each alternate solution, the following cards are punched:

1) (i, j, C_{ij}) input indication reproduced
2) Master data card III (reproduced)
3) (ijC_{ij}) table
4) X_{ij} table

e Program Analysis for definition of W_{ij}.

2/15/56
1/46

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The Transportation Problem

S. Poley

Program Analysis

rograms I, II and III

The appropriate program and master data card are loaded. An initialization program inspects the master-data card and sets switches in the main program according as the problem is big or small. Table origins which are functions of m and n are calculated and stored. Control is returned to the card reader and loading continues until the blank card is read which sends control to the main program.

rogram I: Initial Distribution

The D_i's and S_j's are unpacked and their totals are computed and compared. During the unpacking process D_i is replaced by $(D_i + n \times 10^{-3})$ and all the S_j's are replaced by $(S_j + 10^{-3})$. This device maintains the availability - requirement balance while resulting in an initial distribution which may be iterated by Program I even though the given problem is degenerate.

We now select the minimum element in the first row of the cost matrix and set the corresponding X_{ij} equal to D_i or S_j, whichever is smaller. If the Di requirement is thus fulfilled, we proceed to the next row and repeat this procedure. Otherwise we return to the cost matrix, select the next minimum C_{ij} in the same row and set the corresponding X_{ij} equal to S_{ij} or what remains to be filled at D_i, whichever is smaller. We continue in this manner row by row in the cost matrix until we have completed the last row.

ogram II: Iteration

Phase 1:

We construct a U_i and V_j for each element in the basis table, i.e., there will be m U_i's and n V_j's such that

$$U_i + V_j = C_{ij}$$

Let i' be the i subscript associated with the first element of the basis table. We begin by arbitrarily assigning to $U_{i'}$ the value zero. We then pass through the basis table calculating U_i or V_i depending on whether or not V_j or U_i is available for the i or j. One or more additional passes through the basis table are made until the UV table is completed.

A degenerate situation exists if during a pass of the basis table no new U_i's or V_j's are added to the UV table.

Phase 2:

For every element of the cost matrix, we compute the quantity

$$W_{ij} = U_i + V_j - C_{ij}$$

and select W_{IJ} where

$$W_{IJ} = \text{maximum } (W_{ij} \geqq 0)$$

If $W_{IJ} = 0$, a minimal solution has been found. If not, we go to phase 3.

Phase 3:

We begin by constructing a $\overline{U}\,\overline{V}$ table where

$\overline{U}_i$ = number of basis elements with subscripts i

$\overline{V}_j$ = number of basis elements with subscripts j

Secondly an auxiliary $\mu\nu$ table is constructed with which we calculate a $\overline{\mu}$ table. We begin by setting the $\mu\ \nu$ table to zero and then setting $\mu_I = \nu_J = 1$. Passing through the basis table we calculate μ, ν and $\overline{\mu}$ as follows:

If $\overline{U}_i = 1$, replace $\overline{V}_j$ by $(\overline{V}_j - 1)$, ν_j by $(\nu_j - u_j)$

and set $\overline{\mu} = \mu_1$

If $\overline{U}_i \neq 1$ but $\overline{V}_j = 1$, replace $\overline{U}_i$ by $(\overline{U}_i - 1)$, μ_i by $(\mu_i - \nu_j)$

and set $\overline{\mu} = \nu_j$

If neither $\overline{U}_i$ nor $\overline{V}_j$ equals 1, proceed to the next basis element.

In this manner, successive passes thru the basis table are made until a $\overline{\mu}$ has been found for each element in the basis table. It should be noted that $\overline{\mu}$ may assume only the values +1, -1, or zero.

Packing: [0000xx , 00xx] ± (sign that of μ or ν)

- 0000**xx** = $\overline{U}$, 00**xx** = μ

[000xxx, 00xx] ±

- 000**xxx** = $\overline{V}$, 00**xx** = ν

[$\overline{\mu}_0\ \overline{\mu}_1 \cdots \overline{\mu}_p \cdots \overline{\mu}_9$] (10 $\overline{\mu}$'s stored per word)

$\overline{\mu}$ code: $0 \Rightarrow 0$ $\quad 2 \Rightarrow -1$

$1 \Rightarrow 1$ $\quad 3 \Rightarrow -0$

Phase 4

We pass through the basis table once calculating a quantity Θ where

$$\Theta = \text{minimum } X_{ij} \text{ for which } \bar{\mu} = +1$$

Phase 5

We pass through the basis table once making the following alterations:

If $\bar{\mu} = +1$, replace X_{ij} by $(X_{ij} - \Theta)$

If $\bar{\mu} = -1$, replace X_{ij} by $(X_{ij} + \Theta)$

Replace the basis element ij C_{ij} $(X_{ij} = \Theta)$ with IJC_{IJ} $(X_{IJ} = \Theta)$.

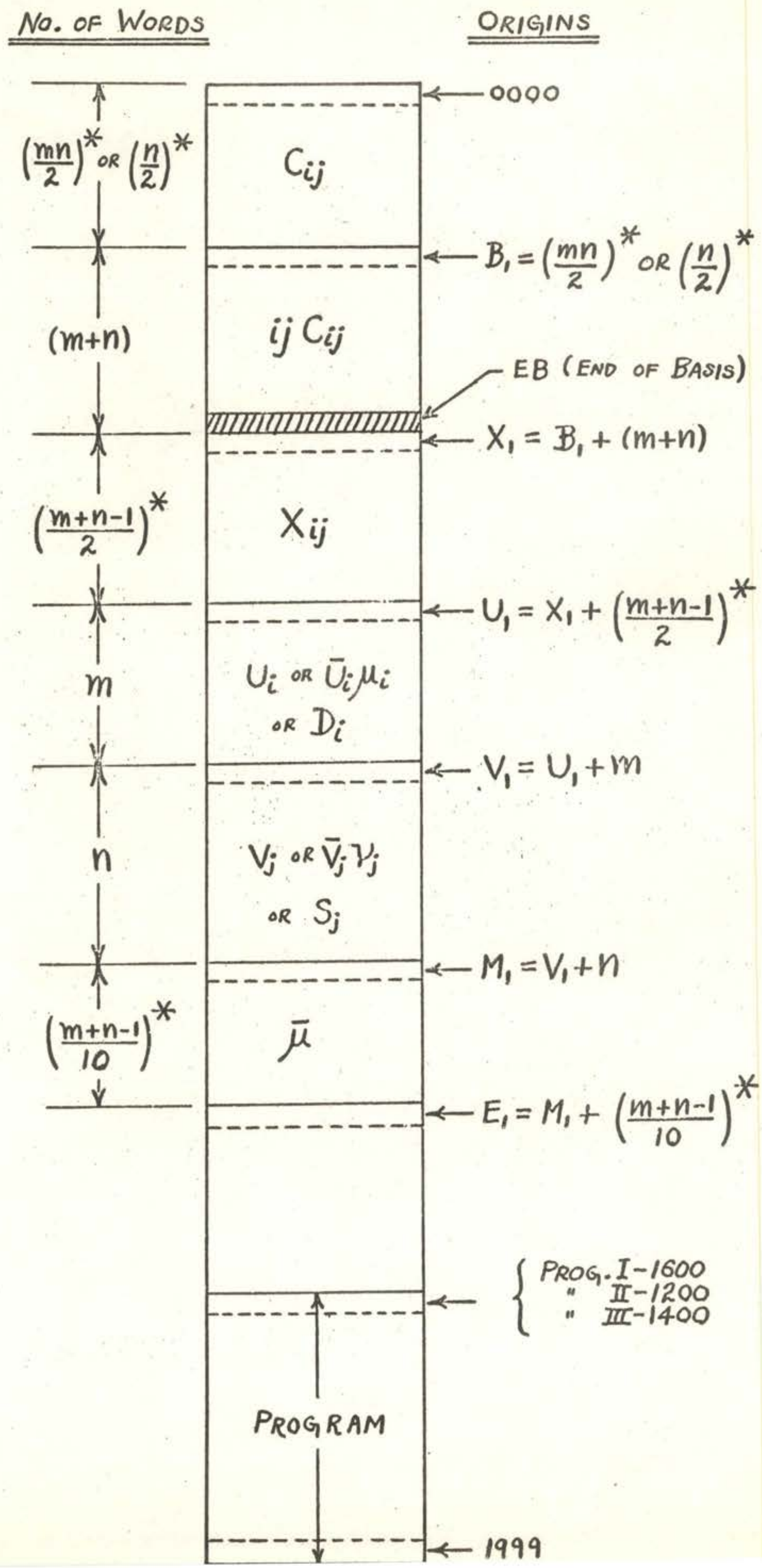
Phase 6:

The new $\sum X_{ij}$ is compared with $\sum S_i$. The change in cost is calculated using two independent methods and these are compared. We then return to phase 1.

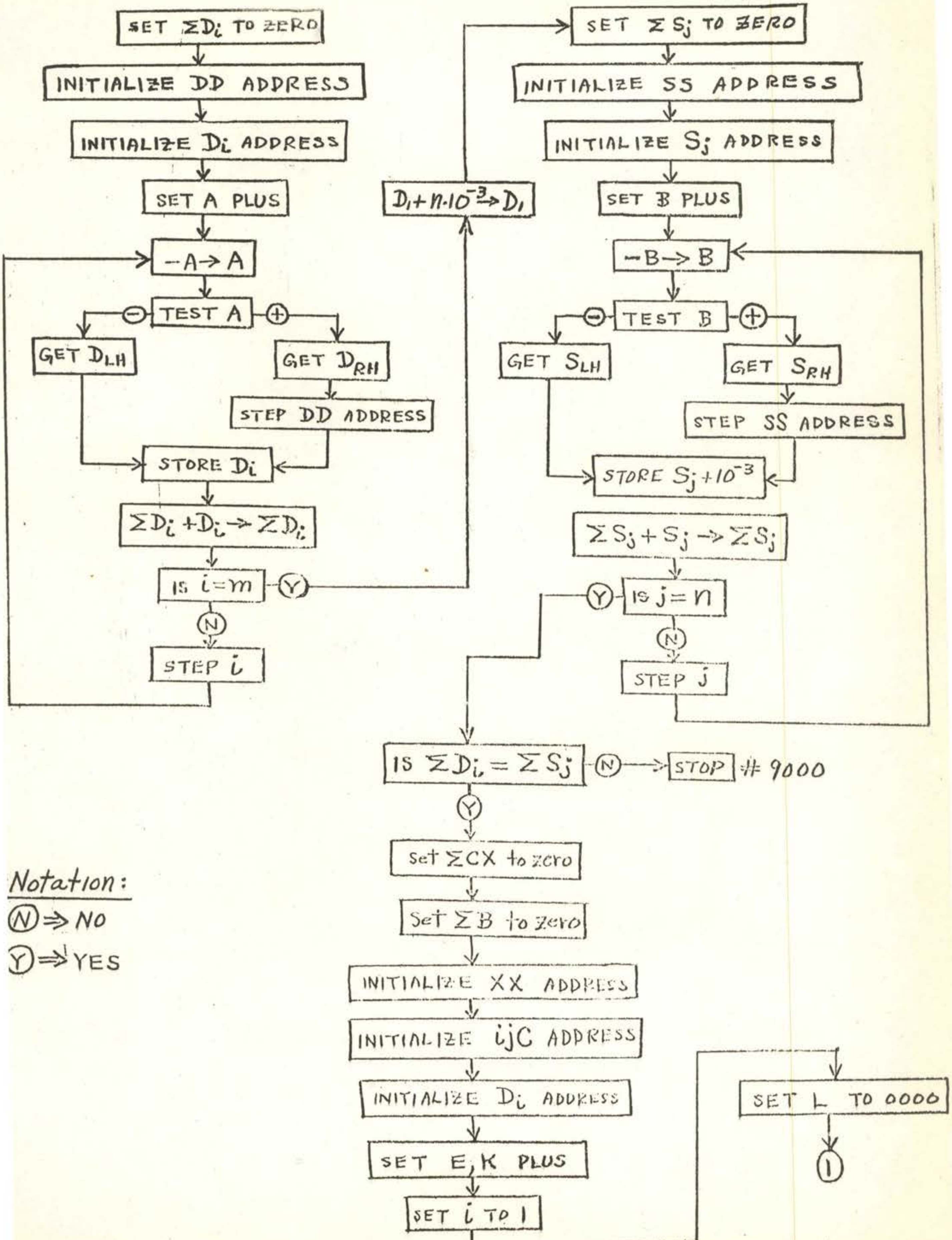
Program III: Alternate Optima

(See flow chart)

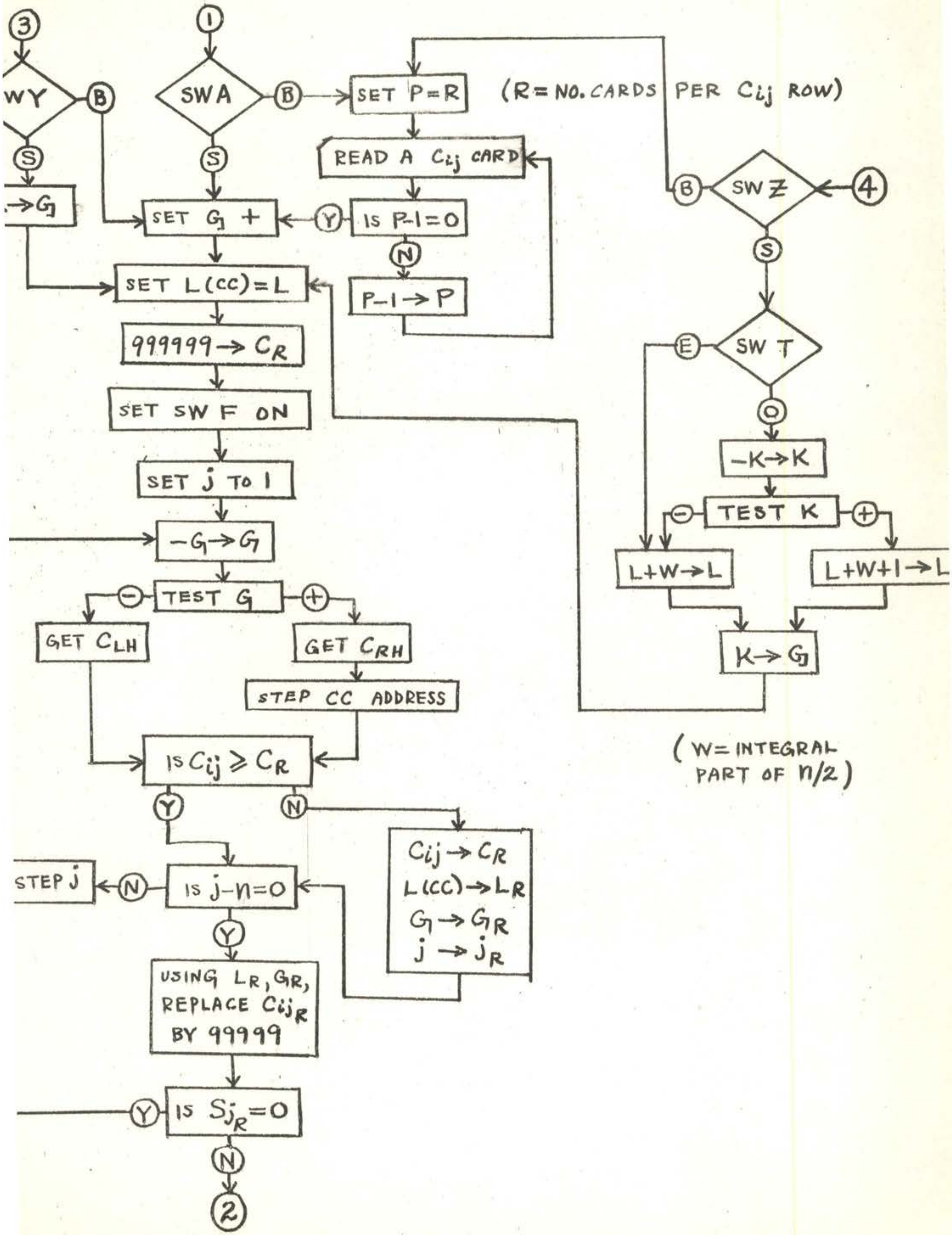
STORAGE ALLOCATION



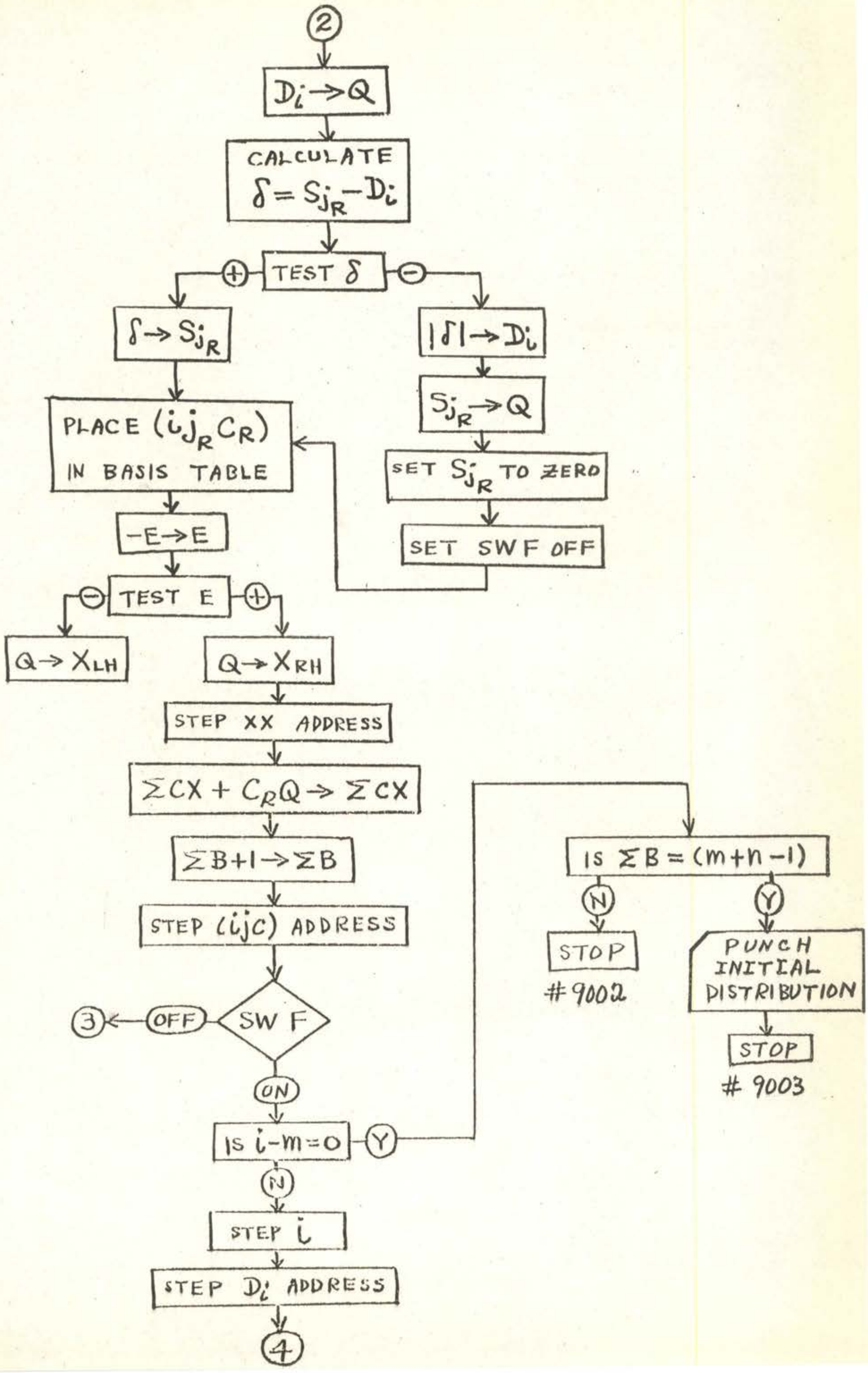
PROGRAM I: INITIAL DISTRIBUTION



PROGRAM I (SHEET 2)

