AD-A148 348 COSAGE (CONCEPTS ANALYSIS AGENCY'S COMBAT SAMPLE GENERATOR) ANALYSIS AND..(U) SCIENCE APPLICATIONS INC LA JOLLA CA D A HEIMBURGER ET AL. 29 APR 84 1/2

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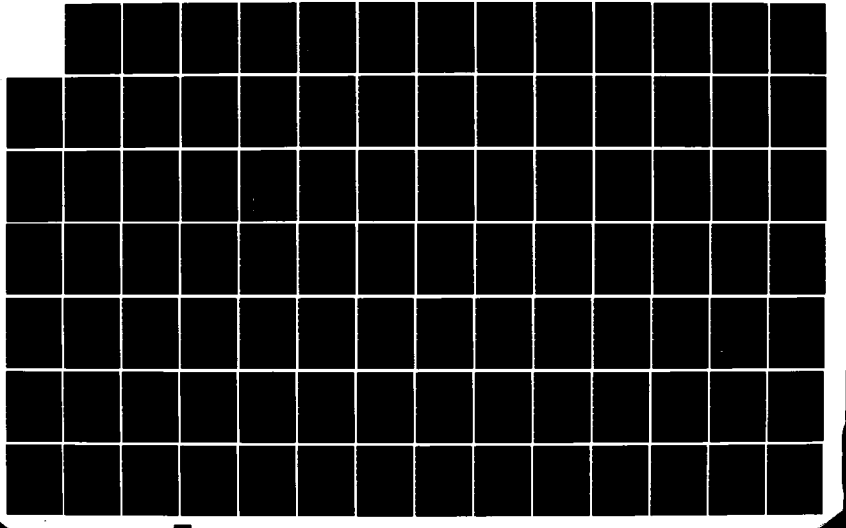

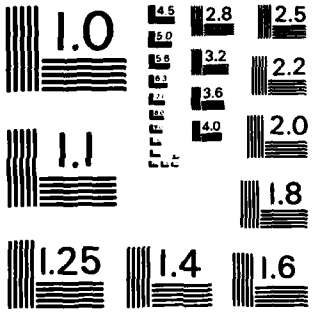

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FINAL DESIGN REPORT
FOR THE
STUDY ENTITLED
"COSAGE ANALYSIS AND DESIGN REPORT"
Volume I

SCIENCE APPLICATIONS, INC.

FINAL DESIGN REPORT
FOR THE
STUDY ENTITLED
"COSAGE ANALYSIS AND DESIGN REPORT"
Volume I

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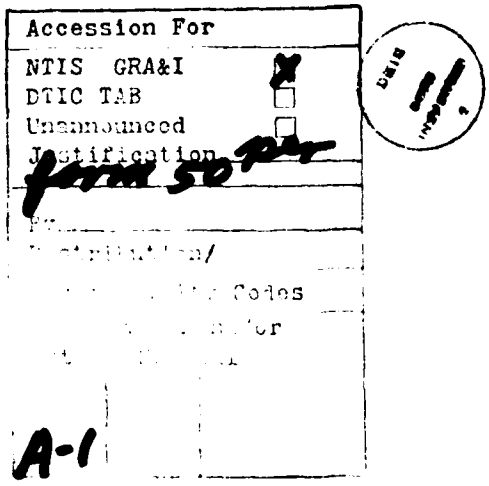

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1.0 INTRODUCTION

Science Applications, Inc. (SAI) has conducted a study of Concepts Analysis Agency's Combat Sample Generator (COSAGE) Program. This program consists of over 30,000 lines of SIMSCRIPT source code. It requires approximately 1.5 hours of SPERRY 1100/83 CPU time to execute and the maximum amount of static memory available (262K words). The goal of this study is to identify fruitful areas for COSAGE optimization which will reduce the COSAGE memory requirement as well as the execution time. To accomplish this, SAI has performed static and dynamic analyses of the source code. The purpose of this report is threefold:

- To present the results of the dynamic analyses effort;
- To preview the recommended changes; and
- To provide suggested COSAGE model PREAMBLE revisions.

This report is presented in three (3) volumes. The remainder of Volume I is organized in five sections:

- Section 2.0 presents the tools and techniques which were utilized to perform the dynamic analyses.
- Section 3.0 discusses the dynamic analyses performed and the results obtained.
- Section 4.0 previews the recommended optimization changes.
- Section 5.0 contains revision recommendations for the COSAGE model PREAMBLE.

- Section ~~8.0~~ 6 provides a summary of the optimization effort.

Volume II is the COSAGE SIMSCRIPT source code for the VAX computer which has been processed by SAI-SDDL*; Volume III contains COSAGE Hourly Invocation Reports for random number seeds 3, 6, and 10, respectively.

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2.0 ANALYSIS TOOLS AND TECHNIQUES

To facilitate the required analyses, SAI rehosted the COSAGE model on a virtual memory VAX computer in a "test suite" environment. This "test suite" incorporates numerous software tools and techniques:

- Science Applications, Inc.'s Software Design and Documentation Language (SAI-SDDL) was used to format the COSAGE source code and provide automated summaries such as a table of contents, module invocation hierarchy tree, and a variety of cross-reference listings. SAI-SDDL was also used for developing COSAGE input format specifications

- System Performance Monitoring (SPM) Tool was utilized to analyze COSAGE model execution at the operating system level

- Metrics were applied to obtain quantitative assessments of the complexity of the COSAGE source code

- VAX SIMSCRIPT Compiler was used to identify source code anomalies which the SPERRY compiler is unable to detect.

The remainder of this section discusses in more detail the tools and techniques which were utilized for the dynamic analyses.

2.1 Source Code Instrumentation

SAI has instrumented the COSAGE model source code in order to identify areas that would most benefit from optimization (i.e., routines most frequently invoked during model execution as well as COSAGE CPU usage by simulated hour). In order to capture routine invocations, counters were inserted into every COSAGE routine/process/event. These counters were incremented each time the module was invoked. Additionally, an event was develo[illegible]nat writes the counter values to a data file on an hourly [illegible]ulated time) basis and then clears the counters for the next data collection period. CPU usage was determined by [illegible]izing appropriate VAX system routines. In addition, the event mentioned above was modified to write the CPU usage for each simulated hour to a data file.

2.2 VAX System Performance Monitoring (SPM) Tool

SAI analysts applied the SPM tool to the COSAGE model. VAX-11 SPM is a set of programs which collect and report performance statistics for VAX/VMS systems. General performance statistics can be collected on a system-wide basis, and detailed statistics can be collected on a per-process basis.

Included in the SPM set is a package for measuring where a user's program is spending its time. To do so, the package periodically samples the program counter of the running program, determines in which portion/routine of the program each such sample falls, and displays the resulting information in histogram

form. Program counter samples are collected by trapping a clock interrupt every 10 milliseconds. The user is able to specify how the program is to be divided into sections called buckets for performance data collection. A bucket is defined by an address range, and accumulates the number of program samples in that address range through the use of a counter. The structure of the program to be measured may be specified in terms of very large divisions or individual routines as well as starting and ending addresses.

2.3 Metrics Analysis

SAI has employed two metrics analysis techniques with the COSAGE model. The first metric, control complexity, was developed by McCabe (Ref. [1], Appendix A, Volume III) and identifies software modules that are difficult to test and maintain. Control complexity is measured by cyclomatic number, which is the number of independent paths through the code. The criterion value for cyclomatic number is usually 10. That is, if there are more than 10 independent paths in a routine, then it is usually not possible to fully test all paths. Consequently, the program reliability and maintainability could be adversely affected.

The second metric, operand complexity, is traditionally measured by Halstead's length metric (Ref. [2], Appendix A, Volume III) which is the sum of the operator occurrences (e.g., +, -, *, /, >,< =, ≠, **, ADD, SUBTRACT) and operand occurrences (e.g., variables, attributes, entities, sets).

Typically, if the Halstead length metric is 270 or above per routine, it is indicative of poor design practices during the module/submodule allocations (modularization phase). It has also

been correlated with other measures such as number of bugs in a program, required programming/reprogramming time, and the quality of programs (Ref. [3], Appendix A,Volume III).

2.4 VAX SIMSCRIPT Compiler Error Checking

SAI re-hosted the COSAGE model on a VAX computer to perform the required analyses for a variety of reasons. One major consideration was the upgraded SIMSCRIPT compiler features which are implemented in the VAX computer version and not currently available in the SPERRY computer compiler. The VAX SIMSCRIPT enhancements include:

- Checking for subscripts out of bounds to an array, permanent entity, or temporary entity
- Identifying references to a temporary attribute or an array element of a quantity that has been destroyed or released
- Verifying that the number of words for arguments agree in definition and use
- Mode checking

3.0 ANALYSES PERFORMED AND RESULTS OBTAINED

Numerous analyses were performed by SAI. This section discusses these analyses and presents the results obtained.

3.1 Analysis Of COSAGE Model Invocations

In order to capture the number of invocations for each COSAGE source code routine, an "ADD" statement was inserted as the first executable statement in each routine. These statements increment an array element associated with a particular routine each time the routine is executed. The array (ANAL.CTR) was defined in the COSAGE PREAMBLE; it was dimensioned by the number of routines in the source code.

In order to report the number of invocations per hour of simulated time, an event was written and added to the COSAGE model that writes to a disk file the name of each routine and the number of invocations recorded per simulated hour. It then clears the counter array and reschedules itself to execute in one simulated hour.

In order to increase the useability of the data gathered in this manner, a formatting postprocessor was written which ranks the routines by highest number of invocations. For any user-specified number of routines in the COSAGE model (e.g., top 10, top 50, all), the number of invocations, the percent of hourly

calls, and an accumulated hourly percent of calls for each hour of simulated time is printed. Appendix B (Volume III) contains the output of the postprocessor when all 264 modules were requested using random number seed 3.

In addition, a summary report is produced at the end of the simulation. This COSAGE summary invocation report ranks the selected number of routines, giving the number of invocations for each, the percent of total calls, and the accumulated total percentage. Figure 3.1 presents this summary report.

A second summary report shows the number of invocations per hour of simulated time and the percent of total invocations as a number and as a line on a bar chart. Figure 3.2 presents this hourly invocation summary.

Analysis of this output has helped to direct and focus the optimization investigation. It is clear from the results of Figure 3.1 that 10% (26) of the COSAGE modules account for over 93% of all module invocations and should be closely scrutinized. Seven of the 26 were already noted for optimization with the \OPTIMIZE token during the static analysis, and one was marked as a deletion candidate. The two processes, ASSESSMENT and SHOOTOUT, were both in the largest dozen modules ranked by source lines.

Figure 3.1 also reveals two closely coupled sets of program modules. The routines JOHNSON.CRITERIA, PROB.INF, PROB.TIME, and SEARCH were each invoked 344,157 times, accounting for over 20% of all invocations; MRT.TO.FREQ and TEMPERATURE.ATTENUATION were each invoked 75,923 times. These algorithms and their interfaces should be streamlined to minimize the overhead of the invocations themselves.

COSAGE SUMMARY INVOCATION REPORT

TOP 26 (10%) INVOKED ROUTINES		TOTAL INVOCATIONS	PCT TOTAL CALLS	ACC TOTAL PCT
1	FUNCTION_ACT.RANGE	1189098	17.459	17.459
2	ROUTINE_RANGE.COMPUTE	792643	11.638	29.097
3	ROUTINE_PK.COMPUTE	741236	10.883	39.980
4	ROUTINE_PROX.CHECK	399966	5.872	45.852
5	ROUTINE_JOHNSON.CRITERIA	344157	5.053	50.906
6	ROUTINE_PROB.INF	344157	5.053	55.959
7	ROUTINE_PROB.TIME	344157	5.053	61.012
8	ROUTINE_SEARCH	344157	5.053	66.065
9	ROUTINE_TIME.TO.DETECT	312629	4.590	70.655
10	ROUTINE_FRAC.COMPUTE	291000	4.273	74.927
11	ROUTINE_CONTRAST.TO.FREQ	268234	3.938	78.866
12	ROUTINE_LOCATE.SECTOR	142090	2.086	80.952
13	ROUTINE_CHECK.ENGAGEMENT	129648	1.904	82.856
14	ROUTINE_SIZE.ESTIMATE	128398	1.885	84.741
15	ROUTINE_MRT.TO.FREQ	75923	1.115	85.855
16	ROUTINE_TEMPERATURE.ATTENUATION	75923	1.115	86.970
17	ROUTINE_FINAL.COVERAGE	74273	1.091	88.061
18	PROCESS_ASSESSMENT	53613	.787	88.848
19	ROUTINE_PDB.DETECTION	44444	.653	89.500
20	FUNCTION_COMBINATIONS	41320	.607	90.107
21	ROUTINE_DEQ.FEBA.SET	40041	.588	90.695
22	ROUTINE_ENQ.FEBA.SET	39866	.585	91.280
23	PROCESS_SHOOT.OUT	36804	.540	91.821
24	EVENT_PDB.ACTIVATION	35159	.516	92.337
25	ROUTINE_WEIBULL.F	23942	.352	92.688
26	FUNCTION_EST.RANGE	23356	.343	93.031
	TOTAL INVOCATIONS =	6810855		

Figure 3.1

COSAGE Summary Invocation Report

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COSAGE INVOCATION SUMMARY

SIMULATED HOUR	INVOCATIONS	PCT OF TOTAL INVOCATIONS	BAR CHART
1	16767	.25	
2	13097	.19	
3	1939	.03	
4	14152	.21	
5	44843	.66	
6	308729	4.53	****
7	427946	6.28	******
8	323244	4.75	****
9	2235910	32.83	**********
10	542160	7.96	*******
11	713853	10.48	**********
12	327358	4.81	****
13	765553	11.24	**********
14	411541	6.04	******
15	135217	1.99	*
16	213329	3.13	***
17	82955	1.22	*
18	52353	.77	
19	29260	.43	
20	38559	.57	
21	31171	.46	
22	29454	.43	
23	24582	.36	
24	26843	.39	
TOTAL	6810855	100.00	

10 20 30 40
PERCENT OF TOTAL INVOCATIONS

Figure 3.2

COSAGE Hourly Invocation Summary Report

Finally, infrequently used routines may be eliminated, thereby reducing the overall size of the COSAGE program. Appendix B, Volume III, provides a good departure point to purge the program.

It should be noted that the analyses performed and results obtained in this section are based on executing the COSAGE model using SIMSCRIPT's random number seed 3. However, SAI analysts also conducted analyses using two additional random number seeds; namely, 6 and 10. The analyses results for random number seed 6 are included in Appendix C, Volume III; the results from seed 10 are in Appendix D, Volume III.

3.2 Analysis of COSAGE Model CPU Usage

An additional analysis was performed by instrumenting the COSAGE source code. This analysis yielded CPU usage by simulated hour. To ascertain this information, LIB$INIT_TIMER was invoked during the COSAGE initialization phase. This routine initialized the VAX system timing mechanism. Then, LIB$STAT_TIMER (another VAX system routine) was called after each hour of simulated time. This was accomplished by modifying the event which was written to capture the number of invocations. The change caused the hourly CPU usage data to be written to a data file. Additionally, the postprocessor which was developed to produce the COSAGE Hourly Invocation Report was enhanced to present hourly CPU usage. A sample COSAGE CPU Usage Summary report is shown in Figure 3.3. The next step involved integrating the results of the COSAGE Hourly Invocation Summary report and the COSAGE CPU Usage Summary report into a single summary. A sample COSAGE Invocation and CPU Usage Summary is shown in Figure 3.4.

COSAGE CPU USAGE SUMMARY

SIMULATED HOUR	CPU SECONDS	PCT OF TOTAL CPU SECONDS	BAR CHART
1	227.38	1.36	o
2	7.94	.05	
3	2.06	.01	
4	7.84	.05	
5	58.88	.35	
6	710.93	4.25	oooo
7	914.34	5.46	ooooo
8	724.03	4.33	oooo
9	5484.19	32.76	oooooooooooooooooooooooooooooooo
10	1191.71	7.12	ooooooo
11	1532.83	9.16	oooooooooo
12	814.74	4.87	ooooo
13	1368.14	8.17	oooooooo
14	1026.07	6.13	oooooo
15	455.59	2.72	ooo
16	598.46	3.58	oooo
17	391.89	2.34	oo
18	313.35	1.87	oo
19	147.43	.88	o
20	190.23	1.14	o
21	154.16	.92	o
22	145.85	.87	o
23	124.44	.74	o
24	145.84	.87	o
TOTAL	16738.32	100.00	

10 20 30 40
PERCENT OF TOTAL CPU SECONDS

Figure 3.3
COSAGE CPU Usage Summary

COSAGE INVOCATION AND CPU USAGE SUMMARY

SIMULATED HOUR	PERCENT OF INVOCATIONS AND CPU SECONDS
1	.25
	1.36
2	.19
	.05
3	.03
	.01
4	.21
	.05
5	.06
	.35
6	4.53
	4.25
7	6.28
	5.46
8	4.75
	4.33
9	32.83
	32.76
10	7.96
	7.12
11	10.48
	9.16
12	4.81
	4.87
13	11.24
	8.17
14	6.04
	6.13
15	1.99
	2.72
16	3.13
	3.58
17	1.22
	2.34
18	.77
	1.87
19	.43
	.88
20	.57
	1.14
21	.46
	.92
22	.43
	.87
23	.36
	.74
24	.39
	.87

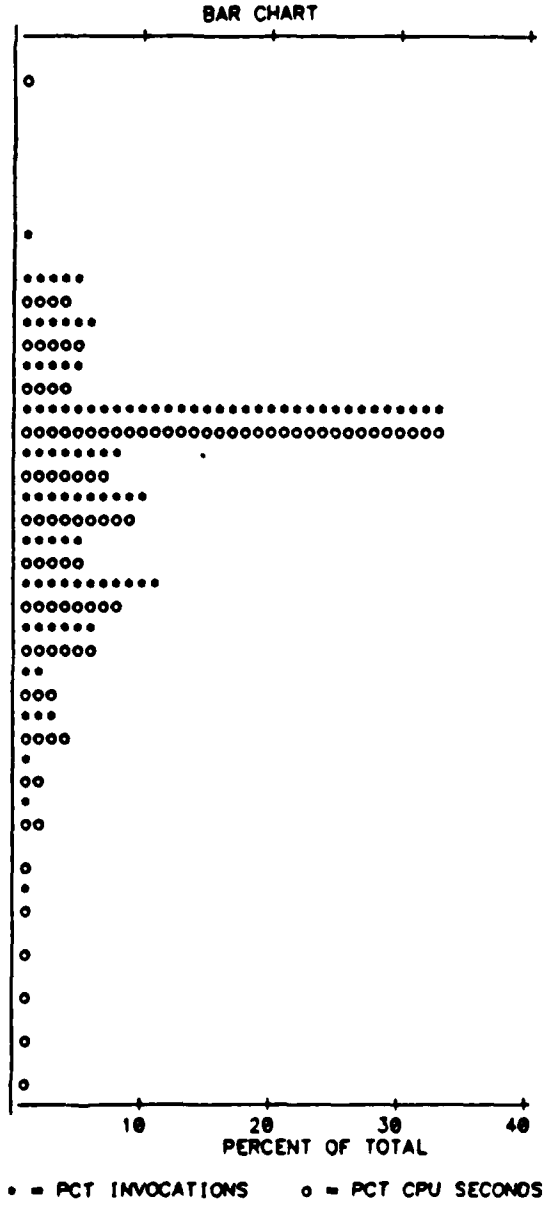

Figure 3.4

COSAGE Invocation and CPU Usage Summary

3.3 Analysis Of COSAGE Model Execution

SAI instrumented the COSAGE model environment with the System Performance Monitoring (SPM) tool to gather samples of the model counter. This was done to determine where the program was spending its time.

