Evaluation of GIS Workstation Performance Within a Distributed Network Environment

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As part of the initial development phase of GIS implementation at the North Carolina Department of Transportation, a GIS workstation evaluation was carried out from December 1, 1988, to April 30, 1989. The primary purpose of the evaluation was to test the performance of graphics workstations within a distributed network environment. The workstation evaluation tested hardware, network capabilities, and operating systems for a transportation GIS (GIS–T). During the project, workstation vendors were selected; criteria were developed for the testing of workstation performance; performance tests were executed; and recommendations for GIS workstation procurement were made. The methods used to evaluate graphics workstation performance for a statewide transportation GIS are outlined. Workstation products from three vendors, International Business Machines (IBM), Digital Equipment Corporation (DEC), and SUN Microsystems were evaluated. Results of the evaluation are presented in the context of workstation performance tests, network capabilities, operating systems, vendor support, and workstation prices. Recommendations for workstation procurement specific to the needs of the North Carolina Department of Transportation are made.

A geographic information system (GIS) workstation evaluation for the North Carolina Department of Transportation (NCDOT) was performed as part of an initial development phase of GIS implementation. The evaluation took place from December 1, 1988, to April 30, 1989. The objectives of the workstation evaluation were to model proposed physical and operational computer environments, evaluate graphic workstation performance, and formulate recommendations for hardware procurement for a GIS for transportation (GIS–T).

Technical information presented in this paper was gathered from a variety of sources, and because of the dynamic nature of the hardware and software markets, is subject to change without notice. This evaluation was performed under a strict set of guidelines specific to one agency's needs and requirements at a particular point in time, and the recommendations detailed in the evaluation are based on those constraints. These recommendations are not meant as a general endorsement of any products and should not be construed as such; rather, the overall goal of this paper is to present in an actual context the methodological framework used in performing a GIS workstation evaluation.

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The workstation evaluation tested hardware, network capabilities, and operating systems for a GIS–T. The GIS software used in this evaluation was Environmental Systems Research Institute's (ESRI's) ARC/INFO software. The primary tasks accomplished during the initial phase of GIS implementation at NCDOT consisted of the following: (a) selection of workstation vendors, (b) development of workstation performance test criteria, (c) execution of workstation performance tests, (d) evaluation of performance test results, and (e) recommendations for GIS workstation procurement.

The evaluation of workstation performance was based on a number of criteria, including the speed with which workstations responded to various functions, networkability, analysis of operating systems, vendor support, system problems, and the formal and informal documentation of system performance by members of the NCDOT GIS development team and GIS delegates.

GIS WORKSTATION VENDORS

GIS workstation vendors were selected on the basis of criteria established by NCDOT's GIS Implementation Committee between July and September 1988:

1. The vendor must have been ported to ESRI's ARC/INFO software at the beginning of the evaluation period;
2. The vendor must be recognized as a national leader in GIS technology and must have a strong financial portfolio;
3. The vendor must be able to support the pilot project and ensuing statewide implementation of a transportation GIS in North Carolina; and
4. The vendor must have suitable existing GIS workstation products available for testing.

After considerable review, three vendors were chosen to participate: International Business Machines Corporation (IBM), Digital Equipment Corporation (DEC), and Sun Microsystems. These vendors were chosen because they met the selection criteria outlined above.

The vendors were requested to develop proposals for low- and high-end GIS workstation solutions to meet NCDOT's GIS needs at various organizational levels (e.g., state, division, and field). Throughout most of the evaluation period, the GIS laboratory contained five workstations from the three selected vendors. All were networked together on an ethernet local area network (LAN) for most of the evaluation period.

Vendors were allowed to bring in additional equipment during the evaluation period as new workstations were announced. Later during the testing period, DEC brought the VS3100 into the GIS laboratory for evaluation. At the end of the evaluation period, SUN Microsystems made two new workstations available for testing. Following is a list of the workstations that were evaluated by the GIS Implementation Committee:

Vendor	*Workstation*
IBM	RT-PC MODEL 125
	RT-PC MODEL 135
DEC	VS3200
	VS3100
SUN Microsystems	4/110
	386i/250
	4/60
	4/330

GIS WORKSTATION TESTING CRITERIA

In August 1988, the GIS Implementation Committee developed a series of testing criteria to test the performance of graphics workstations in executing various tasks and to evaluate the operating systems and networkability of each workstation. The price of each workstation was also considered.

In order to evaluate the performance of the graphics workstations, a set of benchmark tests was carried out. A series of Arc Macro Language (AML) programs was written to determine the performance of commonly used ARC/INFO commands on various workstations.

