A PROGRAM FOR THE ANALYSIS OF VARIANCE OF HIERARCHICAL CLASSIFICATION DESIGN

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PREFACE

One of the problems confronting the researcher in any field of scientific research is encountered in analyzing the data he collects in experimentation. The researcher might have information on many variables to consider. This data may be derived from a large population. Because of burdensome and lengthy computations necessary for the analysis of such data, programming research was done to investigate the possibility of computing an analysis of variance of the hierarchical classification design having five stages. An investigation of the computer program libraries indicated that several such programs existed, but none was found which computed the coefficients of the variance components in the expected mean squares. It was found also that no program existed which approached the magnitude and scope of the one written in connection with this study.

Because of machine storage limitation, further studies were made to determine the most probable difficulties in such a program and determine ways of circumventing said difficulties. This was done in a manner such that a layman in the field of computers could run this analysis on a problem of great magnitude without being overcome by millions of computations.

Indebtedness is acknowledged to Dr. Robert D. Morrison for his invaluable guidance and resolution in seeing this problem through; to Drs. Franklin A. Graybill, Carl E. Marshall, and Roy B. Deal, for their concurrence in the necessity of this work; to Drs. L. Wayne Johnson and James H. Zant for their encouragement and for giving me the opportunity to work these last four years at the Oklahoma State University Computing Center; and to my wife, Jane, for her tireless efforts in connection with this work.

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CHAPTER I

INTRODUCTION

The problem confronting the scientific researcher is not at all lessened by the lack of an efficient way of analyzing the results of his experiments. Indeed, there is little reason why the researcher should be reduced to the drudgery of systematic button-pushing on a desk calculator which could make him little more than an automaton.

Mathematicians and statisticians have derived procedures which, in some cases, give the researcher a method by which he may reduce experimental data to a more sensible form. Once having done this, he may arrive at better conclusions. Unfortunately, the methods for the reduction of data are, in some instances, quite cumbersome.

How, then, should this problem be resolved in a manner which will enable the experimenter, with little knowledge of mathematics and statistical procedures, to compute a needed analysis of his experimental data? The answer lies with the numerical analyst and programming specialist and with the high-speed digital computer. The numerical analyst and programmer necessarily must have a complete understanding of high-speed computer aritmetics and a voluminous "bag of tricks" to call upon when confronted with a problem of this scope. He not only faces storage limitations and the problem of complicated arithmetics, but indeed faces the fact that large numbers of calculations will introduce errors which must be compensated for.

The program described in this thesis takes into consideration the propagation of error and the limitation in storage space. It gives the experimenter a method which practically eliminates the desk calculator and the endless hours of computation. The speed of the program depends upon the nature of the data. It will vary from approximately sixty cards per minute to card-feed speed (200 cards per minute), depending upon the number of variables to be processed simultaneously.

In the pages that follow, the reader will find a description of the program with instructions for its use. These instructions include suggestions for analyzing any difficulties which may arise and methods for overcoming them. The appendix contains a seven-per-card listing of the program, HI-AOV, as well as a sample problem and its analysis.

CHAPTER II

THE PROGRAM: HI-AOV

This program is designed to compute the analysis of variance for a hierarchical classification design having five stages or less. It also computes the coefficients of the variance components for each mean square. The program will handle as many as ten variables simultaneously, each variable being limited to five digits or less. The mathematical model for each variable may be written as:

$$Y_{ijklm} = \mu + A_i + B_{ij} + C_{ijk} + D_{ijkl} + E_{ijklm} .$$

The IBM 650-653 with the following hardware is necessary:

Sixty words immediate IAS core storage

Three index registers (A, B, and C)

Floating point devices

IBM 533 read-punch unit and proper control panel

This program does not require a header card, since all controls are held within the program. All variable arithmetics are done in double-precision, fixed-point arithmetic. A maximum of 100,000 entries on each of the ten variables is provided for without possibility of overflow. Missing data that is properly identified will not disrupt the processing. This, along with complete validity and sequence checking, makes HI-AOV virtually fool-proof. Since machine time may be restricted to short intervals, a provision is made which will allow the operator to leave the machine any time during processing and complete the processing at a future time.

Preparation of Data

Although the data to be processed may be in a form other than standard 80-80, such a handicap can be overcome by board-wiring. If the standard 80-80 board is to be used, then storage entry is of the following form:

1. Columns 1 through 20 are used for the identification and classification of the variables within each card. Columns 1 through 4 are used for the highest classification; that is, class A. Columns 5 through 8 are used for the next highest classification; that is, class B. The remaining classifications follow this pattern through column 20, columns 17 through 20 containing class E. Sequence checking is done on these twenty columns. This provides for as many as 9,999 items under each of the five classifications, so long as the total number of items under any one variable does not exceed 100,000. If four-digit data is to be used for all the variables, then the maximum number of obser-

vations on any variable may not exceed one million. It is absolutely necessary that the identification field be in sort. If standard 80-80 input is used, sorting begins in column 20 and proceeds normally through column 1. If a special board is used, an equivalent sort must be made. The number of observations in any classification must remain less than 10,000.

