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AIRBORNE BATTLEFIELD COMMAND AND CONTROL CENTER (ABCCC) III CAPACITY STUDY

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ABSTRACT

The capacity study of the Airborne Battlefield Command and Control Center III [1] benefited from the availability of an operationally configured production system, and data from operational use of the initial delivered systems. The model development team measured events on the production system, and developed a family of scenarios based on operational use of the system. Verification and validation of the model was accomplished through comparison of modeled statistics with observations during development, production, and acceptance testing.

1 BACKGROUND

The Airborne Battlefield Command and Control Center (ABCCC) III operates as an airborne command and control facility. It provides communications, displays, and data management support to enable a crew of 15 operators to control air assets. The primary mission of the system is to direct and control air assets in the vicinity of hostilities involving friendly forces, i.e., close air support to allied forces engaging hostile forces. The ABCCC III is designed to provide the functions and capabilities of the Tactical Air Control System. The ABCCC III is designed for operation aboard dedicated EC130 aircraft using aircraft power. It is also designed to operate in a stand-alone ground-based mode using ground power.

ABCCC II is no longer expandable to meet all changing requirements and is becoming difficult to maintain. ABCCC III was built to take advantage of current materials and technology and to provide the same functionality as the older system, while at the same time improving the maintainability and flexibility characteristics of the system. The ABCCC III was designed to accommodate expansion in the hardware and software functionality so that future enhancements to the system could be easily incorporated using excess system capacity, reserved rack space, and hardware and software module replacement.

Potential system enhancements were identified as Pre-Planned Product Improvements (P^3I). Potential enhancements included the incorporation of enhanced communications capability equipment into the ABCCC III and upgrade of the Tactical Battlefield Management System (TBMS) processors through replacement of the CP-2025 processors with Enhanced Processors.

2 MODEL DEVELOPMENT

To support existing and enhanced system functions, we were tasked to:

1. Conduct a capacity study on the present ABCCC systems to establish a baseline.

2. Assess the integration of enhanced communications capabilities.

Preliminary analysis of resource utilization led us to include an additional task:

3. Assess the impact on system capacity of replacing the CP-2025 processors with Enhanced Processors.

2.1 Baseline Model

The ABCCC III hardware configuration modeled is shown in Figure 1. The system includes redundant high reliability components and automatic functionality transfer in case of equipment failure. For purposes of this study, no hardware failures were modeled.

To facilitate modeling processor utilization under a variety of system conditions, processing was subdivided into components representing different types of

