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REENGINEERING THE UNITED STATES ARMY'S TACTICAL COMMAND AND CONTROL OPERATIONAL ARCHITECTURE FOR INFORMATION OPERATIONS

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ABSTRACT

During the past few years, the Army has undertaken a major effort to integrate computer, information, and communication technologies throughout the force. These technologies have made a profound impact on the Army's tactical command and control (C^2) processes, especially at division and below. This paper presents a computer simulation model to support the reengineering of the United States Army's staff organization at division and below for information operations. The simulation model under development will provide force planners with a tool for methodically conducting comparative analyses of specific alternatives for reengineering tactical level Army staffs to improve efficiency and effectiveness of staff work related to information operations.

1 INTRODUCTION

For the United States Armed Forces to win decisively on tomorrow's battlefields, military commanders must make well-informed, timely decisions. The high tempo of joint and coalition military operations during recent years has accelerated the military decision making processes at all levels of command as never before. The pace of military operations demands that military staffs provide commanders with timely information for making decisions. This is necessary to give our land combat forces sufficient time to carefully and thoroughly plan the military operation based on unambiguous commander's guidance.

The Army is presently attempting to meet the future information needs of military commanders by integrating communication, computer, and information technologies at all levels of the force. However, these initial efforts have had the unintended effect of overloading commanders and staffs with battlefield information, thereby degrading the military decision making process rather than making it more efficient. Overcoming these problems will require that the Army reengineer its command and control architecture currently based on a stove-piped military staff organized around traditional battlefield operating systems. Specifically, the military staffs from battalion through division must be reengineered for information operations that consists of the processes for collecting, processing, storing, retrieving, disseminating, displaying, protecting, and denying information.

We present work in sponsored by the Army Digitization Office (ADO), Headquarters, Department of the Army, to develop a computer simulation model for reengineering the current tactical level army staffs into staffs organized for information operations. The simulation model will permit Army force developers to evaluate alternatives for reorganizing military staffs based on measures of performance important to military commanders. We also discuss how the model can support development of the operational and system architectures of the Army Enterprise Strategy.

2 BACKGROUND

Battlefield information requirements of commanders focuses primarily on the status of friendly and enemy forces and the enemy's intentions and capabilities. As straightforward as this may seem, Operations Desert Shield and Desert Storm provide anecdotal evidence of how communication, computer, and information technologies have complicated information operations. For example, according to Lieutenant Colonel John Burke, Office of the Director for Information Systems for Command, Control, Communications and Computers, Department of the Army, approximately 700,000 telephone calls and 152,000 messages were exchanged daily between military units within the theater of operations using 35,000 radio frequencies. Managing the volume of information generated by fast-paced military operations is necessary to provide manage the type and amount of information flowing to military commanders.

Currently, tactical information generally flows along traditional lines of communication defined by traditional relationships between battlefield operating systems. Battlefield operating systems include maneuver, fire support, air defense, intelligence, mobility/counter-mobility, survivability, and combat service support. Standard operating procedures and doctrine generally determine the types of information exchanged between the battlefield operating system staff elements and command and control centers. Tactical Operation Centers (TOCs) serve as the command and control nodes for processing and analyzing information for commander from battalion through division. The staff elements acquire commander's critical information requirements (CCIR) and plan future operations. Key staff actions include developing, analyzing and briefing courses of action, performing intelligence preparation of the battlefield, and wargaming.

To be successful, military commanders and staffs at all levels must effectively manage battlefield information and the time available for planning and executing military operations. Through *FORCE XXI Joint Venture*, the Army is digitizing the battlefield and creating an integrated information architecture where battlefield information is shared horizontally and vertically across the force to enhance command and control. In the end, there is little doubt that information technology will accelerate the operational tempo by compressing the C^2 cycle for military operations. Figure 1 depicts the *I*nformation operations-*D*ecisionmaking-military *A*ction (IDA) loop of the command and control process (McGinnis, Technical Report FY95-6, 1995).

