THE COMMAND CONTROL PROBLEM

AND

THE DATA PROCESSING SOLUTION

by

J. C. Kramer

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THOMPSON RAMO WOOLDRIDGE INC.
RW DIVISION
CANOGA PARK, CALIFORNIA

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SUMMARY

The great stride forward from subsonic to present supersonic flight was not accomplished by just adding bigger and more powerful engines. It required a new look at the aerodynamic problem to establish the significant parameters affecting flight at supersonic speeds. Almost always, the facts dictated a completely new design. By contrast, the trend in meeting new and more complex data processing problems has been to build bigger, faster and more costly central computers instead of taking a fresh look at the entire problem.

When the Ramo Wooldridge Division was confronted with the problem of designing an advanced ground data processing system which could:

1. operate continuously around-the-clock,
2. handle an input and workload which increased with time in an undefined way without depreciating from the system throughput time for output products,
3. provide continuous on-line service and display to analysts within the time constraints set by their jobs,
4. provide processing support for many concurrent activities, and
5. grow in an economical fashion,

a thorough study was made to determine an optimum configuration. The problem was very similar to that of the Military Command Control type organization. The study indicated that the present approach to data processing did not provide the flexibility to meet these combined requirements. The optimal solution was found to be a totally different organization of essentially the same modules. Instead of one huge, costly central computer, a number of smaller, less expensive computers was suggested by the requirement for simultaneous execution of multiple problems. The computer was replaced as the central element by a passive electronic switching exchange to provide the flexibility required for independent parallel

configurations to operate simultaneously in the system. But these independent configurations each required some form of control; hence, control was given to each Computer and Buffer module. Some type of Master Control was required to monitor the performance of independent configurations and to make adjustments for changes in workload or priorities. This Master Control was provided through a Master Control Program. The computer which operates with the Master Control Program becomes the supreme executive of the system.

The distributed nature of the organization was tailor-made for continuous man-machine interaction; in effect, part of the system could be devoted to it exclusively if necessary. This same parallelism and interchangeability of like modules via electronic switching, provided the reliability necessary for continuous system operation, and because the system is composed of many small building blocks instead of one large one, capacity can be added in incremental, economical fashion.

INTRODUCTION

Much has been said about the advantages of one data processing system over another. In most cases, claims of superiority are based strictly on the technical factors (computing speed, memory size, access time, reliability) and cost. Lost in the maze of confusing technical arguments over which magic combination of characteristics is the best one, are the basic issues—that the nature of the job to be done determines which combination is best, and that the particular way machines are organized has profound influence on system efficiency and performance.

Certain jobs fit into a well-defined pattern where the sequence of events and even the particular variations can be predicted or formulated. Because of this predictability, the human experience and knowledge essential to the solution can be built into the machine beforehand. Hence, real-time man-machine interaction and flexibility of equipment organization are generally not vital requirements of such a system. Man's role is primarily limited to programming and to monitoring equipment performance; but what happens when the job is unpredictable in nature? When there is no set pattern of events and the requirements conflict, are subject to change, or cannot be firmly established? This situation usually occurs in interpretive, decision-making jobs where the processes of recognition, classification association and evaluation are involved; where there are wide gaps in available information and great variance in level of detail, credibility, and timeliness of information; and where ultimately trial and error, comparison, human intuition and iteration provide the only feasible solution.

Let us look into a problem which possesses these features plus the complications of (1) an expanding but unpredictable workload, (2) an environment where many different but related activities must go on concurrently, and (3) a requirement for continuous man-machine interaction and continuous around-the-clock operation—the Military Command Control type problem.