2. Columns 21 through 30 are provided as a control, indicating to the machine whether or not a variable is present. Column 21 is used to control variable number 10, which occupies columns 31 through 35. Column 22 is used to control variable number 9, which occupies columns 36 through 40. This pattern continues, and column 30 controls variable number 1, which occupies columns 76 through 80. It is to be noted that the magnitude of each variable occupies a space less than or equal to five digits. If a variable is to be used, a one is placed in the control column governing that variable. Otherwise, a zero is placed in the control column. It is absolutely necessary that the first thirty columns in each card be punched and that columns 21 through 30 have nothing other than zeros or ones. If either of

the two variables within a word is to be used, then the word must be filled completely with numerics, and only that portion of the word designated by the control will be used. The other portion of the word will be disregarded. If the variables appearing within one word are of different signs, then it is necessary to have a second card with the proper sign of the second variable and with proper control digits. The classification of the two cards must be the same, but the control field will necessarily be different. (See examples in the Appendix, Table III.)

3. The <u>trailer card</u> follows the last data card into the machine and causes the final punch-out of the analysis of variance and the values of coefficients of the variance components of the mean square. The trailer card is a non-load card consisting of zeros in columns 1 through 30. If board-wiring difficulties prevent using a trailer card of this form, the operator may manually transfer the computer to location 1913 to obtain the analysis of variance punch-out. Transfer must be made by using the address selection switches, not the console (8000).

Problem Number

If desired, a problem number may accompany the data. A space of two digits is provided for this purpose. The number is entered on a load card (see Appendix, Table III), and this card should be placed at the beginning of the data to be processed. It can, however, be entered any time preceding the trailer card.

Intermediate Memory Dump

It may be desirable to dump the storage of the machine at some time during the processing of the data. This can be done by placing a load card (see Appendix, Table III), which transfers the machine to location 1400. This will cause the storage to be dumped in seven-per-card format with all leading zeros skipped. The last two cards of the memory dump are necessary for reloading. The first of these two cards has the problem number and console setting. The last card contains the classification of the last data card processed, as designated in columns 1 through 20. Zeros are punched in the control field, columns 21 through 30. Word one in all memory dump cards will be negative. This is necessary for output separation, commonly called "bursting".

An alternate method for starting an intermediate memory dump consists of the following sequence of operations:

1. Depress PROGRAM STOP key.

2. Remove the unprocessed data cards from the read hopper.
3. Replace hopper block and depress PROGRAM START key.
4. Depress END OF FILE key, thus allowing the data cards in the read feed to be processed.
5. Manually transfer to location 1400, using address selection switches, not the console (8000), since the console setting will appear as part of the memory dump.
6. Place the unprocessed data cards in the read hopper, and depress READ START key.

The intermediate memory dump routine will momentarily interrupt the flow of data. When the dump is completed, processing will continue as if there had been no memory dump.

Data Stop Card

If desired, the data processing may be halted at any specific point. The data stop is entered on a load card (see Appendix, Table III), and this card can be placed at any point within the data.

A code number may be put in the stop card, and this number will appear in the program register. The range of acceptable code numbers is 0000 through 1999.

Starting the Program

The console settings to follow have reference to a normal setting of the console which will compute the results given in the Appendix,

Table V.

1. Console switches (8000) . . . . 7019511299+
2. Program switch . . . . STOP
3. Half-cycle switch . . . . RUN
4. Address selection switches 1400
5. Control switch . . . . RUN
6. Display switch . . . . PROGRAM REGISTER
7. Overflow switch . . . . STOP
8. Error switch . . . . STOP
9. Standard 80-80 control panel in 533 (load hub column 1)

Once the switches are set as desired and the control panel is in position, place program deck in the read hopper, depress COMPUTER RESET key, PROGRAM START key, and READ START key, in that order. This done, the program will start loading and will automatically transfer control to HI-AOV when loading is completed. After at least six cards have been loaded and before the first data card is read in, it is necessary that the operation code (70) in the console switches (8000) be changed to No-op (00).

The program deck has load punches in some cards. The balance of the program deck, though in seven-per-card format, consists of non-load cards. If a special format for data is used, it will be necessary to load the program with standard 80-80 control panel. Then the control panel must be changed to the special format entry.

All output is in 80-80, and the special control panel must be wired accordingly.

Special Console Settings

If desirable, some of the operations and validity checks may be bypassed. The list which follows will explain the effect of certain control settings on the program.

1. The two low-order digits of 0019511299+ in the console (8000) control the routing of the program internally. The units digit (right) controls the calculation of the coefficients of the variance components in the expected mean squares. Setting this switch to 8 instead of 9 will cause computation of the coefficients to be bypassed. The tens digit (left) controls the hierarchical analysis of variance computation within the machine. Setting this switch to 8 will cause the analysis of variance to be bypassed. Any of four combinations of nines or eights is acceptable to HI-AOV. Either switch may be turned from 9 to 8 during the processing of data in order to bypass computation, but changing from 8 to 9 in either column will cause erroneous results.

2. The sign of the console (8000) controls the intermediate punch-out. Setting the sign positive will bypass the

intermediate punch-out. The sign may be changed during processing at the discretion of the operator without disrupting the processing of data.

3. The program switch can be set to RUN. This will cause out-of-sequence data to be bypassed completely. Setting the switch to RUN will also cause some error stops due to invalid console settings to be bypassed and transfer the machine into a loop which will stop data processing. The stop at the completion of analysis of variance punch-out will also be bypassed. All data storage within the machine will be zeroed out, and the program will be set for a new problem which can be run without interruption.

4. The error switch may be set to SENSE. This will cause any blank column or multiple punch to be sensed. Once sensed, the data card in its entirety will be rejected, and the following data card will be read into the machine. The error signal light will be turned on if a faulty data card has been sensed. The signal light may be turned off by depressing the ERROR RESET key.