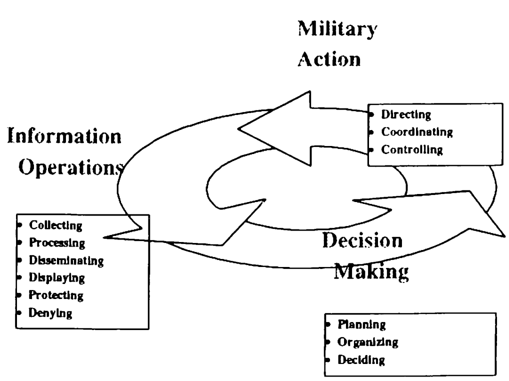

Figure 1. Information-Decisionmaking-Action (IDA) Loop for Command and Control

A major goal of FORCE XXI Joint Venture is to use the information technology, combined with reengineering the military staffs, to create a *relevant common picture* of the battlefield. This involves collecting, analyzing, and disseminating information about the terrain, weather and status and disposition of friendly and enemy forces that can be shared by all levels of command. A higher-level concept closely related to the relevant common picture is *dominant situational awareness* of the battle area (McGinnis et. al., Technical Report FY95-5, 1995). This involves interpreting and exploiting the relevant common picture of the battle area to predict likely enemy actions.

3 THE ARMY ENTERPRISE STRATEGY

In addition to Force XXI Joint Venture, the Army has simultaneously undertaken the development of a high-level data architecture to support future information operations called the *Army Enterprise Strategy*. This strategy involves designing, developing, and implementing the Army's operational, system, and technical architectures. When fully developed, the strategy will specify the Army's information system requirements and how the system will be integrated from the strategic to tactical levels of command. Part of architecture development is the requirement to provide interoperability between the Army's battlefield operating systems, other branches of military service, and allied forces as well.

The Army's operational architecture defines the context and framework for fielding Command, Control, Communications, Computers, and Intelligence (C^4I) systems that meet operational requirements. It defines the force elements and the requirement to exchange information between those elements.

The system architecture describes the systems required to support the operational architecture concept. It also defines C^2 nodes, connected through communications equipment to accomplish the information exchange.

The technical architecture identifies the rules, conditions, and constraints for the technical requirements of the common operating environment and for the data model. This is a preliminary step towards a seamless, interoperable architecture for exchanging information electronically across all levels of command: strategic, operational and tactical.

4 THE ARMY BATTLE COMMAND SYSTEM

An important project related to the Army Enterprise Strategy is the future Army Battle Command System (ABCS) that will link operations on the battlefield with the sustaining base. The design of this system will rely heavily on the operational, system, and technical architectures of the Army Enterprise Strategy discussed above. An important characteristic of the ABCS is seamless exchange information across all battlefield operating systems and levels of command.

Military operations in the 21st century will be conducted by projecting US forces centrally-based within the continental United States to crisis situations around the world. The nature of future operations will require that military units be ready to deploy with little or no notice. The forces will be expected to conduct joint military operations immediately upon arriving in the area of operations.

The ABCS will satisfy two near-term critical battle commander C^2 requirements: development of the Relevant Common (RCP) picture and interoperability. The ABCS will be the Army's integrated command and control system that will carry it into the 21st century It will provide future commanders with a versatile C^2 system supporting them through all force projection stages from mobilization and pre-deployment activities through operations and back to re-deployment and reconstitution. It is the physical realization of the Army Enterprise Strategy.

5 OPERATIONAL ARCHITECTURE

Recent advances in information technology have changed the way many activities conduct business. For example, the world wide web is providing users access to a wide variety of information, products, and services. The Army is currently researching the development of a web-like information architecture for conducting at division and below. The operational architecture will reflect force structure changes for conducting information operations. The operational architecture will also guide the development of the systems architecture by identifying operational requirements for equipment based on likely future operations.

The operational architecture will involve modeling current tactical operations "as is" to establish a baseline for modeling future operations. Operational modeling will include routine command and control (C^2) tasks and the information required to support those tasks. It will also model the flow of information through the C^4I network. The operational model will also simulate the information database that supports the C^2 and C^4I operations. Figure 2 illustrates the dynamics of the processes to be modeled.

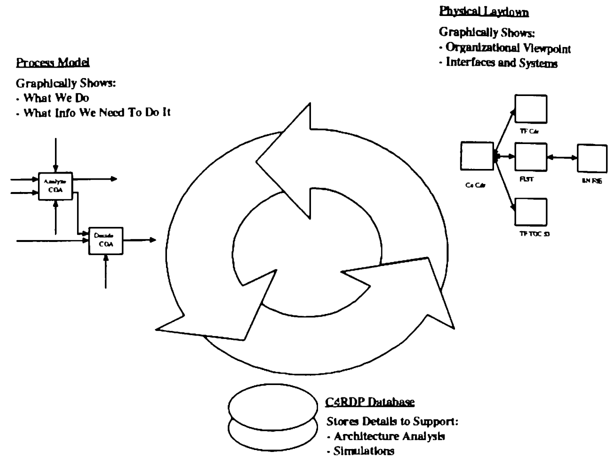

Figure 2. Operational Architecture Modeling

An activity model represents the activities performed by the tactical military units during military operations. For command and control modeling, the primary resource to be modeled is battlefield information used by the commander and staff for making decisions about the tactical situation. Battlefield information is broken down into two categories: critical and routine. The activity model is constructed by decomposing the C^2 processes into tasks and subtasks that must be accomplished by the tactical-level military unit.

