What’s different about the hardware in tactical military systems

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INTRODUCTION

A recent special issue of the Proceedings of the IEEE on computer communications1 provides an excellent state-of-the-art report on the burgeoning field of digital telecommunications and computer networks. Included are papers on terminals, modems, errors and error control, multiplexing, processors and computer communication networks. Many of the system elements and system concepts in Tactical Military data processing systems are similar to those discussed in the above papers but there are also distinct differences. The purpose of this paper is to identify the differences between the hardware required for Tactical Military Data Processing Systems and the better known hardware requirements for fixed commercial and strategic military data processing systems. As system designers will appreciate, it is not possible to address the hardware aspects independently of the overall system design concepts including the software design. Accordingly, some discussion of overall system design concepts is included as background to the discussion of the hardware requirements. Discussion of the software problems, however, will not be covered except as necessary in this context, since other papers will emphasize the unique software requirements of these systems.

An attempt has been made to keep the system concepts as general as possible in recognition of the varying applications among the tactical systems of the different services, i.e., Air Force, Army, Marine Corps, and Navy. Specific examples will tend to emphasize the Navy systems solely because of the greater experience of the authors in the development of the Navy systems.

TYPICAL SYSTEM CONCEPTS

Typical tactical system

Figure 1 is a greatly simplified block diagram of a typical Tactical system. It consists of one or more sensor subsystems, a single command and decision subsystem, and one or more weapons control subsystems. Communication with the outside world, i.e., other tactical systems and higher level command systems, is usually handled by the command and decision subsystem using automatic radio or land line data links.

Typical hardware found in the sensor subsystems are Radar, Electronic Warfare, Sonar, Optical and Navigation sensors and associated preprocessing and display equipment. Sensor subsystems may vary from relatively simple manual entry systems to very complex automatic entry and signal processing systems using very high-speed, large scale digital processors.

Functions of the command and decision subsystem include (1) the coordination of the data collection from the sensor subsystems and from external sources via the communication data links, (2) correlation of the data to provide a "clear" or filtered display of the tactical situation to the system operators, (3) development of threat evaluation and alternative weapon assignment recommendations for the Commander, and (4) communication of the decisions of the Commander to the weapons control subsystems and to other tactical units. Typical hardware
found in the command and decision subsystem are general purpose digital computers, interactive graphic displays and alpha/numeric readouts, A/D and D/A converters, data link modems, and a very limited number of the more conventional computer peripheral devices. In contrast to the typical large scale commercial data processing systems which employ large numbers of auxiliary storage units such as tapes, drums, or discs and many off line card and tape handling devices, the “pure” tactical system uses only that auxiliary memory required to load and change various operating programs. These include operational, maintenance and training programs which in most cases use no off line hardware except for historical record keeping purposes.

Once the decision to employ a weapon is made, the weapons control subsystem generates the detailed ballistic or vectoring solution and launch orders and the weapon is launched or vectored. Typical weapons are guns, missiles, torpedoes, interceptor and attack aircraft, and active countermeasures. Hardware for these control systems vary widely depending on the type of weapon, but, in general, most of these subsystems now use digital computers and associated interactive displays.

The complexity of the tactical system may vary from a single sensor and a single weapon to the very complex multimission systems employing many different sensors and weapons.

In some cases the sensor or weapons control subsystems are physically separated from the command and decision subsystem. This requires specialized high speed data links using radio or land line communication circuits. The separated systems are typical of some of the transportable ground systems of the tactical Air Force, Army, and the Marine Corps. This variation on the basic tactical system is shown in Figure 2.

On the other hand, the sensor, command and decision, and weapons control subsystems installed on a single mobile platform such as a ship or aircraft having very limited real estate require as much consolidation as possible. The stringent space and weight restraints dictate a much higher degree of integration among the subsystems and raise other very difficult technical problems not encountered in the separated systems. A diagram of this variation is shown in Figure 3.