In order to avoid modifying the COSAGE program itself, the executable image was linked with the SPM module IMGSHELL specified as the DEBUG option. The IMGSHELL module is a program which automatically starts and stops the sampling routines. When linked this way, IMGSHELL is invoked by the VMS operating system as if it were the debugger. It thus gets control before the user program. This allows it to initiate clock sampling before starting the user program and to terminate the sampling after the user program exits. The program counter samples are taken every 10 milliseconds and accumulated in a file. Upon completion of a COSAGE execution, the file containing program counter samples can then be used in the analysis.

The next step is to define address ranges of interest. The program, and its associated address space, was divided into smaller units. This was done by specifying five primary areas. These included operating system, program control region, COSAGE image region, user program region at addresses above the COSAGE image, and the SIMSCRIPT library. The addresses were set up for the COSAGE image region so that each program module would be accounted for individually. The SPM module IMGDEFINE was executed; it specifies how the program is to be broken into address buckets for data collection. The output of the IMGDEFINE

module is a single file containing all necessary information about how the user has divided the program into buckets or address ranges. This is an empty bucket file and is ready to be used along with the sampling output from a COSAGE execution.

The sampling output consists of a file produced by clock-driven traps which collect program counter values. This file, along with the empty bucket file generated by the IMGDEFINE module, is then used as input to the IMGREPORT module of SPM. IMGREPORT tallies the program counter samples in the appropriate buckets and produces a histogram showing the number of tallies in each bucket.

The results in the histogram are shown as percentages. For this analysis, the results were as follows:

Operating system	0.00%
Program Control region	0.50%
COSAGE Image region	28.93%
User region above COSAGE	10.36%
SIMSCRIPT Library	60.18%
	99.97%

Of the 28.93% of samplings which were attributed to the COSAGE Image region, the individual routines trapped and their relative percentages are shown in Figure 3.5. These routines, when summed, account for 28.77% of the samplings in the COSAGE Image region. The difference can be attributed to precision of the SPM package which rounds to the nearest one-hundredth of one percent.

There were a total of 1,703,991 samples taken; the percent in defined buckets was 99.97%, and the number of address ranges represented was 535. The program control region represents

```
5.87% RTIME.TO.DETECT
4.74% RFRAC.COMPUTE
4.00% RPK.COMPUTE
2.11% RSHOOT.OUT
1.34% RFINAL.COVERAGE
0.81% RACT.RANGE
0.74% RRANGE.COMPUTE
0.73% RTARGET.ANALYSIS
0.51% RPROB.INF
0.44% RCONTRAST.TO.FREQ
0.44% RPROB.TIME
0.43% RLOCATE.SECTOR
0.42% RPROX.CHECK
0.41% RSEARCH
0.33% RDEQ.FEBA.SET
0.30% RBTRY.EFFECTS
0.30% RNOISE.DEGRADE
0.23% RASSESSMENT
0.22% RLOS.CHECK
0.21% RFORWARD.OBSERVER
0.19% HTIME.R
0.19% RSIZE.ESTIMATE
0.18% RCHECK.ENGAGEMENT
0.15% RUNIT.INPUT
0.14% TSS.SET
0.13% RPDB.DETECTION
0.13% RPDB.ACTIVATION
0.13% RFIRE.MISSION
0.12% RTEMPERATURE.ATTE
0.12% ROUTPUT.ATTRITION
0.11% RCHECK.PROX
0.11% RHE.WLA
0.11% RJOHNSON.CRITERIA
0.11% REST.COVERAGE
0.11% RFA.BN.ASGN
0.10% RDUST.EFFECTS
0.09% RCHK.FD.TR
0.09% RNEW.SEGMENT
0.09% RFO.DETECTION
0.07% RMIN.MOVE
0.07% RVOLLEY
0.06% RCFR.ACTIVATION
0.06% RUPDATE.LOC
0.06% RENQ.FEBA.SET
0.05% RTARGET.REPORT
0.05% RFA.BN.MOVEMENT
0.05% RENGAGEMENT
0.05% RHE.OR.ICM.COMPUT
0.04% RMRT.TO.FREQ
0.04% TFO.CAND.DET.LIST
0.04% RCOMBINATIONS
0.04% RFEBA.BAND
0.04% RCHANGE.LOC
0.04% RWEIGHTED.VOLLEYS
0.04% HUNIFORM.F
```

Figure 3.5
SPM Results of COSAGE Image Region

```
0.04% RICM.WLA
0.04% HNORMAL.F
0.03% ZSS.SET
0.03% REST.RANGE
0.03% RMARGINAL.EFFECTS
0.03% RCFR.DEGRADE
0.03% REMPTY
0.02% DPDB.ACTIVATION
0.02% HGAMMA.F
0.02% RLINE.OF.SIGHT
0.02% USO.LIST
0.02% RCFR.DETECTION
0.02% RHE.LA.INPUT
0.02% RBLOCK.LOS
0.02% TPDB.OP.Q
0.02% HWEIBULL.F
0.02% TFD.TR.QUEUE
0.02% HBINOMIAL.F
0.02% HCOMPUTE.D
0.01% ZIF.RATE.LIST
0.01% RCFR.OPERATOR
0.01% RSTART.BATTLE
0.01% RLOCATE.SEARCH.AR
0.01% DIF.VOLLEY
0.01% ZUE.TARGET.LIST
0.01% ZFO.CAND.DET.LIST
0.01% RSTOP.ARTY.MOVEME
0.01% HRANDI.F
0.01% ROUTPUT.EXPENDITU
0.01% DFIRE.MISSION
0.01% RGENERAL.BATTLE
0.01% RCHK.COMP.TR
0.01% ZBY.FM.QUEUE
0.01% RSTART.MOVE
0.01% RBTRY.FM.DEQ
0.01% RREM.EFFECTS.COMP
0.01% UIF.RATE.LIST
0.01% DFO.DET.CANDIDATE
0.01% RCOMPARE.TRS
0.01% RCLEAN.UP.FIRE.MI
0.01% RPOSITION
0.01% DFIRING.TABLE
0.01% ZSO.LIST
0.01% RCHECK.FORCE
0.01% RCREATE.FORCE
0.01% RSWITCH.FO
0.01% XUN.SEGMENT.LIST
0.01% RWITH.DRAW
0.01% RARTY.ASSESS
0.01% RSTART.ARTY.MOVEM
0.01% RGET.TERRAIN
0.01% XSO.LIST
0.01% UUN.LOS.LIST
0.01% TBY.FM.QUEUE
0.01% RBTRY.INPUT
```

Figure 3.5

SPM Results of CUSAGE Image Region

(continued)

```
0.01% DUPDATE.LOC
0.01% RFINISH.COMPUTATI
0.01% TBN.CAN.FM.SET
0.01% RFDC.TR.DEQ
0.01% XFO.CAND.DET.LIST
0.01% UUE.TARGET.LIST
0.01% DTARGET.REPORT
0.01% RSENSOR.INPUT
0.01% UUN.SEGMENT.LIST
0.01% RUNIT.ENVIR
0.01% DSHOOT.OUT
0.01% RPK.INPUT
0.01% RUNIT.ASSIGNMENT
0.01% RSEGMENT.ADJUST
0.01% RPDB.OPERATOR
0.01% RKV.PRINT
```

Figure 3.5

SPM Results of COSAGE Image Region

(continued)

activities performed by the system on behalf of the image such as user stack usage and image input/output. The user region above COSAGE represents the operating system and the debugger. Any discrepancies between percentages contained in the report and shown in the total may be attributed to round-off. The remaining .03% of activity not accounted for was in an address range which was not requested in this analysis.

3.4 Analysis Of COSAGE Model SIMSCRIPT Execution

The SIMSCRIPT compiler on the VAX computer incorporates language enhancements which are not available on the SPERRY computer. These features made it possible to identify anomalies which heretofore had gone undetected. Anomalies have been grouped into two categories: ones that occurred while reading the input data and ones that occurred during simulated time. These irregularities are discussed further below.

3.4.1 Anomalies Which Occurred While Reading the Input Data

In the course of implementing the COSAGE model on the VAX computer, a number of problems were encountered while reading the data file provided. Each problem and solution is listed below.

1. Problem: Need explicit unit number for input file.

   Solution: Opened unit 4 in new module OPEN.INPUT.OUTPUT.FILES for reading input data.

2. Problem: Divide by zero in SYS.INPUT. Customer provided information that the data items for NUM.POSITION.REPORT and CLP.ON were reversed.

Solution: Corrected order of the data items in the input file.

3. Problem: Unreserved array in PK.INPUT. PK.F.MOV.FAC does not seem to be allocated automatically.

   Solution: Reserved array explicitly.

4. Problem: Subscript out of range in CAT.TU.INPUT. Data originally read with ALPHA 6 format and now being read as TEXT requiring a blank space in data.

   Solution: Inserted a blank space in data item.

5. Problem: Not sufficient virtual address due to size of model.

   Solution: Wrote macro routine to increase MAX VIRTUALADDR to 3 megabytes.

6. Problem: Zero entity pointer or unreserved array in BRTY.INPUT. BRTY's 37 through 40 did not have proper equipment.

   Solution: Added LART1 equipment to units 204, 205, 206 and 207.

7. Problem: Subscript out of range in SENSOR.INPUT. When SENSOR.TYPE is 1 and ST.NAME is "FO", SENSOR.MODEL must be less than 10 or subscript goes out of range.

   Solution: Changed data so that SENSOR.MODEL is 1 for those cases.

8. Problem: Argument passed to H.SIGN.F must be real (called from SENSOR.INPUT).

   Solution: Explicitly defined DISTANCE as a real variable in SENSOR.INPUT.

9. Problem: Subscript out of range in SENSOR.INPUT. (Problem same as 7. above).

   Solution: Changed data so that SENSOR.MODEL is 1 for those cases.

10. Problem: Invalid character in I format in MADS.INPUT. .NUM.RH read in this routine was incorrect in many instances. It is being used as a loop counter for subsequent reads and must correspond to the number of data items following.

    Solution: Determined correct values for .NUM.RH and replaced original incorrect values in the data.

3.4.2 Anomalies Which Occurred During Simulated Time

After the COSAGE program read all the input data and scheduled the initial events and processes, a START SIMULATION statement was executed. From this point to normal execution termination, the SIMSCRIPT compiler-generated timing routine, TIME.R, directed the execution of the program. The timing routine updated the simulated time, TIME.V, and invoked the subroutines corresponding to the required event or process.

As the program executed new paths, or repeated previously executed paths with new data, a variety of SIMSCRIPT execution errors were encountered. A complete list of the

execution problems and the solutions applied to continue execution is contained in the accompanying source code (Volume II). The module entitled PROGRAM CHANGES on page 2 matches a token of the form CHG\NN, where NN is a 2-digit number, with the location(s) in the code which was affected. These changes, while numerous and labor-intensive to implement, resulted from several broad categories of problems. These categories included the following:

- Compiler Variations - These included both VAX and SPERRY implementation idiosynchrocies.

- Zero Subscript Error - There was a wide variety of reasons for the subscript being zero, with misspellings, attributes used but not initialized, and faulty logic leading the list.

- Reference to a Destroyed Entity - A reference to a destroyed entity resulted from an attempt to retrieve data about an entity or process after it had exited from the simulation. The solutions usually required obtaining the data before the entity was destroyed or zeroing-out the pointer that referred to the entity.

- Precision differences - Since a real variable on the VAX defaults to 64 bits (vs 36 on the SPERRY), some differences occurred based on the extended precision and round-off.

- Number and Mode Mismatches for Arguments - Some calls to subroutines contained less than the specified number of arguments; those calls were supplemented to fulfill the list. Some calls specified arguments in a mode

different from that specified in the called routine; those differences were resolved.

- Subscript Out of Range - These almost always were a result of faulty logic.

- Division By Zero - The rare cases where this occurred were tested for and handled as exceptions.

3.5 Metrics Analysis

Two metric analyses were performed on the COSAGE model: the control complexity metric and the operand complexity metric. The details of these two measures and the results are presented below.

3.5.1 Control Complexity Metric

In order to determine the control complexity metric, (number of paths through the code), each COSAGE source routine was examined for the number of IF tests performed. A separate count was kept of the number of IF tests that controlled debug output and the maximum depth of IF test nesting within the routine. This information was tallied using an SAI-developed configuration control form. A sample form is shown in Figure 3.6. Figure 3.7 is provided to illustrate the procedure employed to glean this measure. As can be seen, this section of code has eight IF tests, none of which control debug output. It also has a maximum depth of nesting of four (IFs 2, 3, 5, 6).

A post-processor was written to tabulate the data gathered in this manner and to produce three reports. The first report lists the modules ranked by IF tests (see Figure 3.8). The

			file name			
51	2855	[illegible] ROUTINES				
52	2865	[illegible] MAIN	T001			
53	2870	ROUTINE MAIN1	T002			
54	2901	ROUTINE MAIN2	T003			
55	2926	ROUTINE CREATE.OBJS	T004			
57	2947	ROUTINE CREATE.TERR	T005			
58	3011	ROUTINE FEBA.INITIAL	T006			
60	3088	ROUTINE FILE.FC.SCR	T007			
62	3185	ROUTINE FILE.KAC.SENSOR	T008			
63	3242	ROUTINE FORM.TP.LIST	T009			
64	3275	ROUTINE GENERAL.BATTLE	T010			
68	3459	ROUTINE ORIENTATION	T011			
72	3666	ROUTINE UNIT.ASSIGNMENT	T012			
73	3695	TITLE MOVEMENT/TERRAIN ROUTINES				
76	3795	ROUTINE ADJUST	M001			
77	3825	ROUTINE BLOCK.LOS	M002			
80	3961	ROUTINE CHANGE.LOC	M003			
84	4125	ROUTINE ENG.MOVE	M004			
86	4212	ROUTINE FB.IN.MOVEMENT	M005			
90	4404	ROUTINE INITIAL.DETECT	M006			
91	4425	ROUTINE INITIAL.MOVE	M007			
92	4462	ROUTINE LINE.FEINE	M008			
93	4473	ROUTINE LINE.OF.SIGHT	M009			
95	4575	ROUTINE LOCATE.SEARCH.AREA	M010			
97	4636	ROUTINE LOCATE.SECTOR	M011			
98	4678	ROUTINE LOS.CHECK	M012			
100	4758	ROUTINE MOVE.DELAY	M013			
101	4803	ROUTINE MOVE	M014			
104	4978	ROUTINE NEW.SEGMENT	M015			
107	5037	ROUTINE SMOOTH	M016			
108	5101	ROUTINE SPEED.ADJ	M017			
109	5147	ROUTINE SPHERE.LIST	M018			
110	5215	ROUTINE SPOT.AMMO	M019			
112	5403	ROUTINE SPOT.CHECK	M020			
116	5461	ROUTINE SPOT.ADJ	M021			
118	5564	ROUTINE STOP.ARRIVE	M022			
119	5601	ROUTINE SUBSEGMENT.ADJUST	M025			
119	5631	ROUTINE TIME.TO.GETTO	M024			
120	5641	ROUTINE WHAT.NEXT	M027			
121	5665	ROUTINE DESERT.AREA.SECTOR	M023			
122	5706	ROUTINE SEARCH	M024			
124	5745	TITLE DIRECT FIRE ROUTINES				
125	5794	ROUTINE STL.CHECK	DF01			
127	5856	ROUTINE CHECK.CEAL	DF02			
129	5915	ROUTINE CHECK.ENGAGEMENT	DF03			
130	5960	ROUTINE CHECK.FORCE	DF04			
131	5997	ROUTINE CHECK.FOR.MINES	DF05			
134	6117	ROUTINE CHECK.LIST	DF06			
135	6157	ROUTINE CHECK.PROX	DF07			
136	6236	ROUTINE CHECK.STREN	DF08			
139	6301	ROUTINE DEID.UNIT	DF09			
142	6471	ROUTINE FIN.BATTLE	DF10			
143	6516	ROUTINE INTER.BATTLE	DF11			
144	6672	ROUTINE PK.COMPUTE	DF12			
149	6864	TITLE INDIRECT FIRE ROUTINES				
150	6851	ROUTINE AC.DETECTION	IF01			
155	7087	ROUTINE ATTRIT.SENSOR	IF02			
159	7284	ROUTINE STRV.PK.JEG	IF03			