The physical laydown of the tasks and subtasks provides a graphical representation of the organizational, C^2, and C^4I system relationships that exist within and between tactical organizations.

The primary source of model data and data exchanges for this study is the Command, Control, Communications and Computers Requirements Definition Program (C^4RDP) database maintained by the Army's Signal Center at Fort Gordon, Georgia. It contains over 130,000 approved doctrinal information exchanges that occur at all levels of command from the National Command Authority to the lowest tactical unit. It is the Army's primary source of information exchanged between combat, combat support, and combat service support units.

Two other models related to the development of the command and control activity model for the operational architecture are the Network Assessment Model (NAM) and the C^2NET model. The Network Assessment Model, also maintained by the Signal Center at Fort Gordon, is a communications system simulation model of various communication architectures. It models friendly and enemy force C^2 nodes, their communications equipment, and voice and data communication traffic.

The TRADOC Analysis Center (TRAC), Fort Leavenworth, Kansas, developed the C^2NET model in 1993 to support Force XXI. It is an interactive C^2 workflow model that uses petri-nets to simulate tactical-level command and control processes. C^2NET models military staff processes from Brigade to Corps level.

6 PROCESS MODELING

Functional decomposition of the tactical command and control process into tasks and subtasks is accomplished using the Integrated Definition Method (IDEF) modeling method, specifically, IDEF0 to model C^2 activities and processes. The size and complexity of C^2 systems made it necessary to model the process as a system of sub-systems. This will create a group of IDEF0 models that can be logically joined together based on information exchanges. IDEF3, used for process modeling, will incorporate IDEF0 modeling.

Preliminary work suggests that reengineering the Army's tactical-level operational architecture for information operations as shown in Figure 1 will require changes to the current C^2 system. This work will be accomplished in several steps. First, we diagram the current C^2 processes to depict relationships between activities where events occur sequentially and simultaneously, and to identify precedence conditions between the activities, if any. Next, we use subject matter experts to brainstorm ideas for changing the command and control processes based on reengineering for information operations.

Currently, tactical C^2 systems are organized around the seven battlefield operating systems. The viewpoint taken in our modeling is that of reengineering command and control for the benefit of the tactical commander.

Work-in-progress includes using IDEF0 to IDEF3 linkages to model changes to tactical-level command and control based on integrating new information technology into the process. Figures 3 and 4 depict a partial decomposition of the future command and control process system from the commander's viewpoint using IDEF. The modeling described here is a collaborative effort between the authors and the TRADOC Program Integration Office (TPIO), Fort Leavenworth, Kansas.

