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IMPLEMENTATION AND OPERATING EXPERIENCE WITH A CENTRALIZED MULTI-DISCIPLINARY CAD CAM SYSTEM*

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ABSTRACT

The Stanford Linear Accelerator Center (SLAC) has installed a centralized CAD CAM System to support Electronics, Mechanical, Mechanical Fabrication and Architectural Engineering and Design. The various phases of implementing this system are described, including problems of selection, system software support, maintenance, training, performance evaluation, and future expansion. Some emphasis will be given to the experience with the Electronics disciplines.

1. INTRODUCTION

In late 1983, Stanford Linear Accelerator Center (SLAC) took delivery of a five workstation Intergraph CAD CAM system which utilized a VAX 11/780 and centralized software. The system was obtained by competitive bid where the major emphasis was placed on the interchangeability of workstations among different software disciplines, in particular, Electronics, Mechanical, Mechanical Fabrication, and Architectural; and on the ability of stations to operate remotely up to 3000 feet from the central processor.

Since initial delivery, the major disciplines have been implemented and brought into routine production use. The initial complement of five workstations has been expanded to fifteen, with three more to be added during FY'85. The processes of introducing CAD into the workplace, training and retraining of people, expanding the system capacity, and developing effective management techniques, have proven to be complex and challenging.

Currently, emphasis is being placed upon improving productivity, finding the most effective management techniques, developing standards for the various disciplines, integrating the system with site-wide document archival requirements, and expanding the system to support compute-intensive engineering analysis programs.

The pitfalls of such an ambitious undertaking, the management problems, and future expectations and goals, will be described.

2. SYSTEM SELECTION AND INITIAL CONFIGURATION

The initial procurement of the basic CAD system was preceded by an extensive period of defining the needs of the various Technical Division (Engineering) Departments, and generation of a Specification and Request for Proposal. The most basic principle adhered to was that the system should be a centralized, multi-disciplinary system, in which work stations could support the various disciplines interchangeably, and where software, archiving, system management and maintenance could be centralized. At the same time, recognizing the realities of decentralized departments and the geography of SLAC, it was decided to require that workstations function at least 3000 feet (approximately 1 Km) from the Central Processor, which would allow individual groups autonomy and convenience in the management of their CAD resources. Other requirements were the ability to easily expand the number of workstations and to link to the SLAC IBM 3081 facility, the latter in anticipation of compute-intensive tasks which would use the 3081, as well as for potentially archiving using the existing IBM tape and disk storage facilities.

After the usual solicitation and evaluation of bids, in which valuation points were assigned to various required features of the system, selection was narrowed down to two finalists, with the award going to Intergraph Corporation of Huntsville, Alabama. The initial system consisted of the following:

VAX 11/780 Central Processor W/2MB RAM

Dual 84 MB Disks

Dual 800/1600 bpi tape drives

5 Work Stations with Hardcopy Units

4 Color Pen Plotter (CALCOMP)

System Console (LA 120)

Alphanumeric Terminal

Paper Tape Reader and Punch

DZ11 Communications Interface

The workstations were dual screen units, with high resolution capabilities on both the monochromatic and color screens, together with a digitizing table capable of handling an E-size work surface, and a hardcopy unit. The workstations utilize a menu pad, 12-button cursor, and supporting keyboard, with the various disciplines configured by simply swapping menus.

Software delivered with system included the following:

(a) Vax VMS 3.6 operating system
(b) IGDS (Intergraph Graphic Design System)
(c) DMRS (Data Management & Retrival System)
(d) IEDS (Intergraph Electronic Design System)
(e) Auto-router for Printed Circuit Boards (PCB)
(f) Auto Placement Package and Gate Assignment
(g) NC Drill for PCB
(h) Architectural Production Drawing (Floor Plans, HVAC)
(i) Engineering Production Drawing (Electrical, Piping)
(j) Structural Layout
(k) MDDS (Mechanical Design and Drafting System)
(l) NC Part Programming
(m) NC/APT Interface
(n) Plotting Software including support for offline photoplotting.

The first components of the system arrived in June, 1983, and the basic system became operational with the major applications packages on-line by September, 1983. The system block diagram is shown in Fig. 1, and the workstation configuration in Fig. 2.