Figure 3.6

Configuration Control Form Used for Metrics

```
436
437         IF TP.SENSOR.TYPE(FM.TGT(FM)) = "RPV" AND
438         |       TR.PGM.STATUS(FM.TGT(FM)) = TRUE
439         |       **FREE THE ADJUSTING RPV TO CONTINUE ITS SEARCH
440         |
441      1  |       LET TIME.A(TR.SENSOR.ID(FM.TGT(FM)))=REAL.F(FM.TOF.TIME(FM))/
442         |                                             3600.
443         |
444         |       RESUME REMOTE.PILOT.VEHICLE CALLED TR.SENSOR.ID(FM.TGT(FM))----------------------------------------->(324)
445         ALWAYS
446
447         IF FM IS IN AN FO.CUR.FM.LIST                                                                              \1
448         |       **WHEN THE FIRE MISSION WAS FO ADJUSTED, RESTART THE FO
449         |       **SO THAT HE MAY CONTINUE HIS SEARCH UNLESS HE HAS
450         |       **ANOTHER FIRE MISSION TO ADJUST
451         |
452         |
453         |       REMOVE THE FM FROM FO.CUR.FM.LIST(FO)
454         |       DESTROY EX.FIRE.MISSION CALLED FM.EX.FIRE.MISSION(FM)
455         STORE 0 IN FM.EX.FIRE.MISSION(FM) **                                        \TO_AVOID_REDUNDANT_DESTROYS
456         |       IF FO.CUR.FM.LIST(FO) IS EMPTY
457         |       |       IF TR.PGM.STATUS(FM.TGT(FM)) = TRUE AND FO IS NOT IN EV.S
458         |       |    4  |       LET TIME.A(FO) = REAL.F(FM.TOF.TIME(FM))/3600.
459         |       |       |       RESUME FORWARD.OBSERVER CALLED FO-------------------------------------------->( 55)
460      1  |       |       ALWAYS
461         |    3  ELSE
462         |       |       IF TR.PGM.STATUS(FM.TGT(F.FO.CUR.FM.LIST(FO))) NE TRUE AND
463         |       |       |       TR.PGM.STATUS(FM.TGT(FM)) = TRUE AND FO IS NOT IN EV.S
464         |       |       |       RESUME FORWARD.OBSERVER CALLED FO-------------------------------------------->( 55)
465         |       |    5  ELSE
466         |       |       |       IF TR.PGM.STATUS(FM.TGT(FM)) = TRUE
467         |       |       |    6  |       AND F.FO.CUR.FM.LIST(FO) IS NOT IN EV.S
468         |       |       |       |       RESUME FIRE.MISSION CALLED F.FO.CUR.FM.LIST(FO)------------------------>( 14)
469         |       |       |       ALWAYS
470         |       |       ALWAYS
471         |       ALWAYS
472         ALWAYS
473
474         **AT THE END OF THE FIRE MISSION, CLEAN UP ALL
475         **OWNERSHIP RELATIONSHIPS ASSOCIATED WITH THIS
476         **FIRE MISSION SO THAT THEY ARE NOT LEFT HANGING
477         **AFTER THE PROCESS KILLS ITSELF
478         REMOVE THE FM FROM THE DY.FM.QUEUE(.RTRY)
479          **DESTROY EX.FIRE.MISSION CALLED FM.EX.FIRE.MISSION(FM)                    \REDUNDANT_DESTROY
480         CALL DTRY.FM.DEQ------------------------------------------------------------------------------------------>(198)
481              GIVEN
482                   FM
483         REMOVE THE FM FROM THE TP.FM.LIST(FM.TGT(FM))
484         IF TP.FM.LIST(FM.TGT(FM)) IS EMPTY
485         |       IF FM.TGT(FM) IS NOT IN EV.S
486      7  |    8  |       DEACTIVATE_THE TARGET.REPORT CALLED FM.TGT(FM) NOW------------------------------------------->(667)
487         |       ALWAYS
488         ALWAYS
489
```

Figure 3.7

Level of IF Nesting

RANK		MODULE NAME	IF TESTS
1	ROUTINE	BTRY.EFFECTS	94
2	PROCESS	SHOOT.OUT	61
3	PROCESS	HELICOPTER.FIRE	49
4	PROCESS	TARGET.REPORT	47
5	PROCESS	FIRE.MISSION	45
6	ROUTINE	FD.DETECTION	43
7	PROCESS	HC.ARRIVE.BATTLE	41
8	EVENT	AD.ENGAGEMENT	38
9	PROCESS	AC.ATK.TGT	37
10	ROUTINE	FINAL.COVERAGE	35
11	ROUTINE	FA.BN.MOVEMENT	33
12	PROCESS	HEL.TARGET.ACQUISITION	32
13	ROUTINE	AD.DETECTION	31
14	ROUTINE	CHECK.CAS.CONSTRAINTS	31
15	PROCESS	ASSESSMENT	30
16	ROUTINE	FLIGHT.PATH	30
17	EVENT	OFF.LINE.ATTRITION	30
18	ROUTINE	FA.BN.ASGN	29
19	PROCESS	HC.RETURN.FARP	29
20	PROCESS	AIR.OBSERVER	28
21	EVENT	START.BATTLE	28
22	PROCESS	CAS.MISSION	27
23	ROUTINE	ATTRIT.SENSOR	26
24	ROUTINE	PGM.MSN.ASGN	26
25	ROUTINE	REQUEST.SMOKE	26
26	ROUTINE	UNIT.INPUT	26
27	ROUTINE	PK.COMPUTE	25
28	ROUTINE	AD.SHOOT	23
29	ROUTINE	MINE.EFFECTS	23
30	ROUTINE	UNIT.ENVIR	23
31	ROUTINE	REQUEST.ILLUM	22
32	ROUTINE	AC.BOMB.EFFECTS	20
33	ROUTINE	EST.COVERAGE	20
34	ROUTINE	ANALYSIS.OUTPUT	19
35	PROCESS	ARTY.ASSESS	18
36	ROUTINE	CHECK.PROX	18
37	PROCESS	FORWARD.OBSERVER	18
38	ROUTINE	AC.DF.EFFECTS	17

Figure 3-8

Modules Ranked by IF Tests

RANK		MODULE NAME	IF TESTS
39	ROUTINE	TACAIR.INPUT	17
40	ROUTINE	EMPLOY.HELICOPTERS	16
41	ROUTINE	SENSOR.INPUT	16
42	ROUTINE	END.CAS.MISSION	15
43	EVENT	GET.NX.ORD	15
44	ROUTINE	BTRY.INPUT	14
45	ROUTINE	CHANGE.LOC	14
46	ROUTINE	INTER.BATTLE	14
47	PROCESS	MINE.ASSESS	14
48	ROUTINE	MINE.DELAY	14
49	ROUTINE	CFR.DETECTION	13
50	ROUTINE	DEAD.UNIT	13
51	ROUTINE	HE.OR.ICM.COMPUTATION	13
52	FUNCTION	HE.AREA	13
53	EVENT	HELO.ENGAGEMENT	13
54	ROUTINE	NEW.SEGMENT	13
55	ROUTINE	READ.ORDERS	13
56	ROUTINE	SMOKE.EFFECTS	13
57	ROUTINE	CAS.EVAL	12
58	ROUTINE	ILLUM.EFFECTS	12
59	EVENT	START.MOVE	12
60	ROUTINE	WHAT.NEXT	12
61	ROUTINE	AMMO.RPT	11
62	ROUTINE	LINE.OF.SIGHT	11
63	ROUTINE	PREPARE.LIST	11
64	ROUTINE	REQUEST.WD.FASCAM	11
65	ROUTINE	RPV.DETECTION	11
66	EVENT	UPDATE.LOC	11
67	ROUTINE	CHECK.FOR.MINES	10
68	ROUTINE	DUST.EFFECTS	10
69	ROUTINE	FIND.START.TIME	10
70	ROUTINE	GENERAL.BATTLE	10
71	ROUTINE	TARGET.ANALYSIS	10
72	ROUTINE	BLOCK.LOS	9
73	EVENT	BTL.ENDED	9
74	EVENT	CFR.OPERATOR	9
75	ROUTINE	OUTPUT.ATTRITION	9
76	ROUTINE	PIR.DETECTION	9

Figure 3-8

Modules Ranked by IF Tests

Continued

RANK		MODULE NAME	IF TESTS
77	ROUTINE	WEIGHTED.VOLLEYS	9
78	ROUTINE	ENQ.FEBA.SET	8
79	FUNCTION	FEBA.BAND	8
80	EVENT	FEBA.SORTIE	8
81	ROUTINE	FILE.FD.SCHD	8
82	ROUTINE	HC.EMPTY	8
83	ROUTINE	KV.PRINT	8
84	ROUTINE	ORIENTATION	8
85	ROUTINE	OUTPUT.EXPENDITURES	8
86	ROUTINE	POB.DETECTION	8
87	PROCESS	REMOTE.PILOT.VEHICLE	8
88	ROUTINE	SIZE.ESTIMATE	8
89	ROUTINE	ADJUST	7
90	PROCESS	AIRBORNE.RADAR	7
91	ROUTINE	LOCATE.SEARCH.AREA	7
92	ROUTINE	MARGINAL.EFFECTS.ADJ	7
93	ROUTINE	REQUEST.FASCAM	7
94	ROUTINE	SEARCH.COVERAGE	7
95	ROUTINE	BTL.CHECK	6
96	EVENT	CFR.ON	6
97	ROUTINE	DESTROY.ORD	6
98	ROUTINE	FEBA.INITIAL	6
99	ROUTINE	FIN.BATTLE	6
100	ROUTINE	HE.LA.INPUT	6
101	ROUTINE	LOS.CHECK	6
102	ROUTINE	MINE.INPUT	6
103	ROUTINE	NOISE.DEGRADE	6
104	ROUTINE	REQUEST.DEF.FASCAM	6
105	PROCESS	WITH.DRAW	6
106	ROUTINE	ANGLE.COMPUTE	5
107	EVENT	CFR.ACTIVATION	5
108	ROUTINE	CHECK.DEAD	5
109	ROUTINE	CHECK.FORCE	5
110	ROUTINE	COMPARE.TRS	5
111	ROUTINE	CREATE.FORCE	5
112	ROUTINE	END.MOVE	5
113	EVENT	ENGAGEMENT	5
114	ROUTINE	HC.COMPUTE.TIMES	5

Figure 3-8
Modules Ranked by IF Tests
Continued

RANK		MODULE NAME	IF TESTS
115	ROUTINE	HEL.RANGE.COMPUTE	5
116	FUNCTION	ICM.xLA	5
117	ROUTINE	LOCATE.SECTOR	5
118	EVENT	POb.OPERATOR	5
119	PROCESS	PHOTO.IP.FLIGHT	5
120	ROUTINE	PLAT.COUNT	5
121	ROUTINE	PROX.CHECK	5
122	ROUTINE	SWITCH.FO	5
123	ROUTINE	UNIT.PRIORITY	5
124	ROUTINE	VOLLEY	5
125	EVENT	ACT.ATK	4
126	ROUTINE	AR.DETECTION	4
127	ROUTINE	CFR.DEGRADE	4
128	ROUTINE	CHECK.LIST	4
129	FUNCTION	COMBINATIONS	4
130	ROUTINE	CONTRAST.TO.FREQ	4
131	ROUTINE	EMPTY	4
132	ROUTINE	EO.TE.INPUT	4
133	ROUTINE	FARRP.CHECK	4
134	ROUTINE	FARRP.INPUT	4
135	ROUTINE	GAMMA.F	4
136	ROUTINE	RESET.FEBA.SECTOR	4
137	ROUTINE	SMOKE.COMPUTATION	4
138	EVENT	START.ARTY.MOVEMENT	4
139	EVENT	ACT.MOVDIS	3
140	EVENT	ACT.REINF	3
141	FUNCTION	AR.PROb.DETECT	3
142	ROUTINE	CAT.TU.INPUT	3
143	EVENT	CHANGE.LITE	3
144	ROUTINE	CHK.FO.TE	3
145	FUNCTION	COLLISION	3
146	ROUTINE	DECIDE	3
147	ROUTINE	DEQ.FEBA.SET	3
148	ROUTINE	FSN.FO.INPUT	3
149	ROUTINE	FINISH.COMPUTATION	3
150	ROUTINE	FORM.TF.LIST	3
151	ROUTINE	GET.TERRAIN	3
152	EVENT	HC.DEPART.BATTLE	3

Figure 3-8
Modules Ranked by IF Tests
Continued

RANK		MODULE NAME	IF TESTS
153	PROCESS	HOW.REPAIR	3
154	ROUTINE	ILLUM.COMPUTATION	3
155	ROUTINE	INTER.HELO	3
156	ROUTINE	KV.SCOREBOARD	3
157	ROUTINE	MAIN2	3
158	ROUTINE	MIN.MOVE	3
159	EVENT	POB.ACTIVATION	3
160	ROUTINE	PRED.POS	3
161	ROUTINE	PREP.WITHDRAW	3
162	ROUTINE	REIN.ARRIVE	3
163	ROUTINE	REM.EFFECTS.COMPUTATION	3
164	ROUTINE	REPLACE.HC	3
165	ROUTINE	SNAP.R	3
166	ROUTINE	TACAIR.DATA.REPORT	3
167	ROUTINE	TERM.CHECK	3
168	ROUTINE	TIME.TO.DETECT	3
169	ROUTINE	AC.MUNS.INPUT	2
170	EVENT	ARTY.OCCUPATION	2
171	FUNCTION	BTRY.AVAILABLE	2
172	ROUTINE	BTRY.FM.DEG	2
173	ROUTINE	BTRY.FM.ENG	2
174	ROUTINE	CHK.COMP.TR	2
175	ROUTINE	COMPUTE.WD	2
176	ROUTINE	EST.MIL.WORTH	2
177	ROUTINE	FASCAM.COMPUTATION	2
178	ROUTINE	FD.EFFECTS.REQ	2
179	ROUTINE	FILE.KAD.SENSOR	2
180	EVENT	INIT.PREPLAN.CAS	2
181	ROUTINE	MPT.TO.FREQ	2
182	ROUTINE	NORMAL.F	2
183	ROUTINE	PROB.INF	2
184	ROUTINE	SEARCH	2
185	EVENT	SET.DEBUG	2
186	ROUTINE	SMOKE.INPUT	2
187	EVENT	STOP.ARTY.MOVEMENT	2
188	ROUTINE	TB.INPUT	2
189	ROUTINE	TEMPERATURE.ATTENUATION	2
190	ROUTINE	BETWEEN.ROUTINE	1

Figure 3-8
Modules Ranked by IF Tests
Continued

RANK		MODULE NAME	IF TESTS
191	EVENT	CFR.OFF	1
192	ROUTINE	CHECK.ENGAGEMENT	1
193	ROUTINE	COMBINE.TRS	1
194	ROUTINE	DQ.CMSN.QUEUE	1
195	EVENT	DQ.OLD.SORTIE.QUEUE	1
196	FUNCTION	EST.RANGE	1
197	FUNCTION	EST.TR.RANGE	1
198	ROUTINE	EXPONENTIAL.F	1
199	ROUTINE	FDC.TR.DEQ	1
200	ROUTINE	FDC.TR.ENQ	1
201	ROUTINE	HC.DISENGAGE	1
202	ROUTINE	ILLUM.INPUT	1
203	ROUTINE	INITIAL.MOVE	1
204	ROUTINE	LINE.CIRCLE	1
205	ROUTINE	MPOB.INPUT	1
206	ROUTINE	ORD.MOVCOP	1
207	ROUTINE	PGM.INPUT	1
208	ROUTINE	POSITION.OUT	1
209	ROUTINE	PROB.TIME	1
210	ROUTINE	PROX.POS	1
211	ROUTINE	SEGMENT.ADJUST	1
212	EVENT	SEND.TEAM	1
213	ROUTINE	SYS.INPUT	1
214	ROUTINE	TF.INPUT	1
215	ROUTINE	UNIT.ASSIGNMENT	1
216	ROUTINE	VIS.INPUT	1
217	EVENT	ACT.DEF	0
218	EVENT	ACT.MOVCOR	0
219	FUNCTION	ACT.RANGE	0
220	EVENT	CHANGE.WEATHER	0
221	ROUTINE	CHECK.STREN	0
222	ROUTINE	COMPUTE.D	0
223	ROUTINE	COPY	0
224	ROUTINE	CREATE.TEAMS	0
225	ROUTINE	DECISION.INPUT	0
226	EVENT	END.SIMULATION	0
227	ROUTINE	ERROR.STOP	0
228	ROUTINE	FRAC.COMPUTE	0

Figure 3-8
Modules Ranked by IF Tests
Continued

RANK		MODULE NAME	IF TESTS
229	ROUTINE	HEADING	0
230	ROUTINE	INIT.REINF	0
231	ROUTINE	INITIAL.DETECT	0
232	ROUTINE	JOHNSON.CRITERIA	0
233	ROUTINE	KV.INPUT	0
234	ROUTINE	MADS.INPUT	0
235	PROGRAM	MAIN	0
236	ROUTINE	MAIN1	0
237	ROUTINE	MAIN3	0
238	ROUTINE	MAO.INPUT	0
239	ROUTINE	MCFR.INPUT	0
240	ROUTINE	MFC.INPUT	0
241	EVENT	MOVE	0
242	ROUTINE	MUNS.INPUT	0
243	PROGRAM	OLDER.VERSION.PREAMBLE	0
244	ROUTINE	OPEN.INPUT.OUTPUT.FILES	0
245	ROUTINE	ORD.ATK	0
246	ROUTINE	ORD.DEF	0
247	ROUTINE	ORD.MOVDIS	0
248	ROUTINE	ORD.REINF	0
249	ROUTINE	P.E.M.INPUT	0
250	ROUTINE	PK.INPUT	0
251	ROUTINE	POSITION	0
252	EVENT	POSITION.REPORT	0
253	PROGRAM	PREAMBLE	0
254	ROUTINE	PROXIMITY.REQ	0
255	ROUTINE	RANGE.COMPUTE	0
256	ROUTINE	RJL.EN.INPUT	0
257	EVENT	SCHEDULE.ARTY.MOVEMENT	0
258	ROUTINE	SNAP2	0
259	ROUTINE	ST.INPUT	0
260	FUNCTION	STAY.TIME	0
261	ROUTINE	SUBM.INPUT	0
262	ROUTINE	TBF.INPUT	0
263	ROUTINE	TIME.REQ	0
264	ROUTINE	TT.FACTORS.INPUT	0
265	ROUTINE	TYPE.WEAPON.INPUT	0
266	ROUTINE	WEIBULL.F	0

Figure 3-8
Modules Ranked by IF Tests
Continued

second report lists the modules ranked by functional IF tests, that is, the total number of IFs minus the number of IFs controlling debug output (see Figure 3.9). The third report lists the modules by maximum IF nesting depth (see Figure 3.10).