Items 3 and 4 are inserted for explanation and should not be used under normal circumstances. For instance, should the machine make an electronic error within the arithmetic unit, all processing of data in the buffer storage will be halted, and a new data card will be read in. This could cause erroneous results.

Error Stops

If the computer stops during the processing of data, the following information will aid in determining the reason for the halt. The digits in the left column below refer to the program register, which will be displayed when the computer stops.

0180001206 . . . . . . This instruction indicates either that the operation code in the console has not been changed to read No-op (00) or that the four low-order digits are not acceptable. Correct the console (8000) to read 00195112XX and depress the PROGRAM START key. The "XX" must be either eights or nines as described in "Starting the Program".

0180001303 . . . . . . This instruction indicates that the console setting (8000) does not agree with the console setting during an intermediate memory dump. The correct setting will appear in the distributor (8001). Correct the console setting and depress the START key.

0112381288 . . . . . . This instruction indicates that the next card to be processed is out of sequence. The identification of the last card accepted for processing is displayed in the upper and lower halves of the accumulator. Depressing the PROGRAM START key at this point will cause the out-of-sequence card to be bypassed. If desirable, the out-of-sequence card may be removed for inspection. If inspection is desired, first remove all data cards from the read hopper. Depress the READ START key and run the balance of the cards into the read stacker. Of those cards now in the read stacker, the fourth from the back is the offending data card. The first three cards are unprocessed data cards and should be placed in front of the cards that were removed from the read hopper. If the out-of-sequence card can be corrected and put in its proper place, this should be done. If it is necessary to omit this card, place the unprocessed data cards in the read hopper and depress the PROGRAM START key. Then press the READ START key, and the data processing will continue.

0112001200 . . . . . . This instruction indicates that all processing on a particular set of data is completed. Depress the PROGRAM START key. This will zero out all the data storage within the machine and reset HI-AOV for the next problem.

Error Stop . . . . . . (with signal light) This light almost invariably indicates blanks or multiple punches in the input data. The offending card may be located by following the same procedure as described in "0112381288". If the offending card can be corrected, this should be done and the card put in its proper place in the unprocessed data stack. Place unprocessed data cards in the read hopper. Depress COMPUTER RESET, PROGRAM START, and READ START keys, in that order. Processing will now continue. Examination of the program register may be helpful in locating the error. The low-order digit of the data address will indicate, within ten columns, the faulty region of the input card. Displaying the distributor will indicate precisely what is wrong with the input card.

Error Stop . . . . . . (with no signal light)	Examine the operation code in the program register. If the operation code is in the nineties, locate the faulty data card as described in "0112381288". The control field on the data card thus removed has digits other than zeros or ones in the control field. Correct faulty card, if desired, and place it in front of the unprocessed data cards in the read hopper. Depress COMPUTER RESET, PROGRAM START, and READ START keys, in that order. Processing will now continue. The faulty control field column will appear as a digit other than 9 or 8 in the distributor.
Other Errors	Any other errors are due to faulty control panel wiring or internal difficulties.

Intermediate Punch-Out

At the discretion of the operator, the mean, corrected sum of squares, mean squares, and degrees of freedom within any D (next-to-lowest) classification may be obtained by setting the console switch (8000) to minus. The switch may be changed at will while the program is running without causing an error stop. However, if the tens digit of the console (8000) is set to 8, the sign of the console must be negative during the entire processing of any one D group for which the intermediate punch-out is desired. The output card will contain the identification of the last card accepted within D group, as well as the values mentioned above. (See Appendix, Table IV.) Word two of the intermediate punch-out will be negative for sorting purposes. (See "Bursting".)

Starting the Program after an Interruption

If the operator has been forced to relinquish the machine following an intermediate memory dump, the program can be started again by the following procedure:

1. Remove the transfer card from the back of the program deck. (See Appendix, Table II.)
2. Place the program deck, followed by the intermediate punch-out deck, in the read hopper.
3. The next-to-last card in the memory dump deck must be changed to a load card. Word one in this card will read, "0000PN1303", where "PN" indicates a problem number. Word two will contain the console setting as it was during the intermediate memory dump. (See Appendix, Table IV.)

4. Use the procedure as described in "Starting the Program", and load the program deck and intermediate dump deck completely before placing unprocessed cards in the read hopper.

If special input format is used, the special control panel must be inserted immediately following the loading of the decks mentioned above and before any new data is fed in.

Bursting

During the processing or after the completion of an analysis, the operator may wish to separate the output. This may be done on the sorter in the following sequence where applicable.

1. Sort out only those cards with negative signs in column 10. The cards will be memory dump cards and will be in sequence if sorted properly.
2. Sort out only those cards with negative signs in column 20. These will be the intermediate punch-out cards and will be in sequence if sorted properly.
3. A further bursting can be done at the discretion of the operator by examining the output listings. (See Table V and Table VI in the Appendix.)

Analysis of Variance

Assume there are a A units, each with n_i samples $(\sum_i n_i = N)$;

each A unit has b_i B units, each B unit having n_{ij} samples; each B unit has c_{ij} C units, each C unit having n_{ijk} samples; each C unit has d_{ijk} D units, each D unit having n_{ijkl} samples; each D unit has e_{ijklm} E units, each E unit being a sample.