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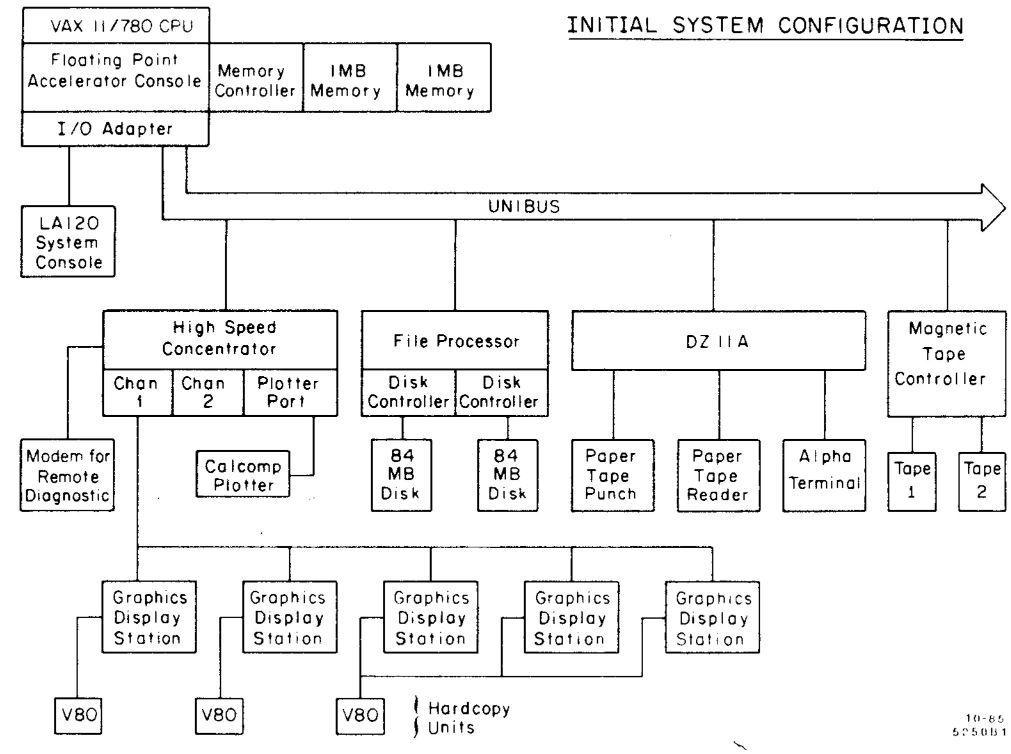

Fig. 1. Initial System Configuration.

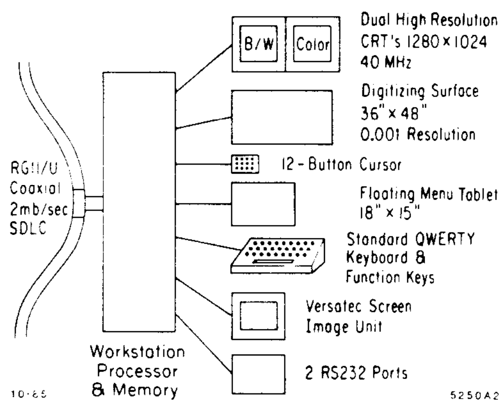

Fig. 2. Graphics Display Station – (typical workstation configuration).

3. INITIAL TRAINING OF OPERATORS

Primary emphasis was placed on initially training operators from the major engineering design groups, such as Electronics and Mechanical Design and Drafting, Printed Circuit Design, Architectural Design and Drafting, and Mechanical NC Programming. The Group Managers, where possible, selected two to three people from each area to undergo intensive training, starting with the general graphics package, followed by specialized training in the various disciplines. During this training, classes were held on-site by factory personnel with all workstations in close physical proximity. After completion of training and a period of operational break-in, various workstations were transferred to their Department locations, in some cases entailing cable runs of close to 6000 feet from the Central Processor. This was accomplished by approximately the end of 1983; hence the operational capabilities of the trainees and the system itself have been established and growing for approximately twenty-one months.