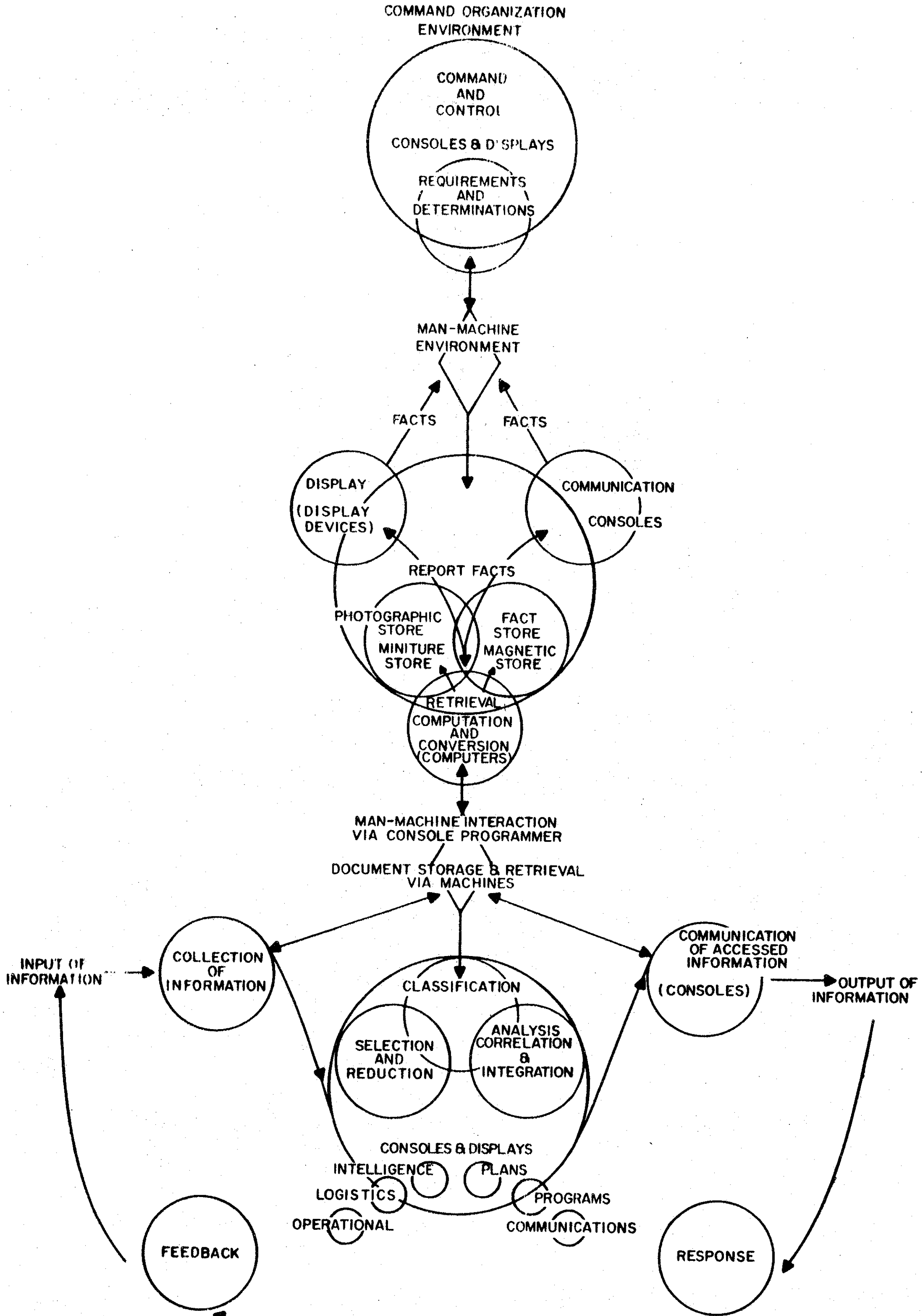
COMMAND CONTROL PROBLEM

Basically, a Military Command Control Headquarters is concerned with continuous surveillance, assessment and reporting of the status, dynamics and capabilities of our forces and those of the enemy. It also has designated responsibilities for planning, directing, and coordinating the response to given situations. To meet these obligations, the Command Control Headquarters has a somewhat complex organization which generally includes intricate communication and coordination ties with various commands, military agencies and government agencies, and its own sections devoted to operations, logistics, planning, programs, communications, intelligence, personnel and administration. Each of these activities has its own problems to solve; however, a steady cross-flow of information among sections as well as between sections and the higher echelons is essential. Consequently, there are many concurrent activities taking place, each of which has its own purpose, but is nevertheless related to the final analysis and command decision.

Information is the lifeline of the Command Control function. The timeliness, completeness and credibility of the information presented to the Commander affects the speed and wisdom of his decisions dealing with National Defense. The system, therefore, must be totally responsive to him and his organization, and must make full use of their experience. Figure 1 illustrates the typical functions and man-machine interactions involved in the information handling and decision-making processes.