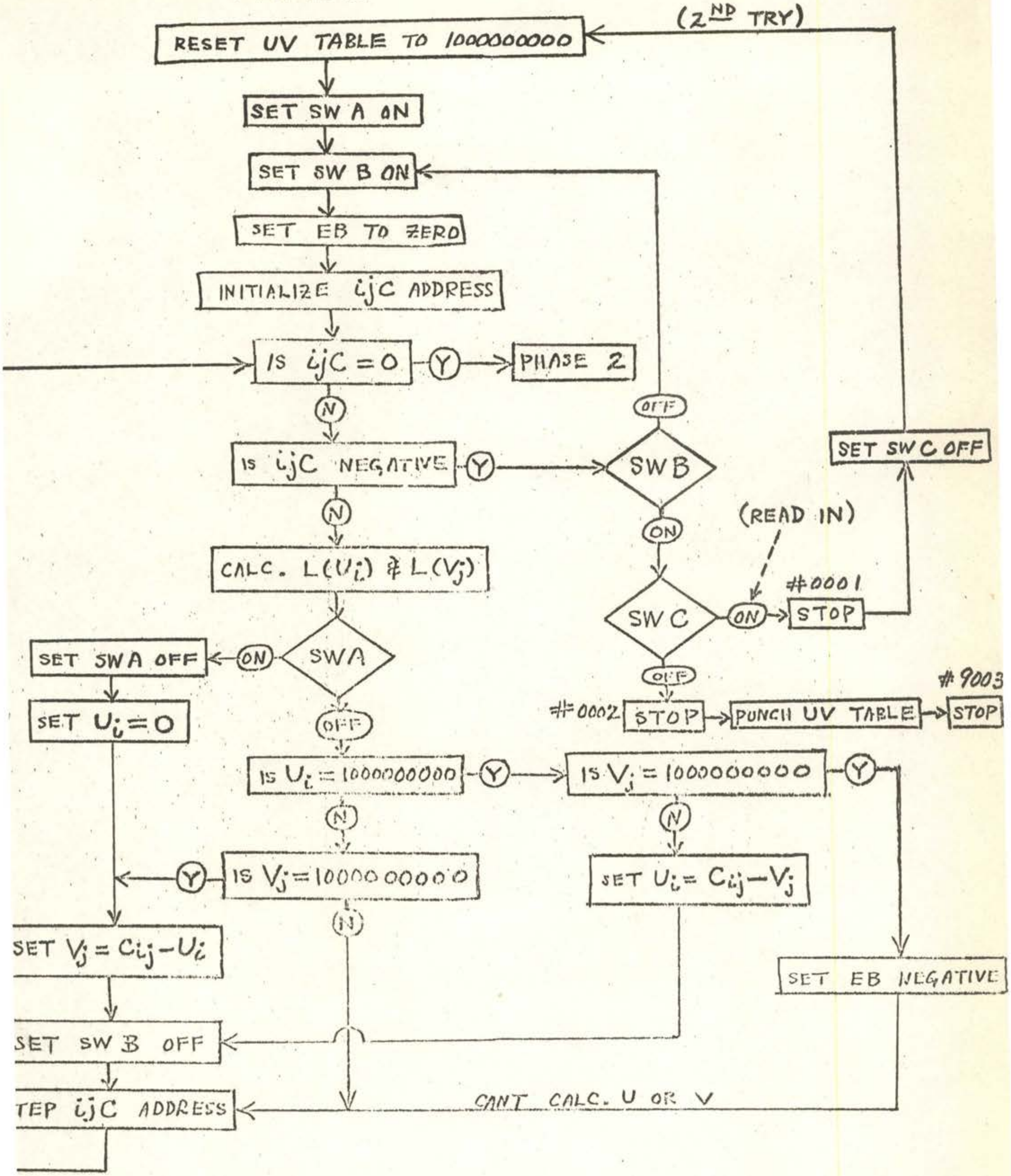


PROGRAM I (SHEET 3)

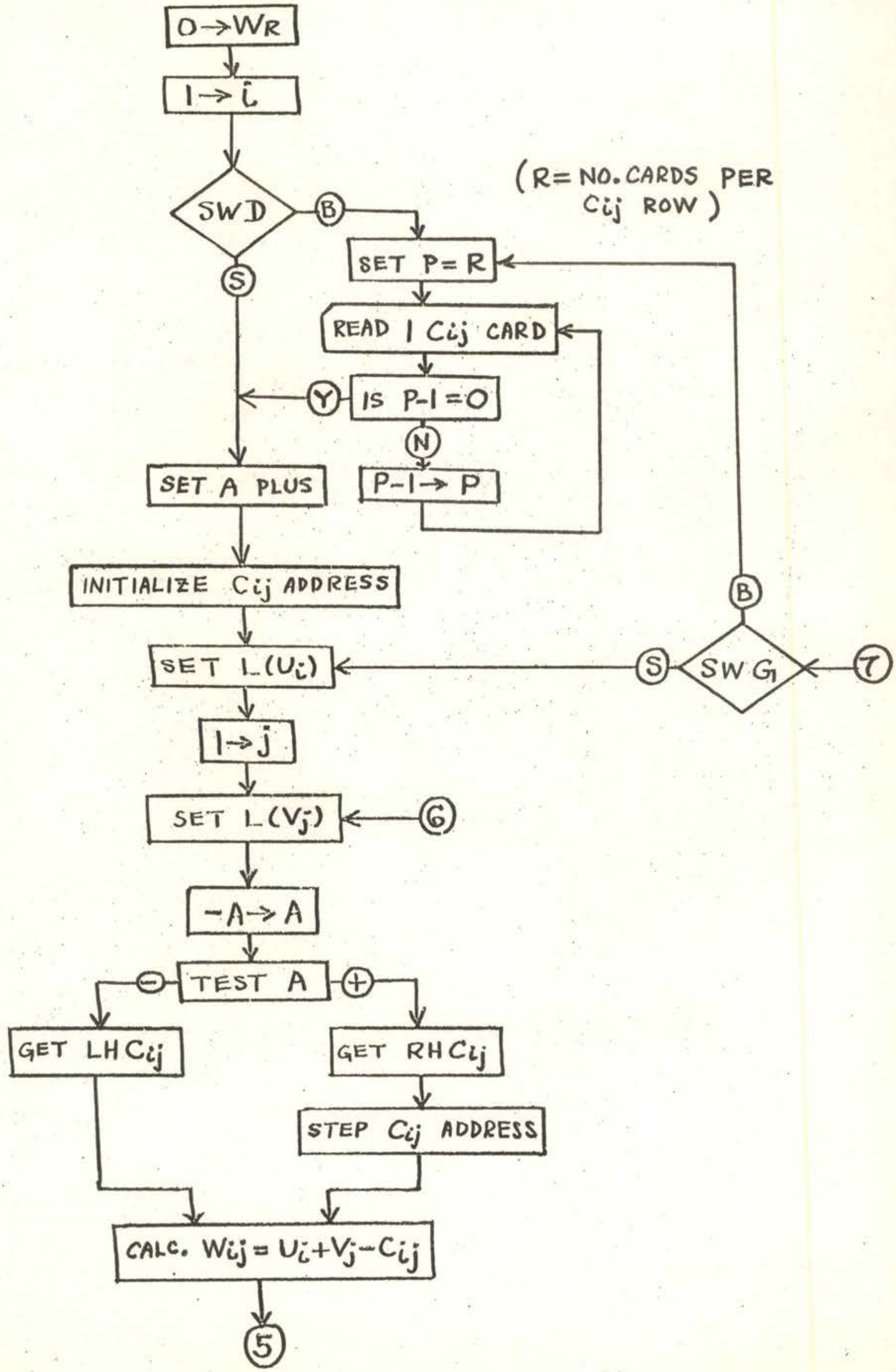


PROGRAM II: ITERATION

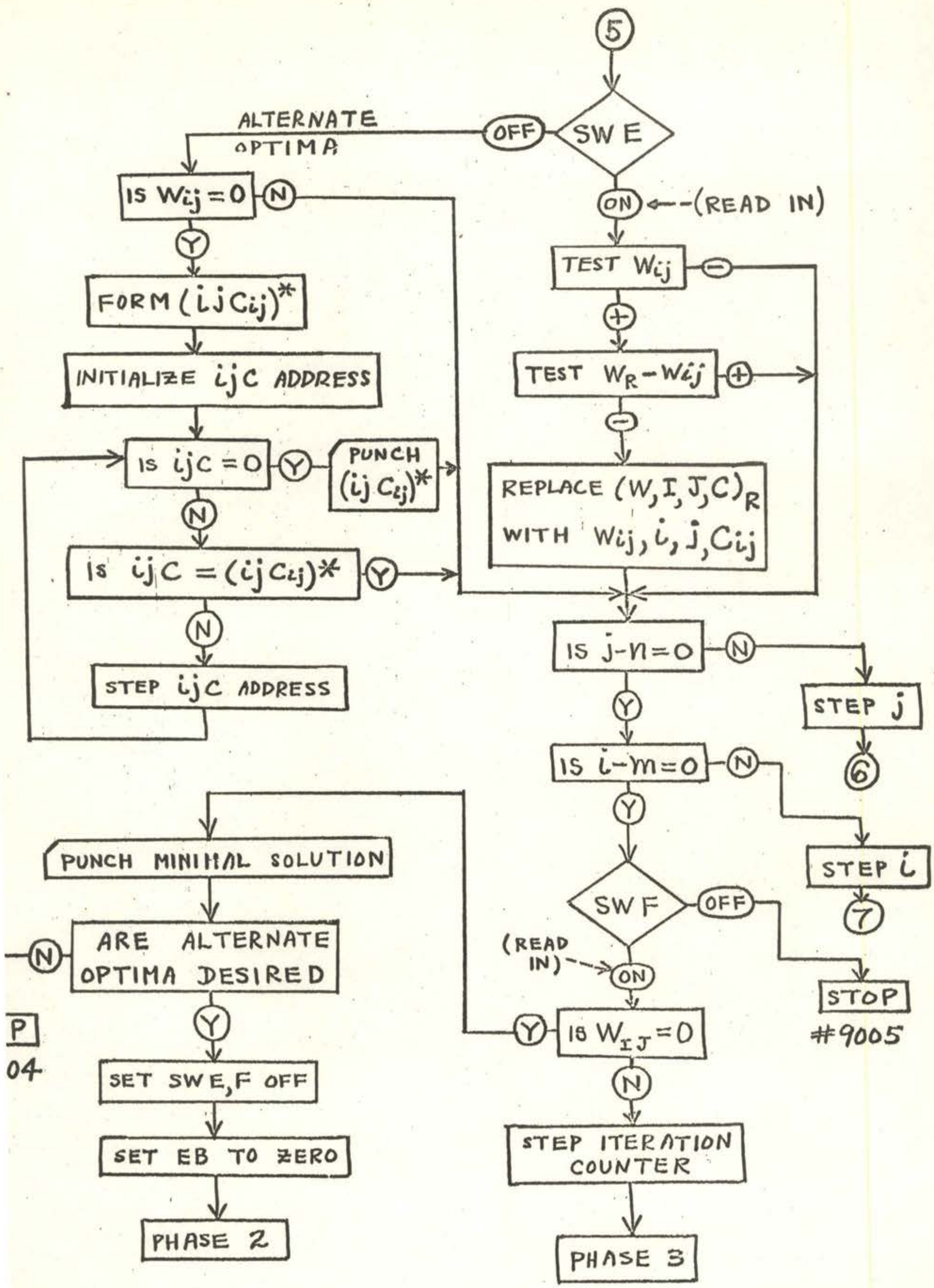
PHASE I: UV TABLE



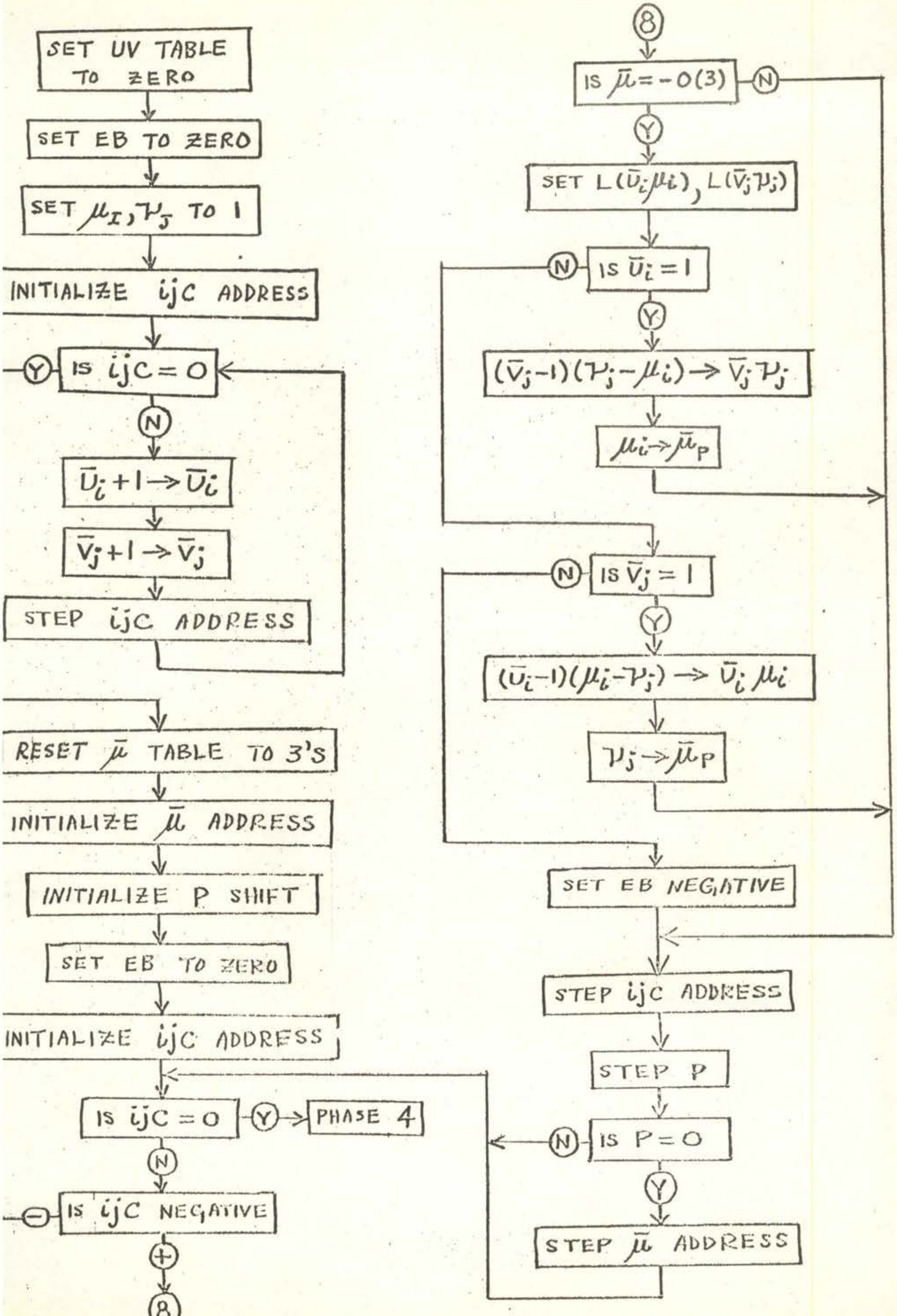
PHASE 2: W_{ij}


0→WR
1→i
SWD
B
S
(R= NO. CARDS PER Cij ROW)
SET P=R
READ 1 Cij CARD
Y
IS P-1=0
N
P-1→P
SET A PLUS
INITIALIZE Cij ADDRESS
B
SET L(Ui)
S
SWG
7
1→j
SET L(Vj)
6
-A→A
−
TEST A
+
GET LHCij
GET RHCij
STEP Cij ADDRESS
CALC. Wij = Ui+Vj−Cij
5

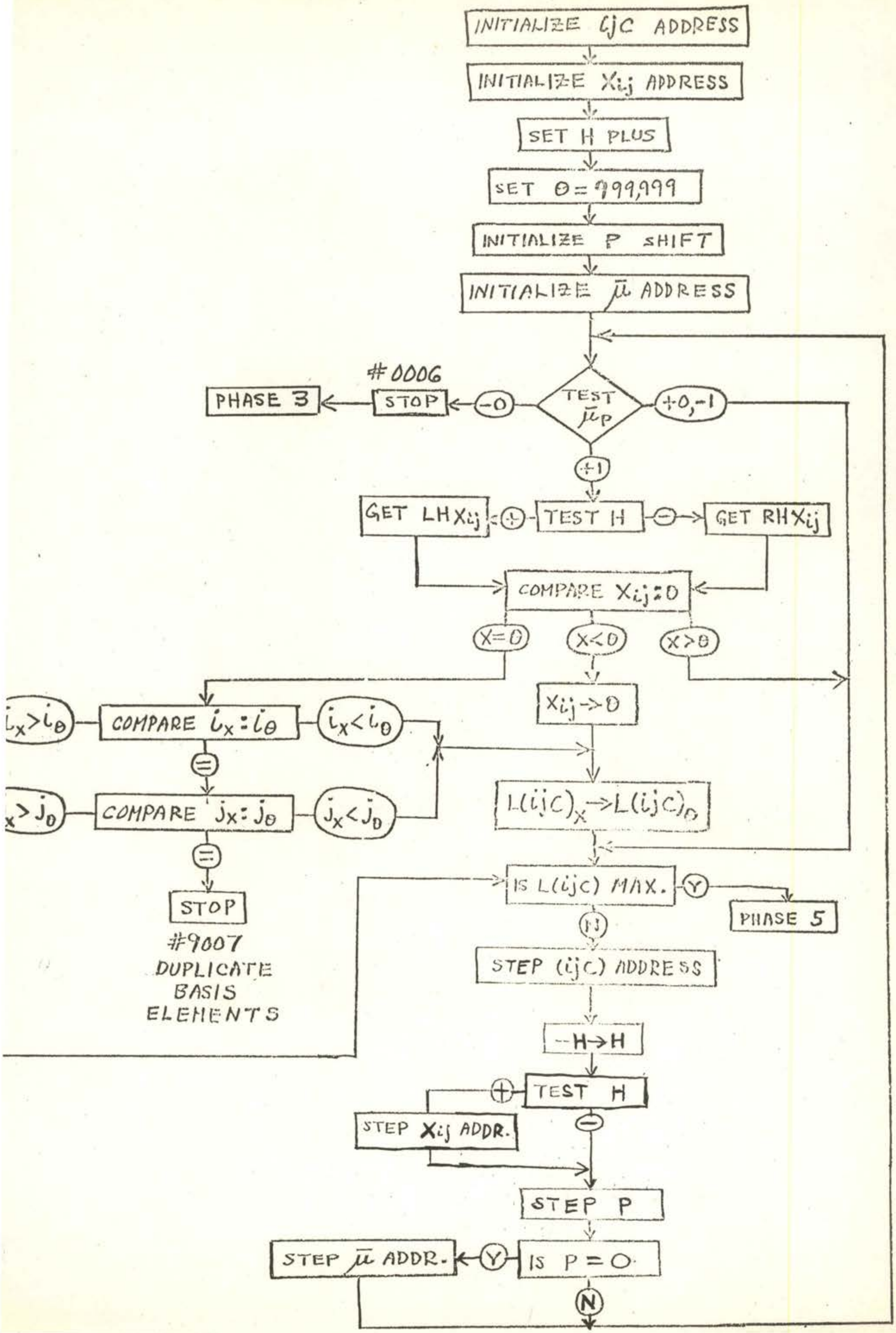
PHASE 2 (SHEET 2)