4. INITIAL SYSTEM PROBLEMS AND SOLUTIONS

Several serious problems were immediately recognized and corrected. The first was that the Calcomp pen plotter software had serious bugs and would not operate reliably. More seriously, it was quickly apparent that the slow throughput, as well as the inordinate amount of operator attention required, made the pen plotter unable to cope with our future total production needs. The chief continuing need for pen plotting was to generate multicolor check plots for printed circuits, plus occasional high quality plots for other applications. The solution was to trade in the Calcomp for a 36" high-speed roll feed electrostatic plotter (Versatek), plus a lower-cost sheet type 8 color pen plotter (Hewlett Packard). An earlier concern was that the Versatek might not produce sufficiently high quality for reproduction via our standard microfilm system; however, upon testing, quality was found to be totally adequate. Furthermore, the Versatek hardware and software has operated very reliably, and throughput is good.

A second problem was that the initial amount of disk storage was under-specified, and it was necessary to rather quickly add a large capacity 675 MB system disk. This was done within the first few months of operation, before disk space became a serious issue. Further disk additions have since been made.

The major hardware maintenance problems experienced were with infant mortalities of various workstation components including CRT's, graphics processor boards, and communication boards. When the long coaxial lines were introduced to remote areas and more workstations added, further problems were experienced, some of which were traced to poor connections, and some of which were due to marginal signal strength caused by excessive cable length and/or system loading. The long-line multidrop serial coaxial problems were non-trivial to diagnose. However, all of these problems were corrected relatively promptly, and in general the hardware has operated very reliably.

5. APPLICATIONS STARTUP EXPERIENCE

Both the Mechanical and Architectural packages started up relatively smoothly. Both software packages are quite mature compared with the Electronics package. Principal problems experienced in startup were due to poor documentation of the applications packages, which placed an undue burden on the System Manager to work out the difficulties, as well as to identify and treat other problems such as system bugs, application bugs, or "cockpit" (user) trouble. Factory response to solve system software and interface problems was less than impressive, again requiring a much higher level of local system software support than was advertised as being necessary. The large majority of these problems were ultimately resolved one way or another; in sum, their presence simply added a significant impedance to the start up process, which is painful with any large-scale system under the best of conditions.

Electronics posed some special problems, some of which are still not completely resolved. One problem is that a CAD system offers a natural coupling via a single data base of two hitherto unconnected manual processes, that of drawing the circuit schematics in final detail, and that of producing the printed circuit artwork. The connected data base carries with it a potential blessing and an immediate curse: The blessing is that if properly used, the system "automatically" checks the pc design against the schematic, and should not allow discrepancies between them, which in turn should obviate the need for extensive manual checking of printed circuit checkplots, a very painful process. The curse is that the two processes must now be performed totally serially–no problem if they can both be done very rapidly and efficiently–which, in a new system with new trainees, they cannot. This has caused great tension and strain between customer and service provider, and produced the temptation to shortcut the process by, for example, trying to bypass the formal schematic "bottleneck" and go straight to the pc stage. This can be done, but advantages of the system are seriously compromised, and overall, time is probably lost, rather than gained. More will be said about this particular problem later.

6. PRODUCTIVITY

Within a few months of completion of training, the Mechanical and Architectural groups were claiming increases in productivity of 2D design drawings compared with straight manual methods. The measure being used was simply the quantities of various sizes of standard drawings. The primary gains were in the ability to more easily replicate repetitious drawings using standard forms, either those in the libraries, or those especially created. So far, only experimental 3D work has been done, so that some of the potential power of the system is yet to be tapped.

For Electronics the productivity of both Schematics and Printed Circuit boards initially dropped fairly dramatically, and for multitudinous reasons, did not show an improvement over the previous method (manual schematics, pencil layups and digitization into a computer for photoplot tape generation) for almost a year. There were several reasons for this: (1) The Electronics package is much more complex to learn than other packages; (2) the package documentation and library structure are poor so that many important facets have to be learned by trial and error, and problems circumvented by developing work-around solutions; (3) almost all of the trainees had no previous computer experience and had difficulty acquiring efficiency in use of this radically new tool; and (4) for a long time, we continued to shortcut the schematic entry process, or failed to back-annotate properly, thus causing contamination of files and chronically negating the potential power of Design Rule Checking (DRC). Even today, there are some aspects of the system which do not work as advertised, either due to bugs or chronic operator misunderstandings.