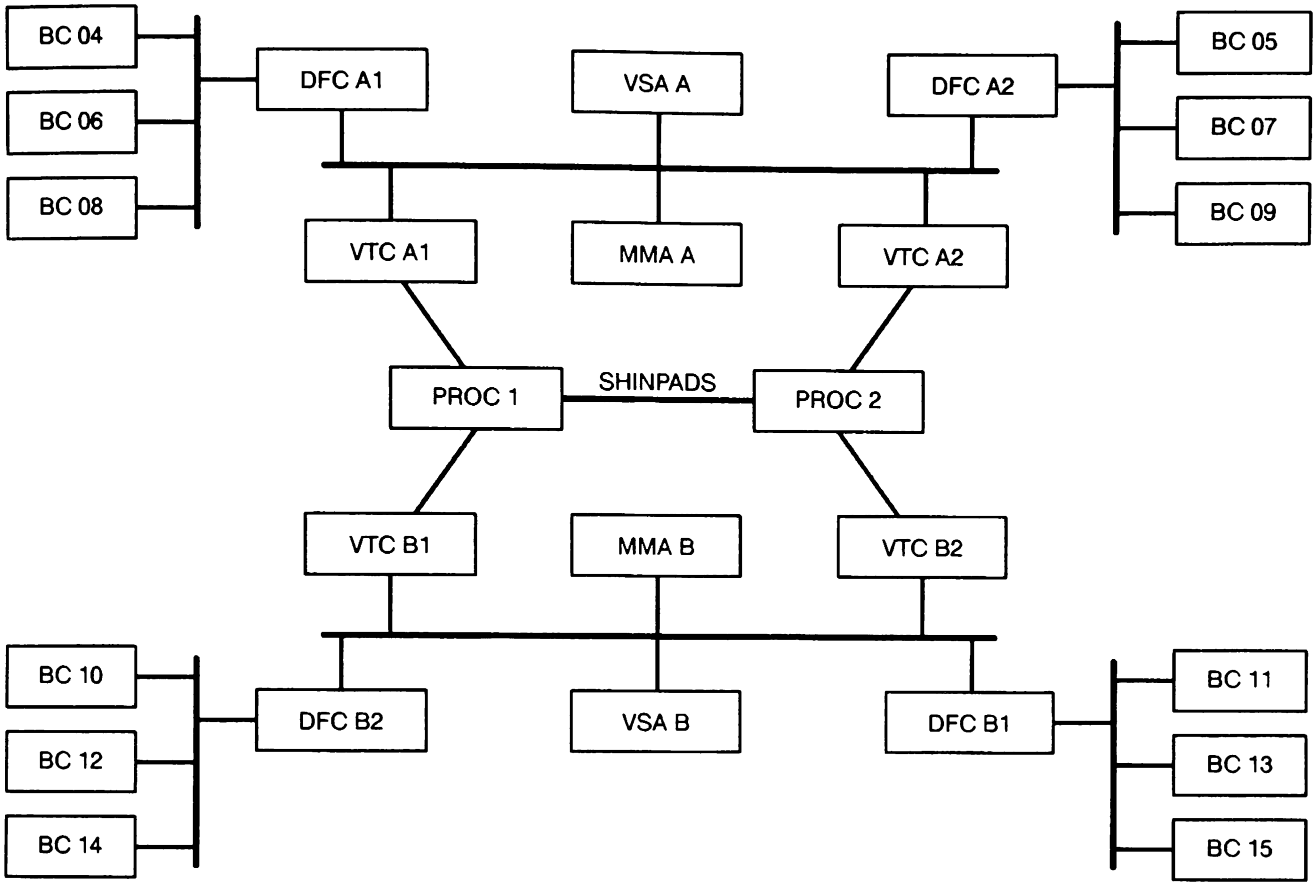


Figure 1: ABCCC III Hardware

independent events. Measurements were then taken for each type of event. By combining these events with varying frequencies of occurrence, it was possible to model different operational scenarios using the same set of event measurements.

This method of data collection and modeling is based on the assumption that the processing time required for a set of events will be approximately equal to the sum of the processing times required for the individual events. This assumption was later validated by measuring processor utilization under a scenario composed of several events and comparing the results with modeled results.

The events selected for measurement represented the minimum set of events from which an operational mission can be constructed. Since it was not practical to attempt to measure every possible operator action, obscure actions or actions taken primarily during preflight setup or system shutdown were not modeled. Also, since it was not practical to examine every possible processing path for the events chosen, events were measured using the average of typical cases.

The ABCCC is never completely idle. Background activities are performed even in the absence of operator inputs. It was necessary to establish a baseline of minimal system activity and measure this baseline before attempting to measure individual events. Once this background baseline was measured, the processing time associated with individual events was measured by introducing an event (or several repetitions of an event) into a system of background activity and measuring the utilization of system resources. By comparing these measurements to the utilizations measured in a background system over the same time interval, it was possible to determine the amount of time used by each resource for processing this event.

For this method to produce reliable data, the background activity had to be measured in a well-defined environment that could be easily recreated. In addition, the background activity had to be reasonably constant. Whenever possible, event times were measured using many repetitions of the event.

The baseline system model represents resource utilization for background processing, six periodic events, and 47 scenario-driven events. Background processing is modeled as a constant utilization of resource each second. Periodic events are modeled to begin resource consumption at random points in time based on the event frequency. Subsequent resource consumption periods reflect the frequency of the periodic events. Periodic history recording is modeled as a sequence of periodic events, reflecting the sequence of occurrences in the ABCCC III system.

Scenario-driven events were randomly scheduled to be activated during a time period determined from the scenario-dependent occurrence frequency. Subsequent activation times were determined by incrementing the initial activation time so that the required frequency of activations was modeled.