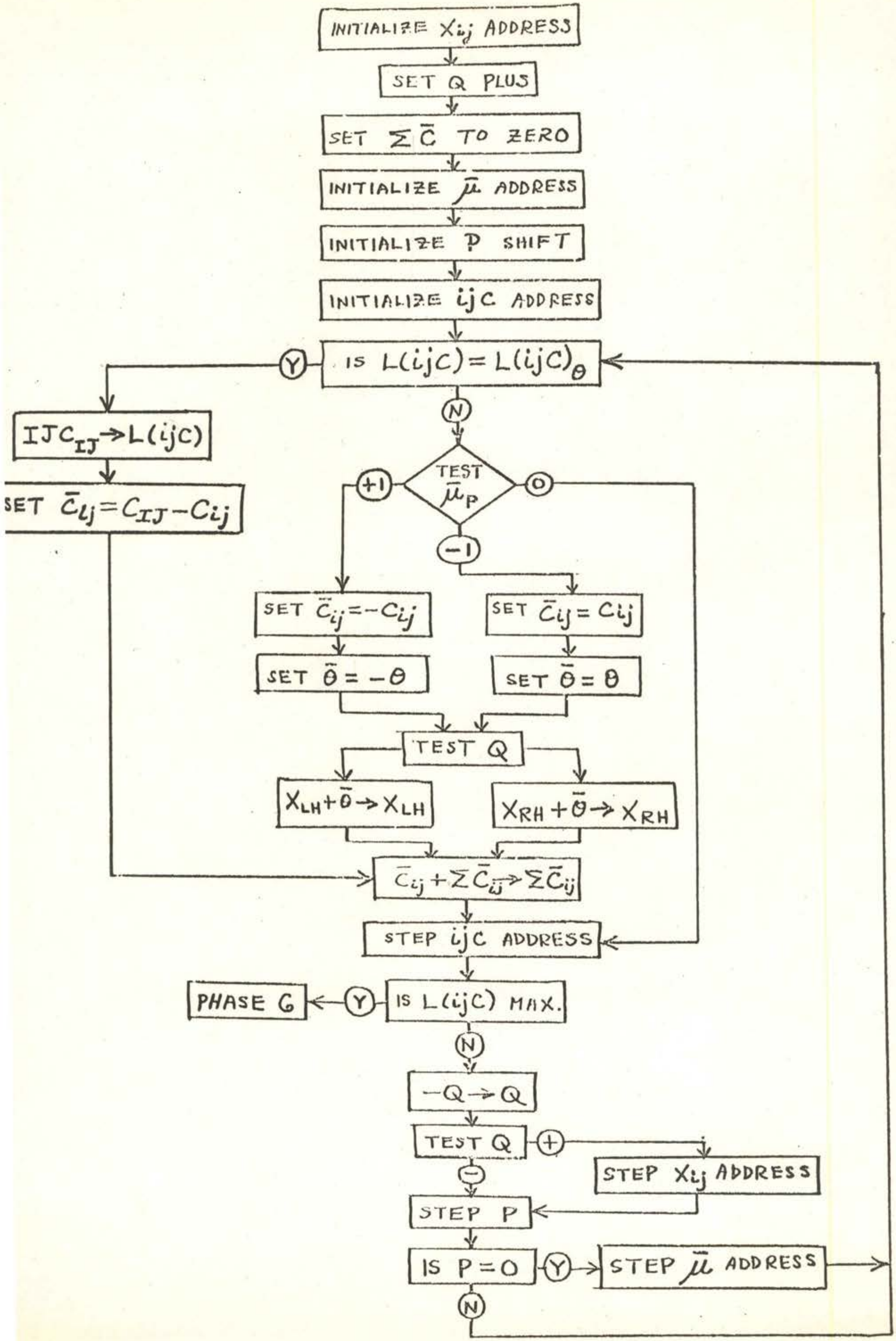
PHASE 3 : μ TABLE



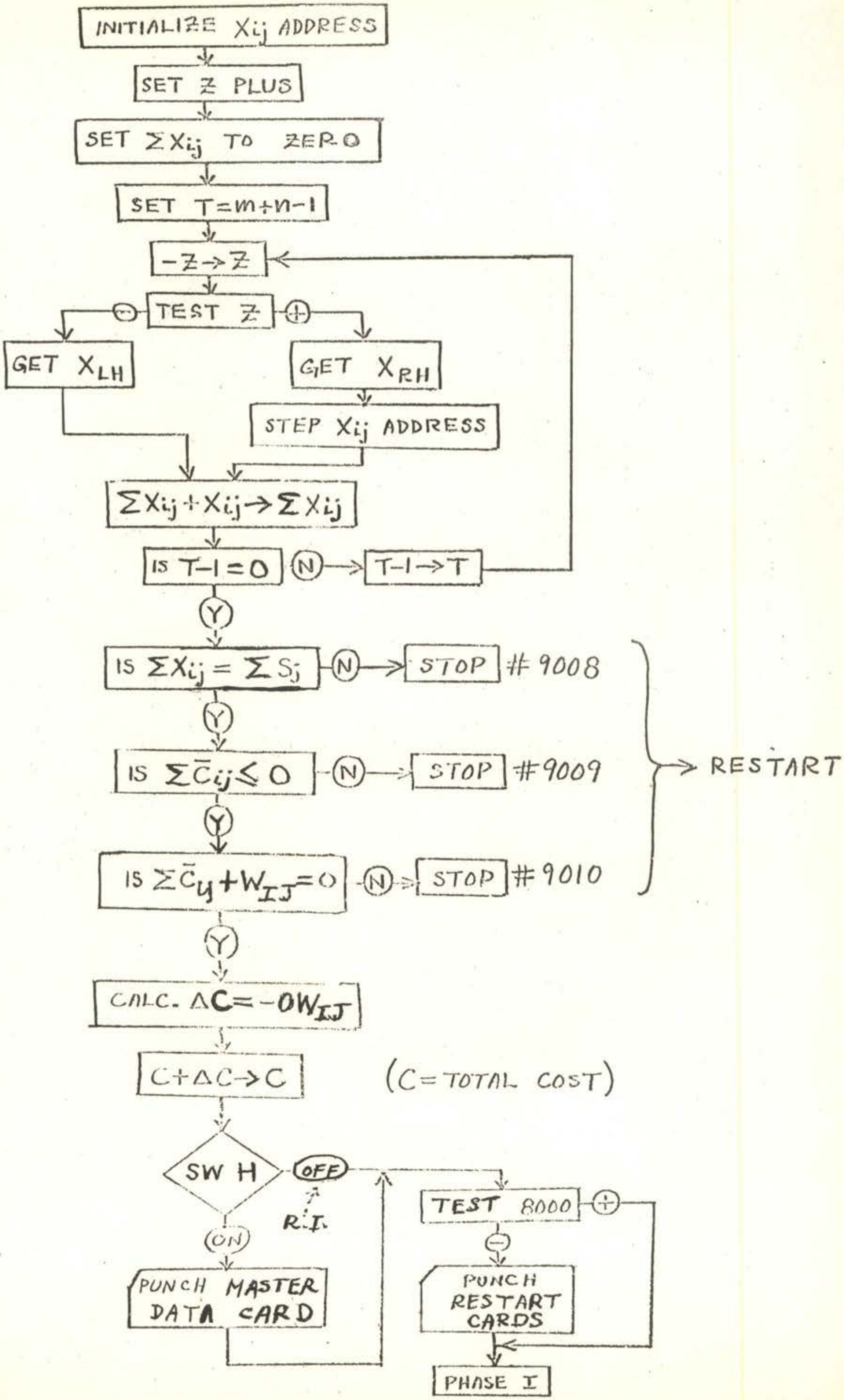
PHASE 4 : θ


INITIALIZE ijC ADDRESS
INITIALIZE Xij ADDRESS
SET H PLUS
SET θ=999,999
INITIALIZE P SHIFT
INITIALIZE μ̄ ADDRESS
#0006
PHASE 3
STOP
-0
TEST μ̄p
+0,-1
+1
GET LHXij
+
TEST H
−
GET RHXij
COMPARE Xij:θ
X=θ
X<θ
X>θ
x>iθ
COMPARE ix:iθ
ix<iθ
Xij→θ
=
x>jθ
COMPARE jx:jθ
jx<jθ
L(ijC)x→L(ijC)θ
=
STOP
#9007
DUPLICATE
BASIS
ELEMENTS
IS L(ijC) MAX.
Y
PHASE 5
N
STEP (ijC) ADDRESS
--H→H
+
TEST H
STEP Xij ADDR.
−
STEP P
STEP μ̄ ADDR.
Y
IS P=0
N

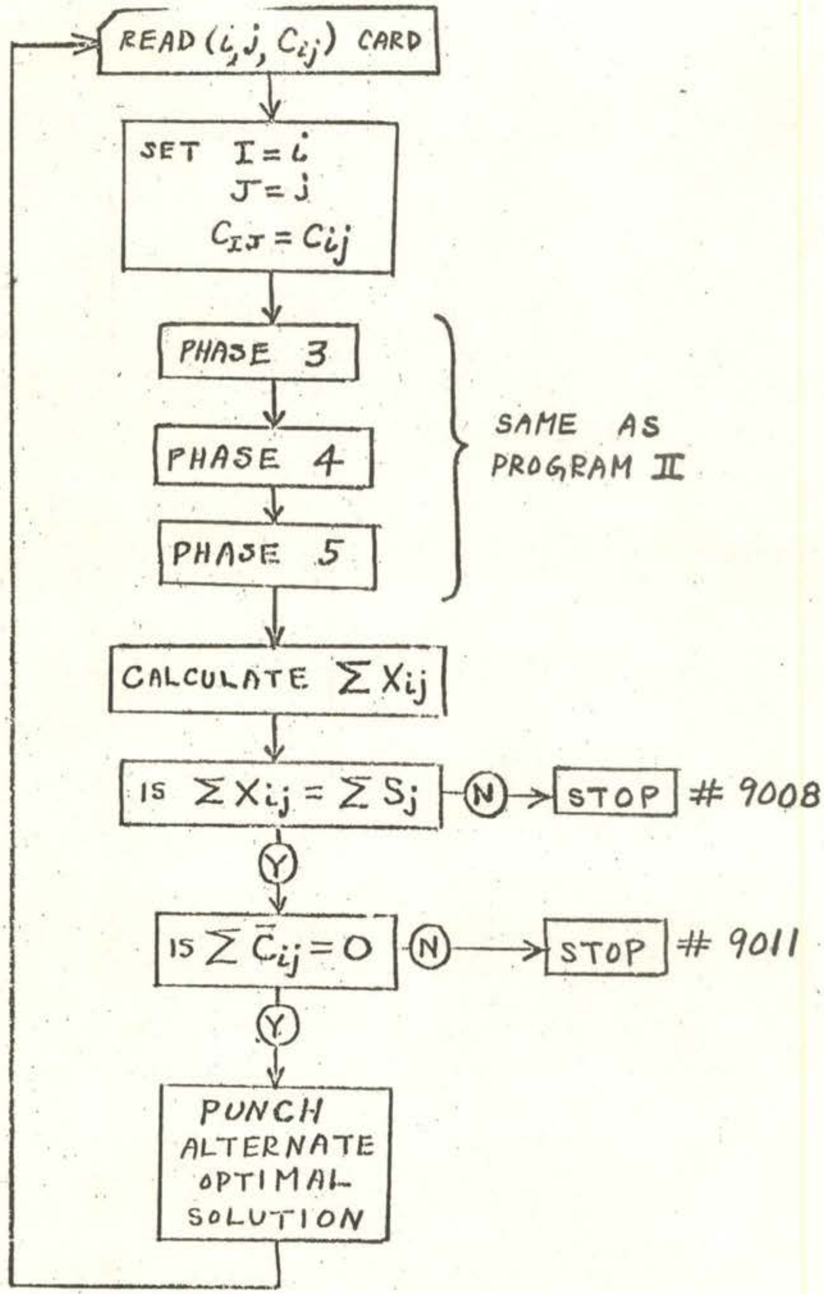
PHASE 5: ALTER BASIS TABE



PHASE 6 : CHECK



PROGRAM III : ALTERNATE OPTIMA



TRANSPORTATION PROBLEM
DPC LIBRARY PROGRAM 496

PROGRAM 1 INITIALIZATION

```
BEGIN   RAU  N                            0001  60  1929  0033
        SRT   0004                        0033  30  0004  0043
        LDD  TAG          TEST            0043  69  1930  0083
        BD2  S70   B70    TAG             0083  92  0036  0038
B70     LDD  71           SET SW A Y      0038  69  0041  0044
        STD  SWA          AND Z           0044  24  1941  0094
        STD  SWZ          TO              0094  24  1969  0022
        LDD  72           BIG             0022  69  0025  0028
        STD  SWY                          0028  24  1660  0013
        LDD  73           SET BIG         0013  69  0016  0019
        STD   1988        READ SWITCH     0019  24  1988  0091
        LDD  74    BOTH   1 TO DIST       0091  69  0045  0048
S70     LDD  75           SET SMALL       0036  69  0039  0042
        STD   1988        READ SWITCH     0042  24  1988  0092
        LDD  M     BOTH   M TO DIST       0092  69  1928  0048
BOTH    MPY   8001        CALC NUMBER     0048  19  8001  0005
        SRT   0004        WORD            0005  30  0004  0015
        DIV  76           FOR             0015  14  0018  0068
        ALO   8003        COST MATRIX     0068  15  8003  0075
        SLT   0004        B1 IN LA        0075  35  0004  0035
        LDD  78           SET             0035  69  0088  0093
        SDA  22           B1              0093  22  1888  0095
        STL  79           ADDRESSES       0095  20  0049  0002
        ALO  M                            0002  15  1928  0034
        ALO  N            X1 IN LA        0034  15  1929  0084
        LDD  80           SET             0084  69  0037  0040
        SDA  21           X1 ADDR         0040  22  1626  0029
        STL  98                           0029  20  0085  0089
        RAL  M                            0089  65  1928  0086
        ALO  N                            0086  15  1929  0087
        SLO  81                           0087  16  0090  0046
        STL  NBE                          0046  20  1796  0099
        SRT   0004                        0099  30  0004  0009
        DIV  82                           0009  14  0012  0062
        ALO   8003                        0062  15  8003  0069
        SLT   0004                        0069  35  0004  0079
        ALO  98                           0079  15  0085  0096
        SLO  83           DO IN LA        0096  16  0050  0055
        SRT   0004                        0055  30  0004  0065
        LDD  79           SET             0065  69  0049  0052
        SIA  63           DO ADDR         0052  23  1730  0047
        SLT   0004                        0047  35  0004  0007
        ALO  84           D1 IN LA        0007  15  0010  0115
        LDD  85           SET             0115  69  0118  0021
        SDA  2            D1              0021  22  1620  0023
        LDD  86           ADDRESSES       0023  69  0026  0129
        SDA  9                            0129  22  1643  0097
        LDD  87                           0097  69  0100  0003
        SDA  10                           0003  22  1655  0008
        LDD  88                           0008  69  0011  0014
```

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      SDA   46                                 0014   22  1862  0066
      ALO   M                                  0066   15  1928  0098
      SLO   89             SO IN LA            0098   16  0051  0105
      LDD   90             SET                 0105   69  0058  0061
      SDA   6              SO                  0061   22  1640  0101
      LDD   91             ADDRESSES           0101   69  0004  0057
      SDA   42                                 0057   22  1850  0053
      ALO   92             S1 IN LA            0053   15  0006  0111
      LDD   93             SET                 0111   69  0064  0017
      SDA   8              S1                  0017   22  1601  0054
      LDD   94             ADDRESSES           0054   69  0107  0060
      SDA   13                                 0060   22  1612  0116
      ALO   N              E1 IN LA            0116   15  1929  0102
      LDD   95             SET E1              0102   69  0056  0059
      SDA   20             ADDRESS             0059   22  1761  0114
      SLO   96             E0 IN LA            0114   16  0067  0071
      LDD   97             SET E0              0071   69  0024  0027
      SDA   19             ADDRESS             0027   22  1698  0103
      RAL   N              SET SMALL           0103   65  1929  0104
      DIV   99             CIJ ROW             0104   14  0108  0109
      SLT    0004          ADDR JUMP           0109   35  0004  0119
      STL   W                                  0119   20  1841  0106
      NZU   103            IS N ODD            0106   44  0110  0112
      LDD   101   104      SET SWT EVEN        0112   69  0117  0020
03    LDD   102   104      SET SWT ODD         0110   69  0063  0020
04    STD   SWT                                0020   24  1823  0076
      RAL   TAG            SET NO CARDS        0076   65  1930  0113
      SRT    0003          PER CIJ ROW         0113   30  0003  0121
      STL   R                                  0121   20  1912  0070
      LDD   100            RESTORE 7           0070   69  0073  0126
      STD    1983   1988   WORD READ SW        0126   24  1983  1988

1     NOP    0000  SWAB    CONSTANTS           0041   00  0000  1752
2     NOP    0000  SWAS                        0025   00  0000  1895
3      70    1994   1997                       0016   70  1994  1997
4      00    0001   0000                       0045   00  0001  0000
5      70    1994  ID                          0039   70  1994  1600
6      00    0000   0002                       0018   00  0000  0002
7      00    0001   0000                       0120   00  0001  0000
8     STL    0000  53                          0088   20  0000  1906
0     STL    0000  UDSCX                       0037   20  0000  1760
1      00    0001   0000                       0090   00  0001  0000
2      00    0000   0002                       0012   00  0000  0002
3      00    0001   0000                       0050   00  0001  0000
4      00    0001   0000                       0010   00  0001  0000
5     STL    0000  5                           0118   20  0000  1703
6     ALO    0000  10                          0026   15  0000  1655
7     STL    0000  11                          0100   20  0000  1803
8     STL    0000  49                          0011   20  0000  1904
9      00    0001   0000                       0051   00  0001  0000
0     STL    0000  5                           0058   20  0000  1703
1     RAL    0000  44                          0004   65  0000  1755
2      00    0001   0000                       0006   00  0001  0000
3     STL    0000  5                           0064   20  0000  1703
4     STL    0000  18                          0107   20  0000  1604
```

```
95      STL   0000  18                      0056  20  0000  1604
96      00    0001  0000                    0067  00  0001  0000
97      STL   0000  18                      0024  20  0000  1604
99      00    0002  0000                    0108  00  0002  0000
100     44    1987  1988                    0073  44  1987  1988
101     NOP   0000  SWTE                    0117  00  0000  1652
102     NOP   0000  SWTO                    0063  00  0000  1602

          PROGRAM 1 INITIAL DISTRIBUTION

ID      RAL   1             UNPACK          1600  65  1753  1707
        STD   GETDD         DD              1707  24  1606  1659
        STU   SUMD                          1659  21  1664  1667
        LDD   2                             1667  69  1620  1623
        STD   STOD                          1623  24  1633  1636
        STD   A     UPD                     1636  24  1603  1650
UPD     RSL   A             REVERSE SIGN    1650  66  1603  1607
        STL   A     GETDD   OF A            1607  20  1603  1606
GETDD   LDD   1200  3       DD TO DIST      1606  69  1200  1653
3       BMI   DLH   DRH     TEST A          1653  46  1656  1657
DLH     RAB   8001          GET DLH         1656  67  8001  1613
        SRT   0005                          1613  30  0005  1625
        SLT   0003  STOD                    1625  35  0003  1633
DRH     RAB   8001          GET DRH         1657  67  8001  1615
        AUP   GETDD         STEP            1615  10  1606  1611
        AUP   4             DD ADDRESS      1611  10  1614  1619
        STU   GETDD                         1619  21  1606  1609
        SLT   0005                          1609  35  0005  1621
        RAL   8002                          1621  65  8002  1629
        SRT   0002  STOD                    1629  30  0002  1633
STOD    STL   0000  5       STORE D         1633  20  0000  1703
5       SRT   0003          UPDATE          1703  30  0003  1661
        ALO   SUMD          SUMD            1661  15  1664  1669
        STL   SUMD                          1669  20  1664  1617
        RAL   STOD          IS I MAX        1617  65  1633  1637
        SLO   6                             1637  16  1640  1645
        NZA         7                       1645  45  1648  1649
        ALO   8             STEP I          1648  15  1601  1605
        STL   STOD  UPD                     1605  20  1633  1650
7       RAL   N             ADD NE          1649  65  1929  1683
        SRT   0004  9       TO              1683  30  0004  1643
9       ALO   0000  10      D1              1643  15  0000  1655
10      STL   0000  11                      1655  20  0000  1803
11      LDD   12            UNPACK          1803  69  1806  1809
        STD   GETSS         SS              1809  24  1706  1859
        RAL   13                            1859  65  1612  1717
        STD   STOS                          1717  24  1641  1644
        STD   B                             1644  24  1853  1856
        STU   SUMS  UPS                     1856  21  1931  1700
UPS     RSL   B             REVERSE SIGN    1700  66  1853  1757
        STL   B     GETSS   OF B            1757  20  1853  1706
GETSS   LDD   1500  14      SS TO DIST      1706  69  1500  1903
14      BMI   SLH   SRH     TEST B          1903  46  1756  1807
SLH     RAB   8001          GET SLH         1756  67  8001  1663
        SRT   0005                          1663  30  0005  1675
```

```
        SLT   0003   15                        1675   35   0003   1733
SRH     RAB   8001           GET SRH           1807   67   8001   1665
        AUP   GETSS          STEP              1665   10   1706   1711
        AUP   16             SS ADDRESS        1711   10   1714   1719
        STU   GETSS                            1719   21   1706   1709
        SLT   0005                             1709   35   0005   1671
        RAL   8002                             1671   65   8002   1679
        SRT   0002   15                        1679   30   0002   1733
15      ALO   17     STOS    S PLUS E          1733   15   1686   1641
STOS    STL   0000   18      STORE S           1641   20   0000   1604
18      SRT   0003           UPDATE            1604   30   0003   1713
        ALO   SUMS           SUMS              1713   15   1931   1635
        STL   SUMS                             1635   20   1931   1634
        RAL   STOS           IS J MAX          1634   65   1641   1695
        SLO   19                               1695   16   1698   1654
        NZA          AEQR                      1654   45   1608   1759
        ALO   20             STEP J            1608   15   1761   1715
        STL   STOS   UPS                       1715   20   1641   1700
AEQR    RAL   SUMS           DOES              1759   65   1931   1685
        SLO   SUMD           AVAIL EQUAL       1685   16   1664   1769
        NZA          201     REQUIREMENTS      1769   45   1622   1673
        HLT   9000   9000    STOP              1622   01   9000   9000
201     RAL   21             INITIALIZE        1673   65   1626   1631
        LDD   55             XX ADDRESS        1631   69   1788   1891
        SDA   STXRH                            1891   22   1810   1917
        LDD   54                               1917   69   1820   1973
        SDA   GETXX                            1973   22   1834   1838
        STL   STXLH                            1838   20   1797   1702
        RAL   46             INITIALIZE        1702   65   1862   1967
        LDD   47             DI                1967   69   1870   1674
        SDA   GETDI          ADDRESS           1674   22   1666   1920
        STL   STODI                            1920   20   1729   1782
        RAL   22             INITIALIZE        1782   65   1888   1943
        STD   STIJC          IJC ADDRESS       1943   24   1785   1938
        STU   SUMBE          ZERO SUMBE        1938   21   1839   1892
        STD   SCXHO          ZERO              1892   24   1932   1939
        STD   SCXLO          TOTAL COST        1939   24   1933   1890
        LDD   23                               1890   69   1694   1748
        STD   E              SET E K           1748   24   1835   1940
        STD   K              AND I             1940   24   1812   1718
        STD   I              TO 1              1718   24   1710   1768
        STU   L      SWA     SET L TO 0        1768   21   1780   1941
SWA     NOP   0000   SWAS                      1941   00   0000   1895
SWAB    RAL   R      25      READ              1752   65   1912   1818
25      STL   P              CIJ               1818   20   1724   1827
        LDD          1995    ROW               1827   69   1830   1995
        RAL   P              IF                1830   65   1724   1681
        SLO   24             BIG               1681   16   1942   1798
        NZA   25     SWAS                      1798   45   1818   1895
SWAS    LDD   26     27      SET G             1895   69   1848   1867
27      STD   G              TO 1              1867   24   1704   1962
        RAL   L              SET LOC CC        1962   65   1780   1744
        LDD   200            TO L              1744   69   1898   1802
        SDA   GETCC                            1802   22   1610   1868
        LDD   28             SET CR            1868   69   1771   1774
```