Collection

The collection task deals with obtaining the raw data for the system. The Command Control organization may have its own collection capability or it may depend on other sources and collecting agencies. Since there are many factors which have implications



COMMAND & CONTROL SYSTEM FUNCTIONAL INTERACTIONS

on status, dynamics and capability, it is usually necessary to establish a broad working data base; also, there are a variety of information sources (reconnaissance, covert activities, visitors, defectors, etc.), some of which provide data in different forms (photographic, electronic, etc.). As a general rule, the more channels of information and types of media, the greater the possible amount of correlation, and hence, the greater the credibility that can be attached to both input data and interpreted results.

Reduction and Classification

Since the inputs come in different formats and media, another key task is reduction of the information to useable, understandable form to facilitate machine handling and human interpretation. Care must be taken not to lose or degrade any content during the process of reduction. It is also necessary to identify the new information and to index or classify it for future retrieval. Classification may be by area, subject matter, time or activity. To reduce the possibility of misfiling and simplify search and retrieval, a system of cross-indexing is normally employed.

Correlation and Assessment

Correlation is probably the most demanding task in the interpretive chain. In effect, it involves recognition, reasoning, and association, or the learning process. In the Command Control situation, the existing coverage is incomplete and varies in detail and reliability; the enemy is trying equally hard to conceal and camouflage his activities and to purposely convey false information and impressions. Hence, correlation must be performed from an inaccurate, incomplete model. Existing information must be evaluated to determine status; new information must be compared with old to detect changes; important details must be sifted, screened and then associated, for it is not facts alone that provide valid conclusions, but rather the logical connection of facts to a specific statement or investigation.

By correlating facts and events to time, space, direction or numbers, it is possible through experience, training and intuition, to draw inferences. These inferences may be correct or in error, and the level of confidence is somewhat related to the number of possible checks and comparisons; however, the fact remains that the process is essentially iterative, consisting of continual examination and comparison to add to the factual store of information. Hopefully, the credibility, detail and coverage improve each time the correlation cycle is completed. The process of assessment or conclusion relies heavily on experience. In essence, the problem is: given these facts, these changes, under these conditions, what is the meaning?

Reporting and Dissemination

The reporting and dissemination function is a continuous one. All during the interpretative process, certain information will be needed for both internal and external use. The conditions that apply here are that the report must be in a form which is useable and meaningful, and that it must be produced and disseminated to the proper destinations within the prescribed time. Other factors which affect these functions as well as the others are security and timeliness. The entire system must be compatible with both prescribed response times and security regulations. The report will generally vary in subject matter, detail, and priority.

Response and Feedback

Under certain conditions, the Command Control Headquarters may respond to particular situations or conclusions. One of the essential differences between a Command Control Headquarters and a purely interpretive function is that the Command has cognizance over certain retaliatory forces under designated conditions. Presumably, when the conclusions require a response, the nature and extent of the response will be reported and disseminated to the applicable parties. To complete the feedback loop, it is necessary to monitor the results or effects of the response and to feed that information back into the system.

Machine Support

Machine support is essential in each of the above processes because of the stringent time requirements and the great quantity of data which must be examined. Some of the typical machine functions are: computation, format conversion, filing and storage, search, retrieval, communications, and generating reports and displays. The digital computer is a vital component of the machine system. Its great speed provides the only feasible solution to on-line interpretive support. It performs the arithmetic computations necessary to compute distance, location, speed, etc.; it makes logical comparisons such as greater than, less than, or equal to; it can store an enormous amount of information in its tape, drum or core memory, and can search and retrieve any part of this information in a matter of seconds; it can generate on-line displays of the data and provide real-time communications through input-output consoles. Perhaps, the greatest contribution is that it allows man to question the machine, ask it to present information, review the information, and manipulate it in a number of ways, then make comparisons—all within the time constraints of the job.

Displays are fundamental to correlation and assessment. They allow the human to assimilate a great deal of information in a very short time, and thus make rapid determinations about status and change. The use of the digital computer to generate displays enables great flexibility in the display format and type of display. Equally important, it enables the human to manipulate the display and use it as an analytical tool. However, the mere display of information is not enough. To be fully effective in aiding the human in situation assessment, the data presented must be:

1. Timely - Within the real-time constraint that permits response before the environment or area of effective action or control can materially change.