The analysis of variance is as follows:

TABLE I

ANALYSIS OF VARIANCE

Source	d.f.	S.S.	M.S.	Coefficients of variance components E(MS)				
Total	N-1	TSS		σ_E^2	σ_D^2	σ_C^2	σ_B^2	σ_A^2
A	a-1	SSA	$\frac{SSA}{a-1}$	1	a_3	a_4	a_5	a_6
B in A	$\sum_i b_i - a$	SSB	$\frac{SSB}{\sum_i b_i - 1}$	1	b_3	b_4	b_5	
C in B	$\sum_i \sum_j c_{ij} - \sum_i b_i$	SSC	$\frac{SSC}{\sum_i\sum_j c_{ij} - \sum_i b_i}$	1	c_3	c_4		
D in C	$\sum_i \sum_j \sum_k d_{ijk} - \sum_i \sum_j c_{ij}$	SSD	$\frac{SSD}{\sum\sum\sum d_{ijk} - \sum\sum c_{ij}}$	1	d_3			
E in D	$N - \sum\sum\sum d_{ijk}$	SSE	$\frac{SSE}{N - \sum\sum\sum d_{ijk}}$	1				

The uncorrected sum of squares is punched out with no decimal places. The coefficients of the variance components are punched in floating point; the mean and other sums of squares and mean squares are rounded to two decimal places more than in the uncorrected sums of squares. These computations are based on the following formulas.

$$TSS = \sum_i \sum_j \sum_k \sum_l \sum_m Y^2_{ijklm} - \frac{(\text{GRAND TOTAL})^2}{N}$$

$$SSA = \sum_i \frac{\left(\sum_j \sum_k \sum_l \sum_m Y_{ijklm}\right)^2}{n_i} - \frac{(\text{GRAND TOTAL})^2}{N}$$

$$SSB = \sum_i \sum_j \frac{\left(\sum_k \sum_l \sum_m Y_{ijklm}\right)^2}{n_{ij}} - \sum_i \frac{\left(\sum_j \sum_k \sum_l \sum_m Y_{ijklm}\right)^2}{n_i}$$

$$SSC = \sum_i \sum_j \sum_k \frac{\left(\sum_l \sum_m Y_{ijklm}\right)^2}{n_{ijk}} - \sum_i \sum_j \frac{\left(\sum_k \sum_l \sum_m Y_{ijklm}\right)^2}{n_{ij}}$$

$$SSD = \sum_i \sum_j \sum_k \sum_l \frac{\left(\sum_m Y_{ijklm}\right)^2}{n_{ijkl}} - \sum_i \sum_j \sum_k \frac{\left(\sum_l \sum_m Y_{ijklm}\right)^2}{n_{ijk}}$$

$$SSE = \sum_i \sum_j \sum_k \sum_l \sum_m Y^2_{ijklm} - \sum_i \sum_j \sum_k \sum_l \frac{\left(\sum_m Y_{ijklm}\right)^2}{n_{ijkl}}$$

$$a_3 = \frac{\sum_i \sum_j \sum_k \sum_l n^2_{ijkl}\left(\frac{1}{n_i} - \frac{1}{N}\right)}{a-1}$$

$$a_4 = \frac{\sum_i \sum_j \sum_k n^2_{ijk}\left(\frac{1}{n_i} - \frac{1}{N}\right)}{a-1}$$

$$a_5 = \frac{\sum_i \sum_j n^2_{ij}\left(\frac{1}{n_i} - \frac{1}{N}\right)}{a-1}$$

$$a_6 = \frac{\Sigma n_i^2 \left(\frac{1}{n_i} - \frac{1}{N} \right)}{a-1}$$

$$b_3 = \frac{\Sigma\Sigma\Sigma\Sigma n_{ijkl}^2 \left(\frac{1}{n_{ij}} - \frac{1}{n_i} \right)}{\Sigma b_i - a}$$

$$b_4 = \frac{\Sigma\Sigma\Sigma n_{ijk}^2 \left(\frac{1}{n_{ij}} - \frac{1}{n_i} \right)}{\Sigma b_i - a}$$

$$b_5 = \frac{\Sigma \Sigma n_{ij}^2 \left(\frac{1}{n_{ij}} - \frac{1}{n_i} \right)}{\Sigma b_i - a}$$

$$c_3 = \frac{\Sigma\Sigma\Sigma\Sigma n_{ijkl}^2 \left(\frac{1}{n_{ijk}} - \frac{1}{n_{ij}} \right)}{\Sigma\Sigma c_{ij} - \Sigma b_i}$$

$$c_4 = \frac{\Sigma\Sigma\Sigma n_{ijk}^2 \left(\frac{1}{n_{ijk}} - \frac{1}{n_{ij}} \right)}{\Sigma\Sigma c_{ij} - \Sigma b_i}$$

$$d_3 = \frac{\Sigma\Sigma\Sigma\Sigma n_{ijkl}^2 \left(\frac{1}{n_{ijkl}} - \frac{1}{n_{ijk}} \right)}{\Sigma \Sigma\Sigma d_{ijk} - \Sigma\Sigma c_{ij}}$$

The analysis of variance punch-out format and the solution to the problem appear in the Appendix, Tables V and VI.

CHAPTER III

SUMMARY AND CONCLUSIONS

A program was written which will compute the hierarchical analysis of variance of a design having as many as five stages and as many as ten different variables. It will also compute the coefficients of the variance components of the expected mean square. All computations are made simultaneously in such a way that error propagation is minimized. The sub-classes may be unequal. The automation within the program will allow for computations, which would otherwise be burdensome and lengthy, to be accomplished quickly. The speed of the program is governed by the number of variables within each card and the frequency of classification changes.