**Tactical support system**

Figure 4 illustrates a very different class of tactical systems which has its origin in commercial batch processing and management information systems. This class of systems provides data processing support to the higher level tactical commander in such functions as intelligence, communications, and logistics, or support to the local tactical unit in supply, maintenance and personnel accounting functions. These support systems typically require batch processing, maintenance of large files, and information retrieval programs. An important distinction between these support systems and the other tactical systems is their data bases. In the basic tactical system much of the data base is volatile. Typically, the tactical system starts an operation with almost zero data base which then builds up to a maximum as the operational activity peaks and finally goes back to zero at the end of the operation. On the other hand, the tactical support system usually has a relatively large, stable data base which changes little from day to day.

Typical hardware in these systems include large scale general purpose computers, fewer interactive displays than in the other tactical systems, a large number of auxiliary memory devices such as magnetic tapes and discs, and conventional off-line card and tape handling devices. Functionally, the hardware in these support systems is identical to many commercial and fixed military systems. The major difference is that most of these support systems require mobility or transportability under adverse conditions and hence, the hardware must be designed to meet the same environmental conditions which will be discussed later for the other tactical systems. In some

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From the collection of the Computer History Museum (www.computerhistory.org)
cases, these support systems require colocation or a high degree of integration with the command and decision subsystem of a tactical system as indicated by the dotted lines in Figure 4.

Other variations

There are many other variations to the basic tactical system which involve combinations of the major variations discussed above. In all cases, the driving force behind the system design is the nature of the tactical operations which will be discussed next.

INFLUENCE OF TACTICAL OPERATIONS ON SYSTEM AND HARDWARE DESIGN

The tactical systems described above are required to operate as a network of systems in a variety of tactical warfare operations. Since it is not possible in this unclassified paper to cover in any depth many of the tactical warfare operations, the discussion in this section will be limited to those generalized operational concepts which most significantly influence system and hardware design.

Mobility and flexibility

Perhaps the single, most important operational requirement for the tactical forces is mobility. Figure 5 is a very simplified illustration of a hypothetical tactical situation involving air, sea, and ground forces. The several tactical systems shown are interconnected with a network of automatic tactical data links. Not shown for simplicity are the many other communication links between the tactical units and higher level or rear echelon commands. Ships and aircraft are continuously moving with respect to the area coordinate system. Although the ground systems are usually fixed during periods of operation, they must be capable of rapid repositioning by means of helicopter, aircraft, truck or ship, frequently over rough terrain and during adverse weather conditions. In the absence of an air strip, initial positioning may only be possible by helicopter lift from a ship, or by ship to shore movement in an amphibious landing craft.

The number of tactical units may change from hour to hour, day to day. Additional units may be assigned to the force or the mix of units may be changed as the operation changes. For example, as more ground forces are moved ashore from ships, or by aircraft after air strips are captured or built, the number of ships may be reduced and the number of ground tactical systems increased. Aircraft on station must be relieved several times a day. If the operation continues over weeks or months, the ships must be relieved on station for refueling and supply replenishment. During this continuously changing situation, the readiness of the overall tactical force must be maintained. The mobile, continuously changing tempo of operations create a need for a high degree of flexibility and many technical requirements not usually found in a fixed network of interconnected computer system. Some of these requirements are:

1. Correlation of the positions of all friendly and enemy units in the area of operation and facilities for the resolution of conflicts caused by the observation of a single target by more than one sensor.
2. 3D coordinates of sensors and weapons must be converted to the coordinate system used by the local data processing system. This requires accurate alignment and calibration of equipment mounted on a single platform such as a ship or aircraft or accurate positioning and coordinate compensation for any separated sensors or weapons used in a ground tactical system.
3. Coordinate conversion from the local tactical systems coordinates to a common area coordinate
The dynamic positioning of the mobile units requires accurate navigation systems in order to successfully achieve the correlation described in (1) above.

(4) Facilities for communication between the computer equipped systems and the tactical units not equipped with data systems. This usually involves additional processing time and some additional hardware such as a D/A converter and display on the receiving end of a low speed data link.