The information contained in these reports was then analyzed. Since the IF tests for debugging are not frequently utilized during COSAGE production runs, it was decided to use the number of functional IFs (adjusted by subtracting debug IFs) as the cyclomatic number for the control complexity metric. As mentioned previously, a routine that has a cyclomatic number greater than 10 (i.e., more than 10 independent paths) will probably not be fully tested. Further, if a routine is not fully tested, then its reliability and maintainability are suspect.

Referring to Figure 3.9, 61 modules in COSAGE have cyclomatic numbers greater than 10. This represents 23% of the COSAGE modules. Of these 61, 41 are routines (representing approximately 21% of all COSAGE routines), 14 are processes (representing approximately 74% of all COSAGE processes), 5 are events (representing approximately 14% of all COSAGE events), and 1 is a function (representing approximately 9% of all functions).

The obvious category which warrants further investigation are processes, since approximately 74% of all the COSAGE processes have cyclomatic numbers (control complexity metrics) greater than 10. Recommended changes to reduce the number of independent paths in these processes are discussed in Section 4.8 of the report.

There are 33 modules (including 8 processes) that contain a maximum depth of IF nesting greater than 3 (see Figure 3.10). The processes are particularly troublesome because they

RANK		MODULE NAME	FUNCTIONAL IF TESTS
1	ROUTINE	BTRY.EFFECTS	88
2	PROCESS	SHOOT.OUT	61
3	PROCESS	FIRE.MISSION	40
4	PROCESS	HELICOPTER.FIRE	38
5	PROCESS	TARGET.REPORT	36
6	ROUTINE	FD.DETECTION	35
7	PROCESS	HC.ARRIVE.BATTLE	34
8	ROUTINE	FINAL.COVERAGE	32
9	PROCESS	ASSESSMENT	30
10	EVENT	OFF.LINE.ATTRITION	30
11	ROUTINE	FA.BN.MOVEMENT	29
12	PROCESS	AC.ATK.TGT	27
13	EVENT	AD.ENGAGEMENT	27
14	PROCESS	AIR.OBSERVER	27
15	ROUTINE	FLIGHT.PATH	26
16	ROUTINE	UNIT.INPUT	26
17	PROCESS	HC.RETURN.FARP	25
18	ROUTINE	PK.COMPUTE	25
19	EVENT	START.BATTLE	25
20	ROUTINE	AD.DETECTION	24
21	ROUTINE	CHECK.CAS.CONSTRAINTS	24
22	PROCESS	HEL.TARGET.ACQUISITION	24
23	ROUTINE	REQUEST.SMOKE	24
24	ROUTINE	FA.BN.ASGN	22
25	ROUTINE	UNIT.ENVIR	21
26	ROUTINE	AC.BOMB.EFFECTS	20
27	ROUTINE	MINE.EFFECTS	20
28	ROUTINE	PGM.MSN.ASGN	20
29	ROUTINE	REQUEST.ILLUM	20
30	ROUTINE	AD.SHOOT	19
31	ROUTINE	ANALYSIS.OUTPUT	19
32	PROCESS	CAS.MISSION	19
33	PROCESS	ARTY.ASSESS	18
34	ROUTINE	ATTRIT.SENSOR	18
35	ROUTINE	CHECK.PROX	18
36	ROUTINE	TACAIR.INPUT	17
37	ROUTINE	AC.OF.EFFECTS	16
38	ROUTINE	SENSOR.INPUT	16

Figure 3-9

Modules Ranked by Functional IF Tests

RANK		MODULE NAME	FUNCTIONAL IF TESTS
39	ROUTINE	END.CAS.MISSION	15
40	EVENT	GET.MX.ORD	15
41	ROUTINE	ENTRY.INPUT	14
42	ROUTINE	CHANGE.LOC	14
43	ROUTINE	EST.COVERAGE	14
44	ROUTINE	INTER.BATTLE	14
45	ROUTINE	CFR.DETECTION	13
46	ROUTINE	DEAD.UNIT	13
47	ROUTINE	MINE.DELAY	13
48	ROUTINE	READ.ORDERS	13
49	ROUTINE	HE.OR.ICM.COMPUTATION	12
50	FUNCTION	HE.WLA	12
51	ROUTINE	WHAT.NEXT	12
52	ROUTINE	AMMO.RPT	11
53	ROUTINE	CAS.EVAL	11
54	ROUTINE	EMPLOY.HELICOPTERS	11
55	PROCESS	FORWARD.OBSERVER	11
56	ROUTINE	LINE.OF.SIGHT	11
57	PROCESS	MINE.ASSESS	11
58	ROUTINE	NEW.SEGMENT	11
59	ROUTINE	REQUEST.WD.FASCAM	11
60	ROUTINE	RPV.DETECTION	11
61	EVENT	START.MOVE	11
62	ROUTINE	CHECK.FOR.MINES	10
63	ROUTINE	DUST.EFFECTS	10
64	ROUTINE	FIND.START.TIME	10
65	ROUTINE	GENERAL.BATTLE	10
66	ROUTINE	PREPARE.LIST	10
67	ROUTINE	BLOCK.LOS	9
68	EVENT	CFR.OPERATOR	9
69	ROUTINE	ILLUM.EFFECTS	9
70	ROUTINE	OUTPUT.ATTRITION	9
71	ROUTINE	PIR.DETECTION	9
72	ROUTINE	SMOKE.EFFECTS	9
73	EVENT	UPDATE.LOC	9
74	EVENT	FEBA.SORTIE	8
75	ROUTINE	FILE.FD.SCHD	8
76	EVENT	HELO.ENGAGEMENT	8

Figure 3-9

Modules Ranked by Functional IF Tests

Continued

RANK		MODULE NAME	FUNCTIONAL IF TESTS
77	ROUTINE	KV.PRINT	8
78	ROUTINE	ORIENTATION	8
79	ROUTINE	OUTPUT.EXPENDITURES	8
80	ROUTINE	POB.DETECTION	8
81	PROCESS	REMOTE.PILOT.VEHICLE	8
82	ROUTINE	SIZE.ESTIMATE	8
83	ROUTINE	TARGET.ANALYSIS	8
84	ROUTINE	ADJUST	7
85	PROCESS	AIRBORNE.RADAR	7
86	EVENT	BTL.ENDED	7
87	ROUTINE	END.FEBA.SET	7
88	FUNCTION	FEBA.BAND	7
89	ROUTINE	MARGINAL.EFFECTS.ADJ	7
90	ROUTINE	SEARCH.COVERAGE	7
91	EVENT	CFR.ON	6
92	ROUTINE	DESTROY.ORD	6
93	ROUTINE	FIN.BATTLE	6
94	ROUTINE	HE.LA.INPUT	6
95	ROUTINE	LOCATE.SEARCH.AREA	6
96	ROUTINE	LOS.CHECK	6
97	ROUTINE	MINE.INPUT	6
98	ROUTINE	NOISE.DEGRADE	6
99	ROUTINE	REQUEST.DEF.FASCAM	6
100	ROUTINE	REQUEST.FASCAM	6
101	ROUTINE	WEIGHTED.VOLLEYS	6
102	PROCESS	WITH.DRAW	6
103	EVENT	CFR.ACTIVATION	5
104	ROUTINE	CHECK.DEAD	5
105	ROUTINE	CHECK.FORCE	5
106	ROUTINE	COMPARE.TRS	5
107	ROUTINE	CREATE.FORCE	5
108	ROUTINE	END.MOVE	5
109	ROUTINE	FEBA.INITIAL	5
110	FUNCTION	ICM.WLA	5
111	EVENT	POB.OPERATOR	5
112	ROUTINE	PLAT.COUNT	5
113	ROUTINE	PROX.CHECK	5
114	ROUTINE	SWITCH.FO	5

Figure 3-9
Modules Ranked by Functional IF Tests
Continued

RANK		MODULE NAME	FUNCTIONAL IF TESTS
115	ROUTINE	VOLLEY	5
116	EVENT	ACT.ATK	4
117	ROUTINE	ANGLE.COMPUTE	4
118	ROUTINE	BTL.CHECK	4
119	ROUTINE	CFR.DEGRADE	4
120	FUNCTION	COMBINATIONS	4
121	ROUTINE	CONTRAST.TO.FREQ	4
122	ROUTINE	EMPTY	4
123	ROUTINE	EQ.TE.INPUT	4
124	ROUTINE	FARRP.INPUT	4
125	ROUTINE	GAMMA.F	4
126	ROUTINE	HC.COMPUTE.TIMES	4
127	ROUTINE	HEL.RANGE.COMPUTE	4
128	PROCESS	PHOTO.IR.FLIGHT	4
129	EVENT	ACT.MOVDIS	3
130	EVENT	ACT.REINF	3
131	ROUTINE	AR.DETECTION	3
132	FUNCTION	AR.PROB.DETECT	3
133	EVENT	CHANGE.LITE	3
134	ROUTINE	CHK.FC.TP	3
135	FUNCTION	COLLISION	3
136	ROUTINE	DECIDE	3
137	EVENT	ENGAGEMENT	3
138	ROUTINE	FARRP.CHECK	3
139	ROUTINE	FBN.FD.INPUT	3
140	ROUTINE	GET.TERRAIN	3
141	PROCESS	HDW.REPAIR	3
142	ROUTINE	KV.SCOREBOARD	3
143	ROUTINE	MIN.MOVE	3
144	EVENT	POS.ACTIVATION	3
145	ROUTINE	PRED.POS	3
146	ROUTINE	PREP.WITHDRAW	3
147	ROUTINE	REIN.ARRIVE	3
148	ROUTINE	RESET.FEBA.SECTOR	3
149	ROUTINE	SMOKE.COMPUTATION	3
150	ROUTINE	SNAP.R	3
151	EVENT	START.ARTY.MOVEMENT	3
152	ROUTINE	TACAIR.DATA.REPORT	3

Figure 3.9

Modules Ranked by Functional IF Tests

Continued

RANK		MODULE NAME	FUNCTIONAL IF TESTS
153	ROUTINE	TERM.CHECK	3
154	ROUTINE	UNIT.PRIORITY	3
155	EVENT	ARTY.OCCUPATION	2
156	ROUTINE	BTRY.FM.DEQ	2
157	ROUTINE	BTRY.FM.ENQ	2
158	ROUTINE	CAT.TU.INPUT	2
159	ROUTINE	CHECK.LIST	2
160	ROUTINE	CHK.COMP.TR	2
161	ROUTINE	COMPUTE.WD	2
162	ROUTINE	DEQ.FEBA.SET	2
163	ROUTINE	FD.EFFECTS.REQ	2
164	ROUTINE	FINISH.COMPUTATION	2
165	ROUTINE	FORM.TF.LIST	2
166	EVENT	HC.DEPART.BATTLE	2
167	ROUTINE	HC.EMPTY	2
168	ROUTINE	ILLUM.COMPUTATION	2
169	ROUTINE	INTER.HELO	2
170	ROUTINE	LOCATE.SECTOR	2
171	ROUTINE	MAIN2	2
172	ROUTINE	MRT.TO.FREQ	2
173	ROUTINE	NORMAL.F	2
174	ROUTINE	PROB.INF	2
175	ROUTINE	SEARCH	2
176	EVENT	SET.DEBUG	2
177	ROUTINE	SMOKE.INPUT	2
178	EVENT	STOP.ARTY.MOVEMENT	2
179	ROUTINE	TB.INPUT	2
180	ROUTINE	TEMPERATURE.ATTENUATION	2
181	ROUTINE	TIME.TO.DETECT	2
182	ROUTINE	AC.MUNS.INPUT	1
183	FUNCTION	BTRY.AVAILABLE	1
184	EVENT	CFR.OFF	1
185	ROUTINE	CHECK.ENGAGEMENT	1
186	ROUTINE	COMBINE.TRS	1
187	ROUTINE	EST.MIL.WORTH	1
188	ROUTINE	EXPONENTIAL.F	1
189	ROUTINE	FASCAM.COMPUTATION	1
190	ROUTINE	FDC.TR.DEQ	1

Figure 3-9

Modules Ranked by Functional IF Tests

Continued

RANK		MODULE NAME	FUNCTIONAL IF TESTS
191	ROUTINE	FDC.TR.ENG	1
192	ROUTINE	FILE.KAD.SENSOR	1
193	ROUTINE	ILLUM.INPUT	1
194	EVENT	INIT.PREPLAN.CAS	1
195	ROUTINE	INITIAL.MOVE	1
196	ROUTINE	LINE.CIRCLE	1
197	ROUTINE	MPOB.INPUT	1
198	ROUTINE	ORD.MOVCOR	1
199	ROUTINE	PGM.INPUT	1
200	ROUTINE	POSITION.OUT	1
201	ROUTINE	PROB.TIME	1
202	ROUTINE	PROX.POS	1
203	ROUTINE	REM.EFFECTS.COMPUTATION	1
204	ROUTINE	REPLACE.HC	1
205	ROUTINE	SEGMENT.ADJUST	1
206	ROUTINE	SYS.INPUT	1
207	ROUTINE	TR.INPUT	1
208	ROUTINE	VIS.INPUT	1
209	EVENT	ACT.DEF	1
210	EVENT	ACT.MOVCOR	1
211	FUNCTION	ACT.RANGE	1
212	ROUTINE	BETWEEN.ROUTINE	1
213	EVENT	CHANGE.WEATHER	1
214	ROUTINE	CHECK.STREN	1
215	ROUTINE	COMPUTE.C	1
216	ROUTINE	COPY	1
217	ROUTINE	CREATE.TEAMS	1
218	ROUTINE	DECISION.INPUT	1
219	ROUTINE	DQ.CMSN.QUEUE	1
220	EVENT	DQ.OLD.SORTIE.QUEUE	1
221	EVENT	END.SIMULATION	1
222	ROUTINE	ERROR.STOP	1
223	FUNCTION	EST.RANGE	1
224	FUNCTION	EST.TR.RANGE	1
225	ROUTINE	FRAC.COMPUTE	1
226	ROUTINE	HC.DISENGAGE	1
227	ROUTINE	HEADING	1
228	ROUTINE	INIT.REINF	1

Figure 3-9
Modules Ranked by Functional IF Tests
Continued

RANK		MODULE NAME	FUNCTIONAL IF TESTS
229	ROUTINE	INITIAL.DETECT	0
230	ROUTINE	JOHNSON.CRITERIA	0
231	ROUTINE	KV.INPUT	0
232	ROUTINE	MADS.INPUT	0
233	PROGRAM	MAIN	0
234	ROUTINE	MAIN1	0
235	ROUTINE	MAIN3	0
236	ROUTINE	MAO.INPUT	0
237	ROUTINE	MCFR.INPUT	0
238	ROUTINE	MFO.INPUT	0
239	EVENT	MOVE	0
240	ROUTINE	MUNS.INPUT	0
241	PROGRAM	OLDEP.VERSION.PREAMBLE	0
242	ROUTINE	OPEN.INPUT.OUTPUT.FILES	0
243	ROUTINE	ORD.ATK	0
244	ROUTINE	ORD.DEF	0
245	ROUTINE	ORD.MOVDIS	0
246	ROUTINE	ORD.REINF	0
247	ROUTINE	P.E.M.INPUT	0
248	ROUTINE	PK.INPUT	0
249	ROUTINE	POSITION	0
250	EVENT	POSITION.REPORT	0
251	PROGRAM	PREAMBLE	0
252	ROUTINE	PROXIMITY.REQ	0
253	ROUTINE	RANGE.COMPUTE	0
254	ROUTINE	RUL.EN.INPUT	0
255	EVENT	SCHEDULE.ARTY.MOVEMENT	0
256	EVENT	SEND.TEAM	0
257	ROUTINE	SNAP2	0
258	ROUTINE	ST.INPUT	0
259	FUNCTION	STAY.TIME	0
260	ROUTINE	SUBM.INPUT	0
261	ROUTINE	TBF.INPUT	0
262	ROUTINE	TIME.REQ	0
263	ROUTINE	TT.FACTORS.INPUT	0
264	ROUTINE	TYPE.WEAPON.INPUT	0
265	ROUTINE	UNIT.ASSIGNMENT	0
266	ROUTINE	WEIBULL.F	0

Figure 3-9
Modules Ranked by Functional IF Tests
Continued

RANK		MODULE NAME	MAXIMUM DEPTH
1	EVENT	GET.NX.ORD	7
2	ROUTINE	CHECK.CAS.CONSTRAINTS	6
3	ROUTINE	DESTROY.ORD	6
4	PROCESS	FIRE.MISSION	6
5	ROUTINE	PK.COMPUTE	6
6	PROCESS	TARGET.REPORT	6
7	ROUTINE	WHAT.NEXT	6
8	ROUTINE	AC.DF.EFFECTS	5
9	ROUTINE	BTRY.EFFECTS	5
10	ROUTINE	CHECK.PROX	5
11	ROUTINE	MINE.EFFECTS	5
12	ROUTINE	POB.DETECTION	5
13	ROUTINE	PLAT.COUNT	5
14	ROUTINE	READ.OFDEPS	5
15	ROUTINE	UNIT.ENVIR	5
16	ROUTINE	AC.BOMB.EFFECTS	4
17	EVENT	AD.ENGAGEMENT	4
18	PROCESS	APTY.ASSESS	4
19	PROCESS	CAS.MISSION	4
20	ROUTINE	CHANGE.LOC	4
21	ROUTINE	DEAD.UNIT	4
22	ROUTINE	FA.EN.ASGN	4
23	ROUTINE	FA.EN.MOVEMENT	4
24	ROUTINE	FLIGHT.PATH	4
25	PROCESS	HC.RETURN.FARP	4
26	PROCESS	HEL.TARGET.ACQUISITION	4
27	PROCESS	HELICOPTER.FIRE	4
28	ROUTINE	MINE.DELAY	4
29	ROUTINE	PREPARE.LIST	4
30	ROUTINE	REQUEST.SMOKE	4
31	ROUTINE	REQUEST.WP.FASCAM	4
32	PROCESS	SHOOT.OUT	4
33	EVENT	START.BATTLE	4
34	EVENT	ACT.REINF	3
35	ROUTINE	AD.SHOOT	3
36	PROCESS	AIR.OBSERVER	3
37	FUNCTION	AP.PROB.DETECT	3
38	PROCESS	ASSESSMENT	3