Following is a brief description of the ARC/INFO commands that were used in the AML performance benchmarking. These commands were chosen as representative of many tasks: editing, topological construction, graphic generation, data conversion, overlay analysis, and attribute file management. These tasks generally would be carried out on a daily or weekly basis within a GIS–T at NCDOT. They place a variety of demands on a workstation and have been broken down into three functional classes:

Input/Output Intensive Processes

- *ADDITEM* adds a new item to an existing INFO attribute file
- *APPEND* combines features from two or more coverages into a single coverage.
- *COPY* duplicates a coverage. All information associated with the coverage is duplicated.
- *DESCRIBE* summarizes information about an ARC/INFO coverage.
- *DISSOLVE* merges adjacent polygons that have the same value for a specified item.
- *DLGARC* converts a digital line graph (DLG) file either in standard or optional format into a set of ARC/INFO coverages.
- *EXPORT* converts an ARC/INFO coverage into an ARC/INFO interchange file.
- *GENERATE* uses flat ASCII files containing X and Y coordinates to produce an ARC/INFO coverage.
- *IMPORT* creates a coverage, INFO file, or flat file from an ARC/INFO export file.
- *KILL* deletes a coverage or specified INFO file.
- *LABELERRORS* checks a coverage for errors in polygon labeling.
- *NODEERRORS* checks a coverage for errors at the intersections of arcs.
- *PLOT* creates an ESRI plot file to be sent to a plotter for plotting.
- *UNGENERATE* converts an ARC/INFO coverage into a flat ASCII file containing X and Y coordinates.

CPU and Input/Output Intensive Processes

- *BUILD* builds topology between arcs and generates attribute files for polygons, lines, or points.
- *CLEAN* checks an ARC/INFO coverage for duplicate lines, breaks up arcs (lines) whenever they cross, snaps together arcs within specified tolerance, deletes arcs under a certain length, and builds topology between arcs.
- *IDENTITY* computes the geometric intersection of two coverages. All features that overlap are preserved.
- *INTERSECT* computes the geometric intersection of two coverages. Only those features in the area common to both coverages will be preserved.

Graphics Output Intensive Processes

- *ARCPLOT* displays a coverage to a graphics terminal screen using ARCPLOT commands.
- *DRAW* displays a coverage to a graphics terminal screen.

In addition to the application benchmarks just described, a number of industry standard performance benchmarks, which pertain specifically to hardware, were examined. Among these are MIPS (millions of instructions per second), Linpack, Dhrystone, and vector draw speeds. The Linpack benchmark involves the use of linear equations that test the performance of floating point computations. The Dhrystone benchmark measures integer performance. At the present time, there are no industry-set standards for vector draw speeds.

GIS WORKSTATION PERFORMANCE TESTS

The results of all AML performance tests were recorded for each workstation. Elapsed times for the performance tests varied significantly among the workstations. Table 1 presents the elapsed time for all processes.

Of the initial five workstations tested, the SUN 4/110 was consistently the fastest in all test categories. It was followed by three workstations that yielded results that were quite similar to each other. In terms of overall averages, the IBM RT 135, VS3200, and SUN 386i were fairly comparable, although the IBM RT 135 was slightly faster than the other two. The IBM RT 125 was much slower than all other models. Figure 1 shows the total time taken for each workstation to perform the AML performance tests and also shows the breakdown by functional classes.

TABLE 1 ARC/INFO WORKSTATION PERFORMANCE TESTING, ALL PROCESSES (ELAPSED TIME IN MIN:SEC)

Test	VAX 3100	VAX 3200	IBM 125	IBM 135	SUN 386i	SUN 4/110	SUN 4/60	SUN 4/330
DLGARC	02:44	03:21	03:54	01:43	04:44	01:32	00:55*	00:33
UNGENERATE	49:33	67:48	04:15	02:02	02:22	01:50	01:17*	00:50
GENERATE	13:29	13:53	142:06	72:22	63:46	36:35	22:54*	17:16
EXPORT	20:28	43:49	23:08	14:57	25:33	10:53	07:51*	06:21
IMPORT	09:36	10:30	27:34	12:29	18:13	08:27	07:33*	04:43
ADDITEM	02:09	03:14	02:36	01:04	03:23	01:26	01:28*	00:43
BUILD	04:19	06:17	04:28	02:03	06:31	03:09	02:44*	01:49
CLEAN	17:01	20:43	54:19	22:25	22:36	12:33	08:40*	04:27
DESCRIBE	00:09	00:12	00:24	00:11	00:30	00:12	00:17*	00:03
DRAW	04:48	04:57	11:55	05:55	08:13	02:51	02:14*	01:26
IDENTITY	35:42	43:25	109:32	57:12	46:26	24:12*	17:25*	08:39
INTERSECT	27:36	31:04	99:00	52:50	39:24	20:49*	13:33*	05:41
DISSOLVE	04:48	07:09	03:26	01:36	06:32	02:09*	01:34*	03:21
LABELERRORS	00:14	00:17	02:29	01:57	00:52	00:42*	00:22*	00:12
NODEERRORS	01:02	01:52	09:22	09:40	02:23	01:32*	01:00*	00:30
APPEND	01:01	01:28	01:14	00:28	05:36	01:02*	00:30*	00:21
COPY	00:42	00:50	00:47	00:28	02:34	01:59*	01:14*	00:09
KILL	00:05	00:07	00:12	00:05	00:50	00:10*	00:04*	00:02
ARCPLOT	00:56	00:52	01:48	00:54	01:41	00:44*	00:39*	00:23
PLOT	01:21	01:27	02:49	01:29	01:35	00:40*	00:46*	00:22
TOTAL TIME (Min:Sec)	197:43	263:15	505:18	261:50	263:44	133:27	93:00	57:51
AVERAGE TIME (Min:Sec)	09:53	13:10	25:16	13:06	13:11	06:40	04:39	02:56
MEDIAN TIME (Min:Sec)	03:32	04:09	04:05	02:00	05:10	01:55	01:22	00:47

Tests were run with no other processes running in the background or over the network.