(5) Provision for rapidly adding or subtracting tactical units from the communications network without interrupting current operations. Each change represents a step function change in the data which must be handled by each of tactical systems in the net.

(6) Provision for the smooth "handover" of the tactical units from one system to another, e.g., shift of control of an interceptor or attack aircraft from a ship to a shore based tactical system.

The hypothetical tactical operation illustrated by Figure 5 is only one of an almost unlimited number of possible combinations of tactical forces. The tactical data systems of each of the services are part of the U.S. general purpose forces which are required to operate globally. In most cases this requires that each system have the flexibility to operate independently or in combination with other tactical systems of its own service and the tactical systems of other services and our allies. In the communication area, this requires a network organization which is designed to meet the essential, common needs of all participating tactical systems rather than to optimize the design for any one system. This also requires a rigid standardization of performance specifications, word formats and operating procedures for all automatic data links used by the tactical systems. The requirement for world wide operation also requires that the hardware for the systems be capable of reliable operation over a wide range of environmental conditions. These environmental requirements which directly result from the mobility requirement represent a major difference between the military tactical hardware and the hardware used in the fixed military and commercial data processing systems.

Continuous on-line, real time operation

There are many so-called real time systems in operation today. Some might consider a payroll to be a real time operation since the objective is to calculate the pay of an employee as of a certain day and deliver the pay check on that same day. The interval between the periodic pay calculations is in terms of a week or weeks and the tolerable delay time is in hours. An airline reservation system is a better example of a real time commercial system. A typical system\(^a\) provides a response time of less than three seconds to the inquiry of a ticket agent. In the tactical data systems there are many events occurring concurrently and asynchronously. Some of the events are created internally by the action of diverse portions of the systems; other events from outside the system, e.g., the motion of a high speed missile or aircraft or automatic communication from another tactical system. The system must handle time critical and time dependent functions and also respond to asynchronous external stimuli. Response time to operator inquiry of a few seconds (as in the airline reservation system) is acceptable for many functions but millisecond response to other operator actions is required. Functions such as target tracking, data base update, automatic communications, and weapons fire control require millisecond response and in some cases with microsecond tolerances.

The real time operations of the tactical systems require that all of the sensor, weapons control, and communication equipment be electrically connected on-line to the system. Delays in switching these equipments in and out of the system or delays in transferring data by means of manual off-line handling to tapes, cards, etc., are not tolerable.

Tactical operations require that the systems be operated around the clock without interruption for long periods of time, sometimes for days or months. This requires very high equipment reliability and redundancy as required to meet some minimum acceptable operational capability at all times. The system must be designed for several alternate modes of operation and "almost real time" system recovery and system reconfiguration when a casualty to any of the system elements is encountered. Ideally, this system recovery and system reconfiguration should occur in "real time," i.e., so that any delays in the operations are imperceptible to the operators required in the alternate mode of operation selected. At present, system recovery and reconfiguration is limited to time of reload of programs from auxiliary storage such as tape or disc and reconstruction of the volatile target tracking data base from own sensors or from target data from other systems by means of automatic data link.

The continuous real time, on-line requirements dictate a multicomputer system with multiprogramming or multiprocessing capability. In fixed commercial or military systems requiring continuous operation, it is possible to provide system reliability by operating redundant computers or completely redundant systems in parallel with the operating system. Examples of this are the airline reservation systems,\(^b\) the SAGE air defense system and some of the NASA ground support systems for the space programs. In most of tactical systems, however, the severe space and weight limitations rule out redundant operation which makes inefficient use of much of the equipment. An alternate design approach has been used successfully in the Naval Tactical Data System for over a decade. In this approach\(^c\) the system on each ship uses two or more identical computers and several identical displays and a minimum of idle or standby equipment. System reliability is achieved by taking advantage of the back up provided by the use of multiple, identical equipments. The system is designed to make use of all the equipment to perform all functions at full capacity, but can be recon-
figured rapidly in the event of casualty to operate at a reduced capacity (e.g., reduced number of tracks) for all functions, or full capacity on the most urgent functions (e.g., full surveillance capability, but reduction in the number of weapons which can be used). During periods of relatively low operational activity this same flexibility permits part of the system to be operated for training or maintenance while the remainder of the system performs the functions required of the operational situation at the time (e.g., surveillance and communication with other ships in the force).