In all cases, for periodic and scenario-driven events, the model simultaneously starts the task that consumes resources on all affected subsystems. This simplification was introduced to enable rapid development of the model, retain the resolution required to study the system and subsystem capacities, and provide expandability for future studies. Data collection methodologies were developed to provide process timing data for this study, but sequencing and contingent relationship data were not collected or modeled.

The tools used during the simulation model development process were selected to provide control over the development process and to incrementally validate the model during the development process. A Computer Assisted Software Engineering (CASE) tool, Excelerator [2], was used for initial data dictionary development and sequencing. The data from Excelerator was transformed, using the Unisys proprietary tool, ISAAC [3]. This tool transformed the Excelerator data dictionary and connectivity diagrams into a database for Network II.5 [4], a large-scale Monte Carlo simulation program. Network II.5 was run against the database which incorporated the system model, the data model, and data reflecting the operational scenario.

2.2 Baseline Data

Modeling of the utilization of resources was required to drive the system model. For each of the background, periodic, and scenario-driven events, estimates were required of the amount of resource utilization associated with the event. These data were gathered by measuring the resource utilization under controlled conditions.

Measurements were taken using ABCCC III Capsule 4 to determine the resource utilization under no load conditions (background processing only), and upon initiation of each of six periodic and 47 scenario-driven events.

For measurement purposes, events were assumed to be independent of each other. In reality, it was felt some events might be dependent on other, concurrent events in the sense that simultaneous occurrence of the two events might result in significantly more or significantly less processing being required on some or all of the subsystems. Preliminary analysis and results from scenarios run on ABCCC III Capsule 4 indicate that this is not a significant problem.

2.3 Operational Scenarios

The last major item required to drive the simulation was operational scenarios. For this study, the frequency of event occurrences was recorded for light, normal, and heavy utilization scenarios representative of operation of the ABCCC III during hostilities in Operation Desert Storm.

The frequency of occurrence of scenario-driven events is a function of where the scenario is staged, what friendly and hostile forces are involved, how the forces are deployed and employed, and resources available to the forces on each side. For the Operation Desert Storm scenario, the majority of the air tasking was pre-planned. This meant, among other things, that the number of unscheduled aircraft support events processed was low in comparison with what would be expected under other scenario assumptions.

For each of the 47 scenario-driven events, the event frequency, measured as number of events per hour, increased monotonically from the light scenario to the normal scenario to the heavy scenario. The normal scenario was developed and validated. Variants of the baseline model were developed for heavy utilization scenarios, for different levels of expanded communications processing, and for a modified system with the CP-2025 replaced by an Enhanced Processor.

2.4 Verification and Validation

The simulation model and the data model were incrementally verified and validated during the development process, as well as during a dedicated validation period following the development of each variant of the baseline model. The simulation model was run with input parameters controlled to yield expected value results that were then compared with analytically derived results for the same input data. Network II.5 intermediate- and low-level outputs were reviewed to ensure that the logic of the model was consistent. High-level results of the model were compared with the results of scenarios run on ABCCC III Capsule 4. The design team provided a panel of experts who were familiar with what the expected results should be under different loads. In each of these cases, the model was judged to be representative of system operation at the level of detail required for performing the capacity study.

The verification and validation process continued throughout the simulation model development, the data model development, and the scenario development process. The same process was applied for each task and model variant developed. Consistency among all of the variants of the model was ensured by parallel development and update cycles.

2.5 Enhanced Communications Processing Model

The baseline model was modified to represent the effects of the incorporation of expanded communications processing at various levels of data receipt. For the normal and heavy utilization scenarios, communications processing events were incorporated at moderate and heavy processing levels.

2.6 Enhanced Processor Model

An additional modification was introduced into the model to develop a version that reflected the CP-2025 processors being replaced with Enhanced Processors. A preliminary study was performed using conservative estimates of the increased throughput characteristics resulting from this replacement. For this study, the heavy utilization scenario was augmented by the inclusion of events representing processing of very heavy communications loads.

3 MODEL DEVELOPMENT

A number of assumptions were made during the development of the simulation model, collection of the resource utilization data, and development of the operational scenario. Where possible, the most realistic assumptions were made. Where uncertainties or data collection constraints dictated, conservative assumptions were made. This approach was taken so that errors in estimation would tend to overstate what resource utilization might be observed under alternative assumptions.