Only recently can it be claimed that overall Electronics productivity has matched or exceeded the old methods in speed. A major effort has been launched to build a more complete library, which is one current shortcoming. A second effort is aimed at finding ways to improve overall speed of schematic entry and pc design, by introducing better hardware (*e.g.*, "Route engine"), software, or both. Thirdly, management has recognized some of the aforementioned problems, and restructured supervision to give closer control of methods and quality of final output.

The Mechanical Fabrication software has not received a high priority in implementation, partly because of shortcomings in the various software interfaces which required considerable local expertise to solve. However, the basic system has recently been brought into operation, and a concerted changeover effort has begun.

The CAD system user statistics for August, 1985 are summarized in Table I.

TABLE I: CAD USER STATISTICS FOR AUGUST 1985

	No. User Accts.	No. Active User Accts.	Hours Used	% of Total System Usage	
Production Groups					
Architectural	12	4	225	13.3	85.4%
Electronics	15	10	373	22.0	
I & C	16	11	244	14.4	
Klystron	6	5	100	5.9	
Mech. Fab.	6	2	96	5.7	
Microwave	4	1	3	0.2	
SLD (Mech/Elec)	8	5	117	6.9	
Vacuum (Mech)	12	11	287	17.0	
Engineering Groups					
Electronics	17	11	23	1.4	6.0%
Mechanical	13	3	24	1.4	
Miscellaneous	14	4	54	3.2	
System Users	19	10	145	8.6	8.6%
TOTALS:	142	77	1691	100%	

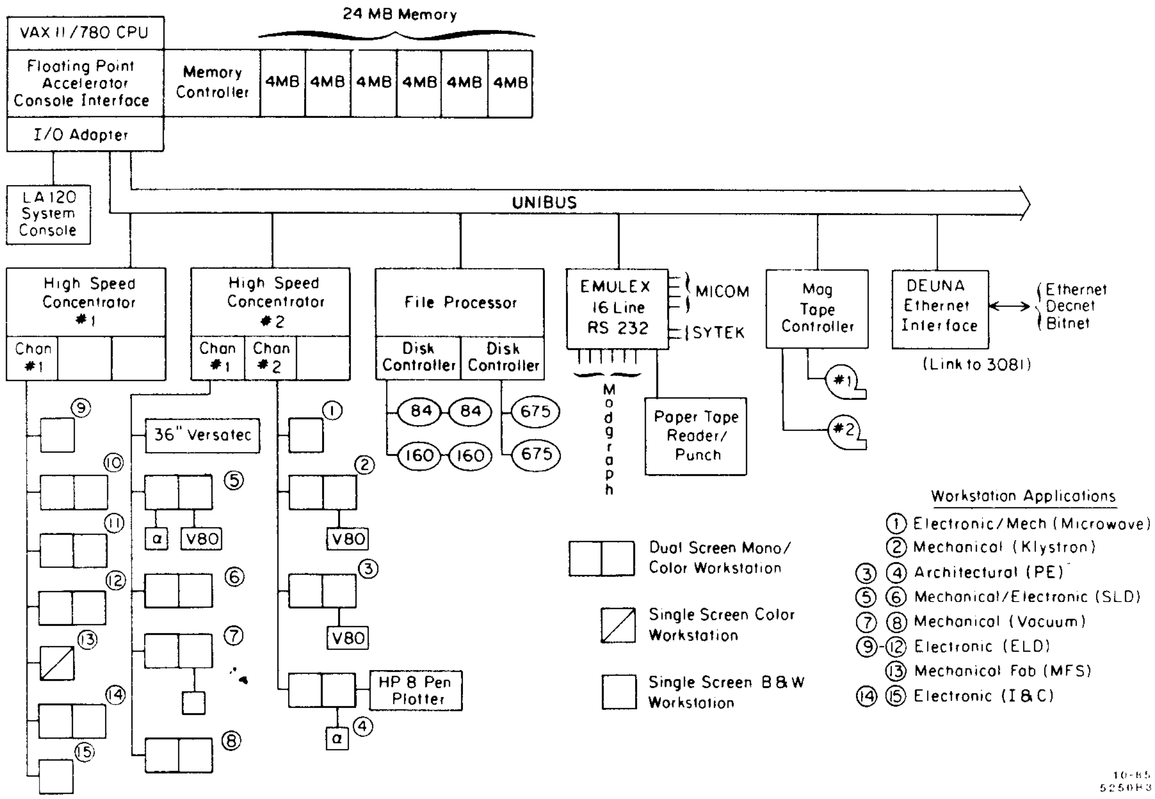

Fig. 3. Expanded System Block Diagram.