2. Credible - The data should have assigned weights of credence so that the viewer can know how much value he should attach to the information in his decision.

3. Useful - The data must be pertinent to the problem at hand, and must contribute something meaningful to the final judgment.

4. Complete - All essential data necessary to an informed evaluation must be given.

5. Readily Understood - The format and amount of information displayed should permit quick assimilation. Too much data on one display could be confusing; hence, only the minimum data required for the solution should be presented.

Two types of displays seem advisable—large group displays for situation summaries and briefings, and on-line console displays for real-time data interrogation monitoring and analysis.

In addition to the digital storage, there is usually a requirement for a photographic storage system. Much of the information will be in report, graphic, map, or photographic form; hence, there must be some means of reducing this information to compact, standard size and storing it in some form that can be rapidly indexed and retrieved. Photographs provide the most convenient method of placing a great deal of information in a small area. Since any photograph in the store must be readily accessible to the human upon demand, it becomes apparent that (1) some form of automatic storage and retrieval system is required, and (2) that a digital indexing scheme must be employed in conjunction with the photograph to permit rapid search and identification.

In summary, the data processing system must have the capability of:

1. Handling and converting vast quantities of information by automatic means to get information into the system rapidly and in reduced form (without loss of content).

2. Performing all necessary computations automatically.

3. Sorting, organizing and filing information automatically according to human instruction, to place new information in the proper context with old for future comparison purposes.

4. Automatic search and retrieval of information upon demand to present pertinent facts extracted from the total arsenal of stored information.

5. Displaying salient factors which contribute to sound analysis of data and thereby facilitate inference and effective judgment.

This would imply semiautomatic or automatic techniques and an analog-pictorial presentation, rather than numerical, for swift mental grasp of meaning and longer retention of key facts. As mentioned before, the system should have the flexibility to present data in a variety of ways and formats so that the Commander and his staff can view the same problem from a number of directions.

6. Human control of machine processes by semiautomatic techniques. These techniques must enable man to control, select, display, and manipulate any portion of the data stored in the system within the time constraints set by the analysis and decision-making processes.

From the above, it is apparent that continuous man-machine interaction must be inherent in the system; but what should be the role of each in an optimum arrangement? Basically, machines are judgment limited—that is, limited in the ability to analyze and draw inferences from data. Man's limitations are physical; he is limited in physical strength, speed of performance, information handling capability, and memory. Consequently, in the optimum system, machines would do all chores except those requiring analysis and judgment. For these tasks, the machine would provide active support to the man and be responsive to his dictates.

PROBLEM CHARACTERISTICS

Let us now review the Command Control problem in terms of some key parameters which determine the nature of the data processing system required. First, what are the input characteristics? In general, the amount of data entering the system will increase with time or emergency, but the limit is not known. There are many different types of inputs which the system must handle. Since the background information in the system, or at least the bulk of it, must be preserved, the nature of the workload is one of continual growth with undefined limits. The historic data base will increase as new facts are derived from fresh information; therefore, the system must be able to accommodate continual growth of an unspecified nature, in a flexible, nondisruptive manner. The system should contain provisions for purging its files, however, experience shows that the tendency is to retain information because of its possible future value. Hence it is likely that less data will be eliminated through purging than will enter the systems data base from new information.

Timeliness of data is vital. In all likelihood, the throughput time will have to remain fixed or possibly even decrease with time. This appears to be a conflicting requirement for although the workload increases with time or its emergencies, the response of the system must not depreciate. The only answer to these conflicting requirements is parallelism (independent channels of capability) — the system must be able to add capability without adding to the processing time. A serial system almost by definition, can only add growth at the expense of time. Another aspect of the Command Control problem, mentioned earlier, is the concurrency of operations in each of the functional branches, as well as between them and the higher echelons. The simultaneity of inputs, activities, outputs, and communications demands a flexible, adaptable, responsive system where each function can have its needs served and the higher echelon has continual access to the system and the information.

The solution to this problem is implied by the Command Control organization itself. There are many individual activities, each performing its own function. At the same time, there is a superior who must be kept informed, provide guidance, and exert control over the individual activities. There is also a need for crossflow of information among the various branches. Thus, the data processing system must be characterized by independent parallel capability (distributed capability) with centralized control. The individual subsystems must be able to carry out their operation independently, but respond to the guidance and control of a master element.

