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MODELING TACTICAL COMMUNICATIONS WITH QSIM

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QSIM is a FORTRAN-based event driven tool which simulates the statistical behavior of networks of queues. It is applicable to many problems involving queueing, including the simulation of computers systems, transportation systems, logistics networks and work flow studies. This paper discusses the application of QSIM to division level tactical communications systems.

1. INTRODUCTION

Tactical communications form the essential link among operating elements in the United States Armed Forces. This link is continually strengthened with the fielding of communications equipments encompassing new technologies and procedures. Quantitative system evaluation through the use of computer simulation has been an effective tool for communications engineers to evaluate the potential of these new technologies and procedures long before the fielding of new equipments.

The BDM Corporation is currently under contract to the U. S. Army Center for Systems Engineering and Integration (CENSEI), a subordinate organization of the U. S. Army Communications Electronics Command (CECOM), to analyze the effectiveness of division level tactical command, control, and communications (C^3) systems. These C^3 systems are being evaluated for several transitional phases from a manual environment to an automated environment.

The goal of this analysis is to evaluate the effectiveness of communications systems in supporting the command and control requirements of the commanders at each echelon within the infantry division. To meet this objective, a simulation tool was developed which determined the timeliness and completeness of the commander's command and control (C^2) process, given the characteristics of the supporting communications systems.

2. PROBLEM SCOPE

The infantry division encompasses over 25 operational facilities, 50 functional staff groups which represent the five major functional segments (maneuver control/force control, air defense artillery, fire support, intelligence/electronic warfare, and combat service support), and over 215 distinct message formats which are exchanged between staff groups. The resulting system is characterized by approximately 120,000 individual information exchanges that may take place over the course of the infantry division C^2 process. Delays in information exchanges between staff groups, due to contention for system resources, impact both completeness and timeliness of tasks and subtasks. The extent to which tasks and subtasks are incomplete or untimely defines the effectiveness of the commander's C^2 process.

Complete assessment of the C^2 process of the infantry division requires tracking information exchanges at the division, brigade, battalion, and company echelons and at appropriate supporting platoons. The communications means available to users at various echelons include sole user and common user multichannel, limited subscriber single channel radio nets, teletype, and message couriers. Information exchanges may also be completed through face to face discussion between individuals of different staff groups which reside in the same operational facility. Equipment components of these systems may only be available on an intermittent basis due to battlefield dynamics resulting from movement of the system or enemy attack.

Other characteristics of the infantry division communications systems include adaptive and deterministic message routing, message priority and preemption, time dependent staff and equipment availability, queue balking and queue reneging.

Several sources were used, for the purposes of the analysis, to provide both the description of the physical system, and the commander's C^2 process. FM 101-5 (Staff Officers Field Manual) was used as a basis for determining the sequence of events that define the commander's C^2 process. The AC^2MP (Army Command and Control Master Plan, a doctrinal statement of system objectives, and C^2 tasks and subtasks) was used to further define the process, and to derive the timeliness standard for executing this C^2 process. Communications systems and staff functions are doctrinal. The staff and equipment assigned to each operating facility are based on official tables of organization and equipment. Doctrinal statements were also used to determine the required information exchanges throughout the infantry division. Information exchanges and operating procedures were field checked and validated at division and brigade levels.

3. SOLUTION METHODOLOGY

Determining the effectiveness of the command and control process within the infantry division required designing a simulation model with several distinct capabilities. First, the model must be able to provide a system level assessment of the command's C^2 process in terms of timeliness and completeness measures. Secondly, the model must be able to provide this assessment for a wide range of communications systems characteristics. These characterisitics account for factors such as message routing, message preemption, staff processing, and time dependent operational availability of equipment possibly due to mobility of units, or survivability of units and equipment.

Third, the model must be able to pinpoint bottlenecks in the physical system, caused by lack of equipment capacity or by the nature of the traffic. These problems must be identifiable in terms of grade of service, speed of service, equipment component utilizations, transmission link utilizations, and detailed message tracking. Additionally, the model must be able to make this assessment for each potential change in the large and complex physical configuration of the infantry division communications system. Physical configuration changes may result from introduction of new equipment, enhancing existing equipment, automation of the C^2 process itself, or reconfiguration of the system.

Discrete event computer simulation was deemed the most appropriate tool for modeling the performance of the infantry division. Specifically, Monte-carlo simulation was chosen to effectively encompass the complexity and size of the problem, as well as the detailed system description input and output requirements. A survey was made of numerous commercially available simulation packages. All packages surveyed required extensive modification to provide either extended modeling capability of communication systems, or required extensive modification of statically dimensioned data structures which limited the potential size of the simulation. The BDM Corporation proprietary queueing simulation program, QSIM, was chosen for developing the C^3 system model of the infantry division for its efficacy in modeling large computer and communication systems.