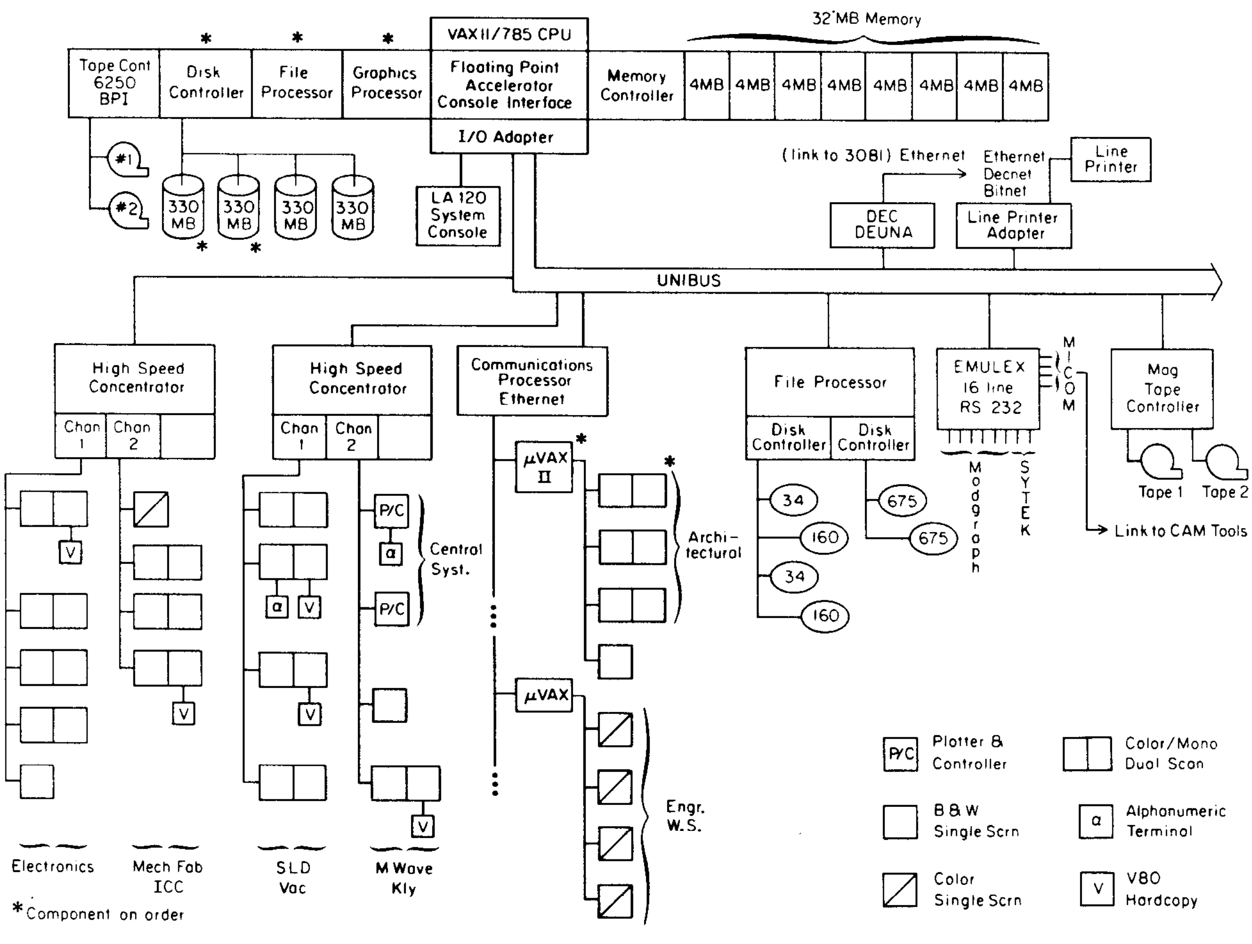

Fig. 4. Future Expansion System Plan.