* Data used for these tests were accessed through remote mounts; the data used for SUN 4/110's was resident on the SUN 386i, and the data used for SUN 4/60's was resident on the SUN 4/330.

In terms of average time taken to perform the 20 tests, the SUN 4/110 was twice as fast as the IBM RT 135, VS3200, and SUN 386i. It was almost four times faster than the IBM RT 125. After the benchmark tests had been completed on the initial five workstations, the same performance tests were carried out on the VS3100 (a late arrival to the performance test process). This workstation was slower than the SUN 4/110, but faster than the IBM RT 135, VS3200, and SUN 386i in all functional categories of testing.

Toward the end of the evaluation period, the new SUN 4/60 and SUN 4/330 workstations were made available for testing. These two workstations were much faster than all of the other six machines tested. Using the 4/110 (the fastest of the other six) as a base indicator, the SUN 4/60 yielded results that were, on the average, nearly 1.5 times faster. The SUN 4/330 was over two times faster than the SUN 4/110. This difference was even more dramatic in the CPU and input/output intensive processes for which the SUN 4/330 was three times faster than the SUN 4/110.

Performance specifications for each workstation, such as MIPS, Linpack, and Dhrystone, are presented in Table 2.

WORKSTATION NETWORK CAPABILITIES

In evaluating the computer environment for the GIS–T, networking capabilities of the workstations were weighted

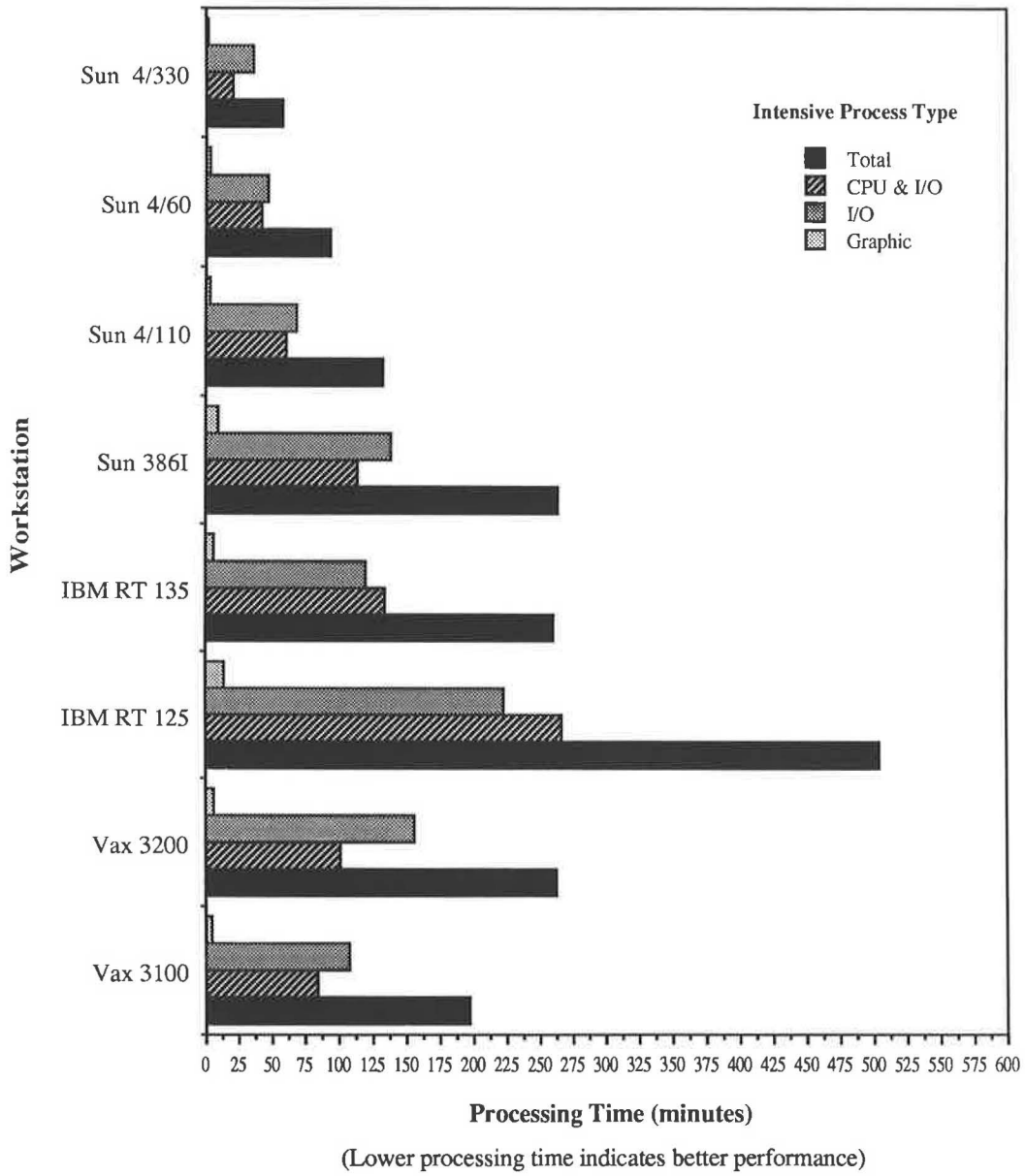

FIGURE 1 ARC/INFO workstation performance tests (overall summary statistics).

heavily. The following networking capabilities were considered.