In the Introduction, the point was made that the nature of the function dictates the optimum data processing configuration and characteristics. Problems were classified as either well-defined or unpredictable in nature. The discussion of the Command Control problem has attempted to show that the nature of this problem does not lend itself to either predictability or complete automation; the input requirements cannot be defined with precision; the throughput requirements conflict with the nature of the workload; the complex flow of information does not fall into a prescribed pattern. Any where, any time, in the maze of activity, the human must be able to intervene, input human experience, try different approaches, request displays, and perhaps control machine processes. When he does this, the system must respond, but at the same time, must be capable of performing its normal assignments. Part of the system capability, therefore, must be devoted full time to the Commander and his staff. The types of outputs will vary—some will be displays summarizing situations and changes; some will be tabulated information; some will be typewritten reports; and some will be graphic or pictorial. There is another overriding factor. The military importance of a Command Control function makes it mandatory that the system operate continuously; failure in individual elements is regretable, but acceptable; total system failure can under no circumstances be tolerated.

Now, one may ask: "What is the point of this elaborate description of the Command Control problem and the attempt to describe its nature and characteristics?" The question is indeed pertinent because of the urgent nature of the job. It is this: we cannot afford piecemeal and stop gap solutions; we cannot employ systems design for the problems of the last decade if they do not meet the demands of the present task. The data processing system designed primarily for accounting operations or for industrial process control—two problems which can be fairly well-defined—just does not measure up to a task of this kind. For example, it cannot meet the continuous operation requirements; it cannot provide real-time service for man-machine interaction at the same time it does payroll inventory; it does not have the flexibility to do many things at once, and it cannot adapt to changing situations or grow economically. What, then, is the answer?

The answer lies in a unique organization of machines. Man has learned that the way people are organized influences the performance and characteristics of a business or military organization. The same people, organized in different ways, produce different effects and characteristics. This human lesson also applies to machines. The same equipment organized in a different fashion can produce startling differences in efficiency and system characteristics.

The power of the advanced multi-modular data processing system concept lies in the unique organization of machines. The concept accommodates changing, conflicting and ill-defined requirements; the system is adaptable. It is responsive to both individual and total requirements, and it provides an efficiency and reliability which was impossible to achieve before. Let us examine some of the features of such a system and then compare the characteristics of this system with those of the conventional data processing system. Before we do this, one point deserves particular emphasis. The advantages of the advanced multi-modular data processing system are inherent from its organization, and independent of the individual capabilities of the various equipment modules.

ADVANCED MULTI-MODULAR DATA PROCESSING SYSTEM

The features which make possible the new approach to the organization of data processing equipment are: (1) the use of multiples of basic functional modules in the same system; (2) an electronic switching exchange which is both modular and expandable; (3) master and distributed control by executive elements; (4) variable speed data shuffling; and (5) a flexible interrupt, communications and interrogation capability. All of these features must be present for the full benefits of the system to be realized. Table 1 lists the basic complement of modules and their functions.

Conventional vs. Advance Multi-Modular System Organization

Perhaps, the best way to determine the relative merits of the Conventional approach and the new Multi-Modular approach is to compare the difference in their organization, and then establish what this difference means in terms of system characteristics and capability for Command Control type applications.

In the Conventional data processing organization, the central element is a digital computer which exercises control over a number of peripheral devices. With this form of organization, the capacity, speed and reliability of the system is limited by the central computer and the only way to add capability is to increase the number of subordinate peripheral devices. This philosophy has caused the central computer to become larger and larger and more and more expensive. Another approach has been to increase the speed of the central computer and then time-share its memory and arithmetic unit by means of interleaved programming techniques; however, this approach has its corresponding limitations. For one thing, speed affects cost, and the time-sharing technique, even with block storage and transfer, is still a serial operation and therefore inefficient. In general, even with these attempts at circumvention, the central computer still