The flexibility built into HI-AOV will allow for eight different processings. These range from sequence and validity checking to intermediate punch-out within all D classifications, the over-all analysis of variance, and coefficients of the variance components. Since complete sequence and validity checking is done prior to the acceptance of any data for calculation, the possibility of erroneous results is virtually eliminated. The error stops and descriptions of these stops are designed with a computer layman in mind. If he follows the suggestions in the section entitled "Error Stops", his work will be greatly simplified. Experience has shown that header card design causes some difficulties, and this problem has been overcome by eliminating the header card entirely. Other common difficulties have been eliminated by advanced programming techniques.

Because of the magnitude of some problems, a provision is made which will allow the operator to relinquish the machine at any time during processing and return to complete his analysis later. This feature allows for a cumulative analysis if desired.

The complexities of the program are such that flow-charting and further alterations should not be undertaken. The entire drum and core are used, and there are no open locations.

APPENDIX

TABLE II

PROGRAM LISTING FOR HI-AOV

```
8000501954 4019531956 5100018003 6119551952 20921-1952 7090029900 1519589004  813008000
6090031957-2920009005 2790108003 5119509006 4090079009 5090089004       2000 2790008002
7090021952 7090129002 Cards 1, 2, and 3 are load cards; following are non-load cards     1
7019519003 6719519004 8880029005 3000049006 8280029007 8040009008 5100019012          2
5060009013 6979519014 2420009015 5900019016 4890079002                                3
0009720007 2790000977 2013011054 3000040985 8080031034 6706001305 2920001052 4109951032
0009790007 6519551309 9909841035  180001206 5112880988 2019611164 9010881035 2390011042
0009860007 3500020993 6709901757 4009910992 3500041149       1094 5100010997 6719511205
0009930007 6080031251 5190051302 6790011153 4010491150 4010500992 8200101354 2390031306
0010320007 4010850986 1567121567 5190011092 6519541409 9110391078    3001091 3000040999
0010390007 1011421078 5800101046 4211696000 6919531356 3500041353 1092301351    1001199
0010460007 6980061552 1526221377 3500031308 6714021757 5100091256 6719531207 4010551156
0010530007 2426011154 2092001062 5100500972 6780021065 2910001202 2426001053 2019531206
0010600007 4010631287 2909501152 4011651066 5006001058 6980051270 6080030973 8009000972
0010670007 2390020974 9512211073 3000051131 3000041081 3500021077 5190031080 6519561311
0010740007 9711270979 2119621315       1427 4409810982 5300011134 2019571210 4109951084
0010810007 2390041038 6539641269 2060901143 4009871138 6711881757 6790081193 7119771279
0010880007 6719511255 3500041349 1014011656 6711441757 4109950996            6710971757
0010950007 2160801083 6080031603    1001427 4516521903 8080031158
0011220007 6566121418 6710761757 3500041135  112381288 8180011182 9809800979 6713311335
0011290007 8890061137 6980031036 2019591212 6790011089 2019811334 3000011041 8080030994
0011360007 3500031195 2790101242 3500041099 2019781281 6560501756 1080061399          1
0011430007 6766021358    4000998 6906018002 2014011304 1515141519 3369421871 1790041507
0011500007 3500041211 6719531307 2790281057 3500041513 5105001060 8888888888 2790381061
0011570007 2911001252 5190041166 5100011215 3000060975 6519581413 9312651167 8080021071
```

TABLE II (continued)

0011640007	6919531068	5100011054	4109951220	6519571261	4616211122	6980021175	5190020978
0011710007	1719521257	3413741226	3000051185	3000041235	9110781130	6580031183	2019551088
0011780007	6790061385	4511221570	4610821184	1790030989	8890061040	1490081146	6711421047
0011850007	2019631216	7119771877	7119771777	1192	2790101194	1090081697	1611421397
0011920007	6710451757	3500021449	960001502	1110931497	6080031653	2066021805	4517021654
0011990007	6714521757	8000591056	6719531857	2790381157	6919531456	6767001555	2190001213
0012060007	6780001163	1711551059	2466001453	2019531042	6919530980	8080031170	6919531074
0012130007	6080021171	3000041225	4009810992	6919531162	3000051079	3100011625	6580001277
0012200007	4011231124	9610741073	2166421645	2119601463	2012291232	2090061132	2119801654
0012270007	6919538002	6490071292		2001284	2390041238	1566221577	2419811086
0012340007	6039641319	2390011088	6719781583	3000041647	3000041249	1061101565	11
0012410007	1490071454	908621614	1180031501	9115081699	1161801685	819901880	3500031855
0012480007	4517521704	2390031606	6712531707	1719521407	6911551058	9015061657	4514081659
0012550007	2190001313	4011590992	6990001263	6580001465	9211621161	3100011917	3500051223
0012620007	2790101317	2390051070	1766001455	9410681167	2790101571	1790051125	112001200
0012690007	1592201327	2490050976	1719521357	3265521779	2119581361	2119771430	3500041285
0012760007	1719841390	9211801082	3500041789	6010931147	6880021139	8890061189	2015141667
0012830007	2019811384	6710371757	1790041043	7119771388	7019511051	7019511151	1288
0012900007	2019841787	1490071504	1090081599	1713011909	7	2190081753	
0012970007	3500031905	1288	1288	6719511858		4109951406	6580001922
0013040007	6080031661	6080021563	3000041067	1711551209	2015141617	3500051371	2119801733
0013110007	3500051273	4212501266	6080021271	2066011204	6580021173	2001320	900001352
0013180007	5980011274	1980031044	6713231757	3000050983	6060301988	3001427	
0013250007	4211281129	2119791704	2092201234	3600001551	6080051387	2119781531	9013691520
0013320007	6092301389	6719781383	6590081191	3500021141	3500021293	3000041797	2010931096
0013390007	6592201247	3000041701	1512941949	1616291938	6017541618	4514981450	2190081853
0013470007	1615141569	3500041973	1790021907	6080021560	1592401459	9015061657	1790051461
0013540007	6906011404	6080021813	9112591161	4511601201	1711421197	6580021217	3100011967
0013610007	6580021069	6080031160	8080031072	1766001605	3000051177	1420	2092401184