Host Connectivity and Terminal Emulation

A critical aspect of the GIS at NCDOT involves the ability to access attribute information that describes characteristics of the road network. Because the majority of this information is stored on the IBM 3090/600 mainframe at the Transportation Data Services Center (TDSC), it is essential that workstations have access to the mainframe. The simplest method for connection to IBM mainframes is by emulating, or functioning as, a 3270 device. Because of the large demand for 3270 communications, many vendors offer 3270 emulation packages and support Systems Network Architecture (SNA). With a combination of communications hardware and software, workstations can function as 3274 controllers or 3278/79 terminals. The abilities of each workstation to emulate various terminal types through software, to support SNA, and to interact with IBM mainframes were of critical importance in the evaluation of hardware for a GIS–T.

File Transfer

File transfer between different types of hardware platforms (i.e., personal computers, workstations, minicomputers, and mainframes) is facilitated by the use of Transmission Control

TABLE 2 WORKSTATION PERFORMANCE SPECIFICATIONS

Workstation	MIPS	Linpack (sp)	Linpack (dp)	Dhrystone (dhry/sec)	2D Vectors/sec
SUN 4/60	12	2.5mf	1.4mf	22,045	406,000
SUN 330 GX	16	3.6mf	2.7mf	27,777	454,000
SUN 4/110	7	1.6mf	1.2mf	13,759	21,000
SUN 386I	5	*	*	8,333	*
VAX 3100	3		0.4mf	4,545	*
(DEC 3100)	14	3.7	1.6mf	25,026	*
VAX 3200	3	*	0.4mf	4,545	*
IBM RT 125	4.5	*	0.4mf	8,200	*
IBM RT 135	6	*	0.4mf	10,416	*

* Not published

Protocol/Internet Protocol (TCP/IP), which was supported by all workstation vendors in the GIS lab.

Distributed Services

More advanced proprietary and nonproprietary network software, like DECnet, Aegis, Network File System (NFS), HPnet, and others, provide sophisticated networking services. These services include block file transfers, remote workstation operation, system kernel services, file interchange capabilities, multiple node access, multiple file sourcing, single sourcing of network-wide software, and remote device access and services.

Among the more important services needed within a GIS environment are remote file and device access. These enable users to use disk space and files on remote workstations. Access to remote files is obtained by mounting remote devices. Remote file access, or mounting, provides an invisible, or transparent, connection between the workspace on the user's machine and the file system being mounted. It has the appearance of being local. The only networking software available to accomplish this task that was supported by all the vendors within the GIS laboratory was NFS, which was developed by SUN Microsystems.

Application Program-to-Program Interface

Before a GIS–T can be fully implemented at NCDOT, a seamless linkage must be created between the cartographic data base, i.e., the road network, and the relational attribute data base, which describes characteristics of this network. The cartographic data base is resident on the workstations in ARC/INFO format and the attribute data base exists on IBM DB2 systems. ESRI has stated that this linkage can be accomplished through IBM's Logical Unit (LU) 6.2. LU 6.2 was developed to allow communication between application programs that operate in a distributed processing environment. Support of LU 6.2 is an essential requirement of a GIS–T workstation.

DOS Server/DOS Applications

MS–DOS, developed by Microsoft, is the standard operating system in use on most IBM and IBM-compatible personal computers. The widespread use of MS–DOS at NCDOT and the organization's substantial investment in software applications that run on MS-DOS mandate that the workstations under evaluation support DOS activities.

Network Flexibility: Ethernet and Token-Rings

As networks of increasing complexity are placed in use at NCDOT, network flexibility will be a key concern in the growth of the GIS–T. GIS workstations will be incorporated into both local and wide area networks and will have linkages to personal computers, minicomputers, mainframes, and other workstations resident within various locations across the state. Important networks to be considered are Ethernet and Token-

Ring. NCDOT has an SNA-statewide Ethernet in Raleigh and is considering the use of Token-Rings in field offices. The ability of workstations to operate within these environments and the level at which they can operate, i.e., capabilities and functions, was of obvious concern in the evaluation.

In the context of these six important considerations, the networking capabilities of the evaluated workstations are discussed.

DEC

Demonstration of GIS network requirements was restricted to the VS3200, because the VS3100 was a late entry into the evaluation process.