Table 1. Elements of an Advanced Multi-Modular Data Processing System

Elements	Functions
Executive Elements	
Computer Modules	Arithmetic and Control Unit. Computer Modules control the switching exchange and all other modules. One Computer Module (any one in the system) exerts Master control over the entire system.
Buffer Modules	Variable speed data shuffling, auxiliary high-speed memory and control. Buffer Modules can control the switching exchange except when they are under control of the Computer Module.
Central Element	
Central Exchange	Central switching and interconnection.
File Storage Element	
Digital Information Storage	
Drum Modules	Working storage for the system.
Tape Modules; Disc Memory Modules	Main data storage and program file element of the system.
Document Storage	
Peripheral Input-Output Elements	
User Modules	Principal Input-Output units for the system.
Display and Analysis Consoles	Selection, control, readout, display and input for interpretive, analytical, or summary-type applications.
High-Speed Plotters	Produce line, dot, symbolic or analog plots.
High-Speed Printers	Product high-speed printouts.

Table 1. Elements of an Advanced Multi-Modular Data Processing System (Continued)

Elements	Functions
Tape-to-Tape Converters	
Tape Adapters	Permits compatibility with non-standard tape modules.
Transitional Storage Elements	
Peripheral Buffer	Data rate buffering for slow speed external systems.
Display Buffer	Provides recirculating digital information for use in displays.

remains the fundamental center of system organization and control. The central computer can only perform one arithmetic operation at a time; hence, when its arithmetic unit is busy with one computation, it cannot simultaneously service human quests for analytical assistance. Thus, by the very nature of its organization, the Conventional system does not have the capability for simultaneous solution of multiple problems concurrently with real-time man-machine interaction.

The advanced Multi-Modular system employs a central switching network as the center of its organization. This switching network interconnects the various elements at electronic speeds into the specific configurations required to handle particular tasks. It is modular and expandable in much the same manner as a telephone switching exchange. Multiples of the basic elements (for example, Computer Module or Buffer Module) are used simultaneously in the system. Since the central switching network is itself expandable, any number or combination of modules can be added.

Control in this organization is distributed between the various Computer and Buffer modules. These modules, in effect, exercise control over the switching exchange and thereby determine the specific processing configurations. The Computer or Buffer modules have access to the total data stored in the system, and each of these controlling devices can maintain simultaneous communication with subordinate peripheral devices through the central switching exchange. Consequently, these computational modules can organize a number of independent configurations to solve many different problems simultaneously, or to execute many parts of a large problem in parallel. Thus, for the problem of an increasing workload with a constant or improved throughput time, new branches of capability can be formed or added to accommodate the increase in work without adding to the throughput time. Its inherent speed advantage stems from its parallel nature or the ability to do things concurrently and independently.

The organization also permits the system to be responsive to changing conditions. The modules in the system can be reorganized at electronic speeds to meet new situations such as changes in priorities of problems, changes in workload, or hardware failure. The system's ability to adapt to changes is definitely related to its organization, the flexible interrupt capability, and the use of an electronic switching exchange as the central element.

The central switching exchange interconnects various modules of the system according to the rules set by the Computer or Buffer modules. This aspect of the system is somewhat analogous to a telephone central exchange. In the telephone system, subscribers can dial any of the other subscribers in the system and the central telephone exchange will make the appropriate connection to permit communication between the two people in question. Many conversations take place simultaneously in a telephone system, and the number of subscribers and the number of simultaneous conversations that can be accommodated can be expanded by the addition of trunks to the telephone central. The same is true of the central exchange in the "polymorphic" system.* The basic difference between the telephone system and this system is that communication takes place between modules as well as people, and the Buffer or Computer modules specify the working configuration and communication path instead of the telephone dialer.

The system's Display and Analysis Consoles operate on-line with the computer and provide the military Commander and his staff with real-time control over analysis and decision-making activities. These consoles enable military personnel to: (1) input data, (2) access, update, display, report and manipulate any information stored in the system; and (3) control and monitor system operations. They permit the integrated interplay between man, computer, and information essential for effective reduction, correlation and assessment of data.

*The Advanced Multi-Modular System has been called polymorphic meaning having or occurring in several different shapes or configurations.