TABLE II (continued)

0013680007	3413241724	5300011325	3000041231	2119561359	2166321440	1001477	
0013750007	2160601414	2012291488	2026221506	6769021460	3413741674	3500031589	1592401239
0013820007	3100011539	1711421597	6766221727	4512791339	2119831436	3000021243	6980001244
0013890007	1592401297	2019841987	6520001876	1616291490	6017541718	4215481945	2019781781
0013970007	2090081254	2790001804	3000021655	6790011873		1556	6911551208
0014040007	9015081709	6080021264	8080031064	3500021363	2090081416	3500051421	1180021820
0014120007	8814621613	3500051075	2060701423	9013691520	6092301573	2390021174	2090081376
0014190007	1060601515	6713731757	2119541457	2166421745	6092301381	6180031831	2161101464
0014260007	6590081538	6719511355	6066321537	3369521479	2119781731	3500031439	2119771330
0014330007	2019811434	6590081241	1560901095	6019841889	6712401395	1016041914	1110931447
0014400007	6060401695	4813441945		6017541818		2019781782	
0014470007	1615141619	4918511902	1780061458	5000011926	6060801635	2001427	8200101609
0014540007	2090081512	8815051613	8200101262	6580021365	3500021715	2192301367	1870021510
0014610007	2119771280	8890061470	6580021321	2061201473	9211681570	2419801233	1790031275
0014680007	2067121516	6490081282	2067001403	3500041181	3266521929	6566121517	2119791682
0014750007	6590081033	2112291638	6712301757	6719781933	3413741924	3266321572	1080061489
0014820007	2010931196	4912361333	2119821785	2019831086	2119801536	3000041897	1566221778
0014890007	3000021145	4513691795	4813941945		6017541918		2019781932
0014970007	1615141819	6520001976	6580021558		3500021908	6766011405	6592201511
0015040007	2090081562	8890061314	5300011312	3500041267	5300011714	1001763	3500041721
0015110007	1561001755	6080031869	1790021471		1560701375	2166121143	2090081224
0015180007	3266321568	1060801435	6980061126	3000021227	2065521369	1980031048	6180031881
0015250007	1490081338	1616291838	1560501705	6068321687	3368421172	3266421622	6060501806
0015320007	2015141817	2119811484	6590081291	9213881140	2119811586	3413241424	1567121468
0015390007	2019791432	3412291480	2090001598				2019781836
0015470007	3500021703	5200011854	6580021708		1016041410	5980011258	6092301561
0015540007	6790011761	6080021364	6715091757	8816071613	1066021608	4513621913	3600001833
0015610007	1592401419	6080031969	1719531557	2119821485	1561201425	1016041616	2067121615
0015680007	2166321369	3100011675	6592201527	2900001288	2166321590	1592401431	2119801883

TABLE II (continued)

0015750007	4611781279	180001303	2066221475	6719781934	3367321964	3266521630	2119791582
0015820007	6019841639	1711421747	2119821935	2019831136	2119821636	6768021810	3600001566
0015890007	2015141767	6060401845	8013031698				3980031849
0015970007	2019781581	7190001648	3100011808		7119771478	2119801533	1515141469
0016040007	0000000060	2090071412	3000041417	2006001203	1167021658	6990071415	1180021870
0016110007	9113691800	1868021662	8200101169	2790401669	2166121665	1180021476	6580031525
0016180007	3261401668	2016231176	9015081709	6790061179	2166421895		6180031931
0016250007	2019791332	2190571840	6490081090	6067321837	100	2166521722	6019841689
0016320007	2119801783	1160801835	2119821985	1560901245	6019841989	3000041098	6080031595
0016390007	3000041499	2166621872	2090081748				6060301888
0016470007	4414511602	4814501851	1790031809		3413741774	6080021811	1515141769
0016540007	7119771678	6990078002	3100011564	6980061713	2190071915	2090081466	3413741474
0016610007	1516231627	3500041673	1080061521	2790101719	6092201523	6790061823	6580001575
0016680007	2161401393	908621664	8080021329	5980011677	3412291580	1719841290	2119811684
0016750007	2119801133	1121	6580001535	6719781786	3266321868	6880021541	1790021739
0016820007	6067421947	2019811534	6069621368	1661901295	1016041762	3369321861	6017541816
0016890007	3000041549	3500041751	7190081741				3412291879
0016970007	3100011803	1780051780	8800101859		1180031862	6080021712	1780061711
0017040007	7119771508	2060501503	2019841087	3500021663	5801001764	8800101765	3413241624
0017110007	3500021867	3600001686	8180011219	4217171268	1713011706	3261301766	6716201725
0017180007	3262401768	2960001411	3500041681	1719841839	2063521772	2119841937	6180031732
0017250007	3500021481	8080021940	1611421547	6013241579	2164521968	3500041591	2119791632
0017320007	3213241651	2119811584	2119811784	2019831186	6013241529	6767021612	6017541916
0017390007	3500041649	1790031348	2790001246				6017541472
0017470007	2019781631	6580001830	1180031760		1790021923	6080021864	2090091260
0017550007	2061001553	3500031815	2014111214	3500041919	6060601965	3500041771	2190001720
0017620007	1180021971	6713161757	1066221927	6980061671	2161301688	6580031775	2162401443
0017690007	6466221532	1790041278	2119841587	6017541822	2113741728	2119821601	1466221482
0017760007	3500041341	5803001333	2066221426	2165521322	6880021641	6066221328	2119791832