QSIM is a FORTRAN-based, event driven tool which simulates the statistical behavior of networks of queues. It is applicable to many problems involving queuing, including the simulation of computer systems, transportation systems, logistics networks, and work flow studies. The user builds a model of the system to be studied using components available in QSIM and describes the model to QSIM using simple input language. QSIM simulates the statistical behavior of the modeled system and provides information about the system performance to the user. System performance statistics include standard output on queue lengths, response time distributions, and resource utilizations as well as user application statistics such as communication system grade of service or computer system speed of service.

QSIM utilizes dynamically allocated linked lists for internal information representation. The QSIM architecture is modular with clear separation of modeling function and generic simulation function. The

QSIM modeling language is oriented towards ease of use, has no imposed physical line structure, and is processed by an LR(1) language processor. User generated software may be easily interfaced with QSIM to provide specialized modeling capabilities. Numerical and symbolic data may be exchanged between QSIM and other software using standard QSIM modeling language elements. QSIM is operational on the VAX-11 computer system. It is very efficient in memory utilization and executes rapidly, allowing large, complex simulations to be conducted.

A system model developed using QSIM contains two parts. First, there is a network which provides a path through a set of queues, time delays, and other components. Second, there is an imposed workload, represented by discrete jobs, which flow through the queueing network. The network through which the job flows is composed of nodes, called classes, and links or resources between these classes. When a job arrives at a class it is assigned either a deterministic or stochastic workload by the class or it is delayed for a specified time interval, depending upon the class definition produced by the user. When a job leaves a class it either proceeds to another class or is removed from the system. The choice of the next class may be made either deterministically or probabilisticaly.

Jobs enter the network through job generators at source classes. Jobs may enter at regular time intervals or according to a statistical time interval distribution. As a job proceeds through the network it is assigned various workloads which define how much service the job requires at the classes through which it passes.

A queue contains one or more classes and is characterized by a queuing discipline, the number of servers, and the service rate. QSIM provides FIFO, LIFO, and processor sharing queueing disciplines. The jobs which arrive at the classes belonging to a particular queue contend for service by the queue server. The order in which the jobs are serviced depends upon the queueing discipline and the assigned priority of the job. In addition, the rate at which a job is serviced depends on the service rate of the queue server.

In many modeling situations, certain resources must be acquired before service can begin. Examples include the acquisition of a frequency on a single channel radio net before message transmission may begin or acquisition of a communications circuit before a telephone call can be established. As a job progresses through the network, additional resources may be acquired, and previously acquired resources may be released. QSIM permits modeling of complex resource allocation and release situations.

4. SOLUTION IMPLEMENTATION

The infantry division C^3 model is developed in QSIM as a series of processing submodels that control the flow of messages to simulate the behavior of the command and control process. Each staff group within an operational facility as well as each communications system is an individual submodel, defined with QSIM statements that represent the processing characteristics and procedural requirements of the group or system function. Individual staff group submodels within each operational facility control the processes involving staff resource acquisition, message generation and transmission selection, receipt of message transmissions, message assimilation, and message posting.

Individual communications system submodels control the physical message transmission path between staff groups at operational facilities. Communications system submodel processes include message transmission path selection, equipment and link acquisition, and equipment operator acquisition. Figure 1 illustrates the C^3 model message flow among 80 submodels representing operational facilities, staff groups, and communications systems.

Each submodel is supported by a set of decision, or routing tables which define the flow of messages between submodels, as well as within submodes. For example, a decision table may indicate that a staff group is to attempt message transmission over a multichannel system before an attempt is made to transmit the message over a limited subscriber single channel radio net. In this case, the decision table defines the flow of messages among submodels. In this example, a communication system selection decision is based on the origin and destination of the message, the current physical location of the message, and the communications system availability at the time of the