1. The VS3200 was able to demonstrate a 3270 session to the mainframe by acting as a 3274 device and was capable of emulating a 3270 device and acting as a server, with 128 concurrent sessions.
2. File transfer between the DEC workstations and all other workstations in the GIS laboratory was executed through the use of TCP/IP's file transfer protocol.
3. Although not demonstrated, DEC stated that remote file access was possible within the VAX/VMS environment through DECnet's Distributed File Service (DFS).
4. DEC stated that their workstations have the capability to provide application program-to-program interface by supporting LU 6.2.
5. Through the use of VAX/VMS services for MS–DOS and DECnet, DOS applications can be run on VAX systems. In addition, VAX servers can be used to store DOS data files and applications. Resources, such as laser printers, can be shared.
6. DEC workstations can function on Ethernet networks but not Token-Rings.

IBM

1. Remote login to the mainframe from the IBM RTs was achieved through the emulation of 3278 terminals.
2. File transfer between the IBM workstations and all other workstations in the GIS laboratory was executed through the use of TCP/IP's file transfer protocol.
3. Initially IBM used their Distributed Services (DS) software to perform remote mounts between the IBM systems; however, considerable problems were encountered. In addition, because DS is not supported by other workstation vendors, it could not be used to mount file systems on non-IBM UNIX systems within the GIS laboratory. Because of these problems and constraints, IBM switched to NFS. Remote mounts through the use of NFS were successfully accomplished among IBM systems and between IBM systems and other UNIX systems within the GIS laboratory; however, at the present time IBM's implementation of NFS has limited file-locking capabilities. Remote logins to other workstations with UNIX operating systems were possible. Remote logins to the VAS/VMS systems were not supported by IBM.
4. IBM stated that their workstations have the capability to provide application program-to-program interface by supporting LU 6.2.
5. A wide range of DOS activities was supported on both IBM workstations.
6. During the evaluation period, IBM workstations were the only workstations in the GIS laboratory to operate within both Ethernet and Token-Ring networks.

SUN

1. Connection to the IBM mainframe was demonstrated by SUN. SUN machines accomplished the generation of 3270 sessions by emulating a 3274 device.
2. File transfers between the SUN workstations and all other workstations in the GIS laboratory were executed through the use of TCP/IP's file transfer protocol.
3. Remote file access was possible through the use of NFS. The SUN workstations in the GIS laboratory were able to mount all other UNIX workstations.
4. Communication between application programs in a SUN environment is supported by SUN's Peer-to-Peer software.
5. DOS files and programs were successfully stored on both SUN workstations. The SUN 386i had an Intel chip that allowed for a separate DOS partition.
6. SUN workstations can operate within an Ethernet network. SUN is currently developing communications software that will allow their equipment to be used within a Token-Ring environment.

OPERATING SYSTEMS

In the evaluation of operating systems, the following criteria were considered: ease of use, network capability (discussed in the previous section), window systems, system security, upwards and downwards compatibility, and history and standardization.

DEC

DEC's workstations (VS3100 and VS3200) used the VAX/VMS operating system. For several years, DEC has worked with MIT to develop the X Windows System. DEC's implementation of X Windows System is DECwindows. DECwindows is a sophisticated, multitasking system that integrates many desk-top publishing features and provides easy access to applications on several operating systems.

SUN

The operating systems on SUN workstations are based on the Berkeley version of UNIX, with the incorporation of most of AT&T's System V features. This operating system is an extremely popular multiprocessing system with many advantages. The UNIX operating system is a portable one that can

be implemented on dozens of different machines. Because of this, software vendors and users become computer independent, and programs and data are easily transported from one machine to another. The UNIX system supports a large number of software applications and programming languages and has a high degree of upwards and downwards compatibility.

SUN workstations have SunView window systems. SUN began developing window systems before X-windows were developed and, as a result, SunView is a mature window system that is much faster than X-windows. More than 2,500 applications are available for the SunView window system.

IBM

The IBM RT workstations used the System V version of the UNIX operating system. This operating system was developed by AT&T and has many of the same positive features as the SUN UNIX system. The IBM RTs used IBM AIX/RT-X Windows, Version 2.1. This window system is based on X-windows and was designed to support graphics applications. With this system, multiple application processes can operate within a given window, and multiple simultaneous windows can be used.

PILOT PROJECT VENDOR SUPPORT

On the whole, support from all three vendors was good during the pilot project, but it varied in certain aspects. Initially, DEC had problems committing their resources, and two months passed before they were able to link their hardware to the GIS LAN. After this occurred, their support improved. SUN support was good throughout the entire project. SUN was the quickest of all three vendors to get workstations running and to respond to and solve any problems that arose. As a result, the SUN workstations experienced the least amount of down time. IBM was the first vendor to commit its resources to the pilot project and it provided the most support. In addition to the workstations, IBM supplied the project with many other resources, including an IBM 6186 eight-pen plotter and an IBM PS/2 Model 80 computer.

In terms of the statewide implementation of a GIS–T, it is essential that good support from vendors continue. One of the most important aspects of this support is the amount of time it takes for a vendor to respond to problems, not only in the Raleigh office, but in field offices throughout the entire state.