```
        STD  CR                TO 999999      1774  24  1630  1794
        LDD  29                SET            1794  69  1948  1852
        STD  SWF               SWF ON         1852  24  1722  1975
        LDD  30                SET J          1975  69  1678  1731
        STD  J      MGTOG      TO 1           1731  24  1736  1750
MGTOG   RSL  G                 REVERSE SIGN   1750  66  1704  1909
        STL  G                 OF G           1909  20  1704  1857
        LDD  GETCC             STORE LOC      1857  69  1610  1763
        STD  LC     8001       OF CC          1763  24  1616  8001
 8001   LDD  0000   31         CC TO DIST     8001  69  0000  1754
31      BMI  GCLH   GCRH       TEST G         1754  46  1907  1658
GCLH    RAB  8001   32         GET CLH        1907  67  8001  1765
32      SRT  0005   34                        1765  30  0005  1627
GCRH    RAB  8001              GET CRH        1658  67  8001  1815
        AUP  GETCC             STEP           1815  10  1610  1865
        AUP  33                CC             1865  10  1618  1723
        STU  GETCC             ADDRESS        1723  21  1610  1813
        SLT  0005                             1813  35  0005  1725
        RAL  8002   32                        1725  65  8002  1765
34      SLO  CR                COMPARE CIJ    1627  16  1630  1735
        BMI         TESTJ      WITH CR        1735  46  1638  1639
        ALO  8001              REPLACE CR     1638  15  8001  1745
        STL  CR                WITH CIJ       1745  20  1630  1783
        LDD  J                 ETC            1783  69  1736  1689
        STD  JR                               1689  24  1642  1795
        LDD  G                                1795  69  1704  1708
        STD  GR                               1708  24  1811  1764
        LDD  LC                               1764  69  1616  1819
        STD  LR     TESTJ                     1819  24  1672  1639
TESTJ   RAL  J                 TEST FOR       1639  65  1736  1691
        SLO  N                 END OF ROW     1691  16  1929  1833
        NZA         REPLC                     1833  45  1786  1687
        ALO  8001              STEP J         1786  15  8001  1693
        ALO  35                               1693  15  1646  1651
        STL  J      MGTOG                     1651  20  1736  1750
REPLC   RAL  LR                REPLACE        1687  65  1672  1677
        LDD  36                MINIMUM        1677  69  1680  1684
        SDA  STOCC             CIJ            1684  22  1737  1690
        LDD  38                WITH           1690  69  1743  1696
        SDA  39     8001       99999          1696  22  1699  8001
 8001   LDD  0000   40                        8001  69  0000  1804
40      STD  CCR                              1804  24  1758  1861
        RAL  GR                               1861  65  1811  1915
        BMI  9LH    9RH                       1915  46  1668  1869
9LH     RAB  CCR                              1668  67  1758  1863
        SLT  0005                             1863  35  0005  1775
        RAL  8002                             1775  65  8002  1734
        SRT  0005                             1734  30  0005  1647
        ALO  41     STOCC                     1647  15  1800  1737
9RH     RAB  CCR                              1869  67  1758  1913
        SRT  0005                             1913  30  0005  1825
        SLT  0005                             1825  35  0005  1787
        ALO  37     STOCC                     1787  15  1740  1737
STOCC   STL  0000   OBSJR                     1737  20  0000  1854
OBSJR   RAL  JR                SET            1854  65  1642  1697
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         ALO  42                SJR            1697  15  1850  1705
         LDD  43                ADDRESS        1705  69  1808  1911
         SDA  STOSJ   8002                     1911  22  1965  8002
8002     RAL   0000   44        SJR TO LA      8002  65  0000  1755
44       NZA  45      SWY       IS SJR ZERO    1755  45  1858  1660
SWY      NOP   0000   68                       1660  00  0000  1814
45       STL  SJR     GETDI     STORE SJR      1858  20  1963  1666
GETDI    RSL   0000   48        DI TO LA       1666  66  0000  1805
48       STD  Q                 DI TO Q        1805  24  1908  1961
         ALO  SJR               CALC DELTA     1961  15  1963  1767
         BMI          STOSJ     TEST DELTA     1767  46  1670  1965
         RAB   8002   STODI     SET DI TO      1670  67  8002  1729
STODI    STL   0000   49        ABVALDELTA     1729  20  0000  1904
49       LDD  SJR               SET Q          1904  69  1963  1716
         STD  Q                 TO SJR         1716  24  1908  1662
         LDD  50                SET            1662  69  1766  1919
         STD  SWF               SWF OFF        1919  24  1722  1875
         RAL  51      STOSJ     SET SJ TO 0    1875  65  1628  1965
STOSJ    STL   0000   52                       1965  20  0000  1855
52       RAL  I                 FORM AND       1855  65  1710  1816
         SLT   0002             STORE          1816  35  0002  1773
         ALO  JR                NEW            1773  15  1642  1747
         SLT   0001             BASIS          1747  35  0001  1905
         ALO  CR      STIJC     ELEMENT        1905  15  1630  1785
STIJC    STL   0000   53                       1785  20  0000  1906
53       RAL  Q                                1906  65  1908  1864
         SRD   0003                            1864  31  0003  1925
         STL  QR                               1925  20  1779  1632
         RSL  E                                1632  66  1835  1739
         STL  E                                1739  20  1835  1688
         BMI  XLH     XRH                      1688  46  1741  1692
XLH      RAB  QR                               1741  67  1779  1784
         SLT   0005   STXLH                    1784  35  0005  1797
STXLH    STL   0000   UDSCX                    1797  20  0000  1760
XRH      RAB  QR      GETXX                    1692  67  1779  1834
GETXX    ALO   0000   STXRH                    1834  15  0000  1810
STXRH    STL   0000   56                       1810  20  0000  1860
56       RAL  GETXX                            1860  65  1834  1789
         ALO  57                               1789  15  1742  1847
         LDD  STXLH                            1847  69  1797  1900
         SDA  STXLH                            1900  22  1797  1701
         LDD  STXRH                            1701  69  1810  1914
         SDA  STXRH                            1914  22  1810  1964
         STL  GETXX   UDSCX                    1964  20  1834  1760
UDSCX    RAU  QR                UPDATE         1760  60  1779  1885
         MPY  CR                TOTAL          1885  19  1630  1935
         AUP  SCXHO             COST           1935  10  1932  1837
         ALO  SCXLO                            1837  15  1933  1887
         STU  SCXHO                            1887  21  1932  1836
         STL  SCXLO                            1836  20  1933  1886
         RAL  SUMBE             UPDATE         1886  65  1839  1793
         ALO  58                SUM OF         1793  15  1746  1751
         STL  SUMBE             BASIS ELEM     1751  20  1839  1792
         RAL  STIJC             STEP           1792  65  1785  1889
         ALO  59                IJC            1889  15  1842  1897
```

	STL	STIJC	SWF	ADDRESS	1897	20	1785	1722
SWF	NOP	0000	0000		1722	00	0000	0000
SWFON	RAL	I		TEST I	1801	65	1710	1866
	SLO	M			1866	16	1928	1936
	NZA		62		1936	45	1790	1791
	ALO	8001		STEP	1790	15	8001	1947
	ALO	60		I	1947	15	1851	1910
	STL	I			1910	20	1710	1916
	RAL	GETDI		STEP	1916	65	1666	1721
	ALO	61		DI	1721	15	1624	1829
	LDD	STODI		ADDRESS	1829	69	1729	1682
	SDA	STODI			1682	22	1729	1732
	STL	GETDI	SWZ		1732	20	1666	1969
SWZ	NOP	0000	SWT		1969	00	0000	1823
62	RAL	SUMBE		CHECK	1791	65	1839	1843
	SLO	NBE		NUMBER OF	1843	16	1796	1901
	NZA		202	BASIS ELEM	1901	45	1712	1762
	HLT	9001	9001	STOP	1712	01	9001	9001
202	PCH	1927		PUNCH	1762	71	1927	1727
	RAL	63		INITIAL	1727	65	1730	1937
	LDD		315P7	DISTRIBUTION	1937	69	1840	1893
	NOP	0000	9002		1840	00	0000	9002
SWT	NOP	0000	0000		1823	00	0000	0000
SWTO	RSL	K		N ODD	1602	66	1812	1817
	STL	K		REVERSE K	1817	20	1812	1966
	BMI	66		TEST K	1966	46	1720	1770
	RAL	64	67	STEP L	1770	65	1873	1777
66	RAL	65	67		1720	65	1923	1777
67	ALO	L			1777	15	1780	1738
	ALO	W			1738	15	1841	1845
	STL	L	68		1845	20	1780	1814
68	LDD	K	27	SET G TO K	1814	69	1812	1867
SWTE	NOP	0000	66		1652	00	0000	1720
1995	STD	1999	1988	READ SUB	1995	24	1999	1988
1997	LDD	1998	1996	SET READ	1997	69	1998	1996
1998	44	1987	1999	1 CARD	1998	44	1987	1999
1996	STD	1983	ID	SWITCH	1996	24	1983	1600
1	LDD	1200	3	CONSTANTS	1753	69	1200	1653
4	00	0001	0000		1614	00	0001	0000
12	LDD	1500	14		1806	69	1500	1903
16	00	0001	0000		1714	00	0001	0000
17	00	0000	0001		1686	00	0000	0001
23	00	0001	0000		1694	00	0001	0000
24	00	0000	0001		1942	00	0000	0001
26	00	1111	0000		1848	00	1111	0000
200	LDD	0000	31		1898	69	0000	1754
28	00	0099	9999		1771	00	0099	9999
29	00	0000	SWFON		1948	00	0000	1801
30	00	0001	0000		1678	00	0001	0000
33	00	0001	0000		1618	00	0001	0000
35	00	0001	0000		1646	00	0001	0000
36	STL	0000	OBSJR		1680	20	0000	1854
38	LDD	0000	40		1743	69	0000	1804
41	99	9990	0000		1800	99	9990	0000

37	00	0009	9999		1740	00	0009	9999
43	STL	0000	52		1808	20	0000	1855
47	RSL	0000	48		1870	66	0000	1805
50	00	0000	SWY		1766	00	0000	1660
51	00	0000	0000		1628	00	0000	0000
54	ALO	0000	STXRH		1820	15	0000	1810
55	STL	0000	56		1788	20	0000	1860
57	00	0001	0000		1742	00	0001	0000
58	00	0001	0000		1746	00	0001	0000
59	00	0001	0000		1842	00	0001	0000
60	00	0001	0000		1851	00	0001	0000
61	00	0001	0000		1624	00	0001	0000
64	00	0001	0000		1873	00	0001	0000
65	00	0000	0000		1923	00	0000	0000
1927	00	1928	0006		1927	00	1928	0006
1934	00	0000	0000		1934	00	0000	0000

PROG 315 P7 PUNCH SUBROUTINE

315PC	RAL	8000	315P7	PCH CONSOLE	1950	65	8000	1893
315P7	STD	315XX		STORE EXIT	1893	24	1846	1749
	LDD	315A		SET	1749	69	1902	1918
	SDA	315A		FWA	1918	22	1902	1968
	SLT	0004		AND	1968	35	0004	1781
	SDA	315B		LWA	1781	22	1844	1799
	RAL	315A	315J	FWA TO LA	1799	65	1902	1970
315J	AUP	315C		LWA TO UA	1970	10	1824	1831
	LDD	315D		SET CONTROL	1831	69	1894	1849
	SDA	P0001	8002		1849	22	1877	8002
315F	AUP	315E		STEP PCH ADR	1821	10	1874	1832
	SLO	315B		HAS LAST	1832	16	1844	1899
	SUP	8003		WORD BEEN	1899	11	8003	1871
	NZA		315G	STORED	1871	45	1924	1676
	AUP	8001			1924	10	8001	1944
	ALO	315E			1944	15	1874	1945
	ALO	315B			1945	15	1844	1949
	SUP	315H		HAVE 7 WORDS	1949	11	1921	1726
	NZU		315I	BEEN STORED	1726	44	1896	1946
	AUP	8001	8002		1896	10	8001	8002
315I	PCH	P0001	315J	PUNCH 7 WDS	1946	71	1877	1970
315G	RAL	8001		MODIFY	1676	65	8001	1971
	SLO	315H		CONTROL	1971	16	1921	1776
	SRT	0004		WORD ON	1776	30	0004	1772
	ALO	P0001		LAST CARD	1772	15	1877	1822
	STL	P0001		PUNCH	1822	20	1877	1872
	PCH	P0001	315XX	LAST CARD	1872	71	1877	1846
315A	69	0000	8003	CONSTANTS	1902	69	0000	8003
315C	24	P0002	315F		1824	24	1878	1821
315D	00	0000	0007		1894	00	0000	0007
315E	00	0001	0000		1874	00	0001	0000
315H	24	P0009	315F		1921	24	1885	1821

PROGRAM 2 ITERATION

PROGRAM 2 INITIALIZATION

```
SETUP   LDD  255                 RESTORE        0001  69  0004  0007
        STD   1983               READ SWITCH    0007  24  1983  0036
        RAU  N                   N TO UA        0036  60  1929  0033
        SRT   0004                              0033  30  0004  0043
        LDD  TAG                 TEST           0043  69  1930  0083
        BD2  SMALL  BIG          TAG            0083  92  0086  0038
SMALL   MPY  M      200          MN IN LA       0086  19  1928  0133
BIG     MPY  201    200          N IN LA        0038  19  0041  0133
200     SRT   0004                              0133  30  0004  0093
        DIV  202                                0093  14  0046  0096
        ALO   8003               B1 IN LA       0096  15  8003  0003
        SLT   0004               SET            0003  35  0004  0013
        STL  164                 B1             0013  20  1873  0026
        LDD  203                 ADDRESSES      0026  69  0029  0032
        SDA  12                                 0032  22  1356  0009
        LDD  204                                0009  69  0012  0015
        SDA  66                                 0015  22  1417  0020
        LDD  205                                0020  69  0023  0076
        SDA  82                                 0076  22  1656  0059
        LDD  206                                0059  69  0062  0065
        SDA  112                                0065  22  1757  0010
        STL  207                                0010  20  0115  0018
        STD  137                                0018  24  1614  0017
        ALO  M                                  0017  15  1928  0183
        ALO  N                   X1 IN LA       0183  15  1929  0034
        SLO  208                 EBO IN LA      0034  16  0037  0091
        STL  148                                0091  20  1397  0050
        ALO  220                 X0 IN LA       0050  15  0053  0057
        LDD  209                 SET            0057  69  0060  0063
        SDA  10                  X0             0063  22  1267  0070
        LDD  210                 ADDRESSES      0070  69  0073  0126
        SDA  31                                 0126  22  1421  0024
        LDD  248                                0024  69  0027  0030
        SDA  65                                 0030  22  1342  0045
        LDD  211                                0045  69  0048  0051
        SDA  73                                 0051  22  1416  0019
        LDD  212                                0019  69  0022  0025
        SDA  110                                0025  22  1890  0143
        LDD  213                                0143  69  0146  0049
        SDA  126                                0049  22  1445  0098
        STL  149                                0098  20  1708  0011
        STD  174                                0011  24  1528  0031
        ALO  214                 X1 IN LA       0031  15  0084  0039
        LDD  215                 SET            0039  69  0042  0095
        SDA  138                 X1             0095  22  1594  0047
        LDD  216                 ADDRESSES      0047  69  0100  0103
        SDA  160                                0103  22  1968  0021
        LDD  217                                0021  69  0074  0077
        SDA  180                                0077  22  1642  0145
        RAL  M                                  0145  65  1928  0087
        ALO  N                                  0087  15  1929  0184
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SLO	218	NO BASIS	0184	16	0137	0141
STL	181	ELEM IN LA	0141	20	1620	0123
SRT	0004		0123	30	0004	0035
DIV	219		0035	14	0088	0138
ALO	8003		0138	15	8003	0195
SLT	0004		0195	35	0004	0005
ALO	149	U0 IN LA	0005	15	1708	0113
STL	U0	STORE U 0	0113	20	1244	0097
LDD	221	SET	0097	69	0150	0153
SDA	76	U0	0153	22	1382	0085
LDD	222	ADDRESSES	0085	69	0188	0191
SDA	91		0191	22	1490	0193
LDD	223		0193	69	0196	0099
SDA	120		0099	22	1496	0149
LDD	207		0149	69	0115	0068
SRT	0004		0068	30	0004	0079
SIA	RPC1		0079	23	1682	0135
SLT	0004		0135	35	0004	0147
ALO	224	U1 IN LA	0147	15	0101	0055
LDD	225	SET	0055	69	0008	0061
SDA	1	U1	0061	22	1239	0092
STL	226	ADDRESSES	0092	20	0197	0151
LDD	227		0151	69	0054	0107
SDA	70		0107	22	1390	0044
ALO	M	V1 IN LA	0044	15	1928	0185
SLO	228	V0 IN LA	0185	16	0089	0094
STL	V0	STORE V0	0094	20	1266	0069
LDD	229	SET	0069	69	0072	0075
SDA	79	V0	0075	22	1344	0148
LDD	230	ADDRESSES	0148	69	0002	0105
SDA	85		0105	22	1210	0163
LDD	231		0163	69	0016	0119
SDA	117		0119	22	1270	0173
ALO	N	M0 IN LA	0173	15	1929	0136
LDD	232	SET	0136	69	0139	0142
SDA	4	M0	0142	22	1206	0109
LDD	233	ADDRESSES	0109	69	0112	0165
SDA	72		0165	22	1506	0159
LDD	226		0159	69	0197	0052
SRT	0004		0052	30	0004	0014
SIA	39		0014	23	1207	0110
SLT	0004		0110	35	0004	0071
ALO	234	M1 IN LA	0071	15	0124	0129
LDD	235	SET	0129	69	0082	0186
SDA	6	M1	0186	22	1218	0121
LDD	236	ADDRESSES	0121	69	0174	0127
SDA	74		0127	22	1568	0171
LDD	237		0171	69	0125	0028
SDA	98		0028	22	1812	0066
LDD	238		0066	69	0169	0122
SDA	104		0122	22	1566	0120
LDD	239		0120	69	0175	0078
SDA	141		0078	22	1813	0116
LDD	240		0116	69	0170	0176
SDA	162		0176	22	1773	0177

	STL	241		STORE M1	0177	20	0081	0187
	RAL	181		CALC SIZE	0187	65	1620	0128
	SRT	0004		OF MUBAR	0128	30	0004	0189
	DIV	242		TABLE	0189	14	0192	0144
	SLT	0004			0144	35	0004	0155
	NZU		243		0155	44	0160	0111
	ALO	244	243		0160	15	0064	0111
43	ALO	241		E1 IN LA	0111	15	0081	0040
	LDD	245		SET E1	0040	69	0194	0198
	SDA	103		ADDRESS	0198	22	1469	0172
	SLO	246		E0 IN LA	0172	16	0178	0090
	LDD	247		SET E0	0090	69	0199	0102
	SDA	101		ADDRESS	0102	22	1657	0161
	RAL	8002			0161	65	8002	0179
	SLO	249		DOES DATA	0179	16	0132	0140
	BMI		9000	OVERLAP PROG	0140	46	0152	9000
	RAL	TAG			0152	65	1930	0190
	BD3	256			0190	93	0104	0154
	LDD	257		SET SW H	0154	69	0157	0162
	STD	SWH		ON	0162	24	1786	0006
	LDD	8002	256		0006	69	8002	0104
56	BD2	8SMAL	9BIG	SIZE TEST	0104	92	0058	0114
BIG	SRT	0003			0114	30	0003	0080
	STL	R			0080	20	1603	0056
	LDD	251		SET SW D	0056	69	0164	0067
	STD	SWD		TO BIG	0067	24	1671	0130
	LDD	252		SET SW G	0130	69	0106	0166
	STD	SWG		TO BIG	0166	24	1301	0156
	LDD	253	BORS	SET	0156	69	0117	0180
SMAL	LDD	254	BORS	READ	0058	69	0167	0180
ORS	STD	1988	8001	SWITCH	0180	24	1988	8001
01	00	0001	0000	CONSTANTS	0041	00	0001	0000
02	00	0000	0002		0046	00	0000	0002
03	RAL	0000	13		0029	65	0000	1205
04	RAL	0000	67		0012	65	0000	1755
05	RAL	0000	83		0023	65	0000	1805
06	RAL	0000	113		0062	65	0000	1706
08	00	0002	0000		0037	00	0002	0000
09	STD	0000	11		0060	24	0000	1453
10	STD	0000	32		0073	24	0000	1353
11	STL	0000	75		0048	20	0000	1703
12	STU	0000	111		0022	21	0000	1604
13	STD	0000	3INCA		0146	24	0000	1627
14	00	0001	0000		0084	00	0001	0000
15	LDD	0000	144		0042	69	0000	1654
16	STL	0000	5UPDS		0100	20	0000	1914
17	LDD	0000	182		0074	69	0000	1520
18	00	0001	0000		0137	00	0001	0000
19	00	0000	0002		0088	00	0000	0002
20	00	0001	0000		0053	00	0001	0000
21	STD	0000	78		0150	24	0000	1753
22	RAL	0000	92		0188	65	0000	1556
23	RAB	0000	121		0196	67	0000	1856
24	00	0001	0000		0101	00	0001	0000