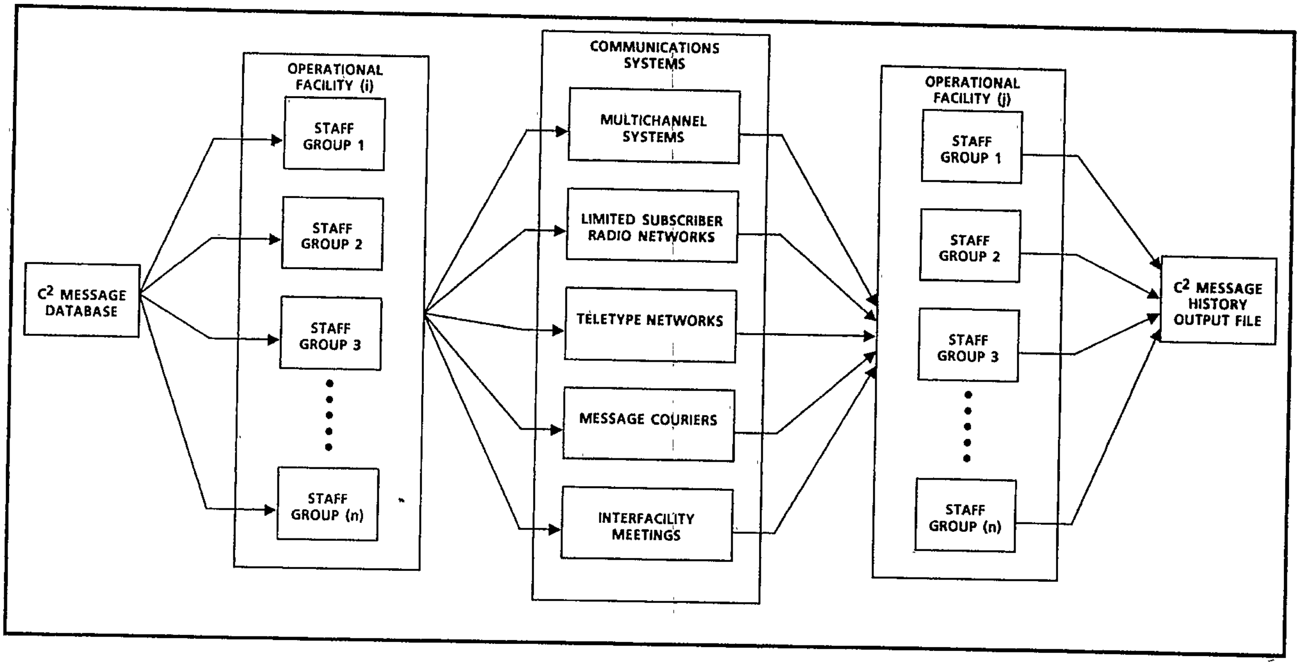

Figure 1: Message Flow Among Submodels

request. If a communications system is unavailable at the time of a request, or the message is blocked within a previously entered communication system submodel, then an alternative system is chosen (according to the decision tables) for message transmission.

Communications system routing tables define the physical transmission paths messages are to follow within a communications system submodel. If a primary path is blocked, due to resource contention or equipment failure alternate paths may be chosen (if equipment capability permits). These tables may represent alternate routing schemes based on the origin and destination of the message, the current physical location of the message, and communications resource availability at the time of request.

Message traffic generation for the infantry division C^3 model is controlled by a deterministic database processor that interfaces with the QSIM processor. This database interface provides the C^3 model with all message formats, staff group interface combinations, message frequencies, message durations, and message information item numbers. The QSIM processor uses this information to schedule arrival events into the simulation and to assign processing attributes to each message such as message origin and destination.

A message arrival into the simulation depicts a need to complete an information exchange between staff groups. This information exchange is required by the receiving staff group within a specified timeframe to be used as input to a command and control task or subtask. If delays in message generation or transmission occur, a decision resulting from task or subtask completion will be untimely or based on incomplete information. Many factors may delay the process of message generation or message transmission. In message generation, staff resources within staff groups have many functions including message generation, message receipt, message assimilation, and message posting. The C^3 model assigns a priority to each of these staff functions in addition to assigning a priority to each message generated. These functional and message priorities are used by the model to determine the sequence of message processing during the course of the simulation. Thus, if a message assimilation process takes priority over the message generation process, at a particular point in the simulation, message generation will be delayed. Figure 2 illustrates the C^3 model decision process in staff resource allocation.

Once a message is generated, message transmission is attempted. Message transmission time is impacted by