TABLE II (continued)

0017830007	2119811634	2119821386	2119831186	17124-1545	3000041198	6017541518	1790051847
0017900007	3500041801	2090571798				6060301540	
0017970007	2190071906	7190571288	1180031911	6012291588	1790051626	1619521972	2119821735
0018040007	2819901852	6980001611	1980031380	6990001863	2119821885	3500041770	1869021860
0018110007	3600001834	3413741974	1719521807	3500041276	6466221382	3262301866	6060601865
0018180007	3266421222	3100011875	2113241378	1719841939	3266621640	4515261828	2119791882
0018250007	2119821585	8300061391	6490071190	6017541716	3266321372	2090091691	3269321660
0018320007	2119801734	1016041610	1016041910	1660901345	2119791886	3368321812	4513421343
0018390007	2019841487	2090581398					3412291530
0018470007	4512881287		2117541666		6713011730	6716761890	2090091360
0018540007	5000011928	6490081218	2019841187	1811551559	3000041670	6780061318	3500041821
0018610007	3413741824	3500041723	2390051370	3600001438	1560701825	2162301738	1713011856
0018680007	2166321369	1590091827	2113741428	3413741874	2063421369	2190591690	2119801884
0018750007	2119801283	2090011441	5901001483	819901802	3266421422	6890571791	3269421920
0018820007	6068421148	6068521710	6013241429	2019831286	2119801936	6019841340	3412291679
0018890007	3000041749	8880021899					6063521672
0018970007	4513501601		3000041726			6580051776	7119771578
0019040007	1580061680	1110931347	4417591310	3500041467	2113011554	2019841437	1180021970
0019110007	3500041921	1867021814	6713661757	1180021773	3500041925	3263301966	2119801433
0019180007	3264521729	2119841337	3413741574	2119841737	2790001878	3500041740	2119811903
0019250007	2119841237	5900011902	1166021758	5900011498	2166521522		3269521379
0019320007	2119791486	1712401445	1712401495	2119831286	2119811986	6766021912	4513921493
0019390007	2019841637	5920001448					6590001904
0019470004	3413241524		2090001826				6590001904
0019640007	3413741326	1560701975	2163301788	2119801683	6017541272	1590091228	2113741528
0019710007	2113741628	4515761300	1790041790	2119791736	3500031633	2094071491	
0019850007	2119831336	2119821887	3000041248	3412291829	3000041799		
0019990001	0000000000	2119821887	3000041248	3412291829	3000041799		
0000001200	TRANSFER	CARD	(load card)				

TABLE III

SAMPLE DATA CONTAINING VARIABLES NUMBER 10, 9, 8

0000991300	Problem number in columns 5 and 6 (load card)			
0001000100	0100010001	1110000000	400004	400000
0001000100	0100010002	1110000000	300003	300000
0001000100	0100020001	1110000000	400004	400000
0001000100	0100020002	1110000000	500005	500000
0001000100	0200010001	1110000000	500005	500000
0001000100	0200010002	1110000000	600006	600000
0001000100	0200020001	1110000000	1000010	1000000
0001000100	0200020002	1110000000	1100011	1100000
0001000200	0100010001	1110000000	1400014	1400000
0001000200	0100010002	1110000000	1500015	1500000
0001000200	0100020001	1110000000	1600016	1600000
0001000200	0100020002	1110000000	1700017	1700000
0001000200	0200010001	1110000000	1800018	1800000
0001000200	0200010002	1110000000	1900019	1900000
0001000200	0200020001	1110000000	2000020	2000000
0001000200	0200020002	1110000000	2100021	2100000
0002000100	0100010001	1110000000	800008	800000
0002000100	0100010002	1110000000	600006	600000
0103331288	Stop card, number 0333 (load card)			
0002000100	0100020001	100000000	800008	800000
0002000100	0100020001	1010000000	800008-	800000-
0002000100	0100020002	1110000000	1000010	1000000
0103341288	Stop card, number 0334 (load card)			
0002000100	0200010001	1110000000	1000010	1000000
0002000100	0200010002	1110000000	1200012	1200000
0000001400	Intermediate memory dump card (load card)			
0002000100	0200020001	1110000000	2000020	2000000
0002000100	0200020002	1110000000	2200022	2200000
0002000200	0100010001	1110000000	2800028	2800000
0002000200	0100010002	1110000000	3000030	3000000
0002000200	0100020001	1110000000	3200032	3200000
0002000200	0100020002	1110000000	3400034	3400000
0002000200	0200010001	1110000000	3600036	3600000
0002000200	0200010002	1110000000	3800038	3800000
0002000200	0200020001	1110000000	4000040	4000000
0002000200	0200020002	1110000000	4200042	4200000
0000000000	0000000000	Trailer card (non-load card)		

TABLE IV

INTERMEDIATE PUNCH-OUTS

Intermediate Memory Dump

0000000007-0000000022	22	22
0000200007-0000000244	244	244
0000500007-0000000204	220	204
0000700007-0000003104	3104	3104
0000900007-0002936000	3096000	2936000
0001500007-0000000204	220	204
0001700007-0000003104	3104	3104
0001900007-0002866000	3058000	2866000
0002000007-0000000016	32	16
0002200007-0000000264	264	264

. . . . . . (CARDS OMITTED) . . . . . .