Figure 3-10

Modules Ranked by Maximum IF Depth

RANK		MODULE NAME	MAXIMUM DEPTH
39	ROUTINE	ATTRIT.SENSOR	3
40	EVENT	ATL.ENDED	3
41	ROUTINE	ATRY.INPUT	3
42	ROUTINE	CAS.EVAL	3
43	EVENT	CFR.ACTIVATION	3
44	ROUTINE	CFR.DETECTION	3
45	EVENT	CFR.OPERATOR	3
46	ROUTINE	CHK.FD.TR	3
47	ROUTINE	COMPARE.TPS	3
48	ROUTINE	CONTRAST.TO.PEL	3
49	ROUTINE	EMPLOY.HELICOPTERS	3
50	ROUTINE	END.CAS.MISSION	3
51	ROUTINE	END.MOVE	3
52	ROUTINE	ENG.FIRE.SET	3
53	ROUTINE	EST.COVERAGE	3
54	ROUTINE	FILE.FD.SCHD	3
55	ROUTINE	FINAL.COV-RAGE	3
56	ROUTINE	FD.DETECTION	3
57	PROCESS	FDAWARD.OBSERVER	3
58	ROUTINE	GET.TERRAIN	3
59	PROCESS	HC.ARRIVE.BATTLE	3
60	ROUTINE	HF.OR.ICM.COMPUTATION	3
61	EVENT	HELO.ENGAGEMENT	3
62	ROUTINE	LOS.CHECK	3
63	PROCESS	MINE.ACCESS	3
64	ROUTINE	NEW.SEGMENT	3
65	EVENT	OFF.LINE.ATTRITION	3
66	ROUTINE	PIP.DETECTION	3
67	ROUTINE	REIN.ARRIVE	3
68	ROUTINE	REQUEST.FASCAM	3
69	ROUTINE	REQUEST.ILLUM	3
70	ROUTINE	RPV.DETECTION	3
71	ROUTINE	SEARCH.COVERAGE	3
72	ROUTINE	SNAP.R	3
73	EVENT	START.MOVE	3
74	ROUTINE	SWITCH.FD	3
75	ROUTINE	TACAIR.INPUT	3
76	ROUTINE	UNIT.INPUT	3

Figure 3-10
Modules Ranked by Maximum IF Depth
Continued

RANK		MODULE NAME	MAXIMUM DEPTH
77	EVENT	UPDATE.LOC	3
78	PROCESS	AC.ATK.TGT	2
79	EVENT	ACT.ATK	2
80	EVENT	ACT.MOVDIS	2
81	ROUTINE	ADJUST	2
82	ROUTINE	AMMO.RPT	2
83	ROUTINE	ANALYSIS.OUTPUT	2
84	ROUTINE	ANGLE.COMPUTE	2
85	ROUTINE	AO.DETECTION	2
86	ROUTINE	BLOCK.LOS	2
87	ROUTINE	BTL.CHECK	2
88	ROUTINE	BTRY.FM.LEG	2
89	ROUTINE	CAT.TU.INPUT	2
90	ROUTINE	CFR.DEGRADE	2
91	EVENT	CHANGE.LITE	2
92	ROUTINE	CHECK.FOR.MINES	2
93	ROUTINE	CHECK.FORCE	2
94	ROUTINE	CHK.COMP.TR	2
95	ROUTINE	CREATE.FORCE	2
96	ROUTINE	DUST.EFFECTS	2
97	ROUTINE	EMPTY	2
98	ROUTINE	EQ.TE.INPUT	2
99	ROUTINE	EST.MIL.WORTH	2
100	ROUTINE	FARRP.CHECK	2
101	ROUTINE	FBM.FD.INPUT	2
102	FUNCTION	FEBA.BAND	2
103	EVENT	FEBA.SORTIE	2
104	ROUTINE	FINISH.COMPUTATION	2
105	ROUTINE	FORM.TF.LIST	2
106	ROUTINE	GENERAL.BATTLE	2
107	ROUTINE	HE.LA.INPUT	2
108	FUNCTION	HE.WLA	2
109	ROUTINE	HEL.RANGE.COMPUTE	2
110	PROCESS	HOW.REPAIR	2
111	ROUTINE	ILLUM.COMPUTATION	2
112	ROUTINE	ILLUM.EFFECTS	2
113	ROUTINE	INTER.BATTLE	2
114	ROUTINE	KV.PRINT	2

Figure 3-10

Modules Ranked by Maximum IF Depth

Continued

RANK		MODULE NAME	MAXIMUM DEPTH
115	ROUTINE	KV.SCOREBOARD	2
116	ROUTINE	LINE.OF.SIGHT	2
117	ROUTINE	LOCATE.SEARCH.AREA	2
118	ROUTINE	MARGINAL.EFFECTS.ADJ	2
119	ROUTINE	MINE.INPUT	2
120	ROUTINE	NOISE.DEGRADE	2
121	ROUTINE	ORIENTATION	2
122	ROUTINE	OUTPUT.ATTRITION	2
123	EVENT	POS.OPERATOR	2
124	ROUTINE	PGM.MSN.ASGN	2
125	ROUTINE	PREP.WITHDRAW	2
126	ROUTINE	PROB.INF	2
127	ROUTINE	PROX.CHECK	2
128	ROUTINE	REPLACE.HC	2
129	ROUTINE	REQUEST.DEF.FASCAM	2
130	ROUTINE	SENSOR.INPUT	2
131	EVENT	SET.DEBUG	2
132	ROUTINE	SMOKE.COMPUTATION	2
133	ROUTINE	SMOKE.EFFECTS	2
134	ROUTINE	TEMPERATURE.ATTENUATION	2
135	ROUTINE	UNIT.PRIORITY	2
136	ROUTINE	VOLLEY	2
137	ROUTINE	WEIGHTED.VOLLEYS	2
138	PROCESS	WITH.DRAW	2
139	ROUTINE	AC.MUNS.INPUT	1
140	PROCESS	AIRBORNE.RADAR	1
141	ROUTINE	AR.DETECTION	1
142	EVENT	ARTY.OCCUPATION	1
143	ROUTINE	BETWEEN.ROUTINE	1
144	FUNCTION	BTRY.AVAILABLE	1
145	ROUTINE	BTRY.FM.ENG	1
146	EVENT	CFR.OFF	1
147	EVENT	CFR.ON	1
148	ROUTINE	CHECK.DEAD	1
149	ROUTINE	CHECK.ENGAGEMENT	1
150	ROUTINE	CHECK.LIST	1
151	FUNCTION	COLLISION	1
152	FUNCTION	COMBINATIONS	1

Figure 3-10

Modules Ranked by Maximum IF Depth

Continued

RANK		MODULE NAME	MAXIMUM DEPTH
229	ROUTINE	HEADING	0
230	ROUTINE	INIT.REINF	0
231	ROUTINE	INITIAL.DETECT	0
232	ROUTINE	JOHNSON.CRITERIA	0
233	ROUTINE	KV.INPUT	0
234	ROUTINE	MADS.INPUT	0
235	PROGRAM	MAIN	0
236	ROUTINE	MAIN1	0
237	ROUTINE	MAIN3	0
238	ROUTINE	MAO.INPUT	0
239	ROUTINE	MCFR.INPUT	0
240	ROUTINE	MFO.INPUT	0
241	EVENT	MOVE	0
242	ROUTINE	MUNS.INPUT	0
243	PROGRAM	OLDER.VERSION.PREAMBLE	0
244	ROUTINE	OPEN.INPUT.OUTPUT.FILES	0
245	ROUTINE	ORD.ATK	0
246	ROUTINE	ORD.DEF	0
247	ROUTINE	ORD.MOVDIS	0
248	ROUTINE	ORD.REINF	0
249	ROUTINE	P.E.M.INPUT	0
250	ROUTINE	PX.INPUT	0
251	ROUTINE	POSITION	0
252	EVENT	POSITION.REPORT	0
253	PROGRAM	PREAMBLE	0
254	ROUTINE	PROXIMITY.REQ	0
255	ROUTINE	RANGE.COMPUTE	0
256	ROUTINE	RUL.EN.INPUT	0
257	EVENT	SCHEDULE.ARTY.MOVEMENT	0
258	ROUTINE	SNAP2	0
259	ROUTINE	ST.INPUT	0
260	FUNCTION	STAY.TIME	0
261	ROUTINE	SUBM.INPUT	0
262	ROUTINE	TBF.INPUT	0
263	ROUTINE	TIME.REQ	0
264	ROUTINE	TT.FACTORS.INPUT	0
265	ROUTINE	TYPE.WEAPON.INPUT	0
266	ROUTINE	WEIBULL.F	0

Figure 3-10

Modules Ranked by Maximum IF Depth

Continued

RANK		MODULE NAME	MAXIMUM DEPTH
191	EVENT	POB.ACTIVATION	1
192	ROUTINE	PSM.INPUT	1
193	PROCESS	PHOTO.IR.FLIGHT	1
194	ROUTINE	POSITION.OUT	1
195	ROUTINE	PRED.POS	1
196	ROUTINE	PROB.TIME	1
197	ROUTINE	PROX.POS	1
198	ROUTINE	REM.EFFECTS.COMPUTATION	1
199	PROCESS	REMOTE.PILOT.VEHICLE	1
200	ROUTINE	RESET.FEBA.SECTOR	1
201	ROUTINE	SEARCH	1
202	ROUTINE	SEGMENT.ADJUST	1
203	EVENT	SEND.TEAM	1
204	ROUTINE	SIZE.ESTIMATE	1
205	ROUTINE	SMOKE.INPUT	1
206	EVENT	START.ARTY.MOVEMENT	1
207	EVENT	STOP.ARTY.MOVEMENT	1
208	ROUTINE	SYS.INPUT	1
209	ROUTINE	TACAIP.DATA.REPORT	1
210	ROUTINE	TARGET.ANALYSIS	1
211	ROUTINE	TB.INPUT	1
212	ROUTINE	TERM.CHECK	1
213	ROUTINE	TIME.TO.DETECT	1
214	ROUTINE	TR.INPUT	1
215	ROUTINE	UNIT.ASSIGNMENT	1
216	ROUTINE	VIS.INPUT	1
217	EVENT	ACT.DEF	0
218	EVENT	ACT.MOVCOR	0
219	FUNCTION	ACT.RANGE	0
220	EVENT	CHANGE.WEATHER	0
221	ROUTINE	CHECK.STREN	0
222	ROUTINE	COMPUTE.D	0
223	ROUTINE	COPY	0
224	ROUTINE	CREATE.TEAMS	0
225	ROUTINE	DECISION.INPUT	0
226	EVENT	END.SIMULATION	0
227	ROUTINE	ERROR.STOP	0
228	ROUTINE	FRAC.COMPUTE	0

Figure 3-10
Modules Ranked by Maximum IF Depth
Continued

RANK		MODULE NAME	MAXIMUM DEPTH
153	ROUTINE	COMBINE.TRS	1
154	ROUTINE	COMPUTE.WD	1
155	ROUTINE	DECIDE	1
156	ROUTINE	DEQ.FEBA.SET	1
157	ROUTINE	DQ.CMSN.QUEUE	1
158	EVENT	DQ.OLD.SORTIE.QUEUE	1
159	EVENT	ENGAGEMENT	1
160	FUNCTION	EST.RANGE	1
161	FUNCTION	EST.TR.RANGE	1
162	ROUTINE	EXPONENTIAL.F	1
163	ROUTINE	FARRP.INPUT	1
164	ROUTINE	FASCAM.COMPUTATION	1
165	ROUTINE	FD.EFFECTS.REQ	1
166	ROUTINE	FDC.TR.DEQ	1
167	ROUTINE	FDC.TR.ENQ	1
168	ROUTINE	FEBA.INITIAL	1
169	ROUTINE	FILE.KAD.SENSOR	1
170	ROUTINE	FIN.BATTLE	1
171	ROUTINE	FIND.START.TIME	1
172	ROUTINE	GAMMA.F	1
173	ROUTINE	HC.COMPUTE.TIMES	1
174	EVENT	HC.DEPART.BATTLE	1
175	ROUTINE	HC.DISENGAGE	1
176	ROUTINE	HC.EMPTY	1
177	FUNCTION	ICM.WLA	1
178	ROUTINE	ILLUM.INPUT	1
179	EVENT	INIT.PREPLAN.CAS	1
180	ROUTINE	INITIAL.MOVE	1
181	ROUTINE	INTER.HELO	1
182	ROUTINE	LINE.CIRCLE	1
183	ROUTINE	LOCATE.SECTOR	1
184	ROUTINE	MAIN2	1
185	ROUTINE	MIN.MOVE	1
186	ROUTINE	MPDB.INPUT	1
187	ROUTINE	MRT.TO.FREQ	1
188	ROUTINE	NORMAL.F	1
189	ROUTINE	ORD.MOVCOR	1
190	ROUTINE	OUTPUT.EXPENDITURES	1

Figure 3-10

Modules Ranked by Maximum IF Depth

can suspend, that is let simulated time elapse, and then restart. There is no guarantee that the conditions that were true prior to a suspension are still true afterward.

3.5.2 Operand Complexity Metric

In order to determine the operand complexity (Halstead Length Metric) of the COSAGE source code, each module was examined for the number of operands and operators. The number of operands was gathered in a semi-automated fashion by scanning the code and marking the occurrences of each operator mentioned in Section 2.3; namely, +, -, *, /, >, <, =, ≠, **, ADD, and SUBTRACT. Additionally, phrases such as UNLESS...IS EMPTY, FOR EVERY, NONE imply a relational operator and were included in the count. In the example given in Figure 3.11, there are 24 operators. (Note: The "ADD" on line 3614 was not included in the count since this line of code was added by SAI as part of the invocation study.)

The number of operands per routine was gathered by manually counting the number of occurrences of line number references that is produced by SIMSCRIPT upon compilation of the COSAGE source code. All references were counted and included the following:

Labels
Global variables
Recursive variables
Define to means
Routines
Arguments
Sets
Temporary attributes
Permanent attributes
Implied subscripts
Permanent entities
Process notices
Function attributes

```
                                CACI SIMSCRIPT II.5 for DEC VAX-11, Release 4.1  Page  34
Options = ID,SUBCHK,TRACE2,OPTIMIZE,TERMINAL,NOLIST,NAME31   5-JAN-1984 12:01       (  1)

 3006  ROUTINE UNIT.ASSIGNMENT                                          *** UNITSASSIGNM
 3007      GIVEN
 3008           SIDE,
 3009           UNITS,
 3010           TYPE.BATTLE.FIELD,
 3011           THETA,
 3012           X,
 3013           Y
 3014      ADD 1 TO ANAL.CTR(12,1)  *** \DYN_ANAL
 3015
 3016      NORMALLY MODE IS INTEGER
 3017      DEFINE ANGLE, THETA, THETA.ONE AS REAL VARIABLES
 3018      DEFINE UNITS AS AN INTEGER, 1-DIMENSIONAL ARRAY
 3019
 3020      LET NO.UNITS = DIM.F(UNITS(*))
 3021      LOOP FOR I = 1 TO NO.UNITS
 3022          UNLESS TEAM.TYPES(TYPE.BATTLE.FIELD) IS EMPTY
 3023          DO THE FOLLOWING
 3024          FOR EVERY TT OF TEAM.TYPES(TYPE.BATTLE.FIELD)
 3025               WITH TT.IN.USE(TT) = NO  AND
 3026                    TT.SIDE(TT) = SIDE  AND
 3027                    TT.TYPE(TT) = UN.TYPE.UNIT(UNITS(I))
 3028          FIND THE FIRST CASE
 3029          IF NONE
 3030               LIST ATTRIBUTES OF TYPE.TEAM CALLED TT
 3031               LIST UN.TYPE.UNIT(UNITS(I)), SIDE, I, UNITS(I)
 3032               CALL ERROR.STOP
 3033          ALWAYS
 3034
 3035          LET TT.IN.USE(TT) = YES
 3036          LOOP FOR EVERY PP OF PATH.SET(II)
 3037               UNLESS PATH.SET(II) IS EMPTY
 3038               DO THE FOLLOWING
 3039               CREATE A POINT
 3040               CALL ANGLE.COMPUTE
 3041                    GIVEN
 3042                         PP.X.POINT(PP),
 3043                         PP.Y.POINT(PP)
 3044                    YIELDING
 3045                         THETA.ONE
 3046               LET ANGLE = THETA + THETA.ONE
 3047               LET R = (PP.Y.POINT(PP)**2 + PP.X.POINT(PP)**2)**.5  *** \OPTIMIZE
 3048               LET P.X(POINT) = X + R * COS.F(ANGLE)
 3049               LET P.Y(POINT) = Y + R * SIN.F(ANGLE)
 3050               FILE THE POINT IN THE UN.PATH(UNITS(I))
 3051          ENDLOOP
 3052      ENDLOOP
 3053
 3054      EXITROUTINE
 3055  ENDROUTINE
```

Figure 3.11

Counting Operators for the Halstead Length Metric

In the example shown in Figure 3.12, the total number of operands is 93.

The Halstead complexity is the sum of the number of operators (24) and the number of operands (93). For the examples shown in Figures 3.11 and 3.12, the Halstead length metric is 117.

As with the control complexity metric, the number of operators and operands were tallied using an SAI-developed configuration control form. An example form is shown in Figure 3.4. A post-processor was written to list the COSAGE source modules ranked by Halstead Length. The results of this post-processor are shown in Figure 3.13.

As mentioned previously, if the Halstead length metric of a code module is 270 or greater, it is likely that the module was not properly designed with respect to module/submodule allocation. It is also likely that the module will be difficult to debug and might be of poor programming qualilty.

Referring to Figure 3.13, 57 COSAGE modules have a Halstead length of 270 or more. This represents approximately 22% of the COSAGE modules. Of these 57, 33 are routines (representing approximately 17% of all COSAGE routines), 16 are processes (representing approximately 84% of all COSAGE processes), 7 are events (representing approximately 2% of all COSAGE events), and 1 is a function (representing approximately 9% of all COSAGE functions).