System Characteristics

The unique organization of the Advanced Multi-Modular System provides flexibility to operate either as a number of independent systems handling individual problems, or as a concentrated system devoted to one huge problem. It permits the response time of the system to adjust to changes in workload by altering the number of parallel chains. This ability to execute multiple problems simultaneously means that the speed of the computer in the parallel application does not have to be as great as the central computer, nor does it have to be as large or as expensive; but there is a much more important aspect of the divisible nature of the system as far as Command Control applications are concerned. The vital purpose of the system here is to satisfy the Commander and his men during the interpretive processes in their requirement for display, interrogation, communications, reports and analysis. The divisibility of the advanced multi-modular system allows part of the system to devote itself to servicing individual requests for assistance. This service can be provided on a continuous basis within the real-time needs of the men concerned, while the rest of the system performs the normal processing operations. For example, it permits continuous on-line man-machine interaction between the men at the display analysis consoles and the computer; it enables the Commander to review the essential data and feedback requirements concurrently with changes in the picture. Thus, one of the most important advantages to the user is that it permits real-time computation and display service during the analytical task.

The flexible and divisible nature of the system is also ideal for applications where sensitive materials and intelligence must be physically isolated and inaccessible to unauthorized persons. If separate quarters are set aside in the Command Control facility for dealing with sensitive material, display consoles and input-output elements could easily be located at these areas. Data stored in the system (photographs, documents, reports, etc.) would be given a machine readable code designating security classification. This code would prevent any processing configuration from obtaining the classified information except the one servicing the secure facility. The consoles and input-output elements located there would have access to this information via the assigned processing configuration so that display, computation, interpretation, and reporting could be accomplished in an isolated atmosphere. This offers protection against disclosure of the system's sensitive information to unauthorized members of the organization; however, the persons in the classified area have full power of the data processing system at their disposal. The system could also maintain an inventory of classified material and serve as an automatic document control system. Machine records would be kept of document title and number, classification, recipient, and date of issuance and return. Daily reports would automatically be printed and sent to the security officer. All of these activities could proceed concurrently with normal system operations because the parallel (distributed) capability of the system permits many functions to be performed simultaneously.

Now, let us consider what this unique organization provides in the way of system reliability. With either organization, failure in one of the subordinate elements results in temporary loss of that element; however, in the Conventional Organization, failure in the central element very likely results in loss of the entire system capability. To avoid this obvious danger and to obtain a reasonable degree of system reliability, the designers of large-scale systems have had to resort to duplicate systems; but this means a complete duplicate central facility with a costly switch-over and alarm system even though the duplicate system only provides a standby capability and the user only gets service from one-half of his investment. Normally, there is a periodic exchange of key data from the active computer to the standby memory so that the data will not be lost if the operating unit fails. This, too, has a negative reaction because it means some circuits of the standby unit are active and thus depreciating in reliability even though the computer is in a standby condition. This is not true in the Advanced Multi-Modular System. The central switching exchange is a matrix-type communications network with many alternate paths of communication between any two units. Failure in any particular path, therefore, does not prevent the same two elements from communicating via a different route. The master computer, upon sensing the breakdown, would reassign a new path between the elements and operation would continue. Furthermore, failure in any one of the modules (say a Computer Module) disables that module only. Since the system consists of multiples of each basic type module, one of the other computer-modules working on a problem of lesser priority (for instance, routine file maintenance) can automatically be switched over to assume the work of the faulty module. At no time, therefore, does the total capability cease. Instead, the system operates at slightly reduced capacity until the failed module is repaired and put back on line.

Another consideration affecting reliability lies in the comparative size and complexity of a central computer as opposed to a Computer Module. Reliability is related to size and complexity, and is a function of the number of critical elements within the computer. Since the traditional central computer is much larger and more complex than the individual computer module, it is inherently less reliable. Thus, in the Advanced Multi-Modular System, the combination of reliability through multiplicity and greater reliability of the individual computer element provides a substantial improvement in total system reliability. In fact, the Advanced Multi-Modular System organization appears to be the only feasible answer to the military systems which require continuous around-the-clock operation (no catastrophic system failure permissible).

The use of identical modules also facilitates maintenance since parts are interchangeable and therefore easily replaced. In addition, this standardization of parts considerably eases the logistic support problem.