3.1 Assumptions

Assumptions were made in all three of the areas of model development: simulation model development, data model development, and operational scenario model development.

The decision to develop the model to evaluate the system and system component capacity determined, to a large degree, the level of detail of the database and the model.

When events occur, the utilization of resources at each of the system nodes is represented as occurring simultaneously rather than sequentially. For capacity analysis, this was felt to be an adequate representation.

The assumption was made in data collection and simulation modeling that all of the randomly scheduled events are statistically independent. In actuality, some events are not random events and are correlated. Other events, such as teletype message processing, would normally occur when the ABCCC is assuming or relinquishing responsibility, and were not included in the model.

The model as it exists represents a steady-state slice of an operational mission. It does not represent correlation among tasks, which could lead to periods of more intense processing demand than those reflected in the model. By assuming that the events could occur across the time slice with equal probabilities of occurrence, simulation models were created with lower instantaneous resource utilization than would be projected under some alternative assumptions. The effects of this assumption are felt to be balanced by other assumptions that have the opposite effect. The net effect of the assumptions is high utilization statistics.

Another major assumption is that the operational scenarios developed are representative of future operations. The operational scenarios were designed based on Operation Desert Storm, with relatively long build-up time and the attainment of air superiority early in the conflict. Impacts of these assumptions include a high percentage of pre-planned sorties and a commensurate low level of immediate air requests. In other scenarios the ratio of pre-planned to immediate tasking might be reversed.

A final assumption has to do with the capacity of the Enhanced Processor. When the data was being collected for this study, collection of data using an Enhanced Processor in a fully configured ABCCC III capsule was not possible. Based on engineering data available, it was determined that the Enhanced Processor should be in the range of from 4 to 12 times as fast as the CP-2025. The actual value would depend on, among other things, the amount of cache memory installed and the mix of events being exercised. A conservative estimate is that the overall effect would be a multiplier of four. In the future, once the Enhanced Processor configuration has been established, this area should be reviewed. The overall multiplier requires validation and the applicability of a single multiplier to all events should be reviewed.

4 RESULTS

A baseline model of the ABCCC was developed. Following verification and validation of the baseline model, specific variants of the model were developed to incorporate additional communications processing, and to study the impact of replacing the CP-2025 processor with an Enhanced Processor.

4.1 Baseline Model

In order to conduct a capacity study on the present ABCCC III computer systems, it was first necessary to establish a baseline model. The model was developed based on observations collected in Capsule 4 and operational scenarios based on Operation Desert Storm activities.

Table 1 shows the average utilization rates for each of the processors modeled in the baseline system under both normal and heavy load scenarios.

Table 1: Utilization Rates (Percent); Baseline System Under Normal and Heavy Load Scenarios

	Normal Workload	Heavy Workload
TBMS PROC 1	50.44%	70.40%
TBMS PROC 2	33.88	48.95
DFC A1–B2	9.24	19.13
BC 04–15	5.31	11.29
MMA A	5.03	9.54
MMA B	.12	.21
VSA A	24.11	50.43
VSA B	8.62	12.15

There was excellent agreement between these average figures and the values calculated analytically using the same scenario data. Figure 2 shows histogram comparisons between the model output and the analytically derived data.

Together, Table 1 and Figure 2 indicate that there is strong agreement between the model and analytically derived results. Figure 3A graphs processor utilization over a representative 8-minute slice. This figure represents typical tasking on the CP-2025 Processor 1 during normal workload conditions. There are occasional spikes which indicate that the average utilization approached 100 percent. The spike between 912 and 960 seconds, for instance, shows the effect on processor utilization when two random events occur almost simultaneously. The spike associated with the first event is elongated so that the maximum utilization is elongated in time. Even so, at this level of traffic, conflicts that would cause queueing delays are unlikely.

4.2 Enhanced Communications Processing Model

To assess the processor capacity following integration of enhanced communications processing capabilities, the baseline model was modified to reflect moderate and heavy communications processing. The results are as shown in Table 2 for the normal workload scenario and Table 3 for the heavy workload scenario. For comparison purposes, the baseline results are shown in the tables also.