Further investigation of the processes in the COSAGE model is obviously necessary since 84% of the COSAGE processes have a Halstead length of 270 or above. Recommended changes to

```
Routine UNIT.ASSIGNMENT      CACI SIMSCRIPT II.5 for DEC VAX-11, Release 4.1  Page  35
Options = ID,SUBCHK,TRACE2,OPTIMIZE,TERMINAL,NOLIST,NAME31   5-JAN-1994 12:01      ( 1)

                              C R O S S - R E F E R E N C E

  NAME                          TYPE                          MODE      LINE NUMBERS OF REFERENCES

ANAL.CTR                        GLOBAL VARIABLE      ASG  378 (2-D) INTEGER  3614*
ANGLE                           RECURSIVE VARIABLE   WORD   1        DOUBLE  3617   3646   3648   3649
ANGLE.COMPUTE                   ROUTINE                             INTEGER  3640
COS.F                           ROUTINE                             DOUBLE   3648
DIM.F                           ROUTINE                             INTEGER  3620
ENDLOOP                         DEFINE TO MEAN                               3651   3652
ENDROUTINE                      DEFINE TO MEAN                               3655
ERROR.STOP                      ROUTINE                             INTEGER  3652
EXITROUTINE                     DEFINE TO MEAN                               3654
F.PATH.SET                      TEMPORARY ATTRIBUTE  AUTO   5        INTEGER  3630
I                               RECURSIVE VARIABLE   WORD   6        INTEGER  3621*  3625   3631*  3650
L.PATH.SET                      TEMPORARY ATTRIBUTE  AUTO   6        INTEGER  3630
LOOP                            DEFINE TO MEAN                               3621   3636
M.TEAM.TYPES                    TEMPORARY ATTRIBUTE  AUTO  10        INTEGER  3630
N.PATH.SET                      TEMPORARY ATTRIBUTE  AUTO   7        INTEGER  3630
NO                              DEFINE TO MEAN                               3625
NO.UNITS                        RECURSIVE VARIABLE   WORD   5        INTEGER  3620   3621
P.TEAM.TYPES                    TEMPORARY ATTRIBUTE  AUTO   3        INTEGER  3630
P.X                             TEMPORARY ATTRIBUTE  AUTO   1        INTEGER  3648
P.Y                             TEMPORARY ATTRIBUTE  AUTO   2        INTEGER  3649
PATH.SET                        SET                         (1-D)    3636   3637
POINT                           TEMPORARY ENTITY                             3639
                              * GLOBAL VARIABLE      ASG  555        INTEGER  3639   3648   3649   3650
PP                              RECURSIVE VARIABLE   WORD  23        INTEGER  3636*  3642   3643   3647*
PP.X.POINT                      TEMPORARY ATTRIBUTE  AUTO   1        INTEGER  3642   3647
PP.Y.POINT                      TEMPORARY ATTRIBUTE  AUTO   2        INTEGER  3643   3647
R                               RECURSIVE VARIABLE   WORD  22        INTEGER  3647   3648   3649
S.TEAM.TYPES                    TEMPORARY ATTRIBUTE  AUTO   9        INTEGER  3630
SIDE                            ARGUMENT             WORD   1        INTEGER  3609   3625   3631
SIN.F                           ROUTINE                             DOUBLE   3649
TEAM.TYPES                      SET                         (1-D)    3622   3624
THETA                           ARGUMENT             WORD   4        DOUBLE   3611   3617   3646
THETA.ONE                       RECURSIVE VARIABLE   WORD   2        DOUBLE   3617   3645   3646
TT                              RECURSIVE VARIABLE   WORD   7        INTEGER  3624*  3625*  3630   3635   3636   3637
TT.IN.USE                       TEMPORARY ATTRIBUTE  AUTO   2        INTEGER  3625   3630   3635
TT.SIDE                         TEMPORARY ATTRIBUTE  AUTO   3        INTEGER  3625   3630
TT.TYPE                         TEMPORARY ATTRIBUTE  AUTO   4        INTEGER  3625   3630
TT.UNIT                         TEMPORARY ATTRIBUTE  AUTO   1        INTEGER  3630
TYPE.BATTLE.FIELD               ARGUMENT             WORD   3        INTEGER  3610   3622   3624
TYPE.TEAM                       GLOBAL VARIABLE      ASG  790        INTEGER  3630*
UN.PATH                         SET                         (1-D)    3650
UN.TYPE.UNIT                    PERMANENT ATTRIBUTE  ASG  795 (1-D) INTEGER  3625   3631
UNIT.ASSIGNMENT                 ROUTINE                             INTEGER  3606
UNITS                           ARGUMENT             WORD   2 (1-D) INTEGER  3609   3618   3620   3625   3631*  3650
X                               ARGUMENT             WORD   5        INTEGER  3612   3648
Y                               ARGUMENT             WORD   6        INTEGER  3613   3649
YES                             DEFINE TO MEAN                               3635
```

Counting Operands for the Halstead Length Metric

Figure 3.12

RANK		MODULE NAME	HALSTEAD LENGTH
1	ROUTINE	BTRY.EFFECTS	1680
2	PROCESS	AC.ATK.TGT	1442
3	PROCESS	SHOOT.OUT	1415
4	PROCESS	AIR.OBSERVER	1034
5	PROCESS	CAS.MISSION	913
6	PROCESS	FIRE.MISSION	881
7	PROCESS	HELICOPTER.FIRE	877
8	ROUTINE	FINAL.COVERAGE	862
9	EVENT	AC.ENGAGEMENT	839
10	ROUTINE	FLIGHT.P-TH	799
11	PROCESS	HEL.TARGET.ACQUISITION	791
12	PROCESS	FORWARD.OBSERVER	768
13	PROCESS	TARGET.REPORT	630
14	ROUTINE	SNAP3	677
15	ROUTINE	AD.DETECTION	674
16	PROCESS	ASSESSMENT	647
17	PROCESS	HC.ARRIVE.BATTLE	647
18	EVENT	START.BATTLE	641
19	ROUTINE	EST.COVERAGE	604
20	ROUTINE	AC.BOMB.EFFECTS	541
21	ROUTINE	FD.DETECTION	515
22	ROUTINE	FA.BN.MOVEMENT	482
23	ROUTINE	ORIENTATION	465
24	ROUTINE	TACAIR.INPUT	451
25	ROUTINE	PGM.MSN.ASGN	431
26	ROUTINE	EMPLOY.HELICOPTERS	425
27	PROCESS	REMOTE.PILOT.VEHICLE	412
28	ROUTINE	FA.BN.ASGN	407
29	PROCESS	HC.RETURN.FARRP	382
30	ROUTINE	AC.DF.EFFECTS	379
31	PROCESS	PHOTO.IR.FLIGHT	379
32	ROUTINE	ATTRIT.SENSOR	362
33	ROUTINE	AD.SHOOT	367
34	ROUTINE	SENSOR.INPUT	359
35	ROUTINE	GENERAL.BATTLE	357
36	EVENT	HELO.ENGAGEMENT	351
37	ROUTINE	REQUEST.SMOKE	340
38	ROUTINE	NEW.SEGMENT	334

Figure 3-13

Modules Ranked by Halstead Length

RANK		MODULE NAME	HALSTEAD LENGTH
39	ROUTINE	MINE.EFFECTS	338
40	ROUTINE	REQUEST.ILLUM	334
41	EVENT	OFF.LINE.ATTRITION	333
42	ROUTINE	CHECK.CAS.CONSTRAINTS	325
43	PROCESS	ARTY.ASSESS	323
44	ROUTINE	DEAD.UNIT	322
45	ROUTINE	ADJUST	310
46	ROUTINE	ANALYSIS.OUTPUT	305
47	PROCESS	AIRBORNE.RADAR	296
48	EVENT	START.MOVE	295
49	ROUTINE	CHECK.FOR.MINES	292
50	ROUTINE	UNIT.ENVIR	292
51	FUNCTION	HE.WLA	286
52	EVENT	UPDATE.LOC	282
53	ROUTINE	MC.EMPTY	281
54	EVENT	FEBA.SORTIE	276
55	ROUTINE	CHANGE.LOC	274
56	ROUTINE	END.CAS.MISSION	273
57	ROUTINE	UNIT.INPUT	272
58	EVENT	CFR.OPERATOR	268
59	ROUTINE	SNAP.P	267
60	ROUTINE	INTER.BATTLE	262
61	PROCESS	MINE.ASSESS	262
62	ROUTINE	FIND.START.TIME	261
63	ROUTINE	PK.COMPUTE	259
64	ROUTINE	LINE.OF.SIGHT	257
65	ROUTINE	RPV.DETECTION	256
66	ROUTINE	CHECK.PROX	252
67	ROUTINE	SMOKE.EFFECTS	248
68	ROUTINE	FILE.FD.SCHD	245
69	ROUTINE	BLOCK.LOS	243
70	ROUTINE	HE.OR.ICM.COMPUTATION	234
71	ROUTINE	CAS.EVAL	228
72	ROUTINE	CFR.DETECTION	222
73	ROUTINE	EMPTY	214
74	ROUTINE	MARGINAL.EFFECTS.ADJ	214
75	PROCESS	WITH.DRAW	213
76	ROUTINE	DUST.EFFECTS	212

Figure 3-13

Modules Ranked by Halstead Length

Continued

RANK		MODULE NAME	HALSTEAD LENGTH
77	ROUTINE	HC.DISENGAGE	209
78	ROUTINE	MINE.DELAY	208
79	EVENT	POB.OPERATOR	207
80	ROUTINE	OUTPUT.EXPENDITURES	206
81	ROUTINE	SEARCH.COVERAGE	205
82	FUNCTION	ICM.WLA	203
83	ROUTINE	MINE.INPUT	201
84	ROUTINE	TARGET.ANALYSIS	188
85	ROUTINE	INTER.HELO	185
86	ROUTINE	PIR.DETECTION	184
87	ROUTINE	WHAT.NEXT	184
88	ROUTINE	LOCATE.SEARCH.AREA	182
89	ROUTINE	MUNS.INPUT	178
90	ROUTINE	BTRY.INPUT	177
91	ROUTINE	ILLUM.EFFECTS	176
92	ROUTINE	BETWEEN.ROUTINE	173
93	ROUTINE	KV.PRINT	171
94	EVENT	GET.NX.ORD	169
95	ROUTINE	POB.DETECTION	168
96	ROUTINE	PREPARE.LIST	162
97	ROUTINE	REQUEST.FASCAM	162
98	ROUTINE	REQUEST.MD.FASCAM	156
99	EVENT	BTL.ENDED	155
100	ROUTINE	OUTPUT.ATTRITION	155
101	EVENT	ACT.ATK	154
102	ROUTINE	FEBA.INITIAL	153
103	ROUTINE	AMMO.RPT	148
104	ROUTINE	WEIGHTED.VOLLEYS	147
105	EVENT	START.ARTY.MOVEMENT	147
106	EVENT	CFR.ON	145
107	ROUTINE	AP.DETECTION	143
108	EVENT	ENGAGEMENT	140
109	ROUTINE	READ.ORDERS	139
110	ROUTINE	FARRP.INPUT	137
111	ROUTINE	CHECK.DEAD	136
112	ROUTINE	CREATE.FORCE	136
113	ROUTINE	TACAIR.DATA.REPORT	136
114	ROUTINE	HC.COMPUTE.TIMES	135

Figure 3-13
Modules Ranked by Halstead Length
Continued

RANK		MODULE NAME	HALSTEAD LENGTH
115	ROUTINE	HE.LA.INPUT	130
116	ROUTINE	TBE.INPUT	125
117	ROUTINE	SIZE.ESTIMATE	125
118	FUNCTION	FEBA.BAND	123
119	ROUTINE	TIME.TO.DETECT	121
120	ROUTINE	SWITCH.FO	118
121	ROUTINE	UNIT.ASSIGNMENT	117
122	ROUTINE	FILE.KAD.SENSOR	116
123	ROUTINE	KV.SCOREBOARD	116
124	ROUTINE	LOS.CHECK	116
125	ROUTINE	BTL.CHECK	110
126	ROUTINE	SMOKE.COMPUTATION	108
127	ROUTINE	AC.MUNS.INPUT	107
128	ROUTINE	END.MOVE	107
129	ROUTINE	CHECK.FORCE	105
130	ROUTINE	VOLLEY	105
131	ROUTINE	CAT.TU.INPUT	102
132	EVENT	ACT.REINF	101
133	ROUTINE	FIN.BATTLE	99
134	ROUTINE	ILLUM.COMPUTATION	99
135	ROUTINE	LINE.CIRCLE	99
136	ROUTINE	TB.INPUT	99
137	ROUTINE	HEL.RANGE.COMPUTE	97
138	ROUTINE	ENG.FEBA.SET	96
139	ROUTINE	CFR.DEGRADE	93
140	ROUTINE	EQ.TE.INPUT	92
141	ROUTINE	NOISE.DEGRADE	92
142	ROUTINE	MFO.INPUT	91
143	ROUTINE	UNIT.PRIORITY	91
144	ROUTINE	COMBINE.TPS	89
145	PROCESS	HOW.REPAIR	88
146	ROUTINE	PK.INPUT	87
147	ROUTINE	FASCAM.COMPUTATION	85
148	ROUTINE	PRED.POS	85
149	ROUTINE	PROX.CHECK	85
150	EVENT	CFR.ACTIVATION	84
151	ROUTINE	SYS.INPUT	83
152	EVENT	POB.ACTIVATION	81

Figure 3-13
Modules Ranked by Halstead Length
Continued

RANK		MODULE NAME	HALSTEAD LENGTH
153	ROUTINE	FARRP.CHECK	80
154	ROUTINE	PLAT.COUNT	80
155	ROUTINE	COPY	79
156	ROUTINE	FBN.FD.INPUT	74
157	ROUTINE	MAD.INPUT	74
158	ROUTINE	REQUEST.DEF.FASCAM	73
159	ROUTINE	TT.FACTORS.INPUT	73
160	ROUTINE	CHECK.LIST	71
161	FUNCTION	BTRY.AVAILABLE	70
162	ROUTINE	TYPE.WEAPON.INPUT	70
163	ROUTINE	FORM.TF.LIST	69
164	EVENT	INIT.PREPLAN.CAS	69
165	ROUTINE	COMPUTE.WD	67
166	ROUTINE	INIT.REINF	66
167	ROUTINE	TEMPERATURE.ATTENUATION	66
168	ROUTINE	RESET.FEBA.SECTOR	64
169	EVENT	ACT.MOVDIS	63
170	ROUTINE	DECIDE	62
171	ROUTINE	GAMMA.F	62
172	ROUTINE	NORMAL.F	62
173	ROUTINE	REM.EFFECTS.COMPUTATION	62
174	ROUTINE	CONTRAST.TO.FREQ	61
175	FUNCTION	AR.PROB.DETECT	60
176	ROUTINE	DESTROY.ORD	60
177	ROUTINE	REIN.ARRIVE	60
178	FUNCTION	COMBINATIONS	59
179	ROUTINE	MAIN2	59
180	ROUTINE	PROB.INF	59
181	FUNCTION	COLLISION	59
182	EVENT	HC.DEPART.BATTLE	58
183	ROUTINE	KV.INPUT	58
184	ROUTINE	PGM.INPUT	58
185	ROUTINE	FRAC.COMPUTE	57
186	ROUTINE	REPLACE.HC	57
187	ROUTINE	PROB.TIME	56
188	ROUTINE	MCFR.INPUT	55
189	ROUTINE	COMPARE.TRS	53
190	ROUTINE	RUL.EN.INPUT	53

Figure 3-13
Modules Ranked by Halstead Length
Continued

RANK		MODULE NAME	HALSTEAD LENGTH
191	ROUTINE	MPOB.INPUT	52
192	ROUTINE	PREP.WITHDRAW	52
193	EVENT	STOP.ARTY.MOVEMENT	52
194	EVENT	ACT.MOVCOR	51
195	ROUTINE	POSITION	51
196	ROUTINE	SEARCH	51
197	ROUTINE	DEQ.FEBA.SET	50
198	ROUTINE	LOCATE.SECTOR	50
199	ROUTINE	P.E.M.INPUT	50
200	ROUTINE	MIN.MOVE	49
201	ROUTINE	SUBM.INPUT	49
202	ROUTINE	SMOKE.INPUT	48
203	EVENT	CFR.OFF	47
204	ROUTINE	TR.INPUT	47
205	ROUTINE	COMPUTE.D	44
206	ROUTINE	MAOS.INPUT	44
207	ROUTINE	ANGLE.COMPUTE	43
208	ROUTINE	ORD.MOVCOR	43
209	EVENT	ACT.DEF	40
210	ROUTINE	CHECK.STREN	39
211	ROUTINE	CHK.FD.TR	39
212	ROUTINE	CREATE.TEAMS	39
213	ROUTINE	ILLUM.INPUT	39
214	ROUTINE	PROX.POS	39
215	ROUTINE	TERM.CHECK	39
216	ROUTINE	FINISH.COMPUTATION	37
217	ROUTINE	EST.MIL.WORTH	36
218	FUNCTION	EST.RANGE	36
219	ROUTINE	MAIN1	36
220	ROUTINE	CHK.COMP.TR	35
221	EVENT	ARTY.OCCUPATION	34
222	EVENT	SET.DEBUG	34
223	EVENT	CHANGE.LITE	33
224	FUNCTION	EST.TR.RANGE	33
225	ROUTINE	POSITION.OUT	33
226	ROUTINE	BTRY.FM.DEQ	31
227	ROUTINE	FD.EFFECTS.REQ	30
228	EVENT	SEND.TEAM	30

Figure 3-13
Modules Ranked by Halstead Length
Continued

RANK		MODULE NAME	HALSTEAD LENGTH
229	ROUTINE	GET.TERRAIN	29
230	ROUTINE	RANGE.COMPUTE	29
231	FUNCTION	ACT.RANGE	27
232	ROUTINE	BTRY.EM.ENG	27
233	ROUTINE	FDC.TR.DEQ	27
234	ROUTINE	VIS.INPUT	27
235	FUNCTION	STAY.TIME	25
236	ROUTINE	CHECK.ENGAGEMENT	24
237	EVENT	DQ.OLD.SORTIE.QUEUE	24
238	ROUTINE	EXPONENTIAL.F	24
239	ROUTINE	FDC.TR.ENQ	23
240	ROUTINE	INITIAL.MOVE	23
241	ROUTINE	MAIN3	23
242	ROUTINE	SEGMENT.ADJUST	22
243	ROUTINE	DECISION.INPUT	21
244	ROUTINE	INITIAL.DETECT	21
245	ROUTINE	ST.INPUT	21
246	ROUTINE	MRT.TO.FREQ	19
247	ROUTINE	WEIBULL.F	19
248	EVENT	CHANGE.WEATHER	17
249	EVENT	SCHEDULE.ARTY.MOVEMENT	17
250	ROUTINE	ORD.DEF	14
251	ROUTINE	ORD.MOVDIS	14
252	ROUTINE	DQ.CMSN.QUEUE	13
253	ROUTINE	ORD.ATK	12
254	ROUTINE	ORD.REINF	12
255	EVENT	POSITION.REPORT	12
256	EVENT	MOVE	11
257	PROGRAM	MAIN	10
258	ROUTINE	TIME.REQ	10
259	ROUTINE	PROXIMITY.REQ	9
260	EVENT	END.SIMULATION	8
261	ROUTINE	JOHNSON.CRITERIA	7
262	ROUTINE	ERROR.STOP	5
263	ROUTINE	HEADING	4
264	ROUTINE	OPEN.INPUT.OUTPUT.FILES	1
265	PROGRAM	OLDER.VERSION.PREAMBLE	0
266	PROGRAM	PREAMBLE	0

Figure 3-13
Modules Ranked by Halstead Length
Continued

reduce the number of operators and operands in the processes are discussed in Section 4.8 of this report.