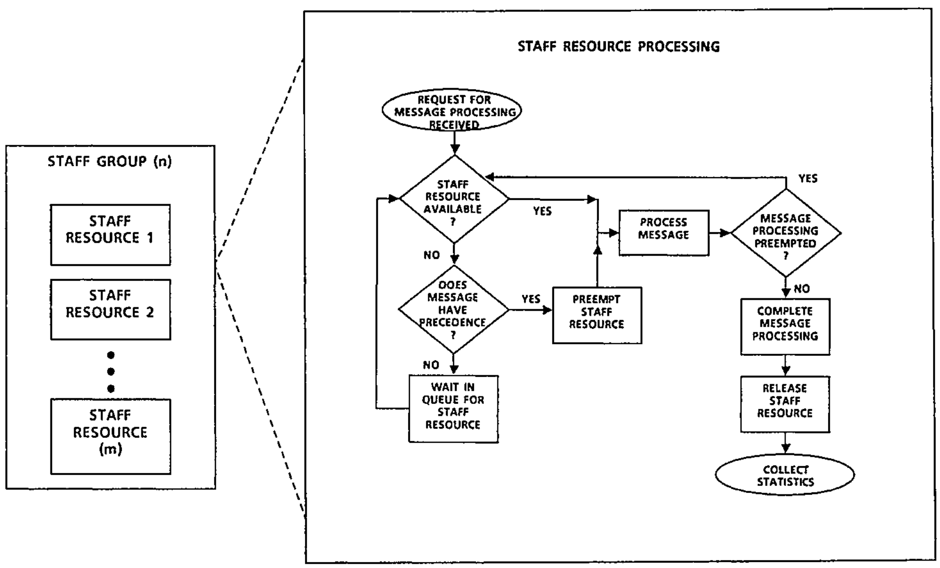

Figure 2: Staff Resource Allocation Decision Process

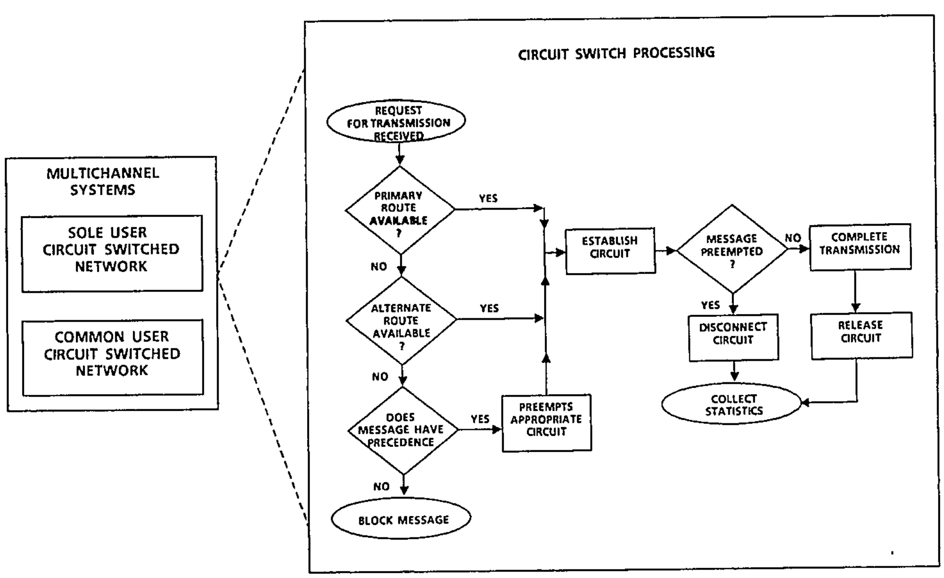

Figure 3: Circuit Resource Allocation Decision Process

the priority of the message and the availability of communications equipment. Figure 3 illustrates the C^3 model decision process of the circuit switched network. Note that this process allows for circuit preemption. A preempted message results in a communications system block, thus, a recall is attempted or an alternate communication system is entered (according to decision tables for the operational facility). If all automated communications system attempts result in a blocked message, a message courier is simulated in the model at each echelon. Upon the completion of message transmission, messages re-enter staff group processing for message assimilation, and message posting. Upon message posting, the C^3 model writes a record to a history file describing the message attributes.

The results obtained from the C^3 model are divided into two categories: (1) application data detailing the history of each message that was transmitted through a communications system, and (2) the default QSIM statistics which include resource utilization, queue lengths, response time distributions, and the total number of jobs processed, blocked, and preempted. The message history file details the message origin, destination, information item number, time entering the system, time exiting the system, communication system utilized for transmission, and a unique message identification number. This message history is input to a FORTRAN-based postprocessor where the results of the simulation are compared to a file describing the objective message requirements for a timely and complete C^2 process. This comparison produces in data relating to task and subtask completeness and timeliness for the simulated scenario at each echelon of the infantry division.

The scenario task and subtask completeness and timeliness data coupled with the communication system utilization and queue length statistics provide the input for manual analysis by military operations experts. This manual analysis is designed to determine the relationship between equipment limitations and system configuration to overall C^3 system performance, as defined by the timeliness and completeness of the commanders command and control process.

5. CONCLUSIONS

This infantry division C^3 model, developed with QSIM, provides a tool for the communication engineer to evaluate the utility of fielding new equipments in terms of an improved command and control process. The C^3 model statistics provide traceability from global system performance measures down to single message transmissions. The efficient memory utilization and rapid execution characteristics of the QSIM processor allow the communications engineer to evaluate large complex physical configurations of the infantry division under a static or dynamic environment. With this capability, the communications engineer may evaluate the infantry division communications system reliability, operational availability, mobility, and survivability in terms of the timeliness and completeness of the command and control process.

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7. REFERENCES

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