An exception to the above discussion is the airborne tactical system where the requirement for continuous operation is in terms of hours instead of days and weeks as in the case of the other tactical systems. The extreme space and weight constraints on the airborne system legislature are what make this possible. The emphasis instead is placed on achieving the hardware reliability required to assure the high availability required for the relatively short mission duration.

Man-machine interaction and time-sharing

Although the real time requirements of tactical systems dictate extensive automation of functions, many decisions are made by the human operators and hence the man-machine interfaces are of major importance in system design. Operators must be provided with effective aids to decision making and operator actions must mesh smoothly with automatic machine operations. In most systems the operator interface is provided by one or more interactive CRT displays which time-share the computers in the system. At first glance, these time-sharing systems look very similar to many commercial time-sharing systems which are now in use, but there are important differences. In most commercial applications, the system and program are designed to insure completely independent operations by each operator, i.e., so that each user appears to have private use of the data processing facilities without interference from other users. In the real time tactical application, the system is designed to achieve a controlled, cooperative interdependence among several operators and the system. For example, an action taken by one operator must be immediately made available to other operators in the system to achieve the team effort required for many tactical operations.

Adaptability

Over the life of a tactical system there will be many changes in the nature of the tactical operations. Some of these changes are the result of changes in the expected enemy threat or changes in the tactics used to counter existing threats. New types of weapons, sensors or communication equipment may be substituted for the old. Certain operations (or functions) within the tactical system will require updating, change or replacement by new functions. Within the data processing capacity of the tactical system, this adaptability is generally accomplished by software revision. It follows that the data processing hardware design must be able to accommodate or adapt to such changes in function without hardware redesign or disruption of other ongoing functions in the system. The requirement for adaptability over the life of a system is a strong argument for modular design and hardware expandability. For example, the computer design should allow for the addition of such modules as CPU's, directly addressable memory modules or I/O channels without any changes in the basic system design.

HARDWARE REQUIREMENTS

It is impractical to make an exact comparison of military and commercial data processing equipment because of the wide variation in the characteristics of these equipments and because of the changes that have been made over the years. Since the military systems were the first major users of real-time and time-sharing techniques, characteristics of the hardware used in these systems were decidedly different than commercial hardware. However, over the years with increased use of real time systems by FAA, NASA, etc., using commercially available equipment, there have been many changes which closely resemble the functions found in military real-time systems. Today it is difficult to identify technical features which are clearly and universally unique to one of the other types of hardware. The discussion of the hardware requirements which follow will emphasize those features which generally are not found in commercial equipment.

Requirements applicable to all hardware

Environmental

As was discussed earlier the hardware for tactical military systems must operate reliably for long periods of time under a wide range of environmental conditions. A detailed examination of the environmental specifications of the various services is beyond the scope of this paper. Discussion will be limited to some of the environmental factors which account for the major differences between the tactical military hardware and the commercial or fixed military hardware.

The hardware of all the services must operate over a wide range of temperature and humidity and also withstand severe shock and vibration. As an example of the difference in requirements, a typical military computer must operate over a 100 degree F range as compared to 20 degrees for commercial. In addition, airborne hardware must be capable of operation at high altitudes and at high "G" forces. Ships hardware must operate under conditions of severe roll, pitch and heave and also withstand the corrosive salt water environment. Ground systems hardware must contend with sand, dust, very rough handling over rugged terrain and extreme storage requirements.
When feasible, a controlled environment (e.g., air conditioning) is provided to improve operator efficiency or system reliability, but in most cases the equipment is required to operate satisfactorily with no long term damage in the event of casualty to the environmental control equipment.

On the mobile platform systems such as ships and aircraft, electromagnetic compatibility becomes a major technical problem. For example, because of the limited real estate, high power radar and communication transmitters frequently must be installed in close proximity to sensitive receivers. The design option of widely spacing the transmitting and receiving antennas to reduce RF interference is not available as in the case of the separated tactical systems.