WORKSTATION SYSTEM PROBLEMS

Each of the workstations varied in terms of the number of system problems that were encountered during use. On the whole, few system problems were encountered on the SUN workstations. The SUN equipment was functional for almost the entire duration of the GIS workstation evaluation (see Figure 2). This was due, in part, to the excellent support from SUN personnel. On the other hand, many problems were encountered with the IBM workstations. Both the IBM 135 and IBM 125 were inoperable for much of the evaluation period. Many of the problems with these two workstations were eventually resolved by software improvements by ESRI and an increase in the expertise of IBM personnel.

As noted in the previous section, there was a significant lapse between the time the VS3200 was first installed and the time it was connected to the LAN. Afterwards, few problems were encountered with this workstation. Three workstations were available for only a short period of time and could not be evaluated thoroughly. These were the VS3100, SUN 4/60, and SUN 4/330. However, the long-term quality of performance of these systems can be inferred from the performance of other VAX and SUN workstations that were evaluated more thoroughly.

GIS Development Team Observations

The GIS development team included GIS analysts and consultants, and representatives from the Transportation Data Services Center. Response of the GIS development team to the SUN 4/110 was positive. The SUN 4/110 was fast and reliable and few problems were encountered with UNIX, the SUN windows, or the text editor. Downloading of files from the mainframe to the SUN 4/110 was efficient and effortless. With respect to the ARC/INFO software, the 4/110 had a number of positive features. One of these involved the boxing in of the map extent in ARCEDIT, a feature that neither the IBMs or DECs exhibited. Without this feature, it was difficult to delineate a map extent accurately. Only one bug was encountered with the SUN 4/110 and this concerned the execution of INFO programs. When INFO programs were run on the system, there was no indication of a program's end (i.e., by returning to INFO). Response to the SUN 386i was also favorable. This workstation possessed most of the positive features noted for the SUN 4/110 with the exception of its slower processing time. The INFO program bug did not occur on the SUN 386i.

The VS3200 elicited positive response from the development team. As previously noted, VAX/VMS is a sophisticated operating system that is easy to use. The window systems and resolution of the monitor were good, but the workstation was slower than the SUN 4/110. File transfer between the mainframe and VS3200 was cumbersome and posed problems because of the limitations on record length with remote job entry (RJE).

The IBM workstations had some problems. The positive features of these workstations were the monitors, with their pure colors, and the UNIX (AIX) operating system. However, many problems were encountered while using ARC/INFO software. Occasionally, certain graphic functions caused the screen to lock up, and the cursor in ARCEDIT was too large to accurately select features. In addition, the IBM 125 was slow compared to all other workstations in the GIS laboratory.

GIS DELEGATE TRAINEE OBSERVATIONS

At the onset of the project, representatives from various departments within NCDOT were appointed as delegates to

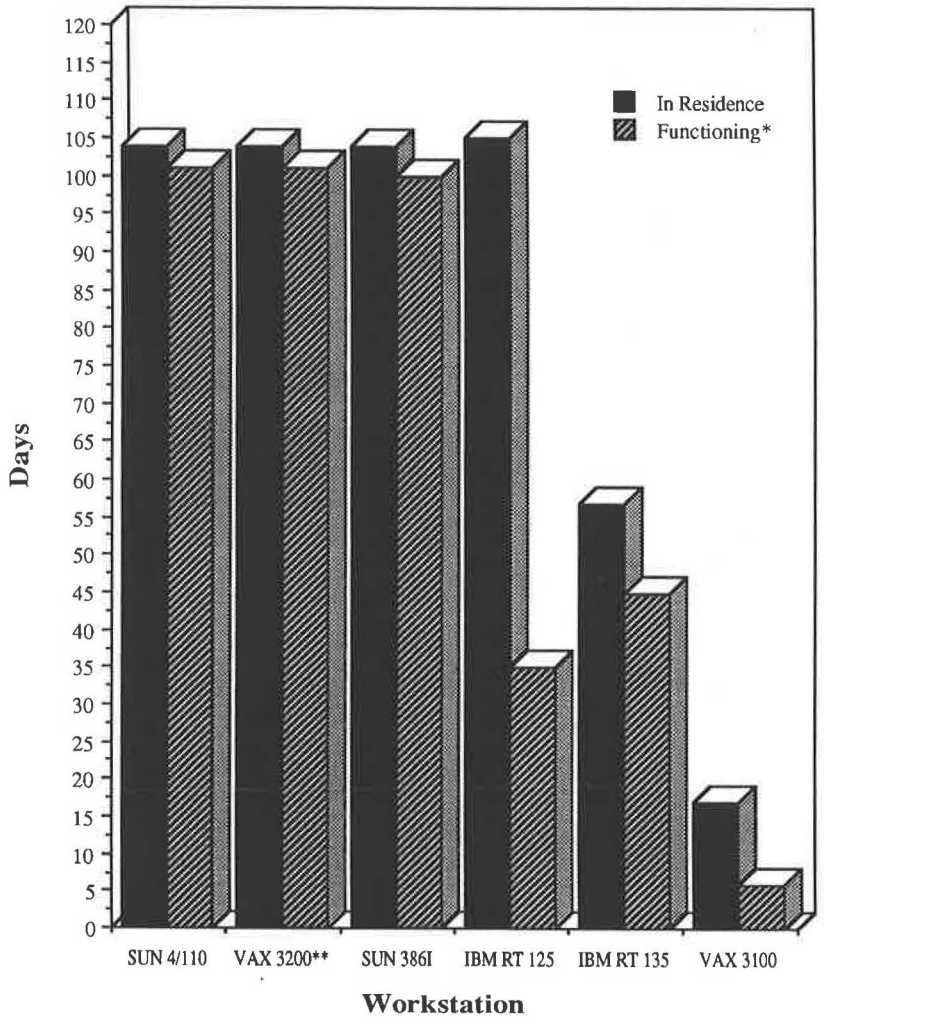

FIGURE 2 Workstation functional performance.