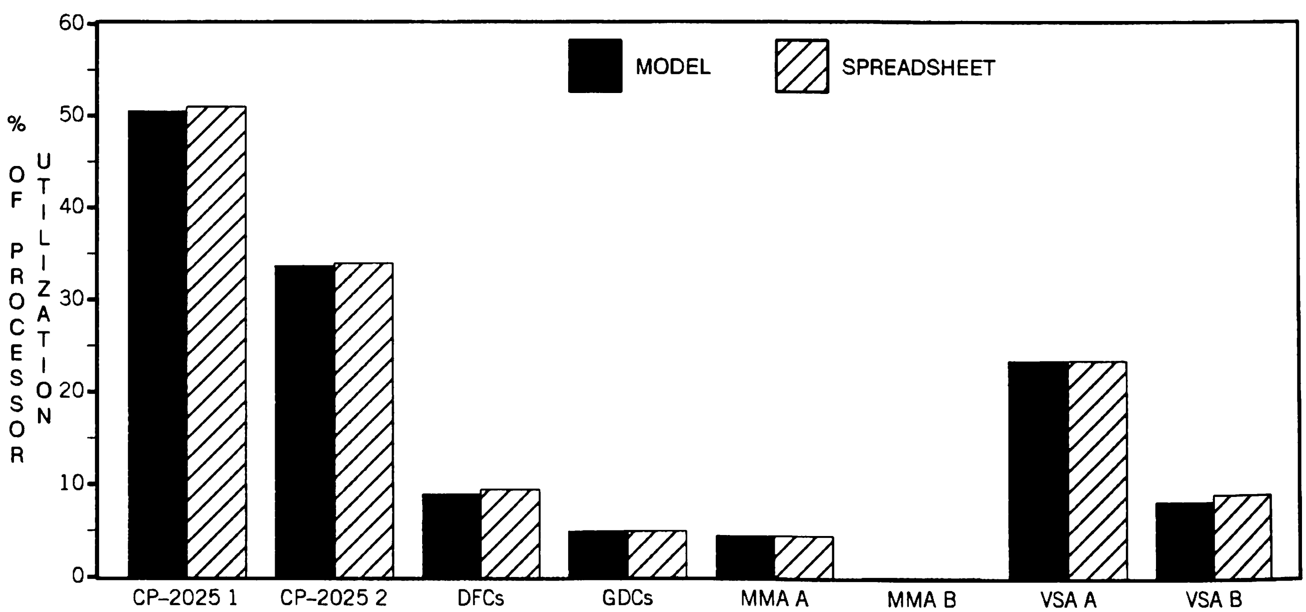
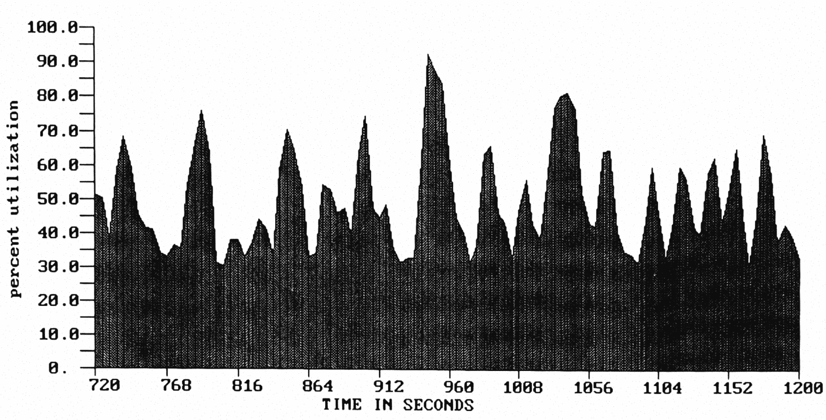
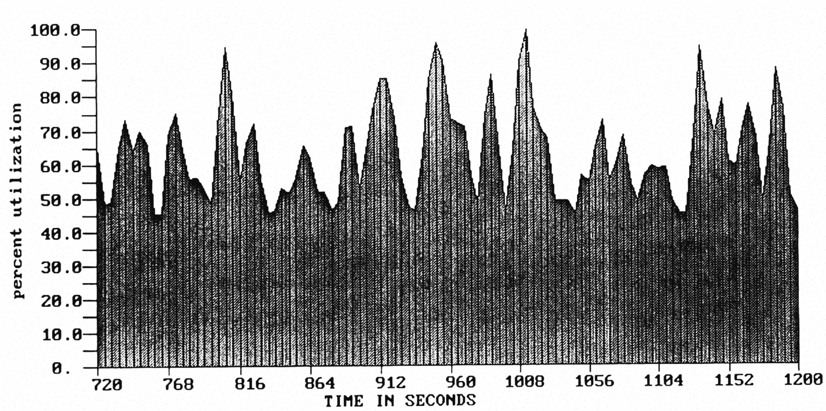