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225      STL    0000    3                           0008   20   0000   1203
227      STL    0000    71                          0054   20   0000   1653
228       00    0001     0000                       0089   00   0001   0000
229      STD    0000    81                          0072   24   0000   1803
230      RAL    0000    86                          0002   65   0000   1855
231      LDD    0000    118                         0016   69   0000   1354
232      STL    0000    3                           0139   20   0000   1203
233      STL    0000    71                          0112   20   0000   1653
234       00    0001     0000                       0124   00   0001   0000
235      STL    0000    3                           0082   20   0000   1203
236      STL    0000    71                          0174   20   0000   1653
237      STL    0000    100                         0125   20   0000   1554
238      RAL    0000    3SHPL                       0169   65   0000   1756
239      RAL    0000    4SHPL                       0175   65   0000   1807
240      RAL    0000    5SHP                        0170   65   0000   1664
242       00    0000     0010                       0192   00   0000   0010
244       00    0001     0000                       0064   00   0001   0000
245      STL    0000    100                         0194   20   0000   1554
246       00    0001     0000                       0178   00   0001   0000
247      STL    0000    100                         0199   20   0000   1554
248      STD    0000    WIJ                         0027   24   0000   1209
249       00    1200     0000                       0132   00   1200   0000
251      STD    2I      SWDB                        0164   24   1418   1300
252      STL    2I      SWDB                        0106   20   1418   1300
253      RDS     1994    1997                       0117   70   1994   1997
254      RDS     1994   UV                          0167   70   1994   1236
255       44     1987    1988                       0004   44   1987   1988
257      STL    SCXLO   SWHON                       0157   20   1933   1850

 1997    LDD     1998    1999                       1997   69   1998   1999
 1998     44     1987    1976    SET READ 1         1998   44   1987   1976
 1999    STD     1983   UV       CARD SWITCH        1999   24   1983   1236
 1975    LDD    TAG      1996    RESTART            1975   69   1930   1996
 1996    BD2     1988    1972    TEST TAG           1996   92   1988   1972
 1972    LDD     1995    1974    RESTORE            1972   69   1995   1974
 1974    STD     1983    1988    READ INSTR         1974   24   1983   1988
 1995     44     1987    1988                       1995   44   1987   1988
 1973    STD     1976    1988    READ SUB           1973   24   1976   1988

            PHASE 1 CONSTRUCT UV TABLE

UV       RAU    1                RESET              1236   60   1239   1243
         ALO    2        8003    UV                 1243   15   1246   8003
 8003    STL     0000   3        TABLE              8003   20   0000   1203
3        SUP    4                TO                 1203   11   1206   1211
         NZU            5        1000000000         1211   44   1215   1216
         AUP    6        8003                       1215   10   1218   8003
5        LDD    7                SET SW A ON        1216   69   1269   1222
         STD    SWA     SWBOF                       1222   24   1252   1555
SWBOF    LDD    8                SET SW B ON        1555   69   1308   1611
         STD    SWB                                 1611   24   1208   1661
         LDD    9       10       SET EB             1661   69   1364   1267
10       STD     0000   11       TO ZERO            1267   24   0000   1453
11       RAL    12      12A      INITIALIZE         1453   65   1356   1219
12A      STL    1GETB    8001    IJC ADDRESS        1219   20   1306   8001
```

```
8001    RAL   0000   13      IJC TO LA       8001   65   0000   1205
13      NZA   SWB    WIJ     IS IJC ZERO     1205   45   1208   1209
SWB     BMI   SWC    14      IS IJC NEG      1208   46   1261   1212
14      SLT   0003                           1212   35   0003   1221
        STU   1I             STORE I         1221   21   1226   1229
        SUP   8001                           1229   11   8001   1237
        SLT   0002                           1237   35   0002   1293
        STU   1J             STORE J         1293   21   1248   1201
        SUP   8001                           1201   11   8001   1259
        SLT   0005                           1259   35   0005   1271
        STU   1CIJ           STORE CIJ       1271   21   1276   1279
        RAL   1I             CALCULATE       1279   65   1226   1231
        SLT   0004           LOCATION        1231   35   0004   1241
        ALO   U0             OF              1241   15   1244   1249
        LDD   15             UI              1249   69   1202   1255
        SDA   16             AND             1255   22   1309   1262
        LDD   17             VJ              1262   69   1265   1268
        SDA   SWAOF                          1268   22   1321   1224
        LDD   18                             1224   69   1227   1230
        SDA   41                             1230   22   1233   1286
        LDD   19                             1286   69   1289   1242
        SDA   20                             1242   22   1245   1298
        RAL   1J                             1298   65   1248   1253
        SLT   0004                           1253   35   0004   1213
        ALO   V0                             1213   15   1266   1371
        LDD   21                             1371   69   1274   1277
        SDA   22                             1277   22   1281   1234
        LDD   23                             1234   69   1287   1240
        SDA   24                             1240   22   1343   1296
        LDD   25     SWA                     1296   69   1299   1252
SWA     SDA   26     SWAON                   1252   22   1305   1258
SWAON   LDD   27             1ST TIME        1258   69   1311   1214
        STD   SWA            SET SWA OFF     1214   24   1252   1355
        RAL   8003   16      SET UI          1355   65   8003   1309
16      STD   0000   28      TO M            1309   24   0000   1303
SWAOF   RAL   0000   28A     UI TO LA        1321   65   0000   1405
28A     SLT   0001           IS UI           1405   35   0001   1361
        NZU   22     24      1000000000      1361   44   1281   1343
22      RSL   0000   29      VJ TO LA        1281   66   0000   1455
29      SLT   0001           IS VJ           1455   35   0001   1411
        NZU          33      1000000000      1411   44   1315   1316
        LDD   30     31      SET EB TO       1315   69   1318   1421
31      STD   0000   32      MINUS 1         1421   24   0000   1353
33      SRT   0001           HAVE VJ         1316   30   0001   1223
        ALO   1CIJ   20      CALC UI         1223   15   1276   1245
20      STL   0000   34      STORE UI        1245   20   0000   1403
24      RAL   0000   35      VJ TO LA        1343   65   0000   1505
35      SLT   0001           IS VJ           1505   35   0001   1461
        NZU   28     32      1000000000      1461   44   1303   1353
28      RAL   1CIJ   41      HAVE UI         1303   65   1276   1233
41      SLO   0000   26      CALC VJ         1233   16   0000   1305
26      STL   0000   34      STORE VJ        1305   20   0000   1403
34      LDD   36             SET SWB         1403   69   1256   1359
        STD   SWB    32      OFF             1359   24   1208   1353
32      RAL   1GETB          STEP            1353   65   1306   1511
```

```
         ALO   37      12A       IJC ADDR        1511     15  1264  1219
SWC      HLT    0001             BASIS DEGEN     1261     01  0001  1365
         LDD   38                SET SW C        1365     69  1368  1471
         STD   SWC     UV        OFF             1471     24  1261  1236
SWCOF    HLT    0002             2ND TRY NG      1200     01  0002  1204
         RAL   39                PUNCH           1204     65  1207  1561
         LDD   40      315P7     UV              1561     69  1314  1217
40       HLT    9003    9003     TABLE           1314     01  9003  9003

2         10    0000    0000     CONSTANTS       1246     10  0000  0000
7        SDA   26      SWAON                     1269     22  1305  1258
8        BMI   SWC     14                        1308     46  1261  1212
9         00    0000    0000                     1364     00  0000  0000
15       STD    0000   28                        1202     24  0000  1303
17       RAL    0000   28A                       1265     65  0000  1405
19       STL    0000   34                        1289     20  0000  1403
21       RSL    0000   29                        1274     66  0000  1455
23       RAL    0000   35                        1287     65  0000  1505
25       STL    0000   34                        1299     20  0000  1403
27       SDA   26      SWAOF                     1311     22  1305  1321
30     -  00    0000    0001                     1318   - 00  0000  0001
36       BMI   SWBOF   14                        1256     46  1555  1212
37        00    0001    0000                     1264     00  0001  0000
38       HLT    0002   SWCOF                     1368     01  0002  1200
18       SLO    0000   26                        1227     16  0000  1305

            PHASE 2 CALCLATE WIJ

WIJ      LDD   42                SET WR          1209     69  1362  1515
         STD   WR                TO ZERO         1515     24  1312  1565
         LDD   43      SWD       SET I           1565     69  1468  1671
SWD      STD   2I      SWDS      TO 1            1671     24  1418  1721
SWDB     LDD   R                 BIG PROBLEM     1300     69  1603  1456
         STD   2P      2READ     READ            1456     24  1459  1412
2READ    LDD            1973     CIJ             1412     69  1615  1973
         RAL   2P                ROW             1615     65  1459  1313
         SLO   44                                1313     16  1366  1771
         NZA           SWDS                      1771     45  1424  1721
         STL   2P      2READ                     1424     20  1459  1412
SWDS     LDD   45                BIG OR SMALL    1721     69  1474  1427
         STD   2A                SET A TO 1      1427     24  1337  1340
         LDD   46                INIT CIJ        1340     69  1543  1446
         STD   2GETC   2SETU     ADDRESS         1446     24  1290  1593
2SETU    RAL   2I      58        SET UI          1593     65  1418  1621
58       ALO   U0                ADDRESS         1621     15  1244  1349
         LDD   47                                1349     69  1302  1705
         SDA   2GETU                             1705     22  1232  1335
         LDD   48                SET J           1335     69  1238  1341
         STD   2J      2SETV     TO 1            1341     24  1280  1483
2SETV    RAL   2J      56        SET VJ          1483     65  1280  1250
56       ALO   V0                ADDRESS         1250     15  1266  1521
         LDD   49                                1521     69  1324  1327
         SDA   2GETV                             1327     22  1331  1284
         RSL   2A                REVERSE SIGN    1284     66  1337  1291
         STL   2A      2GETC     OF A            1291     20  1337  1290
```

```
2GETC   LDD  0000   50     CC TO DIST    1290  69  0000  1503
50      BMI  2CLH   2CRH   TEST A        1503  46  1406  1257
2CLH    RSB  8001   51     GET CLH       1406  68  8001  1263
51      SRT  0005                        1263  30  0005  1225
        STL  2CIJ   2GETU  STORE CIJ     1225  20  1329  1232
2CRH    RAB  8001          GET CRH       1257  67  8001  1415
        AUP  2GETC         STEP CIJ      1415  10  1290  1295
        AUP  52            ADDRESS       1295  10  1348  1553
        STU  2GETC                       1553  21  1290  1393
        SLT  0005                        1393  35  0005  1605
        RSB  8002   51                   1605  68  8002  1263
2GETU   ALO  0000   2GETV  CALC WIJ      1232  15  0000  1331
2GETV   ALO  0000   SWE                  1331  15  0000  1655
SWE     BMI  53            TEST WJ       1655  46  1358  1409
        AUP  WR            TEST WIJ      1409  10  1312  1317
        SLO  8002          AGAINST WR    1317  16  8002  1275
        SUP  8001                        1275  11  8001  1283
        BMI         53                   1283  46  1336  1358
        STD  WR            REPLACE       1336  24  1312  1465
        LDD  2I            WR            1465  69  1418  1571
        STD  2IR           WITH          1571  24  1374  1377
        LDD  2J            WIJ ETC       1377  69  1280  1333
        STD  2JR                         1333  24  1386  1339
        LDD  2CIJ                        1339  69  1329  1282
        STD  2CIJR  53                   1282  24  1235  1358
53      RAL  2J            TEST J        1358  65  1280  1285
        SLO  N                           1285  16  1929  1383
        NZA         54                   1383  45  1436  1387
        ALO  8001          STEP J        1436  15  8001  1443
        ALO  55                          1443  15  1346  1251
        STL  2J     56                   1251  20  1280  1250
54      RAL  2I            TEST I        1387  65  1418  1273
        SLO  M      SWF                  1273  16  1928  1433
SWF     NZA  60     SWFON                1433  45  1486  1437
60      ALO  8001          STEP I        1486  15  8001  1493
        ALO  57     SWG                  1493  15  1396  1301
SWG     STL  2I     58                   1301  20  1418  1621
SWFON   RAL  WR            IS WR ZERO    1437  65  1312  1367
        NZA         2PCH                 1367  45  1220  1821
        RAL  COUNT         STEP          1220  65  1934  1389
        ALO  59            ITERATION     1389  15  1292  1247
        STL  COUNT  MUBAR  COUNTER       1247  20  1934  1487
2PCH    LDD         RPSUB  PUNCH         1821  69  1524  1477
        LDD  TAG           LOADABLE      1524  69  1930  1533
        BD1         GETAO  SOLUTION      1533  91  1536  1288
        HLT  9004   9004   STOP          1536  01  9004  9004
GETAO   LDD  61            ALTERNATE     1288  69  1391  1294
        STD  SWE           OPTIMA        1294  24  1655  1408
        LDD  62            SET SW E      1408  69  1711  1414
        STD  SWF           AND F OFF     1414  24  1433  1586
        LDD  64     65                   1586  69  1439  1342
65      STD  0000   WIJ                  1342  24  0000  1209
63      RAL  2I            FORM          1350  65  1418  1323
        SLT  0002          IJC           1323  35  0002  1379
        ALO  2J                          1379  15  1280  1385
```

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        SLT   0001                            1385   35  0001  1441
        AAB   2CIJ                            1441   17  1329  1633
        STL   CIJAO          STORE CIJ        1633   20  1761  1464
        RAL   66      69     INITIALIZE       1464   65  1417  1583
69      STL   GETCA   8001   IJC ADDRESS      1583   20  1871  8001
 8001   RAL    0000   67     IJC TO LA        8001   65  0000  1755
67      NZA           PCHAO  TEST IJC         1755   45  1458  1509
        SLO   CIJAO          TEST FOR         1458   16  1761  1665
        NZA           53     BASIS ELEM       1665   45  1518  1358
        RAL   GETCA          NOT BASIS        1518   65  1871  1325
        ALO   68      69     STEP IJC ADR     1325   15  1228  1583
PCHAO   LDD   2I             PUNCH            1509   69  1418  1921
        STD   P0001          ALTERNATE        1921   24  1877  1330
        LDD   2J             OPTIMA           1330   69  1280  1683
        STD   P0002          IJC              1683   24  1878  1381
        RAB   2CIJ                            1381   67  1329  1733
        STL   P0003                           1733   20  1879  1332
        PCH   P0001   53                      1332   71  1877  1358

42       00    0000   0000   CONSTANTS        1362   00  0000  0000
43       00    0001   0000                    1468   00  0001  0000
44       00    0000   0001                    1366   00  0000  0001
45       00    1111   0000                    1474   00  1111  0000
46      LDD    0000   50                      1543   69  0000  1503
47      ALO    0000   2GETV                   1302   15  0000  1331
48       00    0001   0000                    1238   00  0001  0000
49      ALO    0000   SWE                     1324   15  0000  1655
52       00    0001   0000                    1348   00  0001  0000
55       00    0001   0000                    1346   00  0001  0000
57       00    0001   0000                    1396   00  0001  0000
59       00    0001   0000                    1292   00  0001  0000
61      NZA   53      63                      1391   45  1358  1350
62      NZA   60      9005                    1711   45  1486  9005
64       00    0000   0000                    1439   00  0000  0000
68       00    0001   0000                    1228   00  0001  0000

           PHASE 3 CONSTRUCT MU BAR TABLE

MUBAR   RAU   70      8003   RESET            1487   60  1390  8003
 8003   STL    0000   71     UV               8003   20  0000  1653
71      SUP   72             TABLES           1653   11  1506  1811
        NZU           73     TO               1811   44  1715  1416
        AUP   74      8003   ZERO             1715   10  1568  8003
73      STL    0000   75     SET EB TO 0      1416   20  0000  1703
75      RAL   2IR            SET MU I         1703   65  1374  1429
        ALO   76             TO 1             1429   15  1382  1537
        LDD   77      8002                    1537   69  1440  8002
 8002   STD    0000   78                      8002   24  0000  1753
78      RAL   2JR            SET NU J         1753   65  1386  1491
        ALO   79             TO 1             1491   15  1344  1399
        LDD   80      8002                    1399   69  1352  8002
81      LDD   82             INITIALIZE       1803   69  1656  1659
        STD   3GETB   8001   IJC ADDRESS      1659   24  1606  8001
 8002   STD    0000   81                      8002   24  0000  1803
 8001   RAL    0000   83     IJC TO LA        8001   65  0000  1805
```

83	NZA		84	TEST IJC	1805	45	1508	1559
	SLT	0003		STORE	1508	35	0003	1467
	STU	3I1		I	1467	21	1272	1375
	SUP	8001			1375	11	8001	1783
	SLT	0002			1783	35	0002	1489
	RAL	8003			1489	65	8003	1297
	SLT	0004		CALC ADDRESS	1297	35	0004	1307
	ALO	85		OF V BAR J	1307	15	1210	1765
	LDD	87			1765	69	1618	1971
	SDA	88	8002		1971	22	1425	8002
8002	RAL	0000	86	ADD 1	8002	65	0000	1855
86	ALO	90	88	TO	1855	15	1558	1425
88	STL	0000	89	V BAR J	1425	20	0000	1853
89	RAL	3I1		CALC ADDRESS	1853	65	1272	1527
	SLT	0004		OF U BAR I	1527	35	0004	1587
	ALO	91			1587	15	1490	1345
	LDD	93			1345	69	1398	1351
	SDA	94	8002		1351	22	1905	8002
8002	RAL	0000	92	ADD 1	8002	65	0000	1556
92	ALO	96	94	TO	1556	15	1609	1905
94	STL	0000	95	U BAR I	1905	20	0000	1903
95	RAL	3GETB		STEP	1903	65	1606	1861
	ALO	97		IJC	1861	15	1514	1319
	STL	3GETB	8001	ADDRESS	1319	20	1606	8001
84	RAU	98		RESET	1559	60	1812	1617
	ALO	99	8003	MU BAR	1617	15	1320	8003
8003	STL	0000	100	TABLE	8003	20	0000	1554
100	SUP	101		TO CODED	1554	11	1657	1862
	NZU		102	MINUS ZERO	1862	44	1516	1363
	AUP	103	8003		1516	10	1469	8003
102	RAL	104		INITIALIZE	1363	65	1566	1422
	STD	105		MU BAR ADDR	1422	24	1254	1707
	LDD	106			1707	69	1510	1563
	SDA	107			1563	22	1607	1560
	LDD	108		INITIALIZE	1560	69	1613	1616
	STD	3SHPL		P SHIFT	1616	24	1756	1909
	LDD	109			1909	69	1912	1666
	STD	3SHPR	110		1666	24	1737	1890
110	STU	0000	111	SET EB TO 0	1890	21	0000	1604
111	LDD	112		INITIALIZE	1604	69	1757	1610
	STD	3OBB	8001	IJC ADDRESS	1610	24	1480	8001
8001	RAL	0000	113	IJC TO LA	8001	65	0000	1706
113	NZA		THETA	TEST IJC	1706	45	1260	1911
	BMI	102			1260	46	1363	1564
	SLT	0003		STORE I J	1564	35	0003	1373
	STU	3I2			1373	21	1278	1431
	SUP	8001			1431	11	8001	1539
	SLT	0002			1539	35	0002	1395
	STU	3J2	105		1395	21	1400	1254
105	RAL	0000	3SHPL	MUS TO LA	1254	65	0000	1756
3SHPL	SLT	0009	114	GET MU P	1756	35	0009	1577
114	STU	3LMUS			1577	21	1432	1435
	SUP	8001			1435	11	8001	1643
	SLT	0001			1643	35	0001	1449
	STL	3RMUS			1449	20	1304	1357