work with the GIS development team to define users' needs and assist with application development. A number of important observations about hardware and operating systems were made by GIS delegates after an ARC/INFO training session that took place in December 1988.

Nearly all comments about the SUN 4/110 were positive. Again, the 4/110 was noted for its speed, reliability, and user-friendly editor. The delegates found the window system easy to use and were favorably impressed by the resolution of the monitor. Attitudes toward the SUN 386i were similar, with the exception that it was significantly slower.

Response to the VS3200 was also favorable. Some trainees felt that the VAX/VMS operating system commands were easier to learn than UNIX commands. The windows, although less sophisticated than SUN windows, provided no problems.

With the exception of comments about the large screen and high quality of the monitor, response to the IBM RTs was less favorable than that of other workstations. Many bugs were encountered with the IBM workstations, including screen lockups, trouble with keyboard cursor control keys, and the inability of the monitor to refresh obscured screens. Many negative comments were made about the two-button mouse, and the windows were harder to use than SUN or DEC windows.

A number of workstation features were viewed by the GIS delegates as being highly desirable. These included speed, reliability, a three-button mouse, keyboards with numeric keypads, mouse-driven system editors, a mouse-driven menu operating system, and the ability to easily recall and edit previously typed commands (history command).

PRICE

There was a considerable amount of variation, not only in the cost of workstations themselves, but in the amount of software or extras that were included in the purchase of the workstation. Figure 3 shows the relative cost of workstations

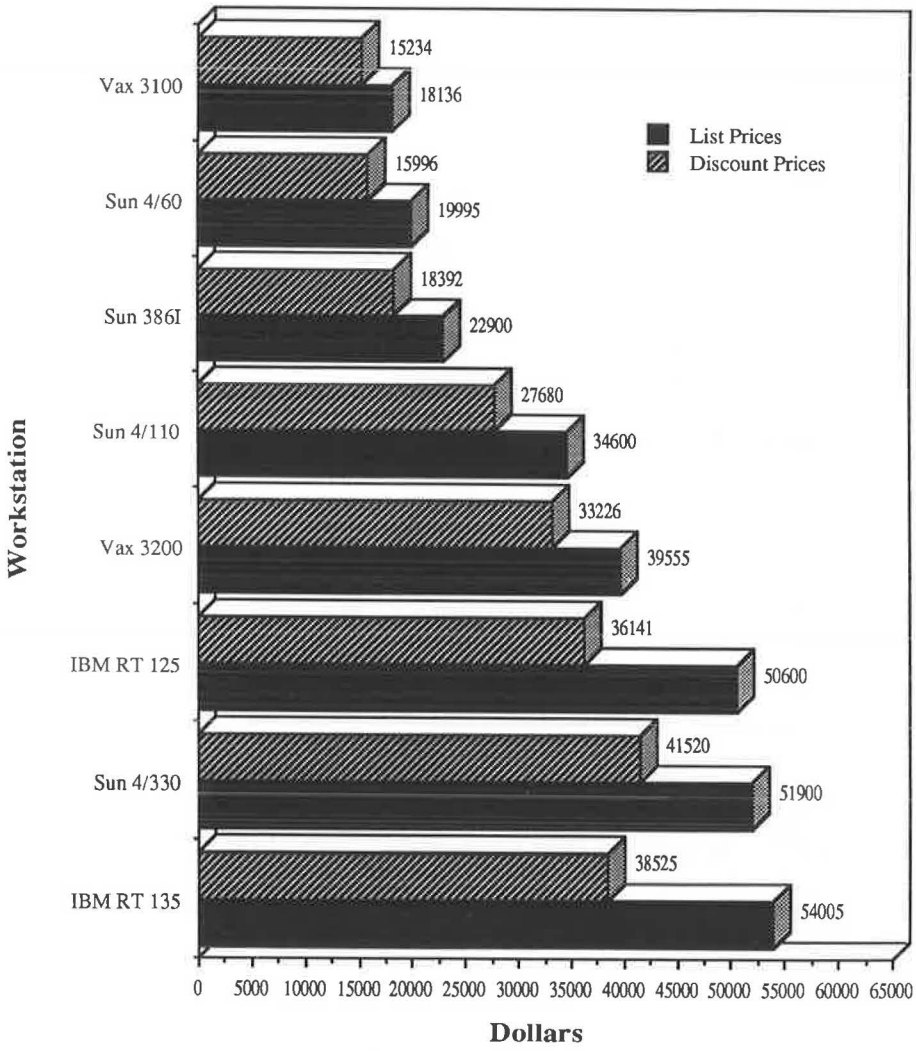

FIGURE 3 GIS workstation prices.

comparably configured (according to April 1989 prices). The cost performance of each workstation is shown in Figure 4. Cost performance was evaluated by devising an index that took into account the price of each workstation and the average time, in seconds, that it took each workstation to perform the 20 AML tests previously discussed.