Figure 2: Model Processor Utilization Rates Versus Calculated Expected Value Utilization Rates

A. PRIMARY CP-2025, NORMAL LOAD, BASELINE COMMUNICATIONS



B. PRIMARY CP-2025, NORMAL LOAD, MODERATE LEVEL EXPANDED COMMUNICATIONS



C. PRIMARY CP-2025, NORMAL LOAD, HEAVY LEVEL EXPANDED COMMUNICATIONS

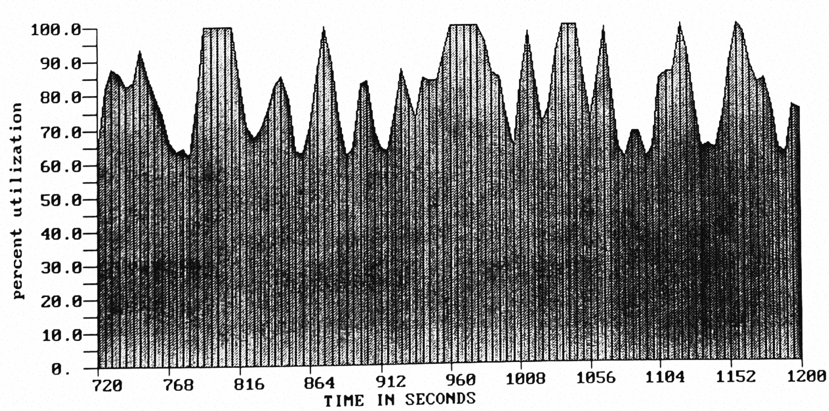


Figure 3: Processor Utilization Rates, Normal Load

Table 2: Utilization Rates, Normal Scenario, Expanded Communications Processing

	Baseline	Mod. Comm.	Heavy Comm.
TBMS PROC 1	50.44%	65.94%	80.87%
TBMS PROC 2	33.88	58.10	78.55
DFC A1	9.24	27.33	27.93
DFC A2-B2	9.24	9.78	9.78
BC 04	5.31	40.63	40.63
BC 05-15	5.31	5.31	5.31
MMA A	5.03	5.05	5.05
MMA B	.12	.12	.12
VSA A	24.11	24.21	24.21
VSA B	8.62	8.62	8.62

Table 3: Utilization Rates, Heavy Scenario, Expanded Communications Processing

	Baseline	Mod. Comm.	Heavy Comm.
TBMS PROC 1	70.40%	85.82%	100.00%
TBMS PROC 2	48.95	73.35	92.32
DFC A1	19.13	37.22	37.81
DFC A2-B2	19.13	19.68	20.28
BC 04	11.29	46.61	46.61
BC 05-15	11.29	11.29	11.29
MMA A	9.54	9.54	9.54
MMA B	.21	.21	.21
VSA A	50.43	50.39	50.39
VSA B	12.15	12.14	12.14

The utilization rates shown in Table 2 and Table 3 are average utilization rates. They do not indicate delays that the system would experience when handling these loads. Graphs of the processor utilization, however indicate that there would probably be significant delays experienced as the processor utilization approached and exceeded 80 percent. Figure 3B shows that these levels are occasionally reached during the normal workload scenario with moderate levels of expanded communications, and are often exceeded during the normal workload scenario with heavy communications processing requirements (Figure 3C) or during heavy workload scenarios with moderate expanded communications processing requirements (Figure 4B).