Data handling efficiency in the Multi-Modular System is achieved through versatile buffering between devices of different speeds. The Buffer Module, operating under self-instruction, can transfer data to or from Tape Modules and Drum Modules without computer intervention. Thus, the computer, which is the fastest and most powerful element in the system, is free to perform useful work during the data loading operations. When the Buffer Module has loaded all required data from the tape or drum, it disconnects itself from the tape or drum and awaits the ready signal from the computer. Upon signal, it transfers the data either in blocks or individual steps at full computer speed. Since the tapes and drums are considerably slower than the computer's core memory, this method of buffering allows substantial computation to be performed in the interim. The Buffer Module, functioning as variable speed data buffering device, imparts a high degree of efficiency to system operations. It can also operate on-line under control of the Computer Module.

The self-adaptiveness of the Multi-Modular System deserves special mention here. In order for the system to process multiple problems simultaneously, service the men in the system on demand, and react to changing conditions or priorities in problems, a monitoring, scheduling and control device must be present. This novel feature is achieved in the Multi-Modular System, through the use of executive and subordinate modules. One Computer Module works with the Master Control Program and this computer is called the "Master Computer". The Master Computer reacts automatically to changes in input conditions, individual requests for service, and equipment needs or failure. For example, it accepts work requests from remote elements, sets up equipment configurations to do the problem, keeps track of the amount of work done on each problem, disrupts and preempts equipment to service priority problems, monitors the status of all equipment in the system, and runs maintenance routines on idle equipment. Any computer in the system can serve as Master Computer. The master-slave concept is a unique answer to control of machine organization. It enables the system to automatically manage itself. This is somewhat analogous to the task of managing a large corporation — top management reviews the jobs in-house, chooses a team to do the job, determines its organization, and monitors the job to determine whether the work being done is satisfactory or if new capabilities must be added. This self management ability of the system frees the men in the system from much of the routine scheduling and monitoring of machine activities.

Because of the newness of the system, many advanced programming techniques still remain to be exploited; however, all indications reveal considerable simplification in ease of programming as a result of the flexibility and divisibility of the system organization. Many computations divide naturally into independent but related parts. These independent parts may be programmed for separate computers or equipment configurations within the Multi-Modular System. Thus, separate computations may proceed simultaneously with resultant low execution time. Also, new programming techniques provide methods of employing more than one computer for fast, economical solution of problems which do not separate naturally into independent parts. For instance, it is possible to employ two computers to evaluate single polynomial in about one-half the time required with a single computer.

Normally, the purchaser of a data processing installation must first estimate his present and future computing needs. To assure that the system will not be outmoded because of growth limitation, and partly because of the unavailability of satisfactory smaller central computers, it is necessary for the buyer to purchase capability in large increments. This has two obvious faults:

1. If the present and future requirements are not the same, then the purchaser is initially buying more capability than his needs demand. In other words, he is paying the full price for only partial use of the equipment.

2. His growth capability is somewhat limited by the central computer purchased. This suggests that if the estimates were in error, or new conditions prevailed, added growth could only be purchased by complete duplicate installations.

The new Multi-Modular System does not have these shortcomings; the buyer is presented with a minimum risk situation. With this system, the purchaser buys the initial capability to meet his present requirements. This gives him the maximum efficiency of equipment utilization or, in other words, he pays only for the amount of equipment he requires at any given time and he gets full use out of that equipment. As requirements change or the demands on the system grow, the purchaser can add any mixture of computation, storage, or input-output modules required to meet the new situation. He can do this without destroying existing programs or disrupting the present system. Added capability is bought for the price of a module rather than the price of a duplicate system. Another important advantage of the Multi-Modular organization is the ability to incorporate new developments in the state of the art. All that is required to mate future equipment into the system is electrical and communications compatibility. The system can accommodate and make use of advanced developments instead of being outmoded by them.

CONCLUSIONS

A military spokesman said: "The contractor does a great disservice to himself and the government when he has an excellent idea or solution but fails to sell it." We hope that we will not be guilty of such an error. The Ramo Wooldridge Division strongly believes in the advanced Multi-Modular approach to data processing for Command Control type applications. We believe that the speed of modern instruments of warfare demands the data processing system which can keep pace — one which is totally responsive to the military commander, his staff and his specialists and one which is flexible enough to accommodate changing, conflicting or new requirements. The data processing systems of yesteryear are not the answer to the problems of the future, particularly when the system of the future is here today, and it is our conviction that the advanced Multi-Modular data processing system is just that.