4.0 RECOMMENDED CHANGES

This section presents the changes recommended for the COSAGE model. These recommendations were compiled based on SAI's efforts in the static and dynamic analyses.

4.1 Exponentiation

A review of the COSAGE source code shows that there has been widespread use of exponentiation for squaring and cubing mathematical expressions. Figure 4.5 shows an example of this type of calculation. The SIMSCRIPT implementation of exponentiation is not a very efficient means of accomplishing squares or cubes. Figure 4.6 illustrates an enhanced method, which multiplies the local variables (DELTA.X and DELTA.Y) times themselves. This method, when benchmarked on both the VAX and SPERRY computers, averaged an execution speed improvement of approximately [redacted].

When only two of the most frequently invoked COSAGE modules were revised in the manner discussed above and benchmarked on the VAX version of COSAGE, system execution time decreased by [redacted] improvement. (Details of this benchmark are discussed more fully in Section 4.7 of this report.) Based on this testcase, SAI analysts concluded that the exponentiation optimization holds a very high potential for reducing COSAGE execution time. Although it is difficult to estimate the precise

savings which can be recognized by this revision, there are more than one hundred calculations in COSAGE which use exponentiation. Therefore, it is realistic to expect an overall execution time savings in the range of 5-10% when all COSAGE calculations using exponentiation have been upgraded to use the demonstrated technique.

4.2 Inefficient Mathematical Expressions

Writing source code is frequently a tradeoff between clarity and efficiency. Because of the unusual units of measure (e.g., hexadecameters), conversion of expressions are often performed with factors such as (16.0/10.0) or (10.0/16.0). These factors make the code clearer, but are extremely inefficient since they must be re-evaluated every time they are executed. This type of factor is found at several hundred locations in the COSAGE source code.

SAI analysts recommend replacing the inefficient expressions with pre-calculated global variables using meaningful names. For example, the SIMSCRIPT statement:

```
LET TEN.16THS = 10.0/16.0
```

would allow all the expressions (10.0/16.0) to be replaced with a meaningful variable (TEN.16THS) containing the same value. This optimization would reduce both the execution time and the memory requirements.

4.3 Unnecessary SQRT.F Usage

At many places in the COSAGE source code, the distance between two points is calculated using the square root of the sum of the delta X squared and delta Y squared.

When the actual distance between the points is required, this type of algorithm is relatively efficient; but often, the actual distance is not required. The objective may be to select the closest alternative to a particular location, in which case the square root is not required.

When distances are being compared to a threshold or range, it is much more efficient to square the threshold or range once and compare the sum of squares to this value, than to take the square root many times to compare the actual distances. Benchmarks performed by SAI analysts indicate identical results can be obtained with 30% to 65% less execution time required.

4.4 Schedules/Reschedules

COSAGE contains many events which are scheduled to occur at various points in simulated time. Some events schedule re-occurrences of the same event at a later instance in simulated time. This type of event is best illustrated by the periodic update of location that can occur at regular intervals for moving units.

The SIMSCRIPT compiler by default automatically deallocates the memory used by the event notice just before the event is executed. For these types of periodic events, the optional phrase "SAVING THE EVENT NOTICE" should be appended to

the EVENT statement. Then SIMSCRIPT will allow the event notice to be re-used.

The re-use is accomplished by replacing the repeated "SCHEDULE A" statement with a "RESCHEDULE THIS" statement. The overhead savings for frequently used events can be substantial. SAI analysts wrote two programs to test the efficiencies of replacing repeated schedule statements with the reschedule option.

The program which appears in Figure 4.1 schedules an event which in turn schedules itself again at 1 hour intervals over a period of 1000 hours. The program which appears in Figure 4.2 is identical in every way to the first program except that the event notice is saved and the event reschedules itself. The elapsed CPU time savings are summarized below.

24.06	seconds	(SCHEDULE)
10.16	seconds	(RESCHEDULE)
12.90	seconds	(54% savings)

There are several places which have been identified in the COSAGE source code where SCHEDULE statements should be replaced with RESCHEDULE ones, and the event notices should be saved. The events identified include:

CPR.OPERATOR
CHANGE.LITE
FEBA.SORTIE
PDB.OPERATOR
POSITION.REPORT
SCHEDULE.ARTY.MOVEMENT
UPDATE.LOC

In addition to saving execution time, this recommended change also has the advantage of saving memory since the previously allocated space is reused, and no new space is required.

4.5 Removal/Replacement of Identified Modules

```
''PROGRAM'' PREAMBLE
   EVENT NOTICES INCLUDE SCHEDULE_E
END

''PROGRAM'' MAIN
   SCHEDULE AN SCHEDULE_E IN 1 HOUR
   START SIMULATION
END

EVENT TO SCHEDULE_E
   SCHEDULE AN SCHEDULE_E IN 1 HOUR
   IF TIME.V > 1000
      STOP
   OTHERWISE
   RETURN
END
```

Figure 4.1
Schedule Testcase

```
''PROGRAM'' PREAMBLE
   EVENT NOTICES INCLUDE SCHEDULE_E
END

''PROGRAM'' MAIN
   SCHEDULE AN SCHEDULE_E IN 1 HOUR
   START SIMULATION
END

EVENT TO SCHEDULE_E SAVING THE EVENT NOTICE
   RESCHEDULE A SCHEDULE_E IN 1 HOUR
   IF TIME.V > 1000
      STOP
   OTHERWISE
   RETURN
END
```

Figure 4.2
Reschedule Testcase

There are eleven modules identified in the accompanying SAI-SDDL processed COSAGE source code (see Volume II) which have been categorized as un-used and/or deletion candidates. Some of the modules simply return a constant value; they should be replaced by a global variable. Some modules are not currently implemented in the program. Each should be evaluated to determine where removal/replacement should be performed. A recommended action is listed for each in Table 4.1.

One such module (JOHNSON.CRITERIA) was invoked 344,157 times in COSAGE. This routine simply returns a value of 1.0. A testcase was written which replicates 344,157 calls (see Figure 4.3). Another testcase was rewritten which simply assigns a variable the value of 1.0 (see Figure 4.4). The results are summarized below:

13.59	CPU seconds for Call Statements
3.51	CPU seconds for Assignment Statements
10.08	Savings (74%)

4.6 Utilize SIMSCRIPT Text Feature

Utilization of the recently-implemented SIMSCRIPT text feature is recommended. The replacement of alpha variable types with text variable types will serve two purposes: efficiency of memory usage and transportability of the source code.

Alpha variables or constants are left justified when stored in a computer work. It depends on the implementation for the particular machine whether a single character or more is stored per word. Regardless of the implementation, however, if fewer characters are stored per word than the number of bytes in the computer word, storage is wasted.

Text variables, on the other hand, regardless of implementation, are represented by a pointer giving the address of a memory location where one or more words contain the represented characters, one character per byte.

Module Name	Comments
GAMMA.F	Not used - Delete
AIRBORNE.RADAR	Not used - Delete
AR.DETECTION	Called by AIRBORNE.RADAR (not used) - Delete
AR.PROB.DETECTION	Called by AR.DETECTION (not used) - Delete
PHOTO.IR.FLIGHT	Not used - Delete
STAY.TIME	Called by PHOTO.IR.FLIGHT (not used) - Delete
JOHNSON.CRITERIA	Returns a Constant Value (1.0) Called 344,157 times (5% of all invocations) 33rd most frequently sampled Should be replaced by a Global Variable
PROXIMITY.REQ	Returns a constant value (5) Should be replaced by a Global Variable
TIME.REQ	Returns a constant value (0.1) Should be replaced by a Global Variable
OLDER VERSION PREAMBLE	Should be deleted from file to avoid confusion and errors
PLAT.COUNT	Only calls are from event START.BATTLE Calls are commented out Remove comments and delete routine

TABLE 4.1

Modules To Be Deleted/Replaced

```
''PROGRAM'' MAIN

   DEFINE I AS AN INTEGER VARIABLE
   FOR I = 1 TO 344157
   DO
      CALL JOHNSON.CRITERIA YIELDING .NO.BARS
   LOOP
END

ROUTINE JOHNSON.CRITERIA YIELDING .NO.BARS
   LET .NO.BARS = 1.
   RETURN
END
```

Figure 4.3

344,157 Call Statements Testcase

```
''PROGRAM'' MAIN

   DEFINE I AS AN INTEGER VARIABLE

   LET .NO.BARS = 1.
   FOR I = 1 TO 344157
   DO
      LET X = .NO.BARS
   LOOP
END
```

Figure 4.4
344,157 Assignment Statements Testcase

Further, when code is transported from one machine to another, it must first be determined if the implementations of alpha modes is compatible before alpha variables may be used with confidence. The convention of using text modes instead of alpha mode would be both more efficient and would increase transportability of code.

4.7 Perform a Thorough Analysis on the 26 Most Frequently Invoked Modules

SAI dynamic execution analysis has shown the following group of 26 modules (10%) of the COSAGE program to account for over 93% of all invocations (see Figure 3.1). It is recommended that SAI analyze each of these 26 modules in detail and in close co-operation with the COR. Small individual changes in efficiency can result in large overall savings since these modules are invoked frequently.

For example, the two program modules most frequently invoked were FUNCTION ACT.RANGE (1,189,098 invocations) and ROUTINE RANGE.COMPUTE (792,643). Together, these two modules account for over 29% of all invocations in the baseline 24 hour COSAGE simulation. Both modules had been highlighted by SAI analysts during our static analysis with the \OPTIMIZE cross-reference identifier.

The first module, ACT.RANGE, Figure 4.5, computes the intermediate values DELTA.X and DELTA.Y; the values are squared, summed, and used as an argument to the SIMSCRIPT SQRT.F function. This method of squaring the values is exponentiation; during static analysis benchmarks, analysts found this method of squaring to require up to twice as much execution time with SIMSCRIPT.

```
FUNCTION ACT.RANGE                                                    ''~ F001
    GIVEN
         UNIT1,
         UNIT2

    ADD 1 TO ANAL.CTR(239,1)   ''~ \DYN_ANAL
    ''THIS FUNCTION COMPUTES THE ACTUAL RANGE BETWEEN TWO UNITS

    NORMALLY MODE IS INTEGER
    DEFINE RANGE AS A REAL VARIABLE

    LET DELTA.X = UN.X.COORD( UNIT1 ) - UN.X.COORD( UNIT2 )          -
    LET DELTA.Y = UN.Y.COORD( UNIT1 ) - UN.Y.COORD( UNIT2 )
    LET RANGE = SQRT.F( DELTA.X ** 2  +  DELTA.Y ** 2 ) ''~ \OPTIMIZE

    RETURN WITH RANGE
ENDFUNCTION
```

Figure 4.5
Current Function ACT.RANGE

Therefore,. we recommend replacing this function with the code indicated in Figure 4.6.

The second module, RANGE.COMPUTE, Figure 4.7, performs the same function with three basic differences: 1) the module is a routine, not a function (this only affects how it is invoked and used), 2) it uses real intermediate variables and returns an integer answer, and 3) the square-root is implemented via exponentiation. Benchmark runs indicate this method of finding the square root requires approximately 70% more execution time. Augmented with the same method of squaring proposed for ACT.RANGE, the recommended revision is shown in Figure 4.8.

Benchmarks when these two revised routines were implemented in SAI's VAX Virtual Test Suite for COSAGE show a decrease of more than 2.7% in execution time. A similar savings would be reasonable to expect with the SPERRY SIMSCRIPT version of COSAGE. Further, examination of the calling locations shows that two modules which perform the same purpose (one yielding an integer result, the other a real result) are not necessary. Any required mode conversions can be performed after the call. This integration would decrease the memory requirement as well and provide a uniform, efficient approach to fulfilling a single function. Comparisons made using these inconsistent methods may result in unexpected program behavior.

4.8 Modularize Candidate Processes

The following COSAGE processes were identified because they have source code line counts in excess of 120 (approximately 2 pages):

AC.ATK.TGT
AIR.OBSERVER

```
FUNCTION ACT.RANGE                                              ''~ F001
    GIVEN UNIT1 AND UNIT2

    ADD 1 TO ANAL.CTR(239,1)   ''~ \DYN_ANAL
    ''THIS FUNCTION COMPUTES THE ACTUAL RANGE BETWEEN TWO UNITS

    DEFINE UNIT1, UNIT2, DELTA.X, AND DELTA.Y AS INTEGER VARIABLES
    DEFINE RANGE AS A REAL VARIABLE

    LET DELTA.X = UN.X.COORD( UNIT1 ) - UN.X.COORD( UNIT2 )
    LET DELTA.Y = UN.Y.COORD( UNIT1 ) - UN.Y.COORD( UNIT2 )
    LET RANGE = SQRT.F(REAL.F(DELTA.X*DELTA.X+DELTA.Y*DELTA.Y)) ''~ \OPTIMIZE

    RETURN WITH RANGE
END
```

Figure 4.6

Proposed Function ACT.RANGE

```
ROUTINE RANGE.COMPUTE                                          ''~ C018
    GIVEN
         UNIT.A,
         UNIT.B
    YIELDING
         RANGE.

    ADD 1 TO ANAL.CTR(129,1)   ''~ \DYN_ANAL
    NORMALLY MODE IS INTEGER
    DEFINE D.X., D.Y. AS REAL VARIABLES

    LET D.X. = UN.X.COORD(UNIT.A)-UN.X.COORD(UNIT.B)
    LET D.Y. = UN.Y.COORD(UNIT.A)-UN.Y.COORD(UNIT.B)
    LET RANGE = (D.X**2+D.Y**2)**.5    ''~ \OPTIMIZE

    EXITROUTINE
ENDROUTINE
```

Figure 4.7

Current Routine RANGE.COMPUTE

```
ROUTINE RANGE.COMPUTE                                          '~ C018
    GIVEN UNIT.A AND UNIT.B
    YIELDING RANGE

    ADD 1 TO ANAL.CTR(129,1)   '~ \DYN_ANAL
    DEFINE D.X., D.Y. AS REAL VARIABLES
    DEFINE UNIT.A, UNIT.B, AND RANGE AS INTEGER VARIABLES

    LET D.X. = UN.X.COORD(UNIT.A)-UN.X.COORD(UNIT.B)
    LET D.Y. = UN.Y.COORD(UNIT.A)-UN.Y.COORD(UNIT.B)
    LET RANGE = SQRT.F(D.X.*D.X. + D.Y.*D.Y.)    '~ \OPTIMIZE

    RETURN
END
```

Figure 4.8

Proposed Routine RANGE.COMPUTE

AIRBORNE.RADAR
ARTY.ASSESS
ASSESSMENT
CAS.MISSION
FIRE.MISSION
FORWARD.OBSERVER
HC.RETURN.FARRP
HELICOPTER.FIRE
HEL.TARGET.ACQUISITION
HC.ARRIVE.BATTLE
REMOTE.PILOT.VEHICLE
SHOOT.OUT
TARGET.REPORT

These 15 processes represent 84% of all COSAGE processes. All of these processes have a Halstead length of 270 or greater. The two remaining processes, PHOTO.IR.FLIGHT and WITH.DRAW have 115 and 112 source lines respectively and Halstead lengths of 379 and 213.

SAI analysts recommend modularizing at least the top 15 processes (ranked by number of source lines) to increase understandability and maintainability. A procedure similar to the following one is recommended.

- First, in close conjunction with the COR, identify a high-level system of comments. An example, using FIRST-NEXT comments is shown in Figure 4.9.