0010880007-6719511255	3500041349	1014011656	6711441757	4109950996		6710971757
0010950007-2160801083	6080031603	1001427	4516521903	8080031158	8888888888	8888888888
0011210001-0000000000	6080031603	1001427	4516521903	8080031158	8888888888	8888888888

0000991303-0019511299 Problem number and console setting (must be load card for reloading)

0002000100-0200010002 Identification of last card processed (non-load)

Intermediate Punch-Outs Within D Classification

Identification	Mean	Sum of Squares (Corr.)	Mean Square	Deg. Frdm. / Vbl. No. / Prob. No.
0002000100 0100020002-	100	16200	16200	11099
0002000100 0100020002-	900	200	200	10999
0002000100 0100020002-	100	16200	16200	10899

TABLE V

ANALYSIS OF VARIANCE OUTPUT FORMAT

Source	Word 1 Identification	Word 2	Word 3	Word 4	Word 5	Word 6	Word 7	Word 8
O_i	zero	zero	Overall Mean	Total S.S. (Corr.)		Total S.S. (Uncorr.)		Deg. Frdm. Columns 71 - 76; Vbl. No. Columns 77 - 78; Prob. No. Columns 79 - 80
A_i	zero	1	zero	SSA (fixed point)		MSA (fixed point)		
B_i	zero	2	zero	SSB	"	MSB	"	
C_i	zero	3	zero	SSC	"	MSC	"	
D_i	zero	4	zero	SSD	"	MSD	"	
E_i	zero	5	zero	SSE	"	MSE	"	
		Coefficients of the Expected Mean Square						
a_i	zero	11	a_3	a_4	a_5	a_6		
b_i	zero	22	b_3	b_4	b_5			
c_i	zero	33	c_3	c_4				
d_i	zero	44	d_3	(The a's, b's, c's, and d's in floating point)				

TABLE VI

ANALYSIS OF VARIANCE PUNCH-OUT

0000000000	0000000000	1713		481550		14200	311099
0000000000	0000000001			92450		92450	11099
0000000000	0000000002			302900		151450	21099
0000000000	0000000003			48000		12000	41099
0000000000	0000000004			20200		2525	81099
0000000000	0000000005			18000		1125	161099
0000000000	0000000011	2000000051	4000000051	8000000051	1600000052		11099
0000000000	0000000022	2000000051	4000000051	8000000051			21099
0000000000	0000000033	2000000051	4000000051				41099
0000000000	0000000044	2000000051					81099
0000000000	0000000000	1763		425950		14200	310999
0000000000	0000000001			110450		110450	10999
0000000000	0000000002			264500		132250	20999
0000000000	0000000003			32000		8000	40999
0000000000	0000000004			17000		2125	80999
0000000000	0000000005			2000		125	160999
0000000000	0000000011	2000000051	4000000051	8000000051	1600000052		10999
0000000000	0000000022	2000000051	4000000051	8000000051			20999
0000000000	0000000033	2000000051	4000000051				40999
0000000000	0000000044	2000000051					80999
0000000000	0000000000	1713		481550		14200	310899
0000000000	0000000001			92450		92450	10899
0000000000	0000000002			302900		151450	20899
0000000000	0000000003			48000		12000	40899
0000000000	0000000004			20200		2525	80899
0000000000	0000000005			18000		1125	160899
0000000000	0000000011	2000000051	4000000051	8000000051	1600000052		10899
0000000000	0000000022	2000000051	4000000051	8000000051			20899
0000000000	0000000033	2000000051	4000000051				40899
0000000000	0000000044	2000000051					80899

VITA

Paul Eugene Pulley, Jr.

Candidate for the Degree of

Master of Science

Thesis: A PROGRAM FOR THE ANALYSIS OF VARIANCE HIERARCHICAL CLASSIFICATION DESIGN

Major Field: Mathematics

Biographical:

Personal Data: Born in Oklahoma City, Oklahoma, November 14, 1924, the son of Paul Eugene and Nelle R. Pulley.

Education: Attended grade school and junior high school in Oklahoma City; graduated with honors and as a member of National Honor Society from Classen High School, Oklahoma City, in 1942; received the Bachelor of Science degree from the Oklahoma State University, with a major in mathematics, in May, 1957; completed requirements for the Master of Science degree, with a major in mathematics, oriented in the field of numerical analysis as applied to high-speed digital computers, in May, 1959.

Professional experience: Assisted in the initial installation of the Computing Center at the Oklahoma State University in 1956; worked as a graduate assistant in the Computing Center at the Oklahoma State University, doing special programming for the IBM 650-653 and teaching short courses and regular four-hour lecture sessions on the computer; did programming research for International Business Machines Corporation in New York City in the Scientific Research and Applied Programming Division, during the summer of 1957; helped set up an automation system for the Dallas Regional Office of the United States Department of Agriculture during the summer of 1958, the programming having been done for the IBM 705; is a member of Pi Mu Epsilon, national honorary mathematics fraternity; has accepted an appointment as Assistant Director of the Computation Center at the University of Kansas.