7. SYSTEM EXPANSION

One of the strong features of the Intergraph system is the ability to support an impressively large number of workstations. Each of the stations has three local processors and 1 MB of RAM.

The Processors are:

(a) A 5 MIPS Display Processor

(b) A 15 MIPS View Processor

(c) A 0.5 MIPS 68000 Workstation Control Processor

This computing power serves local 2D and 3D pan and zoom operations, and interfaces to local peripherals and to the host via the 2 Mb SDLC serial coaxial link.

As soon as the initial five stations became operational, shift or extended operations were begun in several areas in order to make maximum use of the system, and more workstations were ordered. Along with this development, Central System enhancements were added, including an additional 675 MB disk, a new memory backplane with 24 MB of RAM for the VAX 780, and a second high speed communications interface. The total number of workstations now installed is 15, with three more on order. Of this number, all but three stations are the full dual screen color units. Also on order are additional system enhancements such as a Graphics Processor (to offload and speed up the plot stroking function, currently one of the most compute-intensive tasks); and, most significantly, a MICROVAX II distributed CPU, which will support up to four workstations in stand-alone mode, and communicate with the CPU via Ethernet. The expanded system is shown in the Block Diagram of Fig. 3; planned future add-ons are shown in Fig. 4. Note that although a hardware link currently exists to the IBM 3081, it is not in routine operation. Also note the indication of future direct linkage to CAM tools in order to eliminate paper tape as a transport medium, and the currently installed linkages to DECNET, BITNET and ETHERNET.

A total of nine low cost graphics viewing terminals, the Modgraph GX100, with support software, also have been added to the expanded system. These terminals currently are used to view and do minor editing of 2D design files. The stations are linked via 9600 baud RS232 lines; 3D software support is anticipated in 1986 (second quarter).

Planned future software acquisitions include the following:

1. Data Set Management System (DSMS)*
2. Stress Analysis (ANSYS)†
3. 3D Solids Modelling, Surface Shading *etc.*
4. Plant Design Piping
5. Cable Tray Layout and Placement
6. Electrical Power Utilities
7. IGES† and ISIF† Graphics Exchange Packages
8. Hybrid Circuit Design
9. Logic Analysis and Simulation
10. Circuit Analysis and Simulation
11. Silicon Compilation (VLSI Custom Design)
12. Wirewrap and Multi-wire
13. 3D Support for Modgraph GX100

* Package installed on IBM 3081; training in progress.

† Package received and being implemented.

8. ENGINEERING WORKSTATIONS AND APPLICATIONS

It has long been a goal to expand the applications to include various engineering applications, such as stress analysis, logic and circuit simulation, *etc.*

To date the system has not been equipped for these tasks; and, in fact, it is clear that the existing VAX 780 could not absorb the added load of these demanding packages, unless run off-hours on a totally noninterfering basis, which is not very practical. One current plan is to use the Intergraph as the workstation to access a new Stress Analysis program, which itself would run in batch mode on the IBM 3081. This plan is being pursued, although there is also concern about the potential impact of a buildup of analysis programs on the IBM facility. The more practical approach may well be distributed processing on dedicated Microvax II's and "engines" (accelerators) which can greatly speed up execution of programs such as simulation, pc auto-routing, *etc.*

Currently, engineers utilize the existing production workstations on an as-available basis. Electronics engineers have learned the system on their own time and, after a rather short self-training period, produced prototype printed circuit boards, schematic packages, and hybrid circuit designs. One obvious future direction is to acquire a lower cost engineering workstation which will not only support quick turnaround of engineering prototypes in this fashion, but will also incorporate analysis functions such as logic and circuit simulation, logic verification, testability analysis, *etc.* These tools are just now becoming a reality, and in 1986 it is hoped to acquire some of them for dedicated engineering use.

It is also worth noting that placing more workstations in the hands of electronics engineers could alleviate the schematic entry bottleneck mentioned earlier. In this scenario, engineers would do the complete design necessary to produce a quick prototype board, including the pc layout, and then hand the design files over to the production design group for a more formal, total design and documentation package prior to final manufacture. In either event, it is visualized that there is a continuing strong need for CAD tools for both engineers and the production design group, and that these tools should ideally exist on an integrated data base which encompasses CAE (analysis) tools on the one end, and CAM (manufacturing and test) tools on the other.