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        SLO   8001                                 1357   16   8001   1815
        SUP   115                 IS MU BAR        1815   11   1668   1423
        NZU   3INCA               KNOWN            1423   44   1627   1328
        LDD   116                 SET D TO 8       1328   69   1481   1334
        STD   3D                  CALC LOC OF      1334   24   1637   1540
        RAL   3J2                 UBARMU AND       1540   65   1400   1806
        SLT   0004                                 1806   35   0004   1517
        ALO   117     8002        VBARNU AND       1517   15   1270   8002
8002    LDD   0000    118         STORE THEM       8002   69   0000   1354
118     STD   3F                                   1354   24   1407   1310
        LDD   119                                  1310   69   1413   1466
        SDA   3STVN                                1466   22   1369   1322
        RAL   3I2                                  1322   65   1278   1833
        SLT   0004                                 1833   35   0004   1693
        ALO   120                                  1693   15   1496   1401
        LDD   122                                  1401   69   1404   1457
        SDA   3STUM   8002                         1457   22   1961   8002
8002    RAB   0000    121         UBARMU TO LA     8002   67   0000   1856
121     STD   3E                                   1856   24   1709   1462
        SLT   0006                IS UBAR 1        1462   35   0006   1677
        SUP   123                                  1677   11   1380   1485
        NZU           3CAL                         1485   44   1589   1590
        RAB   3F                  IS VBAR 1        1589   67   1407   1512
        SLT   0006                                 1512   35   0006   1727
        SUP   124                                  1727   11   1430   1535
        NZU           3DTO9                        1535   44   1639   1640
        LDD   125     126         SET EB TO 70     1639   69   1392   1445
126     STD   0000    3INCA       MINUS 1111       1445   24   0000   1627
3DTO9   LDD   127                 SET D            1640   69   1743   1596
        STD   3D                  TO 9             1596   24   1637   1690
        RAL   3E                  INTERCHANGE      1690   65   1709   1463
        LDD   3F                  E AND F          1463   69   1407   1360
        STD   3E                                   1360   24   1709   1562
        STL   3F      3CAL                         1562   20   1407   1590
3CAL    RAL   3E                  GET 2            1590   65   1709   1513
        SLT   0006                                 1513   35   0006   1777
        STL   3CIR2               STORE 2          1777   20   1531   1384
        RAL   3F                                   1384   65   1407   1612
        SLT   0006                                 1612   35   0006   1827
        STU   3CIR3               STORE 3          1827   21   1482   1585
        RAL   8002                4 IN LA          1585   65   8002   1793
        SLO   3CIR2               4 MIN 2          1793   16   1531   1635
        SRT   0006                                 1635   30   0006   1499
        STL   34M2                STORE 4MIN2      1499   20   1454   1507
        RAB   3CIR3               AB3 TO LA        1507   67   1482   1687
        SLT   0004                                 1687   35   0004   1347
        SLO   128                                  1347   16   1450   1906
        LDD   34M2                                 1906   69   1454   1557
        SDA   129                                  1557   22   1662   1865
        RAL   8001                                 1865   65   8001   1473
        LDD   3D                  TEST D           1473   69   1637   1740
        BD1   3STVN   3STUM                        1740   91   1369   1961
3STVN   STL   0000    3STMB       D IS 8           1369   20   0000   1504
3STUM   STL   0000    3STMB       D IS 9           1961   20   0000   1504
3STMB   RAL   3CIR2               CALCULATE        1504   65   1531   1685
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         NZA          130     CODED         1685  45  1338  1689
         BMI          131     MUBAR         1338  46  1541  1442
         RAU   132    130                   1541  60  1394  1689
131      RAU   133    130                   1442  60  1495  1689
130      ALO   3RMUS                        1689  15  1304  1759
         SRT   0001           ASSEMBLE      1759  30  0001  1915
         AUP   3LMUS  3SHPR   AND STORE     1915  10  1432  1737
3SHPR    SRT   0009   107     NEW MUBAR     1737  30  0009  1607
107      STL   0000   3INCA   WORD          1607  20  0000  1627
3INCA    RAL   30BB           STEP          1627  65  1480  1735
         ALO   134            IJC           1735  15  1388  1843
         STL   30BB           ADDRESS       1843  20  1480  1434
         RAL   3SHPL          STEP          1434  65  1756  1712
         ALO   135            P SHIFT       1712  15  1965  1419
         LDD   3SHPR                        1419  69  1737  1790
         SDA   3SHPR                        1790  22  1737  1840
         STL   3SHPL                        1840  20  1756  1809
         SLT   0005           IS P ZERO     1809  35  0005  1372
         RAL   8002                         1372  65  8002  1581
         SLT   0001                         1581  35  0001  1787
         NZU   30BB                         1787  44  1480  1492
         RAL   105            STEP          1492  65  1254  1859
         ALO   136            MUBAR         1859  15  1762  1567
         LDD   107            ADDRESS       1567  69  1607  1410
         SDA   107                          1410  22  1607  1460
         STL   105    30BB                  1460  20  1254  1480

77       00    0000   0001    CONSTANTS     1440  00  0000  0001
80       00    0000   0001                  1352  00  0000  0001
87       STL   0000   89                    1618  20  0000  1853
90       00    0001   0000                  1558  00  0001  0000
93       STL   0000   95                    1398  20  0000  1903
96       00    0001   0000                  1609  00  0001  0000
97       00    0001   0000                  1514  00  0001  0000
99       33    3333   3333                  1320  33  3333  3333
106      STL   0000   3INCA                 1510  20  0000  1627
108      SLT   0000   114                   1613  35  0000  1577
109      SRT   0000   107                   1912  30  0000  1607
115      00    0000   0003                  1668  00  0000  0003
116      00    0000   0008                  1481  00  0000  0008
119      STL   0000   3STMB                 1413  20  0000  1504
122      STL   0000   3STMB                 1404  20  0000  1504
123      00    0000   0001                  1380  00  0000  0001
124      00    0000   0001                  1430  00  0000  0001
125    - 00    1111   0000                  1392 -00  1111  0000
127      00    0000   0009                  1743  00  0000  0009
128      00    0001   0000                  1450  00  0001  0000
132      00    0000   0002                  1394  00  0000  0002
133      00    0000   0001                  1495  00  0000  0001
134      00    0001   0000                  1388  00  0001  0000
135      00    0001   0000                  1965  00  0001  0000
136      00    0001   0000                  1762  00  0001  0000
```

PHASE 4 CALCULATE THETA

```
THETA    LDD  137              INITIALIZE       1911   69  1614  1717
         STD  4LIJC            IJC ADDR CTR     1717   24  1438  1891
         LDD  138              INITIALIZE       1891   69  1594  1497
         STD  4LXIJ            XIJ ADDRESS      1497   24  1857  1760
         STD  4H               SET H PLUS       1760   24  1500  1904
         LDD  139              SET THETA TO     1904   69  1810  1763
         STD  4T               9999999999       1763   24  1532  1885
         LDD  140              SET P SHIFT      1885   69  1488  1941
         STD  4SHPL            TO ZERO          1941   24  1807  1860
         RAL  141    153       INITIALIZE       1860   65  1813  1804
153      STL  4LMB    8001     MUBAR ADDR       1804   20  1741  8001
 8001    RAL   0000  4SHPL                      8001   65  0000  1807
4SHPL    SLT   0009  142                        1807   35  0009  1378
142      RAL   8002            GET AND          1378   65  8002  1837
         SLT   0001            TEST MUBAR       1837   35  0001  1893
         AUP  143     8003                      1893   10  1646  8003
 8003    NOP   0000   0000     TR ON MUBAR      8003   00  0000  0000
K0004    HLT   0006  MUBAR     HLT MU IS MZ     1549   01  0006  1487
K0003    NOP   0000  K0001     TRA TO K0001     1548   00  0000  1546
K0002    RAL  4H     4LXIJ     H TO LA          1547   65  1500  1857
4LXIJ    LDD   0000  144       XX TO DIST       1857   69  0000  1654
144      BMI  4GXRH  4GXLH     TEST H           1654   46  1907  1608
4GXLH    RAL   8001  145       GET XIJ LH       1608   65  8001  1716
145      SRT   0005  146                        1716   30  0005  1479
4GXRH    RAU   8001            GET XIJ RH       1907   60  8001  1766
         SRT   0005                             1766   30  0005  1529
         RAL   8002  145                        1529   65  8002  1716
146      SLO  4T               COMPARE XIJ      1479   16  1532  1887
         NZA         4XEQT     WITH THETA       1887   45  1940  1591
         BMI         K0001                      1940   46  1943  1546
         ALO   8001            REPLACE          1943   15  8001  1451
         STL  4T     147       THETA BY XIJ     1451   20  1532  1785
147      LDD  4LIJC            AND LIJCT        1785   69  1438  1641
         STD  4LT    K0001     BY LIJCX         1641   24  1444  1546
K0001    RAL  4LIJC            IS IJC           1546   65  1438  1494
         SLO  148              COUNTER          1494   16  1397  1501
         NZA         ABT       MAXIMUM          1501   45  1704  1658
         ALO  149              STEP IJC         1704   15  1708  1663
         STL  4LIJC            COUNTER          1663   20  1438  1691
         RSL  4H               REVERSE          1691   66  1500  1758
         STL  4H               SIGN OF H        1758   20  1500  1754
         BMI  4INPS            TEST H           1754   46  1808  1858
         RAL  4LXIJ            STEP XX          1858   65  1857  1962
         ALO  150              ADDRESS          1962   15  1816  1472
         STL  4LXIJ  4INPS                      1472   20  1857  1808
4INPS    RAL  4SHPL            STEP             1808   65  1807  1713
         ALO  151              P                1713   15  1866  1522
         STL  4SHPL            SHIFT            1522   20  1807  1660
         SLT   0005            IS               1660   35  0005  1523
         RAL   8002            P                1523   65  8002  1631
         SLT   0001            ZERO             1631   35  0001  1937
         NZU  4LMB                              1937   44  1741  1542
         RAL  4LMB             STEP MUBAR       1542   65  1741  1545
         ALO  152    153       ADDRESS          1545   15  1448  1804
4XEQT    RAL  4LIJC            XIJ EQ THETA     1591   65  1438  1544
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        ALO   154    8002                      1544   15   1447   8002
8002    RAL   0000   155     IJCX TO LA        8002   65   0000   1908
155     SLT   0003                             1908   35   0003   1667
        STU   4IX            STORE IX          1667   21   1572   1475
        SUP   8001                             1475   11   8001   1484
        SLT   0002                             1484   35   0002   1791
        STU   4JX            STORE JX          1791   21   1696   1599
        RAL   4LT                              1599   65   1444   1699
        ALO   156    8002                      1699   15   1402   8002
8002    RAL   0000   157     IJCT TO LA        8002   65   0000   1710
157     SLT   0003                             1710   35   0003   1519
        STU   4IT            STORE IT          1519   21   1574   1428
        SUP   8001                             1428   11   8001   1835
        SLT   0002                             1835   35   0002   1841
        STU   4JT            STORE JT          1841   21   1746   1749
        RAL   4IX            COMPARE           1749   65   1572   1478
        SLO   4IT            IX WITH IT        1478   16   1574   1579
        NZA          158                       1579   45   1582   1534
        BMI   147    K0001                     1582   46   1785   1546
158     RAL   4JX            COMPARE           1534   65   1696   1551
        SLO   4JT            JX WITH JT        1551   16   1746   1601
        NZA          9007                      1601   45   1854   9007
        BMI   147    K0001                     1854   46   1785   1546

139     99    9999   9999    CONSTANTS         1810   99   9999   9999
140     SLT   0000   142                       1488   35   0000   1378
143     00    0000   K0001                     1646   00   0000   1546
150     00    0001   0000                      1816   00   0001   0000
151     00    0001   0000                      1866   00   0001   0000
152     00    0001   0000                      1448   00   0001   0000
154     RAL   0000   155                       1447   65   0000   1908
156     RAL   0000   157                       1402   65   0000   1710

            PHASE 5 ALTER BASIS TABLE

ABT     RAL   160            INITIALIZE        1658   65   1968   1723
        LDD   161            XIJ ADDRESS       1723   69   1376   1729
        SDA   5GETX                            1729   22   1814   1819
        STL   5STOX                            1819   20   1849   1602
        STD   5Q             SET Q PLUS        1602   24   1600   1869
        STU   5SCB           SET SCBAR 0       1869   21   1867   1420
        LDD   162            INITIALIZE        1420   69   1773   1426
        STD   5GMB           MUBAR ADDR        1426   24   1452   1919
        LDD   163            INITIALIZE        1919   69   1823   1476
        STD   5SHP           P SHIFT           1476   24   1664   1969
        LDD   164            INITIALIZE        1969   69   1873   1526
        STD   5LIJC  5LOOP   IJC ADR CTR       1526   24   1910   1550
5LOOP   RAL   5LIJC          LIJC TO LA        1550   65   1910   1916
        ALO   165            SET               1916   15   1569   1573
        LDD   166            IJC               1573   69   1326   1629
        SDA   5SIJC  8002    ADDRESSES         1629   22   1584   8002
8002    RAB   0000   167     IJC TO LA         8002   67   0000   1863
167     SLT   0005                             1863   35   0005   1525
        RAL   8002                             1525   65   8002   1634
        SRT   0005                             1634   30   0005   1597
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        STL  5CIJ          STORE CIJ       1597  20  1651  1913
        RAL  5LIJC         IS LIJC EQ      1913  65  1910  1966
        SLO  4LT           TO LIJCT        1966  16  1444  1799
        NZA  5GMB   5RBE                   1799  45  1452  1963
5GMB    RAL  0000   5SHP   GET MUBAR       1452  65  0000  1664
5SHP    SLT  0009   168                    1664  35  0009  1935
168     RAL  8002                          1935  65  8002  1644
        SLT  0001          TRANSFER        1644  35  0001  1701
        AUP  169           ON MUBAR        1701  10  1714  1619
        LDD  5CIJ   8003   CIJ TO DIST     1619  69  1651  8003
F0002   RSL  8001          MUBAR IS        1648  66  8001  1764
        STL  5CBAR         PLUS 1          1764  20  1669  1622
        RSL  4T     170                    1622  66  1532  1538
F0003   STD  5CBAR         MUBAR IS        1649  24  1669  1672
        RAL  4T     170    MINUS 1         1672  65  1532  1538
170     STL  5TBAR                         1538  20  1694  1697
        RAL  5Q     5GETX  Q TO LA         1697  65  1600  1814
5GETX   LDD  0000   171    XX TO DIST      1814  69  0000  1864
171     BMI  5XRH   5XLH   TEST Q          1864  46  1767  1718
5XRH    RAL  8001          ADD             1767  65  8001  1575
        ALO  5TBAR  5STOX  THETA BAR       1575  15  1694  1849
5XLH    RAL  8001          TO              1718  65  8001  1625
        SLT  0005          XIJ             1625  35  0005  1588
        AUP  5TBAR                         1588  10  1694  1899
        SRT  0005   5STOX                  1899  30  0005  1849
5STOX   STL  0000   5UPDS  STORE NEW X     1849  20  0000  1914
5RBE    RAL  2IR           CONSTRUCT       1963  65  1374  1679
        SLT  0002          IJCIJ 2         1679  35  0002  1636
        ALO  2JR                           1636  15  1386  1592
        SLT  0001                          1592  35  0001  1949
        AAB  2CIJR  5SIJC  STORE NEW       1949  17  1235  1584
5SIJC   STL  0000   172    BASIS ELEM      1584  20  0000  1964
172     RAB  2CIJR         SET CBAR TO     1964  67  1235  1739
        SLO  5CIJ          CIJR MINUS      1739  16  1651  1817
        STL  5CBAR  5UPDS  CIJ             1817  20  1669  1914
5UPDS   RAL  5SCB          UPDATE          1914  65  1867  1722
        ALO  5CBAR         SIGMA CBAR      1722  15  1669  1623
        STL  5SCB   F0001                  1623  20  1867  1647
F0001   RAL  5LIJC         STEP IJC        1647  65  1910  1917
        ALO  173           ADDR CTR        1917  15  1370  1675
        SLO  174           IS LIJC MAX     1675  16  1528  1684
        NZA         CHECK                  1684  45  1638  1789
        ALO  8001                          1638  15  8001  1595
        STL  5LIJC                         1595  20  1910  1967
        RSL  5Q            REVERSE SIGN    1967  66  1600  1768
        STL  5Q            OF Q            1768  20  1600  1818
        BMI  176           TEST Q          1818  46  1772  1822
        RAL  5GETX         STEP XIJ        1822  65  1814  1719
        ALO  175           ADDRESSES       1719  15  1872  1578
        LDD  5STOX                         1578  69  1849  1502
        SDA  5STOX                         1502  22  1849  1552
        STL  5GETX  176                    1552  20  1814  1772
176     RAL  5SHP          STEP P          1772  65  1664  1769
        ALO  177           SHIFT           1769  15  1922  1628
        STL  5SHP                          1628  20  1664  1868
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        SLT   0005          IS P ZERO       1868  35  0005  1681
        RAL   8002                          1681  65  8002  1839
        SLT   0001                          1839  35  0001  1645
        NZU   5LOOP                         1645  44  1550  1650
        RAL   5GMB          STEP            1650  65  1452  1918
        ALO   178           MUBAR           1918  15  1673  1678
        STL   5GMB   5LOOP  ADDRESS         1678  20  1452  1550

161     LDD   0000   171    CONSTANTS       1376  69  0000  1864
163     SLT   0000   168                    1823  35  0000  1935
165     RAB   0000   167                    1569  67  0000  1863
166     STL   0000   172                    1326  20  0000  1964
169     00    0000   F0001                  1714  00  0000  1647
173     00    0001   0000                   1370  00  0001  0000
175     00    0001   0000                   1872  00  0001  0000
177     00    0001   0000                   1922  00  0001  0000
178     00    0001   0000                   1673  00  0001  0000

          PHASE 6 CHECK NEW DISTRIBUTION

CHECK   RAL   180           INITIALIZE      1789  65  1642  1797
        STD   6GETX         XX ADDR         1797  24  1923  1626
        STD   6Z            SET Z PLUS      1626  24  1470  1724
        STU   6SUMX         SET SX TO 0     1724  21  1747  1800
        LDD   181           SET T TO        1800  69  1620  1774
        STD   6T     6LOOP  M PL 1 MIN N    1774  24  1570  1700
6LOOP   RSL   6Z            REVERSE SIGN    1700  66  1470  1725
        STL   6Z     6GETX  OF Z            1725  20  1470  1923
6GETX   LDD   0000   182    XX TO DIST      1923  69  0000  1520
182     BMI   6XLH   6XRH   TEST Z          1520  46  1624  1674
6XLH    RAL   8001   184                    1624  65  8001  1731
184     SRT   0005   6UPSX  X IN LA         1731  30  0005  1744
6XRH    RAL   8001                          1674  65  8001  1781
        AUP   6GETX         STEP XX         1781  10  1923  1728
        AUP   183           ADDRESS         1728  10  1831  1686
        STU   6GETX                         1686  21  1923  1576
        SLT   0005                          1576  35  0005  1889
        RAL   8002   184                    1889  65  8002  1731
6UPSX   ALO   6SUMX         UPDATE          1744  15  1747  1751
        STL   6SUMX         SUM X           1751  20  1747  1750
        RAL   6T            END OF          1750  65  1570  1775
        SLO   185           LOOP TEST       1775  16  1778  1734
        NZA          6CXWS                  1734  45  1688  1939
        STL   6T     6LOOP                  1688  20  1570  1700
6CXWS   RAL   6SUMX         COMPARE SUMX    1939  65  1747  1801
        SLO   SUMS          WITH SUMS       1801  16  1931  1736
        NZA          186                    1736  45  1692  1742
        HLT   9008   9008   STOP            1692  01  9008  9008
186     RAL   5SCB          HAS TOTAL       1742  65  1867  1824
        BMI   187           COST INCR       1824  46  1828  1779
        NZA          187                    1779  45  1632  1828
        HLT   9009   9009   STOP            1632  01  9009  9009
187     ALO   WR            COMP SUMCBAR    1828  15  1312  1670
        NZA          188    WITH WIJ        1670  45  1874  1825
        HLT   9010   9010   STOP            1874  01  9010  9010
```

188	RSU	8001		CALC CHANGE	182	61	8001	1784
	MPY	4T		IN COST	1784	19	1532	1738
	AUP	SCXHO		UPDATE	1738	10	1932	1788
	ALO	SCXLO		TOTAL	1788	15	1933	1838
	STU	SCXHO	SWH	COST	1838	21	1932	1786
SWH	STL	SCXLO	SWHOF		1786	20	1933	1835
SWHON	PCH	1927	SWHOF	PCH MAS CARD	1850	71	1927	1836
SWHOF	RAL	8000		IS RESTART	1836	65	8000	1794
	BMI		UV	INFO DESIRED	1794	46	1847	1236
	LDD		RPSUB		1847	69	1900	1477
	NOP	0000	UV		1900	00	0000	1236
183	00	0001	0000	CONSTANTS	1831	00	0001	0000
185	00	0001	0000		1778	00	0001	0000

RESTART PUNCH SUBROUTINE

RPSUB	STD	RPXX		PUNCH	1477	24	1530	1834
	PCH	1927		MASTER DATA	1834	71	1927	1829
	RAL	RPC1		CARD AND	1829	65	1682	1888
	LDD	RPXX	315P7	IJC XX	1888	69	1530	1217
RPC1	00	0000	0000	TABLES	1682	00	0000	0000
1927	00	1928	0007		1927	00	1928	0007

PROG 315 P7 PUNCH SUBROUTINE

315PC	RAL	8000	315P7	PCH CONSOLE	1950	65	8000	1217
315P7	STD	315XX		STORE EXIT	1217	24	1720	1924
	LDD	315A		SET	1924	69	1580	1886
	SDA	315A		FWA	1886	22	1580	1936
	SLT	0004		AND	1936	35	0004	1897
	SDA	315B		LWA	1897	22	1851	1770
	RAL	315A	315J	FWA TO LA	1770	65	1580	1938
315J	AUP	315C		LWA TO UA	1938	10	1792	1947
	LDD	315D		SET CONTROL	1947	69	1901	1820
	SDA	P0001	8002	WORD	1820	22	1877	8002
315F	AUP	315E		STEP PCH ADR	1652	10	1870	1875
	SLO	315B		HAS LAST	1875	16	1851	1920
	SUP	8003		WORD BEEN	1920	11	8003	1630
	NZA		315G	STORED	1630	45	1842	1892
	AUP	8001			1842	10	8001	1702
	ALO	315E			1702	15	1870	1925
	ALO	315B			1925	15	1851	1970
	SUP	315H		HAVE 7 WORDS	1970	11	1676	1732
	NZU		315I	BEEN STORED	1732	44	1942	1844
	AUP	8001	8002		1942	10	8001	8002
315I	PCH	P0001	315J	PUNCH 7 WDS	1844	71	1877	1938
315G	RAL	8001		MODIFY	1892	65	8001	1752
	SLO	315H		CONTROL	1752	16	1676	1782
	SRT	0004		WORD ON	1782	30	0004	1894
	ALO	P0001		LAST CARD	1894	15	1877	1832
	STL	P0001		PUNCH	1832	20	1877	1680
	PCH	P0001	315XX	LAST CARD	1680	71	1877	1720
315A	69	0000	8003	CONSTANTS	1580	69	0000	8003
315C	24	P0002	315F		1792	24	1878	1652

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315D     00   0000    0007                           1901   00   0000   0007
315E     00   0001    0000                           1870   00   0001   0000
315H     24   P0009   315F                           1676   24   1885   1652
```