- Next, identify which comment blocks can be modularized and moved out-of-line (into separate routines).

```
                                MOVEMENT/TERRAIN ROUTINES                                    PAGE    1
23 ROUTINE LOS.CHECK ''                                                                      LOS$CHECK
24     GIVEN UNIT
25
26     ***************************************************************************************************
27     * THIS ROUTINE CHECKS TO SEE IF LINE-OF-SIGHT STILL EXISTS AT THIS POINT                          *
28     ***************************************************************************************************
29
30     FIRST, DEFINE VARIABLES
31        DEFINE UNIT, FORCE, OTHER.UNIT, RANGE, RNG. AS INTEGER VARIABLES
32
33     NEXT, LOCATE THE CLOSEST ENEMY FORCE
34        FOR EVERY FORCE OF BTL.FORCE.SET(UN.BATTLE.INDEX(UNIT))
35        WITH FR.SIDE(FORCE) NE UN.COLOR(UNIT)
36        FIND THE FIRST CASE
37        IF NONE,
38           CALL ERROR.STOP  ''------------------------------------------------------------ \1>(600)
39        ENDIF
40        LOOP
```

Figure 4.9
Example of High-level Comment

```
41
42     NEXT, FIND A UNIT IF THIS ONE IS NOT VISIBLE
43        FOR EVERY OTHER.UNIT OF FR.UNIT.SET(FORCE)
44        DO THE FOLLOWING
45           FOR EVERY VISIBLE.UNIT OF UN.LOS.LIST(OTHER.UNIT)
46           WITH VU.POINTER(VISIBLE.UNIT) = UNIT
47           FIND THE FIRST CASE
48           IF NONE,
49              IF UN.STATUS(UNIT) = STATIONARY OR UN.STATUS(UNIT) = STA.TO.WITH
50                 IF UN.STATUS(OTHER.UNIT) = STATIONARY OR UN.STATUS(OTHER.UNIT) = STA.TO.WITH
51                    LET RNG. = TT.STATIONARY.LOS.BREAK(BTL.TERRAIN.TYPE(UN.BATTLE.INDEX(UNIT)))
52                 ELSE
53                    LET RNG. = TT.M.S.LOS.BREAK(BTL.TERRAIN.TYPE(UN.BATTLE.INDEX(UNIT)))
54                 ALWAYS
55              ELSE
56                 IF UN.STATUS(OTHER.UNIT) = STATIONARY OR UN.STATUS(OTHER.UNIT) = STA.TO.WITH
57                    LET RNG. = TT.M.S.LOS.BREAK(BTL.TERRAIN.TYPE(UN.BATTLE.INDEX(UNIT)))
58                 ELSE
59                    LET RNG. = TT.MOVING.LOS.BREAK(BTL.TERRAIN.TYPE(UN.BATTLE.INDEX(UNIT)))
60                 ALWAYS
61              ALWAYS
62              CALL RANGE.COMPUTE----------------------------------------------------->(337)
63              GIVEN UNIT, OTHER.UNIT
64              YIELDING RANGE
65              IF RANGE LE RNG.
66                 CREATE A VISIBLE.UNIT
67                 LET VU.POINTER(VISIBLE.UNIT) = UNIT
68                 LET VU.STATUS(VISIBLE.UNIT) = NO
69                 FILE THIS VISIBLE.UNIT IN THE UN.LOS.LIST(OTHER.UNIT)
70                 CREATE A VISIBLE.UNIT
71                 LET VU.POINTER(VISIBLE.UNIT) = OTHER.UNIT
72                 LET VU.STATUS(VISIBLE.UNIT) = NO
73                 FILE THIS VISIBLE.UNIT IN THE UN.LOS.LIST(UNIT)
74              ALWAYS
75           ALWAYS
76           CALL CHECK.ENGAGEMENT-------------------------------------------------->(129)
77           GIVEN OTHER.UNIT
78        ENDLOOP
79
80     LAST, CHECK TO SEE IF UNIT IS ALREADY ENGAGED
81        CALL CHECK.ENGAGEMENT-------------------------------------------------->(129)
82        GIVEN UNIT
83  <-----EXITROUTINE
84  ENDROUTINE
```

Figure 4.9

Example of High-level
System and Code Standardization
(continued)

- Next, perform metric analyses on identified submodules.
- Next, move submodules into separate routines and make required coding changes.
- Last, test modularized processes.

4.9 Standardize the COSAGE Source Code

While performing the various analyses of the COSAGE source code, it became apparent to the SAI analysts that numerous, varying coding conventions and styles had been used in the model development. These inconsistencies made it difficult to read and understand the SIMSCRIPT source code; they also represent inefficiencies in COSAGE. Therefore, it is recommended that a consistent set of coding standards be developed and applied to the COSAGE source code. Other standardization issues should also be addressed; these issues include:

- Examining SIMSCRIPT DEFINE-TO-MEAN statements in COSAGE to determine if they are required or in need of modification.
- Checking for redundant NORMALLY statements.
- Deleting SIMSCRIPT comment statements which are obsolete or unclear.
- Developing a system of high-level comments, with the assistance of CAA personnel knowledgable of the COSAGE model, which provides insight into the operations/functions being performed by a block of source code.

- Verifying that output units are consistent between routines.

- Developing an @ADD file for the SPERRY which will process the COSAGE source code with the SAI-SDDL processor to automate the production of up-to-date documentation.

Figure 4.10 represents a current COSAGE routine; Figure 4.9 is the same routine which has been updated with the recommended coding standards and processed by SAI-SDDL.

4.10 Develop Graphical Input/Output Capabilities

It is recommended that graphical input/output capabilities be developed for the COSAGE model. The COSAGE model requires voluminous input data. This data requires considerable time as well as in-depth knowledge of the COSAGE program to prepare. The existing EDITS program provides a data checking capability; however, it is recommended that an enhanced data preparation tool be developed. A possible scenario for such an input generation tool would allow a COSAGE user to graphically configure units on a specified terrain, and then have the input processor automatically generate the coordinates, equipment lists, etc. Additionally, this tool could check for typical input data errors (like the ones listed in Section 3.4.1 of this report). Likewise, the development of a graphical output is recommended. Such a tool could display unit movement, attrition, etc.

SAI has developed the Tactics, Operations, and Planning Station (TOPS*). TOPS is a minicomputer-based, color graphics system based on digital map technology. Preliminary investigation indicates that this graphics system could provide input/output

* A trademark of Science Applications, Inc.

```
   1  ROUTINE LOS.CHECK
   2  GIVEN
   3  UNIT
   4  **LOS.CHECK
   5  NORMALLY HOLD IN INTEGER
   6  FOR EVERY FORCE OF BTL.FORCE.SET(UN.BATTLE.INDEX(UNIT))
   7  WITH FD.SIDE(FORCE) NE UN.COLOR(UNIT)
   8  FIND THE FIRST CASE
   9  IF NONE, CALL ERROR.STOP
  10  END IF
  11  LOOP
  12  FOR EVERY OTHER.UNIT OF FP.UNIT.SET(FORCE)
  13  DO THE FOLLOWING
  14  FOR EVERY VISIBLE.UNIT OF UN.LOS.LIST(OTHER.UNIT)
  15    WITH VU.POINTER(VISIBLE.UNIT) = UNIT
  16  FIND THE FIRST CASE
  17  IF NONE,
  18  IF UN.STATUS(UNIT) = STATIONARY
  19  OR UN.STATUS(UNIT) = STA.TO.WITH
  20  IF UN.STATUS(THEN.UNIT) = STATIONARY
  21  OR UN.STATUS(OTHER.UNIT) = STA.TO.WITH
  22  LET ENG. = TT.STATIONARY.LOS.BREAK(BTL.TERRAIN.TYPE(UN.BATTLE.INDEX(UNIT)))
  23  ELSE
  24  LET ENG. = TT.M.S.LOS.BREAK(BTL.TERRAIN.TYPE(UN.BATTLE.INDEX(UNIT)))
  25  ALWAYS
  26  ELSE
  27  IF UN.STATUS(OTHER.UNIT) = STATIONARY
  28  OR UN.STATUS(OTHER.UNIT) = STA.TO.WITH
  29  LET ENG. = TT.M.S.LOS.BREAK(BTL.TERRAIN.TYPE(UN.BATTLE.INDEX(UNIT)))
  30  ELSE
  31  LET ENG. = TT.MOVING.LOS.BREAK(BTL.TERRAIN.TYPE(UN.BATTLE.INDEX(UNIT)))
  32  ALWAYS
  33  ALWAYS
  34  CALL RANGE.COMPUTE
  35  GIVE
  36  UNIT,
  37  OTHER.UNIT
  38  YIELDING
  39  RANGE
  40  IF RANGE LE ENG.
  41  CREATE A VISIBLE.UNIT
  42  LET VU.POINTER(VISIBLE.UNIT) = UNIT
  43  LET VU.STATUS(VISIBLE.UNIT) = NO
  44  FILE THIS VISIBLE.UNIT IN THE UN.LOS.LIST(OTHER.UNIT)
  45  CREATE A VISIBLE.UNIT
  46  LET VU.POINTER(VISIBLE.UNIT) = OTHER.UNIT
  47  LET VU.STATUS(VISIBLE.UNIT) = NO
  48  FILE THIS VISIBLE.UNIT IN THE UN.LOS.LIST(UNIT)
  49  ALWAYS
  50  ALWAYS
  51  CALL CHECK.ENGAGEMENT
  52  GIVEN
  53  OTHER.UNIT
  54  ENDLOOP
  55  CALL CHECK.ENGAGEMENT
  56  GIVE
  57  UNIT
  58  EXITROUTINE
  59  ENDROUTINE
```

FIGURE 4-10 CURRENT COSAGE ROUTINE

processors for simulation models such as COSAGE. Therefore, it is recommended that the linkage between COSAGE and TOPS be studied.

5.0 PROPOSED PREAMBLE

Since the PREAMBLE of a SIMSCRIPT program serves as a definition of data structures and of program events and processes, SAI analysts conducted an analysis of it in order to identify areas which could be optimized or updated in order to increase its clarity and maintainability. This section presents the specific observations made and changes recommended.

5.1 Existing Structure

Examination of the COSAGE PREAMBLE indicated that the prevailing scheme of organization is alphabetization (see Figure 5.1). However, this scheme does not appear to be rigorously followed. Further, data structures are usually grouped into categories such as permanent entities, temporary entities, processes, events, global variable, set, array, and function definitions, and substitutions.

5.2 Proposed Structure

SAI's analysts recommend restructuring the COSAGE PREAMBLE using a hierarchical scheme for organizing the permanent and temporary entities, sets, and attribute definitions. An example of the recommended hierarchical structure is shown in Figure 5.2. Such a scheme should provide more clarity into data structure relationships.

```
EVERY AO.RANGE.BAND HAS
     AN AO.RB.RANGE,
BELONGS TO
     THE AO.RB.SET
HAS
     A P.AO.RB.SET,
     A S.AO.RB.SET,
     A M.AO.RB.SET

EVERY BTRY HAS
     A BY.BN,
     A BY.STATUS,
     A BY.TYPE,
     A BY.PGM.FM,
     A BY.CUR.FM,
     A BY.N.ROUNDS,
     A BY.UNIT,
     A BY.BN.RANK,
     A BY.FIRE.RATE,
     A BY.PGM.CAP,
     A BY.STOP.FASCAM.SUPP   ''TIME.V * 60
OWNS
     A BY.HOW.SET,
     A BY.SCHD.LIST,
     A BY.FM.QUEUE
BELONGS TO
     A BN.BTRY.SET
HAS
     A F.BY.HOW.SET,
     A L.BY.HOW.SET,
     A F.BY.SCHD.LIST,
     A L.BY.SCHD.LIST,
     A F.BY.FM.QUEUE,
     A L.BY.FM.QUEUE,
     A P.BN.BTRY.SET,
     A S.BN.BTRY.SET,
     A M.BN.BTRY.SET,
     A N.BY.HOW.SET,
     A N.BY.SCHD.LIST,
     A N.BY.FM.QUEUE

EVERY CATEGORY HAS
     A CT.NAME,
     A CT.GROUP,
     A CT.MIN.FEBA
OWNS
     A CT.TU.SET
BELONGS TO
     A GP.CAT.SET
HAS
     A F.CT.TU.SET,
     A L.CT.TU.SET,
     A N.CT.TU.SET,
     A P.GP.CAT.SET,
     A S.GP.CAT.SET,
     A M.GP.CAT.SET

EVERY CATEGORY,DIST.FROM.FEBA.BAND, IC.MUNITION HAS
     A CDI.USAGE.INDICATOR

EVERY CATEGORY, DIST.FROM.FEBA.BAND, TYPE.BTRY HAS
```

Figure 5.1
Existing PREAMBLE Scheme

```
PERMANENT ENTITIES
EVERY FA.BN HAS
     A FB.MISSION,
     A FA.BN.UNIT
OWNS
     A BN.BTRY.SET
HAS
     A F.BN.BTRY.SET,
     A L.BN.BTRY.SET,
     A N.BN.BTRY.SET
     DEFINE FB.MISSION AS A TEXT VARIABLE

EVERY BTRY HAS
     A BY.BN,
     A BY.STATUS,
     A BY.TYPE,
     A BY.PGM.FM,
     A BY.CUR.FM,
     A BY.N.ROUNDS,
     A BY.UNIT,
     A BY.BN.RANK,
     A BY.FIRE.RATE,
     A BY.PGM.CAP,
     A BY.STOP.FASCAM.SUPP  ''TIME.V * 60
OWNS
     A BY.HOW.SET,
     A BY.SCHD.LIST,
     A BY.FM.QUEUE
BELONGS TO
     A BN.BTRY.SET
HAS
     A F.BY.HOW.SET,
     A L.BY.HOW.SET,
     A F.BY.SCHD.LIST,
     A L.BY.SCHD.LIST,
     A F.BY.FM.QUEUE,
     A L.BY.FM.QUEUE,
     A P.BN.BTRY.SET,
     A S.BN.BTRY.SET,
     A M.BN.BTRY.SET,
     A N.BY.HOW.SET,
     A N.BY.SCHD.LIST,
     A N.BY.FM.QUEUE
     DEFINE BN.BTRY.SET AS A SET RANKED BY LOW BY.BN.RANK
     DEFINE BY.BN.RANK, BY.FIRE.RATE AND BY.STOP.FASCAM.SUPP AS SIGNED INTEGERS

TEMPORARY ENTITIES
EVERY HOW HAS
     A HW.BTRY,     ''OWNING BTRY
     A HW.SFAIL.RNDS, ''ROUNDS TILL SHORT TERM FAILURE
     A HW.LFAIL.RNDS, ''ROUNDS TILL LONG TERM FAILURE
BELONGS TO
     A BY.HOW.SET ''WHEN NOT FAILED
HAS
     A P.BY.HOW.SET,
     A S.BY.HOW.SET,
     A M.BY.HOW.SET
     DEFINE BY.HOW.SET AS A LIFO SET
     DEFINE HW.BTRY, HW.SFAIL.RNDS, AND HW.LFAIL.RNDS AS SIGNED INTEGERS
```

Figure 5.2

Recommended Hierarchical PREAMBLE Sheme

It is also suggested that sections like the events and substitutions be re-alphabetized. This will make it easier to find names which have already been used, since inadvertant reusage could cause errors in COSAGE that would be difficult to trace.

Another recommended PREAMBLE change is to replace inefficient define to means, such as:

```
DEFINE NORTH TO MEAN PI.C/2
DEFINE SOUTH TO MEAN 3.*PI.C/2
```

with statements like:

```
DEFINE NORTH TO MEAN 1.5707963
DEFINE SOUTH TO MEAN 4.7123889
```

This would decrease both execution time (since expressions would not have to be evaluated) and memory requirements (because space would not be required to perform calculation).

A recommended addition to the COSAGE PREMABLE is the definition of several real global variables. Variables identified to this point are:

```
TEN.16THS
16.TENTHS
```

These variables would then need to be set to 10/16 and 16/10 respectively in the COSAGE source code.

6.0 SUMMARY

SAI has conducted a study of the COSAGE model. The focus of this study was to identify fruitful areas for COSAGE optimization which would reduce memory requirements and/or execution time.

In order to accomplish this, SAI applied various analysis tools and techniques to the COSAGE program. These tools and techniques included:

- Processing the COSAGE SIMSCRIPT Source Code with SAI-SDDL. The results of this effort provided a standardized format for reviewing the source code. It enhanced the source code with automated indentation and program flow of control arrows. Additionally, source code summary information (i.e., table of contents, module invocation hierarchy tree, and various cross reference listings) was generated.

- Developing Input Format Specifications for the COSAGE Program. They were developed directly from the source code and included such information as the required data item name, meaningful description, unit of measure, mode, and dimensionality.

- Utilizing the System Performance Monitoring (SPM) tool to analyze COSAGE model execution at the operation system level.

- Applying metrics to obtain quantitative assessments of the complexity of the source code.

- Using the VAX SIMSCRIPT compiler to convert the SPERRY COSAGE source code to the VAX and to identify source code anomalies which the SPERRY compiler was unable to detect. The SIMSCRIPT language was also used to instrument the COSAGE source code.

Both static and dynamic analyses were performed on the COSAGE model. Static analyses included:

- Determining all places in the source code where memory was allocated (via the CREATE and RESERVE statements) and deallocated (via the DESTROY and RELEASE keywords).

- Identifying modules of considerable size. This was done for actual source code lines as well as the size of the object code (compiled source code).

- Tallying the modules most frequently invoked statically.

Dynamic analyses were:

- Accumulating the number of times each routine was invoked dynamically (during program execution).

- Determining CPU usage per simulated hour of program execution.

- Identifying the routines which accounted for highest CPU usage.

- Locating and correcting anomalies which occurred while reading the COSAGE input data as well as those which occurred during simulated time.

- Performing control complexity, Halstead length, and level of nesting metrics on the COSAGE source code.

As a result of these analyses, a variety of changes are recommended. They include:

- Changing the method used to accomplish exponentiation in the COSAGE model.

- Replacing inefficient mathematical expressions.

- Streamlining unnecessary usage of the SIMSCRIPT square root function.

- Changing SCHEDULE statements to RESCHEDULE statements when appropriate.

- Removing/replacing routines. Some of these routines are unused and some should be replaced by a global variable.

- Utilizing the SIMSCRIPT TEXT feature to save memory and enhance COSAGE transportability.

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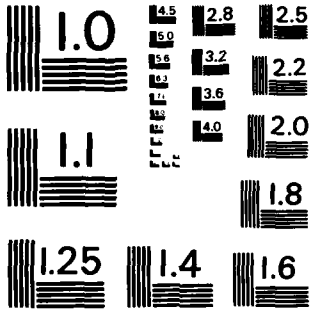

- Performing a thorough analysis of the 26 most frequently invoked modules.

- Modularizing identified processes to increase clarity and maintainability.

- Standardizing the COSAGE source code by developing a set of coding conventions and then applying them to the COSAGE model.

- Developing graphical input/output capabilities to assist the COSAGE user.

- Reorganizing the COSAGE PREAMBLE in a hierarchical fashion rather than the current semi-alphabetical manner.

END

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