For the simulation model runs with the heavy load scenario and heavy expanded communications processing requirements, Processor 1 is unable to keep up with the traffic (Figure 4C). It is 100 percent utilized, indicating that delay times would be growing and data would have to be discarded to keep up with the inputs, or that lower priority functions would have to be disabled.

4.3 Enhanced Processor Model

To assess the impact on system capacity of replacing the CP-2025 processors with Enhanced Processors, the model was modified by replacing the CP-2025 processors with Enhanced Processors. The results of this study are shown in Figure 5 and Table 4 , which show the utilization rates using the Enhanced Processor in the heavy load scenario while processing very heavy additional communications processing.

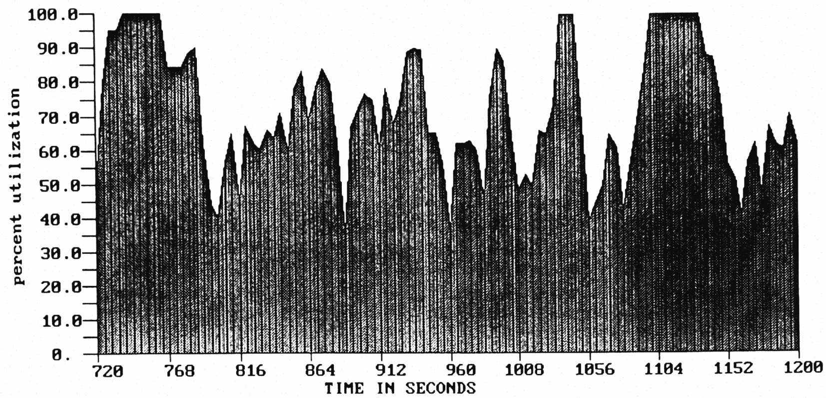
Under the assumptions of this study, the Enhanced Processor easily handles the increased processing requirements at a level far in excess of the projected capabilities of the existing system.

5 SUMMARY

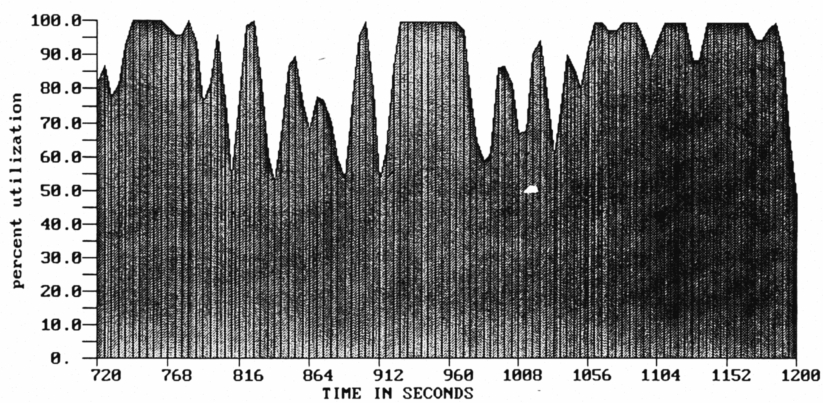
Development of the ABCCC III model benefited greatly from the availability of a production version of the system for measuring processor utilization associated with each of the identified events, and from the ability to develop realistic operational scenarios based on Operation Desert Storm activities. The verification and validation of the baseline model led to high confidence in the results of the enhanced communications and Enhanced Processor studies.

Results of the study (footnote 1) support the substitution of the Enhanced Processor for the CP-2025 processor when expanded communications processing capabilities are added to the baseline system. With the CP-2025 processor, message queueing and system delays can be anticipated under heavy utilization scenarios or under heavy communications processing loads. The Enhanced Processor can simultaneously handle heavy utilization scenarios and heavy communications processing.