The hardware for all of the systems and particularly for the mobile systems must meet severe size, weight and power limitations which require special packaging and cooling techniques not required in the hardware for commercial systems. To illustrate the size difference, large scale military computers including memory, CPU and I/O are typically packaged in less than 10 to 15 cu. ft. This is an order of magnitude smaller than the equivalent commercial computer.

Meeting all of the above requirements is a major factor in achieving the high reliability required in the tactical military system and has a major impact on the cost of military hardware. An important factor is the extensive testing which is necessary to prove that the reliability requirements will be met in the operational environment.

Logistics support

The tactical military systems must be designed so that they can be operated and maintained by military personnel in remote locations without ready access to field engineers or rear echelon repair and supply activities. This requirement for self sufficiency requires an approach to system and hardware design different from commercial systems. For example, maintenance documentation must be more extensive and diagnostics more highly developed for the military technician because of the absence of engineering backup in the field. Rapid repair requires extensive use of replacement modules and the design of modules must match the support philosophy used. On board repair of modules requires on board piece part support. Rear echelon repair of modules or throw away modules require that spare modules be available to the technician.

The maintenance philosophy differs widely for the various tactical systems and is strongly influenced by the nature of the operations. For example, Navy ships are required to operate for several weeks or months away from bases. The Navy maintenance policy is primarily on-board maintenance of all hardware with very limited rear echelon support over the duration of the ships operation. On the other hand, most airborne systems have mission durations of only a few hours and hence are normally designed for no on board repair during the mission but require rear echelon support upon return to base (e.g., to an aircraft carrier or shore air base).

Computers

Military computers are typically required to meet reliability requirements which are an order of magnitude greater than equivalent commercial computers. To meet this higher reliability under the environmental conditions discussed above, circuits must be designed to operate with much wider margins and use special components, e.g., lithium cores for memory to meet the temperature requirements.

Some of the specific functional characteristics which are associated with military computers are:

1. Large, high speed, directly addressable memories are required since in most instances these systems cannot tolerate the delays of “rolling” information in and out from auxiliary memories. This is governed by the requirement that many of the systems must respond to tasks within specific critical time frames.

2. Automatic system recovery and reconfiguration requires special hardware features such as small, read only memories to bootstrap the reloading of the operational program.

3. Since tactical systems are not designed for maximum throughput but rather to respond to job requests within specific time intervals, the use of high resolution clocks and well-organized interrupt capability with many different states and priority levels is required.

4. Because of the large number and types of inputs and outputs to these real time systems the actual system operation is dependent upon efficient I/O operation. As a result there are normally many bidirectional, buffered 1/O channels with separate access to memory. In addition, special I/O functions such as externally specified index, externally specified address and intercomputer operations are features in these systems. It should be noted that when commercial computers have been adapted to shorebased, real time systems usually there have been special I/O cabinets and multiplexers added to the computers to meet the abnormal I/O requirements.

5. Since data used in these systems is usually bit oriented and byte oriented, word lengths are not necessarily dependent upon some multiple of a byte, but are determined by accuracy of required calculations. Military computers have had word lengths of 14, 16, 18, 21, 24, 30, 32, and 36 bits.