The Electronics CAE directions are clear: more designs will be produced using custom chip and hybrid techniques, and the necessary support tools, such as silicon compilers, simulation and testing, will be implemented in time. In addition, more powerful printed circuit design tools are rapidly becoming available and will be implemented to upgrade the present system. Most of these improvements will run on stand-alone hardware, such as a Microvax II, networked to the central system.

9. SYSTEM SUPPORT AND MAINTENANCE

To date, the system has been implemented and operated with one full-time professional System Manager, a part-time System Programmer assistant, and backup help for simple tasks, such as running tape backups, from the applications groups. The pressure to provide more expert help and service has recently resulted in the formalization of a group as shown in Fig. 5. The key permanent people, in addition to the Manager,

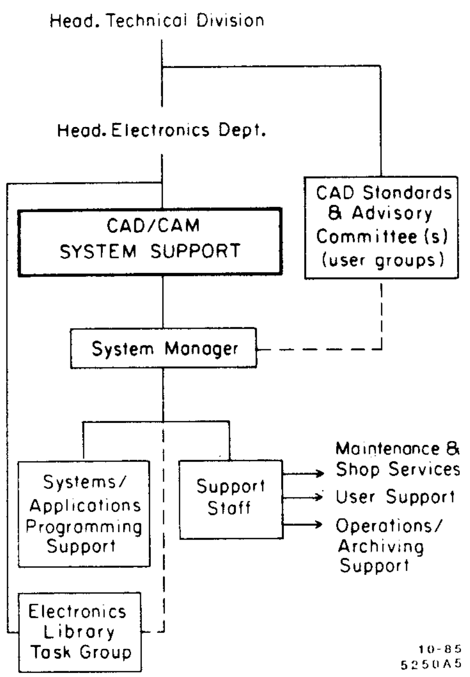

Fig. 5. CAD/CAM System Support Organization.

are two System Programmers, one specializing in Electronics applications, and the other in Mechanical Engineering and CAM applications. In addition, a support staff of three provides support for the Data Set Management System being implemented (DSMS); and for coordination of system expansion and maintenance, plotter attendance, tape and disk management, and general facility housekeeping. As currently constituted, the group resides in the Electronics Department.

Maintenance is provided by contract to local Intergraph support people. A plan is underway to have a resident site field engineer starting in FY'86. Hardware maintenance response in general has been excellent, but on-site support is justified in view of the large size of the current system. Software maintenance response comes through company headquarters and has been less responsive. The support group also maintains a liaison with a CAD/CAM advisory group, and, currently, with an Electronics Library Task group.

10. MANAGEMENT ISSUES

The general charter of the Systems Group and the CAD/CAM facility as a whole is to provide a platform for the eventual total conversion of manual design and drafting to computer supported systems and techniques, and for the introduction and growth of engineering analysis tools. Obviously, this is a continuing task. A ground rule is to maintain integrity and compatibility with the long-established manual documentation standards and control procedures. The system is fully operational, although traditional manual design and drafting is still in wide use. The CAD system archive consists of disk and tape storage, plus hardcopy prints and microfilms stored in the central document storage vaults. Special provisions have to be made for handling valuable photoplots, and for controlling revisions to CAD documents.

The Data Set Mangagement System (DSMS) software has recently been acquired to support organization of CAD document filing, search and retrieval. This system, currently being implemented, will hopefully result in an efficient archiving of documents by Project, System, Subsystem *etc.* Unfortunately, it is already known that DSMS is incompatible with the current software structure of the Architectural System, which has its own built-in project-oriented filing and archiving system. For this applications package, we will have to design an overlay system of some type which will allow easier access to the archives as currently structured, and a level of future compatibility with DSMS.

Currently, archival standards and procedures are being worked out through recommendations from the aforementioned standing Advisory Committee in the Technical Division, which reports to the head of the Technical Division. This committee contains representation from all the user groups. To date, it has defined the general system needs, helped formulate documentation standards and procedures, and set up subgroups to continue study of various problems.

There appears to be a clear consensus that CAE/CAD/CAM will pay off handsomely if the investment, both managerial and financial, is made by the laboratory; and if careful plans can be laid so that future acquisitions can be made to maintain compatibility with the systems already in use. This does not necessarily mean identical hardware and software, but rather the careful definition of acceptable interface data formats and hardware/software tools, to assure an orderly workflow from engineering design through production design, manufacture and testing.