PROGRAM 3 ALTERNATE OPTIMA

PROGRAM 3 INITIALIZATION

```
SETUP    LDD  255              RESTORE               0001   69   0004   0007
         STD   1983            READ SWITCH           0007   24   1983   0036
         RAU  N                N TO UA               0036   60   1929   0033
         SRT   0004                                  0033   30   0004   0043
         LDD  TAG              TEST                  0043   69   1930   0083
         BD2  SMALL   BIG      TAG                   0083   92   0086   0038
SMALL    MPY  M       200      MN IN LA              0086   19   1928   0133
BIG      MPY  201     200      N IN LA               0038   19   0041   0133
200      SRT   0004                                  0133   30   0004   0093
         DIV  202                                    0093   14   0046   0096
         ALO   8003            B1 IN LA              0096   15   8003   0003
         SLT   0004            SET                   0003   35   0004   0013
         STL  164              B1                    0013   20   1770   0023
         LDD  205                                    0023   69   0026   0029
         SDA  82                                     0029   22   1556   0009
         LDD  206                                    0009   69   0012   0015
         SDA  112                                    0015   22   1607   0010
         STL  207                                    0010   20   0065   0018
         STD  137                                    0018   24   1962   0115
         ALO  M                                      0115   15   1928   0034
         ALO  N                X1 IN LA              0034   15   1929   0084
         SLO  208              EBO IN LA             0084   16   0037   0091
         STL  148                                    0091   20   1446   0049
         ALO  220              X0 IN LA              0049   15   0002   0057
         LDD  211                                    0057   69   0060   0063
         SDA  73                                     0063   22   1416   0019
         LDD  212                                    0019   69   0022   0025
         SDA  110                                    0025   22   1688   0141
         LDD  213                                    0141   69   0044   0047
         SDA  126                                    0047   22   1493   0146
         STL  149                                    0146   20   1707   0110
         STD  174                                    0110   24   1526   0079
         ALO  214              X1 IN LA              0079   15   0032   0087
         LDD  215              SET                   0087   69   0040   0143
         SDA  138              X1                    0143   22   1694   0097
         LDD  216              ADDRESSES             0097   69   0050   0053
         SDA  160                                    0053   22   1916   0069
         LDD  217                                    0069   69   0072   0075
         SDA  180                                    0075   22   1640   0094
         RAL  M                                      0094   65   1928   0134
         STU  COUNT            ZERO COUNT            0134   21   1934   0137
         ALO  N                                      0137   15   1929   0035
         SLO  218              NO BASIS              0035   16   0088   0144
         STL  181              ELEM IN LA            0144   20   1851   0054
         SRT   0004                                  0054   30   0004   0165
         DIV  219                                    0165   14   0068   0118
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         ALO  8003                        0118  15  8003  0125
         SLT   0004                       0125  35  0004  0085
         ALO  149          U0 IN LA       0085  15  1707  0011
         STL  U0           STORE U 0      0011  20  0016  0119
         LDD  221          SET            0119  69  0122  0175
         SDA  76           U0             0175  22  1414  0017
         LDD  222          ADDRESSES      0017  69  0020  0073
         SDA  91                          0073  22  1440  0045
         LDD  223                         0045  69  0048  0051
         SDA  120                         0051  22  1444  0147
         LDD  207                         0147  69  0065  0168
         SRT   0004                       0168  30  0004  0129
         SIA  RPC1                        0129  23  1632  0135
         SLT   0004                       0135  35  0004  0095
         ALO  224          U1 IN LA       0095  15  0098  0103
         LDD  227                         0103  69  0006  0059
         SDA  70                          0059  22  1435  0138
         ALO  M            V1 IN LA       0138  15  1928  0136
         SLO  228          V0 IN LA       0136  16  0039  0145
         STL  V0           STORE V0       0145  20  0099  0052
         LDD  229          SET            0052  69  0005  0008
         SDA  79           V0             0008  22  1466  0169
         LDD  230          ADDRESSES      0169  69  0172  0076
         SDA  85                          0076  22  1460  0113
         LDD  231                         0113  69  0066  0070
         SDA  117                         0070  22  1516  0120
         ALO  N            M0 IN LA       0120  15  1929  0089
         LDD  233          ADDRESSES      0089  69  0042  0148
         SDA  72                          0148  22  1456  0109
         ALO  234          M1 IN LA       0109  15  0062  0067
         LDD  235          SET            0067  69  0170  0123
         SDA  6            M1             0123  22  0027  0030
         LDD  236          ADDRESSES      0030  69  0139  0092
         SDA  74                          0092  22  1418  0021
         LDD  237                         0021  69  0024  0077
         SDA  98                          0077  22  1662  0116
         LDD  238                         0116  69  0071  0074
         SDA  104                         0074  22  1564  0117
         LDD  239                         0117  69  0121  0124
         SDA  141                         0124  22  1713  0166
         LDD  240                         0166  69  0171  0174
         SDA  162                         0174  22  1873  0126
         STL  241          STORE M1       0126  20  0031  0090
         RAL  181          CALC SIZE      0090  65  1851  0055
         SRT   0004        OF MUBAR       0055  30  0004  0167
         DIV  242          TABLE          0167  14  0173  0127
         SLT   0004                       0127  35  0004  0140
         NZU        243                   0140  44  0149  0100
         ALO  244   243                   0149  15  0102  0100
243      ALO  241          E1 IN LA       0100  15  0031  0142
         LDD  245          SET E1         0142  69  0150  0153
         SDA  103          ADDRESS        0153  22  1518  0028
         SLO  246          E0 IN LA       0028  16  0081  0101
         LDD  247          SET E0         0101  69  0104  0107
         SDA  101          ADDRESS        0107  22  1507  0160
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	LDD	254		SET	0160	69	0163	0078
	STD	1988	8001	READ SWITCH	0078	24	1988	8001
201	00	0001	0000	CONSTANTS	0041	00	0001	0000
202	00	0000	0002		0046	00	0000	0002
205	RAL	0000	83		0026	65	0000	1455
206	RAL	0000	113		0012	65	0000	1655
208	00	0002	0000		0037	00	0002	0000
211	STL	0000	75		0060	20	0000	1453
212	STU	0000	111		0022	21	0000	1604
213	STD	0000	3INCA		0044	24	0000	1423
214	00	0001	0000		0032	00	0001	0000
215	LDD	0000	144		0040	69	0000	1654
216	STL	0000	5UPDS		0050	20	0000	1764
217	LDD	0000	182		0072	69	0000	1967
218	00	0001	0000		0088	00	0001	0000
219	00	0000	0002		0068	00	0000	0002
220	00	0001	0000		0002	00	0001	0000
221	STD	0000	78		0122	24	0000	1503
222	RAL	0000	92		0020	65	0000	1605
223	RAB	0000	121		0048	67	0000	1805
224	00	0001	0000		0098	00	0001	0000
227	STL	0000	71		0006	20	0000	1403
228	00	0001	0000		0039	00	0001	0000
229	STD	0000	81		0005	24	0000	1553
230	RAL	0000	86		0172	65	0000	1505
231	LDD	0000	118		0066	69	0000	1753
233	STL	0000	71		0042	20	0000	1403
234	00	0001	0000		0062	00	0001	0000
236	STL	0000	71		0139	20	0000	1403
237	STL	0000	100		0024	20	0000	1504
238	RAL	0000	3SHPL		0071	65	0000	1705
239	RAL	0000	4SHPL		0121	65	0000	1806
240	RAL	0000	5SHP		0171	65	0000	1913
242	00	0000	0010		0173	00	0000	0010
244	00	0001	0000		0102	00	0001	0000
245	STL	0000	100		0150	20	0000	1504
246	00	0001	0000		0081	00	0001	0000
247	STL	0000	100		0104	20	0000	1504
254	RDS	1994	AO		0163	70	1994	1400
255	44	1987	1988		0004	44	1987	1988
257	STL	SCXLO	SWHON		0151	20	1933	0152
AO	RDS	1975	3000	READ IJC CD	1400	70	1975	3000
1975	LDD	1951		STORE	1975	69	1951	1404
	STD	2IR		I	1404	24	1407	1410
	STD	A0001		J	1410	24	1827	1430
	LDD	1952		C	1430	69	1952	1405
	STD	2JR			1405	24	1408	1411
	STD	A0002			1411	24	1828	1431
	LDD	1953			1431	69	1953	1406
	STD	2CIJR			1406	24	1409	1412
	STD	A0003	MUBAR	TO PHASE 3	1412	24	1829	1432

PHASE 3 CONSTRUCT MU BAR TABLE

MUBAR	RAU	70	8003	RESET	1432	60	1435	8003
8003	STL	0000	71	UV	8003	20	0000	1403
71	SUP	72		TABLES	1403	11	1456	1461
	NZU		73	TO	1461	44	1415	1416
	AUP	74	8003	ZERO	1415	10	1418	8003
73	STL	0000	75	SET EB TO 0	1416	20	0000	1453
75	RAL	2IR		SET MU I	1453	65	1407	1511
	ALO	76		TO 1	1511	15	1414	1419
	LDD	77	8002		1419	69	1422	8002
8002	STD	0000	78		8002	24	0000	1503
78	RAL	2JR		SET NU J	1503	65	1408	1413
	ALO	79		TO 1	1413	15	1466	1421
	LDD	80	8002		1421	69	1424	8002
8002	STD	0000	81		8002	24	0000	1553
81	LDD	82		INITIALIZE	1553	69	1556	1509
	STD	3GETB	8001	IJC ADDRESS	1509	24	1506	8001
8001	RAL	0000	83	IJC TO LA	8001	65	0000	1455
83	NZA		84	TEST IJC	1455	45	1458	1459
	SLT	0003		STORE	1458	35	0003	1417
	STU	3I1		I	1417	21	1472	1425
	SUP	8001			1425	11	8001	1433
	SLT	0002			1433	35	0002	1439
	RAL	8003			1439	65	8003	1447
	SLT	0004		CALC ADDRESS	1447	35	0004	1457
	ALO	85		OF V BAR J	1457	15	1460	1465
	LDD	87			1465	69	1468	1471
	SDA	88	8002		1471	22	1475	8002
8002	RAL	0000	86	ADD 1	8002	65	0000	1505
86	ALO	90	88	TO	1505	15	1508	1475
88	STL	0000	89	V BAR J	1475	20	0000	1603
89	RAL	3I1		CALC ADDRESS	1603	65	1472	1427
	SLT	0004		OF U BAR I	1427	35	0004	1437
	ALO	91			1437	15	1440	1445
	LDD	93			1445	69	1448	1401
	SDA	94	8002		1401	22	1555	8002
8002	RAL	0000	92	ADD 1	8002	65	0000	1605
92	ALO	96	94	TO	1605	15	1558	1555
94	STL	0000	95	U BAR I	1555	20	0000	1653
95	RAL	3GETB		STEP	1653	65	1506	1561
	ALO	97		IJC	1561	15	1464	1469
	STL	3GETB	8001	ADDRESS	1469	20	1506	8001
84	RAU	98		RESET	1459	60	1662	1517
	ALO	99	8003	MU BAR	1517	15	1420	8003
8003	STL	0000	100	TABLE	8003	20	0000	1504
100	SUP	101		TO CODED	1504	11	1507	1961
	NZU		102	MINUS ZERO	1961	44	1565	1611
	AUP	103	8003		1565	10	1518	8003
102	RAL	104		INITIALIZE	1611	65	1564	1669
	STD	105		MU BAR ADDR	1669	24	1451	1554
	LDD	106			1554	69	1557	1510
	SDA	107			1510	22	1905	1858
	LDD	108		INITIALIZE	1858	69	1712	1615
	STD	3SHPL		P SHIFT	1615	24	1705	1908
	LDD	109			1908	69	1762	1665
	STD	3SHPR	110		1665	24	1635	1688

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110     STU   0000    111      SET EB TO 0      1688   21  0000  1604
111     LDD   112              INITIALIZE       1604   69  1607  1560
        STD   30BB    8001     IJC ADDRESS      1560   24  1476  8001
 8001   RAL   0000    113      IJC TO LA        8001   65  0000  1655
113     NZA           THETA    TEST IJC         1655   45  1608  1559
        BMI   102                               1608   46  1611  1462
        SLT   0003             STORE I J        1462   35  0003  1521
        STU   3I2                               1521   21  1426  1429
        SUP   8001                              1429   11  8001  1487
        SLT   0002                              1487   35  0002  1443
        STU   3J2     105                       1443   21  1498  1451
105     RAL   0000    3SHPL    MUS TO LA        1451   65  0000  1705
3SHPL   SLT   0009    114      GET MU P         1705   35  0009  1525
114     STU   3LMUS                             1525   21  1480  1483
        SUP   8001                              1483   11  8001  1441
        SLT   0001                              1441   35  0001  1497
        STL   3RMUS                             1497   20  1501  1454
        SLO   8001                              1454   16  8001  1661
        SUP   115              IS MU BAR        1661   11  1514  1519
        NZU   3INCA            KNOWN            1519   44  1423  1474
        LDD   116              SET D TO 8       1474   69  1477  1530
        STD   3D               CALC LOC OF      1530   24  1533  1436
        RAL   3J2              UBARMU AND       1436   65  1498  1703
        SLT   0004                              1703   35  0004  1463
        ALO   117     8002     VBARNU AND       1463   15  1516  8002
 8002   LDD   0000    118      STORE THEM       8002   69  0000  1753
118     STD   3F                                1753   24  1606  1609
        LDD   119                               1609   69  1512  1515
        SDA   3STVN                             1515   22  1569  1522
        RAL   3I2                               1522   65  1426  1481
        SLT   0004                              1481   35  0004  1491
        ALO   120                               1491   15  1444  1449
        LDD   122                               1449   69  1402  1755
        SDA   3STUM   8002                      1755   22  1659  8002
 8002   RAB   0000    121      UBARMU TO LA     8002   67  0000  1805
121     STD   3E                                1805   24  1658  1711
        SLT   0006             IS UBAR 1        1711   35  0006  1575
        SUP   123                               1575   11  1428  1583
        NZU           3CAL                      1583   44  1537  1438
        RAB   3F               IS VBAR 1        1537   67  1606  1761
        SLT   0006                              1761   35  0006  1625
        SUP   124                               1625   11  1478  1633
        NZU           3DT09                     1633   44  1587  1488
        LDD   125     126      SET EB TO 70     1587   69  1490  1493
126     STD   0000    3INCA    MINUS 1111       1493   24  0000  1423
3DT09   LDD   127              SET D            1488   69  1541  1494
        STD   3D               TO 9             1494   24  1533  1486
        RAL   3E               INTERCHANGE      1486   65  1658  1513
        LDD   3F               E AND F          1513   69  1606  1709
        STD   3E                                1709   24  1658  1811
        STL   3F      3CAL                      1811   20  1606  1438
3CAL    RAL   3E               GET 2            1438   65  1658  1563
        SLT   0006                              1563   35  0006  1527
        STL   3CIR2            STORE 2          1527   20  1531  1434
        RAL   3F                                1434   65  1606  1861
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        SLT   0006                         1861  3.  0006  1675
        STU   3CIR3         STORE 3        1675  21  1580  1683
        RAL   8002          4 IN LA        1683  65  8002  1591
        SLO   3CIR2         4 MIN 2        1591  16  1531  1485
        SRT   0006                         1485  30  0006  1499
        STL   34M2          STORE 4MIN2    1499  20  1803  1656
        RAB   3CIR3         AB3 TO LA      1656  67  1580  1535
        SLT   0004                         1535  35  0004  1495
        SLO   128                          1495  16  1598  1853
        LDD   34M2                         1853  69  1803  1706
        SDA   129                          1706  22  1759  1562
        RAL   8001                         1562  65  8001  1619
        LDD   3D            TEST D         1619  69  1533  1536
        BD1   3STVN  3STUM                 1536  91  1569  1659
3STVN   STL   0000   3STMB  D IS 8         1569  20  0000  1903
3STUM   STL   0000   3STMB  D IS 9         1659  20  0000  1903
3STMB   RAL   3CIR2         CALCULATE      1903  65  1531  1585
        NZA          130    CODED          1585  45  1538  1489
        BMI          131    MUBAR          1538  46  1641  1442
        RAU   132    130                   1641  60  1544  1489
131     RAU   133    130                   1442  60  1545  1489
130     ALO   3RMUS                        1489  15  1501  1855
        SRT   0001          ASSEMBLE       1855  30  0001  1911
        AUP   3LMUS  3SHPR  AND STORE      1911  10  1480  1635
3SHPR   SRT   0009   107    NEW MUBAR      1635  30  0009  1905
107     STL   0000   3INCA  WORD           1905  20  0000  1423
3INCA   RAL   30BB          STEP           1423  65  1476  1581
        ALO   134           IJC            1581  15  1484  1539
        STL   30BB          ADDRESS        1539  20  1476  1479
        RAL   3SHPL         STEP           1479  65  1705  1809
        ALO   135           P SHIFT        1809  15  1612  1467
        LDD   3SHPR                        1467  69  1635  1588
        SDA   3SHPR                        1588  22  1635  1638
        STL   3SHPL                        1638  20  1705  1708
        SLT   0005          IS P ZERO      1708  35  0005  1571
        RAL   8002                         1571  65  8002  1529
        SLT   0001                         1529  35  0001  1685
        NZU   30BB                         1685  44  1476  1540
        RAL   105           STEP           1540  65  1451  1756
        ALO   136           MUBAR          1756  15  1859  1613
        LDD   107           ADDRESS        1613  69  1905  1758
        SDA   107                          1758  22  1905  1808
        STL   105    30BB                  1808  20  1451  1476

7       00    0000   0001   CONSTANTS      1422  00  0000  0001
0       00    0000   0001                  1424  00  0000  0001
7       STL   0000   89                    1468  20  0000  1603
0       00    0001   0000                  1508  00  0001  0000
3       STL   0000   95                    1448  20  0000  1653
6       00    0001   0000                  1558  00  0001  0000
7       00    0001   0000                  1464  00  0001  0000
9       33    3333   3333                  1420  33  3333  3333
06      STL   0000   3INCA                 1557  20  0000  1423
08      SLT   0000   114                   1712  35  0000  1525
09      SRT   0000   107                   1762  30  0000  1905
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115       00    0000   0003                         1514    00  0000  0003
116       00    0000   0008                         1477    00  0000  0008
119       STL   0000   3STMB                        1512    20  0000  1903
122       STL   0000   3STMB                        1402    20  0000  1903
123       00    0000   0001                         1428    00  0000  0001
124       00    0000   0001                         1478    00  0000  0001
125     - 00    1111   0000                         1490  - 00  1111  0000
127       00    0000   0009                         1541    00  0000  0009
128       00    0001   0000                         1598    00  0001  0000
132       00    0000   0002                         1544    00  0000  0002
133       00    0000   0001                         1545    00  0000  0001
134       00    0001   0000                         1484    00  0001  0000
135       00    0001   0000                         1612    00  0001  0000
136       00    0001   0000                         1859    00  0001  0000

          PHASE 4 CALCULATE THETA

THETA     LDD   137           INITIALIZE            1559    69  1962  1965
          STD   4LIJC         IJC ADDR CTR          1965    24  1738  1941
          LDD   138           INITIALIZE            1941    69  1694  1747
          STD   4LXIJ         XIJ ADDRESS           1747    24  1856  1710
          STD   4H            SET H PLUS            1710    24  1450  1854
          LDD   139           SET THETA TO          1854    69  1760  1663
          STD   4T            9999999999            1663    24  1482  1835
          LDD   140           SET P SHIFT           1835    69  1788  1642
          STD   4SHPL         TO ZERO               1642    24  1806  1810
          RAL   141    153    INITIALIZE            1810    65  1713  1804
153       STL   4LMB   8001   MUBAR ADDR            1804    20  1891  8001
8001      RAL   0000   4SHPL                        8001    65  0000  1806
4SHPL     SLT   0009   142                          1806    35  0009  1577
142       RAL   8002          GET AND               1577    65  8002  1735
          SLT   0001          TEST MUBAR            1735    35  0001  1691
          AUP   143    8003                         1691    10  1594  8003
8003      NOP   0000   0000   TR ON MUBAR           8003    00  0000  0000
K0004     HLT   0006   MUBAR  HLT MU IS MZ          1549    01  0006  1432
K0003     NOP   0000   K0001  TRA TO K0001          1548    00  0000  1546
K0002     RAL   4H     4LXIJ  H TO LA               1547    65  1450  1856
4LXIJ     LDD   0000   144    XX TO DIST            1856    69  0000  1654
144       BMI   4GXRH  4GXLH  TEST H                1654    46  1657  1909
4GXLH     RAL   8001   145    GET XIJ LH            1909    65  8001  1567
145       SRT   0005   146                          1567    30  0005  1579
4GXRH     RAU   8001          GET XIJ RH            1657    60  8001  1715
          SRT   0005                                1715    30  0005  1627
          RAL   8002   145                          1627    65  8002  1567
146       SLO   4T            COMPARE XIJ           1579    16  1482  1637
          NZA          4XEQT  WITH THETA            1637    45  1590  1741
          BMI          K0001                        1590    46  1543  1546
          ALO   8001          REPLACE               1543    15  8001  1551
          STL   4T     147    THETA BY XIJ          1551    20  1482  1785
147       LDD   4LIJC         AND LIJCT             1785    69  1738  1791
          STD   4LT    K0001  BY LIJCX              1791    24  1644  1546
K0001     RAL   4LIJC         IS IJC                1546    65  1738  1593
          SLO   148           COUNTER               1593    16  1446  1601
          NZA          ABT    MAXIMUM               1601    45  1704  1906
          ALO   149           STEP IJC              1704    15  1707  1812
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          STL   4LIJC            COUNTER         1812  20  1738  1841
          RSL   4H               REVERSE         1841  66  1450  1757
          STL   4H               SIGN OF H       1757  20  1450  1754
          BMI   4INPS            TEST H          1754  46  1807  1610
          RAL   4LXIJ            STEP XX         1610  65  1856  1862
          ALO   150              ADDRESS         1862  15  1765  1719
          STL   4LXIJ  4INPS                     1719  20  1856  1807
4INPS     RAL   4SHPL            STEP            1807  65  1806  1912
          ALO   151              P               1912  15  1815  1769
          STL   4SHPL            SHIFT           1769  20  1806  1660
          SLT    0005            IS              1660  35  0005  1473
          RAL    8002            P               1473  65  8002  1631
          SLT    0001            ZERO            1631  35  0001  1687
          NZU   4LMB                             1687  44  1891  1492
          RAL   4LMB             STEP MUBAR      1492  65  1891  1595
          ALO   152    153       ADDRESS         1595  15  1698  1804
4XEQT     RAL   4LIJC            XIJ EQ THETA    1741  65  1738  1643
          ALO   154    8002                      1643  15  1496  8002
 8002     RAL    0000  155       IJCX TO LA      8002  65  0000  1857
155       SLT    0003                            1857  35  0003  1865
          STU   4IX              STORE IX        1865  21  1470  1523
          SUP    8001                            1523  11  8001  1681
          SLT    0002                            1681  35  0002  1737
          STU   4JX              STORE JX        1737  21  1542  1645
          RAL   4LT                              1645  65  1644  1599
          ALO   156    8002                      1599  15  1452  8002
 8002     RAL    0000  157       IJCT TO LA      8002  65  0000  1907
157       SLT    0003                            1907  35  0003  1915
          STU   4IT              STORE IT        1915  21  1520  1573
          SUP    8001                            1573  11  8001  1731
          SLT    0002                            1731  35  0002  1787
          STU   4JT              STORE JT        1787  21  1592  1695
          RAL   4IX              COMPARE         1695  65  1470  1725
          SLO   4IT              IX WITH IT      1725  16  1520  1775
          NZA          158                       1775  45  1528  1629
          BMI   147    K0001                     1528  46  1785  1546
158       RAL   4JX              COMPARE         1629  65  1542  1597
          SLO   4JT              JX WITH JT      1597  16  1592  1697
          NZA          9007                      1697  45  1500  9007
          BMI   147    K0001                     1500  46  1785  1546

139        99    9999  9999      CONSTANTS       1760  99  9999  9999
140       SLT    0000  142                       1788  35  0000  1577
143        00    0000  K0001                     1594  00  0000  1546
150        00    0001  0000                      1765  00  0001  0000
151        00    0001  0000                      1815  00  0001  0000
152        00    0001  0000                      1698  00  0001  0000
154       RAL    0000  155                       1496  65  0000  1857
156       RAL    0000  157                       1452  65  0000  1907

            PHASE 5 ALTER BASIS TABLE

ABT       RAL   160              INITIALIZE      1906  65  1916  1771
          LDD   161              XIJ ADDRESS     1771  69  1524  1777
          SDA   5GETX                            1777  22  1664  1817
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	STL	5STOX			1817	20	1847	1800
	STD	5Q		SET Q PLUS	1800	24	1748	1751
	STU	5SCB		SET SCBAR 0	1751	21	1717	1670
	LDD	162		INITIALIZE	1670	69	1873	1576
	STD	5GMB		MUBAR ADDR	1576	24	1502	1966
	LDD	163		INITIALIZE	1966	69	1720	1923
	STD	5SHP		P SHIFT	1923	24	1913	1867
	LDD	164		INITIALIZE	1867	69	1770	1973
	STD	5LIJC	5LOOP	IJC ADR CTR	1973	24	1904	1550
5LOOP	RAL	5LIJC		LIJC TO LA	1550	65	1904	1860
	ALO	165		SET	1860	15	1763	1617
	LDD	166		IJC	1617	69	1570	1623
	SDA	5SIJC	8002	ADDRESSES	1623	22	1677	8002
8002	RAB	0000	167	IJC TO LA	8002	67	0000	1910
167	SLT	0005			1910	35	0005	1673
	RAL	8002			1673	65	8002	1781
	SRT	0005			1781	30	0005	1693
	STL	5CIJ		STORE CIJ	1693	20	1797	1600
	RAL	5LIJC		IS LIJC EQ	1600	65	1904	1813
	SLO	4LT		TO LIJCT	1813	16	1644	1699
	NZA	5GMB	5RBE		1699	45	1502	1863
5GMB	RAL	0000	5SHP	GET MUBAR	1502	65	0000	1913
5SHP	SLT	0009	168		1913	35	0009	1733
168	RAL	8002			1733	65	8002	1692
	SLT	0001		TRANSFER	1692	35	0001	1749
	AUP	169		ON MUBAR	1749	10	1552	1963
	LDD	5CIJ	8003	CIJ TO DIST	1963	69	1797	8003
F0002	RSL	8001		MUBAR IS	1648	66	8001	1614
	STL	5CBAR		PLUS 1	1614	20	1819	1572
	RSL	4T	170		1572	66	1482	1837
F0003	STD	5CBAR		MUBAR IS	1649	24	1819	1622
	RAL	4T	170	MINUS 1	1622	65	1482	1837
170	STL	5TBAR			1837	20	1742	1745
	RAL	5Q	5GETX	Q TO LA	1745	65	1748	1664
5GETX	LDD	0000	171	XX TO DIST	1664	69	0000	1714
171	BMI	5XRH	5XLH	TEST Q	1714	46	1667	1568
5XRH	RAL	8001		ADD	1667	65	8001	1825
	ALO	5TBAR	5STOX	THETA BAR	1825	15	1742	1847
5XLH	RAL	8001		TO	1568	65	8001	1875
	SLT	0005		XIJ	1875	35	0005	1887
	AUP	5TBAR			1887	10	1742	1897
	SRT	0005	5STOX		1897	30	0005	1847
5STOX	STL	0000	5UPDS	STORE NEW X	1847	20	0000	1764
5RBE	RAL	2IR		CONSTRUCT	1863	65	1407	1814
	SLT	0002		IJCIJ 2	1814	35	0002	1621
	ALO	2JR			1621	15	1408	1864
	SLT	0001			1864	35	0001	1671
	AAB	2CIJR	5SIJC	STORE NEW	1671	17	1409	1677
5SIJC	STL	0000	172	BASIS ELEM	1677	20	0000	1914
172	RAB	2CIJR		SET CBAR TO	1914	67	1409	1964
	SLO	5CIJ		CIJR MINUS	1964	16	1797	1651
	STL	5CBAR	5UPDS	CIJ	1651	20	1819	1764
5UPDS	RAL	5SCB		UPDATE	1764	65	1717	1721
	ALO	5CBAR		SIGMA CBAR	1721	15	1819	1723
	STL	5SCB	F0001		1723	20	1717	1647