Displays

The interactive CRT displays, which are widely used in the tactical systems, are similar to some of the displays
found in the commercial time-sharing systems. There are, however, some differences in addition to the requirement for an order of magnitude increase in reliability over the commercial displays. For example, some of the displays are required to display raw sensor data (video) concurrently with computer generated spots, symbols, and vectors. This requires very wide bandwidth deflection amplifiers and higher deflection speeds than required for the more conventional interactive displays, which display alpha-numeric or graphics. Typical tactical displays are required to display the tactical "picture" over a wide range of geographical coordinates; from the large area surveillance "picture" to the very short range "picture" of the local tactical situation, or an expanded "picture" of the area of action around a distant remote tactical unit. This requires a "smart terminal" (i.e., small processor in the display) or a combination of some logic in the display and the remainder of the processing in one of the system computers. The computer generated data on CRT displays must be refreshed at a high rate to provide a "flicker free" picture, either by means of a small memory in the display, or from one of the system computers. Trade off between the "smart display" and displays driven from a central processor is influenced by the overall system design. The "smart display" is usually found in systems requiring very few displays. In systems requiring many displays (e.g., 6 to 25) or interaction among many operators, it is usually more cost effective to drive the displays from central processors. The design of these display systems requires adequate consideration for casualty modes of operation. This requires that most of the displays be designed with the flexibility to be used for several functions and the capability for rapid switching in and out of the system and for change in functions without program changes, e.g., change of function by a selector switch on the display which automatically changes labels on operator action buttons and readouts and informs computer of change of function. The design of the display hardware and software must also insure that the system is resistant to inadvertent operator error.

Communications

The real time, on-line tactical systems require automatic computer to computer communications without human intervention, except for network initialization or change in network participation. Extensive error detection and correction is required to achieve reliable communications over a wide range of noise conditions. This is particularly true in the case of the radio links where there are wide variations in error rates caused by changes in propagation paths or by jamming.

There are two types of automatic data links used in tactical systems. One is used to net all the tactical systems together, and the other is used to interconnect two widely separated subsystems, or as a control link to a mobile weapons systems, e.g., a ground to air link to control an aircraft.

The data link used to net all of the systems together must necessarily be designed to rigid technical performance specifications including data word formats. In addition, the design and operating philosophy of each of the tactical systems in the net must be compatible with the design restraints of the common links. For example, the mobility requirements of many of the tactical systems require that the common operating net make use of radio data links. Because of the limited bandwidth available for these radio links, each data source in the net must preprocess the raw data in order not to monopolize the link or saturate the processors at the receiving end.

On the other hand, the point to point subsystem interconnecting and control links can be designed to provide a more optimum match between subsystems. When such links are required to be used by several different tactical systems, however, rigid standardization is required, e.g., the surface to air data links to aircraft which must be controlled by either ship or ground systems.

Functionally, the hardware in the military systems is identical to that used in many commercial digital communication systems. The major differences are in the higher reliability requirements and the facilities required for flexible network control.

Other peripherals

In some of the tactical systems, large numbers of equipment must be connected on line to the system by means of A/D and D/A converters. Functionally, these converters are identical to many converters found in industry, except for the requirement to achieve high accuracy and rapid response times over a wide range of environmental conditions.

Other peripherals such as magnetic tape units, discs, printers, punched card and paper tape devices, when used, are usually adaptations of commercially available hardware to meet the stringent environmental requirements.

SYSTEM STATUS AND TRENDS

Systems

The design, development, production and operational introduction of military tactical data processing systems has been and continues to be a difficult and challenging problem for both the military and industry. An indication of the difficulty of the design of these systems is that very few of the many systems under development since the mid 50's have survived the development cycle and reached operational maturity. There are many reasons for the failures but, in the opinion of the authors, the major factors are (1) premature obsolescence of the systems because of faulty systems design concepts which did not recognize the continuously changing nature of tactical operations, and (2) management of system development by people who did not understand the operational prob-
On the positive side, there are several tactical systems now being operated successfully. One such system is the Navy Tactical Data System (NTDS)\(^3\) which was first installed on 3 ships in 1961 and is now on 48 ships and planned for most future combatant ships. For over a decade this system has been operated reliably by Navy operators and technicians for long periods of time (for months in many cases) and with practically no support required from contractors’ engineers or rear echelon repair activities. Since 1961 this real time, on-line system has continuously demonstrated the feasibility of:

1. Multiprogramming in multiple computer systems (1-4 computers)
2. Time sharing with many (up to 25) interactive CRT displays.
3. Automatic computer to computer communications between ships using digital radio links, and since the mid 60’s between ships, the Navy Airborne Tactical Data System (ATDS) and the Marine Corps Tactical Data System (MTDS).