CONCLUSIONS

Workstation technology is evolving rapidly in the computer industry, a fact substantiated by the continued introduction of new lines of highly advanced workstations. Workstations with increased speeds and prices near those of personal computers are now available for GIS technology. Graphics capabilities and processing performance, however, are superior to personal computer technology.

The UNIX operating system, although marketed in several versions and in varying stages of development, offers many advantages over other operating systems and is rapidly becoming the operating system of choice among workstation vendors. Multitasking and enhanced window performance, increased CPU performance through Reduced Instruction Set Computer (RISC) architecture, ease of porting new applications, and compatibility from vendor to vendor are some of the significant enhancements offered by UNIX. The UNIX operating system also has many advantages in terms of network flexibility. UNIX, in conjunction with NFS, provides interoperability across a heterogeneous computer network, allowing users to store and access files that reside within a multivendor environment. Although not actually a standard, many vendors are implementing NFS on their systems. NFS was developed by SUN Microsystems and has been tested on many networks, including Ethernet, Token-Ring, Apple Talk, and others. UNIX has incorporated commonly used communications protocols, such as TCP/IP, into its command language to provide for a variety of network services, such as remote login and remote file transfer. Because of its many advantages, the UNIX operating system should be an important consideration in GIS applications.

After reviewing the results of the 5-month workstation evaluation, NCDOT's GIS development team recommended SUN

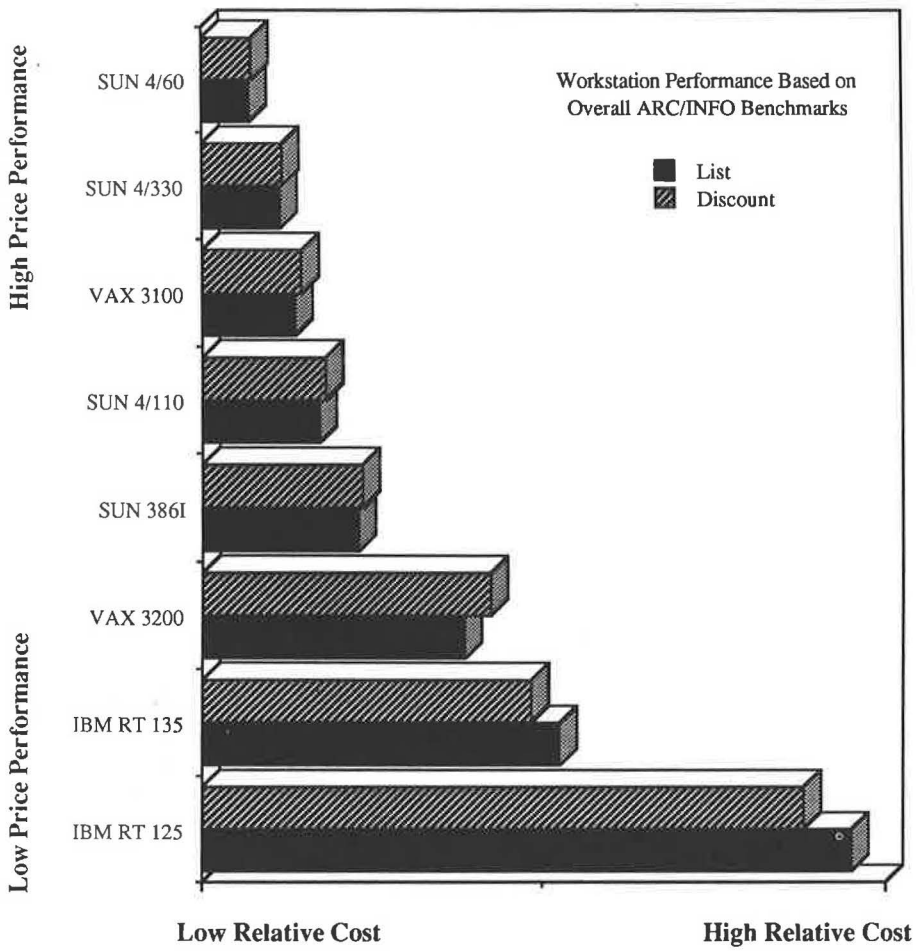

FIGURE 4 GIS workstation price performance (based on vendor's list and discount prices).

Microsystems as the workstation of choice for the initial implementation of GIS at NCDOT. SUN was able to demonstrate clearly superior levels of price, performance, reliability, network flexibility, ease of use, system integrity, and support. The newly released SUN 4/60 workstation was the lowest priced workstation in the test and performed at double the speed of the nearest competition. The SUN equipment worked nearly every day since its installation. When repairs or modifications were necessary, they were made quickly and effectively. In all network functions tested, SUN workstations performed as though they were designed for the end user rather than a computer programmer.

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