```
F0001   RAL  5LIJC           STEP IJC          1647  65  1904  1566
        ALO  173             ADDR CTR          1566  15  1869  1773
        SLO  174             IS LIJC MAX       1773  16  1526  1532
        NZA        CHECK                       1532  45  1586  1937
        ALO   8001                             1586  15  8001  1743
        STL  5LIJC                             1743  20  1904  1616
        RSL  5Q              REVERSE SIGN      1616  66  1748  1666
        STL  5Q              OF Q              1666  20  1748  1701
        BMI  176             TEST Q            1701  46  1716  1766
        RAL  5GETX           STEP XIJ          1766  65  1664  1919
        ALO  175             ADDRESSES         1919  15  1672  1727
        LDD  5STOX                             1727  69  1847  1650
        SDA  5STOX                             1650  22  1847  1700
        STL  5GETX 176                         1700  20  1664  1716
176     RAL  5SHP            STEP P            1716  65  1913  1767
        ALO  177             SHIFT             1767  15  1620  1925
        STL  5SHP                              1925  20  1913  1816
        SLT   0005           IS P ZERO         1816  35  0005  1679
        RAL   8002                             1679  65  8002  1838
        SLT   0001                             1838  35  0001  1795
        NZU  5LOOP                             1795  44  1550  1750
        RAL  5GMB            STEP              1750  65  1502  1866
        ALO  178             MUBAR             1866  15  1969  1823
        STL  5GMB  5LOOP     ADDRESS           1823  20  1502  1550

161     LDD   0000 171       CONSTANTS         1524  69  0000  1714
163     SLT   0000 168                         1720  35  0000  1733
165     RAB   0000 167                         1763  67  0000  1910
166     STL   0000 172                         1570  20  0000  1914
169      00   0000 F0001                       1552  00  0000  1647
173      00   0001  0000                       1869  00  0001  0000
175      00   0001  0000                       1672  00  0001  0000
177      00   0001  0000                       1620  00  0001  0000
178      00   0001  0000                       1969  00  0001  0000

          PHASE 6 CHECK NEW DISTRIBUTION

CHECK   RAL  180             INITIALIZE        1937  65  1640  1895
        STD  6GETX           XX ADDR           1895  24  1820  1624
        STD  6Z              SET Z PLUS        1624  24  1917  1920
        STU  6SUMX           SET SX TO 0       1920  21  1845  1848
        LDD  181             SET T TO          1848  69  1851  1668
        STD  6T    6LOOP     M PL 1 MIN N      1668  24  1801  1850
6LOOP   RSL  6Z              REVERSE SIGN      1850  66  1917  1821
        STL  6Z    6GETX     OF Z              1821  20  1917  1820
6GETX   LDD   0000 182       XX TO DIST        1820  69  0000  1967
182     BMI  6XLH  6XRH      TEST Z            1967  46  1870  1871
6XLH    RAL   8001 184                         1870  65  8001  1578
184     SRT   0005 6UPSX     X IN LA           1578  30  0005  1792
6XRH    RAL   8001                             1871  65  8001  1729
        AUP  6GETX           STEP XX           1729  10  1820  1626
        AUP  183             ADDRESS           1626  10  1779  1783
        STU  6GETX                             1783  21  1820  1574
        SLT   0005                             1574  35  0005  1888
        RAL   8002 184                         1888  65  8002  1578
```

```
6UPSX   ALO  6SUMX         UPDATE          1792  15  1845  1799
        STL  6SUMX         SUM X           1799  20  1845  1798
        RAL  6T            END OF          1798  65  1801  1618
        SLO  185           LOOP TEST       1618  16  1921  1676
        NZA        6CXWS                   1676  45  1630  1582
        STL  6T    6LOOP                   1630  20  1801  1850
6CXWS   RAL  6SUMX         COMPARE SUMX    1582  65  1845  1849
        SLO  SUMS          WITH SUMS       1849  16  1931  1885
        NZA        186                     1885  45  1938  1589
        HLT   9008  9008   STOP            1938  01  9008  9008
186     RAL  5SCB          IS SIGCBAR      1589  65  1717  1971
        NZA        187     ZERO            1971  45  1674  1726
        HLT   9011  9011   STOP            1674  01  9011  9011
187     PCH  A0001         PUNCH IJC       1726  71  1827  1628
        PCH   1927         PUNCH           1628  71  1927  1678
        RAL  RPC1          ALTERNATE       1678  65  1632  1639
        LDD  AO    315P7   OPTIMAL         1639  69  1400  1718
 1927    00   1928  0007   SOLUTION        1927  00  1928  0007

183      00   0001  0000   CONSTANTS       1779  00  0001  0000
185      00   0001  0000                   1921  00  0001  0000
```

RESTART PUNCH SUBROUTINE

```
RPSUB   STD  RPXX          PUNCH           1900  24  1768  1722
        PCH   1927         MASTER DATA     1722  71  1927  1728
        RAL  RPC1          CARD AND        1728  65  1632  1689
        LDD  RPXX  315P7   IJC XX          1689  69  1768  1718
RPC1     00   0000  0000   TABLES          1632  00  0000  0000
```

PROG 315 P7 PUNCH SUBROUTINE

```
315PC   RAL   8000 315P7   PCH CONSOLE     1950  65  8000  1718
315P7   STD  315XX         STORE EXIT      1718  24  1772  1776
        LDD  315A          SET             1776  69  1680  1534
        SDA  315A          FWA             1534  22  1680  1584
        SLT   0004         AND             1584  35  0004  1945
        SDA  315B          LWA             1945  22  1899  1602
        RAL  315A  315J    FWA TO LA       1602  65  1680  1935
315J    AUP  315C          LWA TO UA       1935  10  1739  1793
        LDD  315D          SET CONTROL     1793  69  1596  1949
        SDA  P0001  8002   WORD            1949  22  1877  8002
315F    AUP  315E          STEP PCH ADR    1901  10  1818  1724
        SLO  315B          HAS LAST        1724  16  1899  1868
        SUP   8003         WORD BEEN       1868  11  8003  1826
        NZA        315G    STORED          1826  45  1730  1682
        AUP   8001                         1730  10  8001  1789
        ALO  315E                          1789  15  1818  1774
        ALO  315B                          1774  15  1899  1918
        SUP  315H          HAVE 7 WORDS    1918  11  1822  1778
        NZU        315I    BEEN STORED     1778  44  1732  1782
        AUP   8001  8002                   1732  10  8001  8002
315I    PCH  P0001 315J    PUNCH 7 WDS     1782  71  1877  1935
315G    RAL   8001         MODIFY          1682  65  8001  1839
        SLO  315H          CONTROL         1839  16  1822  1780
```

	SRT	0004		WORD ON	1780	30	0004	1842
	ALO	P0001		LAST CARD	1842	15	1877	1634
	STL	P0001		PUNCH	1634	20	1877	1684
	PCH	P0001	315XX	LAST CARD	1684	71	1877	1772
315A	69	0000	8003	CONSTANTS	1680	69	0000	8003
315C	24	P0002	315F		1739	24	1878	1901
315D	00	0000	0007		1596	00	0000	0007
315E	00	0001	0000		1818	00	0001	0000
315H	24	P0009	315F		1822	24	1885	1901

5/17/56

496 1/5

The Transportation Problem

S Poley

Machine Operating Notes

ut Deck Descriptions:

Program I: (81 cards serially numbered from 496T1 000 to 496T1 081)

	Small	Big
1)	Program I	Program I
2)	Master Data Card I	Master Data Card I
3)	D_i's	D_i's
4)	S_j's	S_j's
5)	Cost Matrix	Blank Card
6)	Blank Card	Cost Matrix

Program II: (148 cards serially numbered from 496T2 000 to 496T2 148)

	Small	Big	
1)	Program II	Program II	
2)	Master Data Card II }	Master Data Card II }	Output of Program I
3)	(ij C_{ij}) Table }	(ij C_{ij}) Table }	
4)	X_{ij} Table }	X_{ij} Table }	
5)	Cost Matrix	Blank Card	
6)	Blank Card	Cost Matrix }	Circulate in Read Feed
		Cost Matrix }	
		⋮	

Program III: (115 cards serially numbered from 496T3 000 to 496T3 115)

1)	Program III	
2)	Master Data Card III }	Output of Program II
3)	(ij C_{ij}) Table }	
4)	X_{ij} Table }	
5)	Blank Card	
6)	(ij C_{ij}) Alternate Optima Indications }	Output of Program II

533: Place appropriate deck in read feed, blanks in punch feed and use 650 Utility Control Panel.

50:

Half-cycle	switch	- RUN
Display	"	- DISTRIBUTOR
Overflow	"	- STOP
Programmed	"	- STOP
Error	"	- STOP
Storage entry switches -		70, 1951, 3000

1) Press computer-reset key
2) " program-start key
3) " read and punch start key on 533.

Program I:

Press end -of-file key when read hopper empties.

Programmed Stops	Cause and Action
9000	$\sum D_i \neq \sum S_j$: terminate run; check input data.
9001	Number of basis elements $\neq (m+n-1)$; should not occur.
9002	Normal stop at end.

Restart Procedure:

If stop is due to key punching error (double punch, blank column, no sign, etc.) fix bad card and place remainder of input deck with error card first in read feed.

a) Press computer-reset key
b) Press read start key on 533
c) Manually transfer control to 1988.

If stop is not due to key punching error, start over.

Program II:

Small: Press end-of-file key when read hopper empties
Big: Circulate cost matrices in 533 read feed.

Programmed Stops	Cause and Action
0001	Cannot calculate UV table; pressing program start will give machine second chance to calculate UV table.
0002	Second chance to calculate UV table unsucessful; basis distribution is degenerate; pressing program start key will cause punching of incomplete UV table for visual study; terminate run.
9003	Normal stop; end of UV punchout
9004	Normal stop; punching of solution over and alternate optima indications are not desired.
9005	Normal stop; punching of alternate optima indications over.
0006	Error in μ table; pressing program start will give machine another chance to calculate μ table.
9007	Duplicate basis element; error restart.
9008	$\sum X_{ij} \neq \sum S_j$ (amount shipped not equal to amount available); error restart. (If not using distribution given by Program I, error may be due to incorrect data)
9009	Total cost has increased; error restart. (This stop should not occur)
9010	This stop should not occur; error restart.

Restart Procedure:

At the end of phase 6 (checking), the sign of the storage entry switches is interrogated. If it is minus (-), the current master data card and basis table * will be punched out in exactly the same form as the input initial distribution. This output serves two purposes:

* (ij C_{ij}) and X_{ij} tables.

1) It may be used as an "initial distribution" at some future time if it is desired to run the problem in stages.
2) It is loaded back into the 650 in the event of an error restart.

Thus the machine operator should periodically, during the course of running a problem, set the sign of the storage entry switches to minus and obtain the punchout described above.

rror Restart:

Place the following deck in the 533 read hopper:

Small	Big
Last restart punchout **	Last restart punchout **
blank card	blank card
	cost matrix
	cost matrix
	⋮

(be sure to "zero" the cost matrices in big problem)

Press computer-reset key and manually send control to 1975. Press read start on 533.

If it is suspected that the program has been damaged, start over using the last restart punchout as an initial distribution. If stop is due to key punching error, follow procedure given under Program I.

rogram III:

Press end-of-file key when read hopper empties.

Programmed Stops	Cause and Action
0006	Same as Program II
9007	Same as Program II
9008	Same as Program II
9011	Change in cost ≠ zero; error restart.

** Master data card, (ij C_{ij}) and X_{ij} tables.

rror Restart:

Place the following deck in the 533 read feed:

master data card (ijC_{ij}) table X_{ij} table	} last good alternate optimal solution punched
blank card	

Press computer-reset key and manually transfer to 1988: Press read start on the 533.

If it is suspected that the program has been damaged, start over using the last good alternate optimal solution in place of the output of Program II.

APPENDIX B

MODIFICATION TO IBM PROGRAM 496

To modify a program listed on a deck of cards, it is only necessary to place the cards containing the modifications at the end of the program deck. The necessary modifications to the IBM program are listed below.

Card Number	Location of Instruction	Operation Code	Data Address	Instruction Address
1.	1247	20	1934	1209
2.	1850	71	1927	1730
3.	1730	65	1748	1776
4.	1748	00	0000	1358
5.	1776	69	1205	1745
6.	1745	23	1205	1836
7.	1655	46	1358	1795
8.	1795	45	1336	1358
9.	1336	20	1312	1465
10.	1282	24	1235	1487

VITA

Richard Hays Gibbs

Candidate for the Degree of

Master of Science

Thesis: THE STUDY OF A MODIFICATION TO IBM PROGRAM 496

Major Field: Industrial Engineering

Biographical:

Personal data: Born in Pittsburgh, Pennsylvania, November 24, 1933, the son of Albert S. and Edith H. Gibbs.

Education: Attended grade school in Pittsburgh, Pennsylvania; graduated from Peabody High School, Pittsburgh, in 1950; received the Bachelor of Science degree from the Pennsylvania State University, with a major in Industrial Engineering, in June, 1954; completed requirements for the Master of Science degree in May, 1957.

Professional experience: Entered the United States Air Force in 1954, and is presently a First Lieutenant.

REPORT TITLE: THE STUDY OF A MODIFICATION TO IBM PROGRAM 496

AUTHOR: Richard Hays Gibbs

REPORT ADVISER: Professor H. G. Thuesen

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TYPIST: Edith M. Peterson