An immediate management issue is how much, if any, of other CAD tools to allow at the Laboratory, in particular those personal-computer based tools which are very attractive for certain kinds of tasks, including engineering analysis, simulation *etc.* In fact, some such software packages currently exist, and more low-cost packages are being tried experimentally. In general, it is hoped to make a full range of powerful tools available to both production designs and engineers on the centralized system, thereby gaining maximum cost-benefit of the initial hardware and software investment. Some of these high-end tools may be from 3rd party hardware and software suppliers. If this is done expeditiously, the personal computer tools will find the most use for limited scale, quick turnaround analysis, simulation, and prototype design, including small, specialized pc artwork. In effect, it is necessary to allow a limited degree of experimentation in CAD systems in order to ascertain the most effective and productive approaches. Overall, however, CAD is a large investment, and non-integrated solutions could become extremely costly and wasteful if not properly managed. The low cost personal computer tools can perform only limited tasks, but they can serve as a valuable entry level tool for certain kinds of tasks, and for training of personnel who have no prior computer experience. It is hoped that very high cost pc-based systems which are not integrated with the central system can be avoided.

11. SUMMARY OF PROGRESS TO DATE

At the date of writing, the CAD system is equipped with 15 workstations which are essentially all in production use on a two-shift (or extended shift) basis. The average utilization for day shift exceeds 120% (due to work on weekends) and on swing is about 70% based on logged-on hours versus workstation hours available.

Productivity measurement for 2D drafting is showing gains of at least a factor of 3 over manual methods. For Electronics, productivity gains have been slowly improving, but schematic entry is only just competitive with manual methods. Of course, one must realize that having the drawings on a computer data base is a huge advantage even if the entry process is only a break-even proposition.

In the printed circuit design area, proper use of DRC and improved training of personnel is yielding good dividends over manual methods. The planned future addition of special hardware and software for automatic routing is expected to make a major improvement in productivity in this particular area. Productivity measurement in printed circuit design can be measured by an algorithm which includes the factors of board density (16 pin IC equivalents per square inch), number of circuit layers, and number of network segments to be routed. Some composite statistics along these lines are planned in future, in order to chart improvements in the use of our tools, and effectiveness of operator training.

Regarding training, most of the permanent production employees who desire to learn CAD have been trained. After training, some have elected not to become CAD operators. We have begun to train some temporary (contract) employees to fill our needs.

SLAC is currently in the midst of a very large construction project (The SLAC Linear Collider Project), and it is gratifying to note that the bulk of the final documentation for this system will ultimately reside on the CAD system. In addition, the accompanying detector project, SLD, will be essentially totally documented on the CAD system.

Two of the applications packages initially purchased have not yet reached the implementation stage. One is the machine tool path generation software; the other is EWS (Electrical Wiring). The former is now ready for full scale implementation, but EWS is still in the evaluation stage, and none of our people are adequately trained to use the system.

12. CONCLUSION

SLAC has embarked on an ambitious program of acquiring and converting to CAD tools for production use, and is beginning to expand toward more engineering CAE tools on the one hand, and better linkage to manufacturing (CAM) on the other. The acquisition program has received excellent management support and the pacing factors at present are in training new people, and implementing new software. The system has performed well overall, and is in some areas fulfilling expectations; while in other areas, notably Electronics and plotter loading of the CPU, more improvement is necessary.

The major future goal is to put CAD tools into the hands of both engineers and production designers, and to provide a smooth work flow between the various tools representing CAE, CAD and CAM. It is believed that the basic management problems are understood and are being solved.

ACKNOWLEDGEMENT

Many people have had a hand in analyzing and implementing SLAC's CAD needs. We particularly wish to acknowledge the support of K. Crook, W. Johnson, D. Downing, J. Fish, and C. Perkins, all of whom have played a major part; and to the users, whose enthusiasm and patience have contributed to the overall success of operations. Additionally, the implementation of a multi-disciplinary system of this size and scope requires a strong commitment from Laboratory Management, and we particularly recognize the critical support given by R. B. Neal, L. Kral, B. Richter and K. D. Lathrop.