The major factors in the successful development of the NTDS were:

1. Continuous, active participation in the development by several key operational officers representing the user.
2. Staffing of the project management office in the developing agency with several key officers and civilian engineers having some knowledge of the operational problem and/or prior experience in digital data processing.
3. Establishment, early in the development, of a Navy programming activity staffed with operational officers and civilian programmers. This activity was initially under the control of the system developing agency but later assigned to a user command to support the operational ships.
4. Excellent performance by several key industrial firms and a Navy Laboratory in the development of systems hardware and software. The high reliability of the hardware from the beginning was a major factor in the rapid solution of early system and software problems.

Development of the early tactical data systems concentrated on the command and control and communication functions, i.e., the Command and Decision Subsystem of the overall tactical system. Most of the sensor and weapons control subsystems at that time were analog systems and the tie-in with the Command and Decision subsystem was made by extensive use of A/D and D/A converters. Today most of the new sensor and weapons control subsystems are being developed using digital computers and digital interactive displays. Much of the current systems development effort is to standardize the hardware and software of the various systems and better integrate the operational functions in order to achieve more effective and less costly overall systems in terms of life cycle costs such as training, software support, supply support, etc. This increased integration and standardization has created a significant management problem because of the greater interaction among the subsystems and the overall tactical system. Progress toward greater integration and standardization is dependent upon the solution of the system management problem, not the technical problems.

In the system reliability area, the requirement for real-time system recovery is being implemented in a specific system and shows promise for widespread use in future systems.

### Hardware

#### Computers and data processors

In 1965 the authors\(^3\) suggested that the multicomputer system using multiprocessing computers appeared to be a competitor to the multiprogrammed, multicomputer system, but that actual experience was required to verify the performance of these systems before they could be seriously considered for use in real-time tactical systems. Enough experience has been accumulated with available multiprocessor computers to warrant their use in tactical systems. Acceptance of their use is slow as indicated by the fact that available multiprocessor computers are in many cases being multiprogrammed. This is a management, not a technical, problem. It is evident that multiprocessing will be more widely accepted and used in both commercial and military systems.

In applying LSI to military computers and processors, the major stumbling block appears to be the problem of testing and proofing the hardware. Because of the high reliability requirements over a wide range of environmental conditions and the relatively low volume production of military systems, it is highly probable that widespread application of LSI to commercial computers will precede its use in tactical military systems.

Preprocessing of sensor data before transmission to the Command and Decision computers is usually done by very specialized high speed processors or combinations of special purpose logic and a general purpose computer. In the area of special purpose logic, it is likely that much of the hard wired logic will be supplanted by associative and/or microprogrammed processors as the reliability and cost problems are overcome, and applications become better understood.

#### Displays

Although there are many promising developments in display technology (e.g., large screen displays) it is unlikely that the interactive CRT display will be replaced in the foreseeable future as the “workhorse” display in
the tactical systems. There will be evolutionary changes in these displays to increase their utility as a standard display in all subsystems and at the same time preserve the unique features required to match each operator to the system. An evolutionary not revolutionary policy is dictated not solely because the state of the technology but by the requirement to maintain a long term commonality of operator functions in order to maximize the effectiveness of operator training. There will also be an evolutionary trend to automate more functions and reduce the number of operators in the system.

Communications

In commercial computer communication networks the trend is to do more processing at the terminals in order to minimize the communication line costs. In the tactical systems, the trend will be the same but for a different reason, i.e., the limited bandwidths available for radio data links.

There will be a trend toward adaptive communications, i.e., automatic adjustment of the redundancy in the data link in response to changes in the error rates.

It is expected that the tactical systems will make extensive use of satellite communications in the future.

Summary

Because of the rapid increase in the use of multiprogramming, multiprocessing, interactive displays, remote terminals and on-line communications in time-sharing and real time commercial and fixed military systems, it is clear that the functional characteristics of the hardware for these systems and the Tactical Military systems will tend to converge. The high reliability requirements of the tactical military hardware under a wide range of environmental conditions will continue to be the major difference.

REFERENCES