A. PRIMARY CP-2025, HEAVY LOAD, BASELINE COMMUNICATIONS



B. PRIMARY CP-2025, HEAVY LOAD, MODERATE LEVEL EXPANDED COMMUNICATIONS



C. PRIMARY CP-2025, HEAVY LOAD, HEAVY LEVEL EXPANDED COMMUNICATIONS

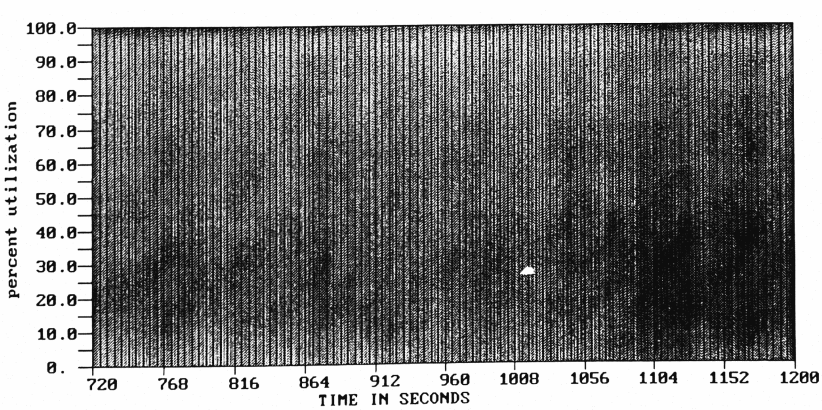


Figure 4: Processor Utilization Rates, Heavy Load

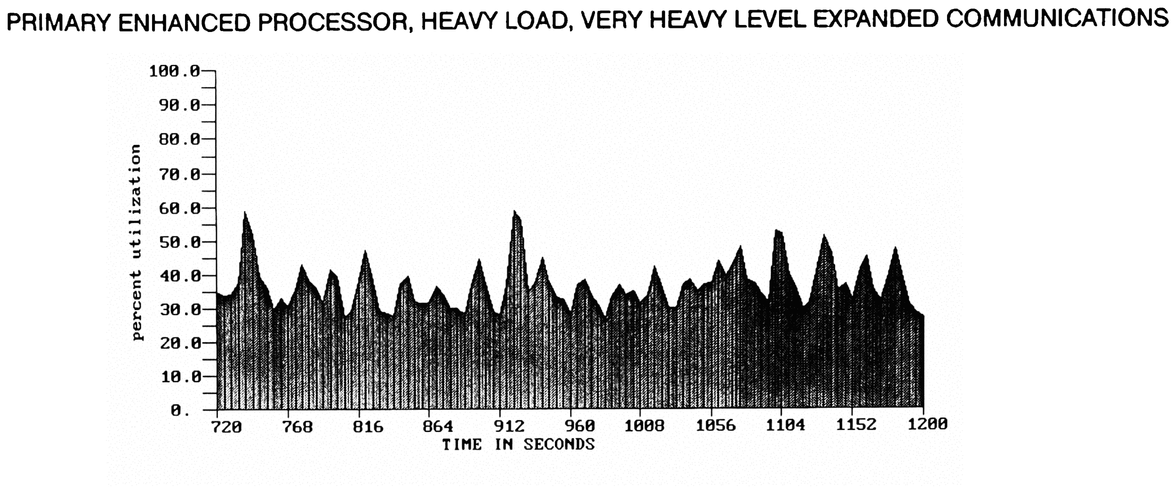


Figure 5: Processor Utilization Rates, Enhanced Processor

Table 4: Utilization Rates, Enhanced Processor, Heavy Scenario

	Baseline Processor			Enhanced Processor
	Baseline	Moderate Comm.	Heavy Comm.	Very Heavy Comm.
TBMS PROC 1	70.40%	85.82%	100.00%	36.43%
TBMS PROC 2	48.95	73.35	92.32	37.78
DFC A1	19.13	37.22	37.81	39.52
DFC A2-B2	19.13	19.68	20.28	21.98
BC 04	11.29	46.61	46.61	46.61
BC 05-15	11.29	11.29	11.29	11.28
MMA A	9.54	9.54	9.54	9.54
MMA B	.21	.21	.21	.21
VSA A	50.43	50.39	50.39	50.39
VSA B	12.15	12.14	12.14	12.14

AUTHOR BIOGRAPHIES

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[1] P^{3}I Computer Timing and Sizing Analysis Report, 29 March 1991. Completed under Contract Number F19628-87-C-0035, ABCCC III P^{3}I Study and Proposal Activity.

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