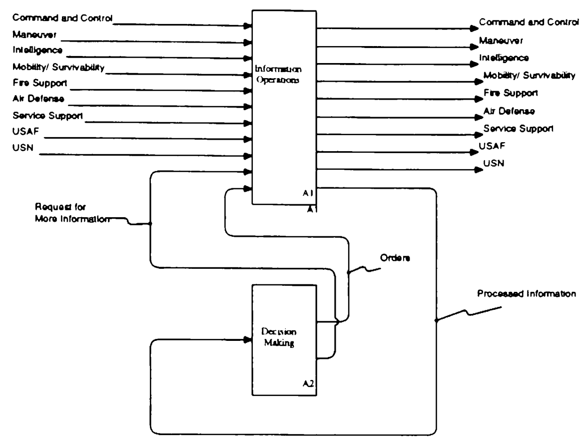

Figure 3. First Level Decomposition of C^2

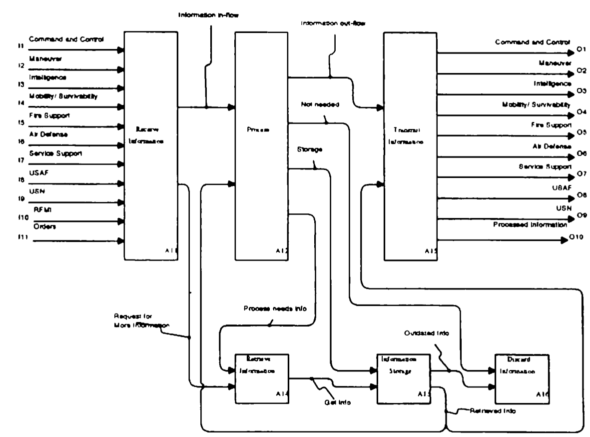

Figure 4. Decomposition of C^2 Information Operations

7 PROCESS SIMULATION

A process-oriented simulation under development will be used for conducting experimental tests to measure the relative effectiveness of the current C^2 system versus alternatives for future systems. Apparently, the reengineering the Army's tactical command and control processes using a discrete event, process-oriented simulation represents a new application of this modeling approach, at least for the Army. If successful, this methodology will (hopefully) be incorporated into existing IDEF0 process models to provide the Army with a flexible, dynamic tool for conducting analysis of competing force design alternatives. This section presents the analytical framework for modeling the C^2 system. The linkages between the current IDEF0 models and the discrete event process simulation model proposed here are also discussed.

Consider the simple C^2 information network depicted in Figure 5. This C^2 node consists of two M/M/1 queues where information arrives into the node with rate λ_1. The information is processed by Server 1 at a rate of μ and is then disseminated. It immediately joins queue 2 for more processing by Server 2 also at rate μ. When Server 2 is finished, the information departs the C^2 node. This model assumes no information is lost and each queue has infinite capacity.

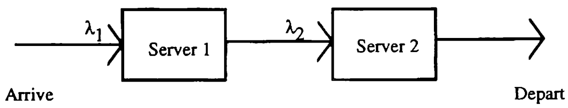

Figure 5. Simplified C^2 Node System

Although each server within this network has a service rate of μ_i associated with it, the information cannot be processed any faster than there is information in the system. Therefore, the rate out of Server i is 0 when that server is in state 0 and μ_i otherwise. The departure rate from Server 1 to queue 2 determines queue 2's arrival rate. In a steady state system this is also queue 1's arrival rate.

Next, consider a generalized network of k servers where information arrives to the C^2 node system and to each Server i, $i \in \{1,2,...,k\}$, according to a Poisson process with rate r_i. The information then joins queue i until processed by the server. Then information is disseminated to the queue for Server j, $j \in \{1,2,...,k\}$, with probability P_{ij} such that $\sum_{j=1}^{k} P_{ij} \le 1$. Alternatively, the information departs Server i with probability $P_{exit} = 1 - \sum_{j=1}^{k} P_{ij}$. Queuing networks of this type are commonly referred to as *Jackson Networks* (Walrand, 1988).

The arrival rates at any server within the network are characterized by the following flow conservation equations: $\lambda_j = r_j + \sum_{i=1}^{k} P_{ij}\lambda_i$ for $i \in \{1,2,...,k\}$. $P_{ij}\lambda_i$ denotes the arrival rate to queue j for information departing from Server i.

Figure 6 depicts a two-server Jackson Network that enumerates the possible paths for disseminating information are enumerated. The values give the information flow rates along each path of the network.

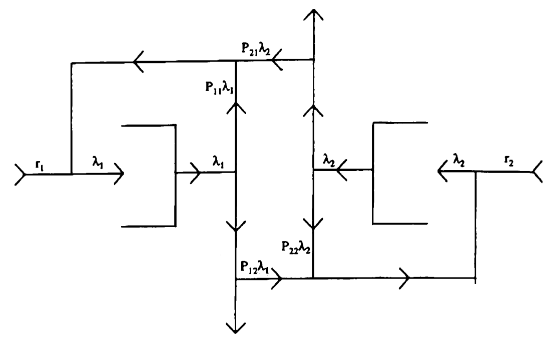

Figure 6. Expanded Jackson Network of a C^2 Node

In general, open Markovian networks can be described in terms of a Jackson Network. A probability routing matrix **P** describes the relative probability that information may take a particular route once it entered the C^2 system. If any $P_{ij} = 0$, then the information path defined from i to j does not exist. If $\mathbf{P} = \mathbf{0}$ then the network is a system of independent queues where information may arrive at any server of the C^2 node and all information departs the C^2 node upon completion of service.

Many aspects of the tactical command and control system can be modeled using Jackson networks. Each stovepiped element within the current C^2 system, and the associated staff functions may be modeled as a M/M/S queuing system. S represents the number of independent servers for processing information within a staff section. The C^2 node, also referred to as a tactical operations center (TOC), may be modeled as an interconnected series of Jackson networks comprised of staff sections representing each battlefield operating systems. Figure 7 diagrams the flow of information within a command and control node.

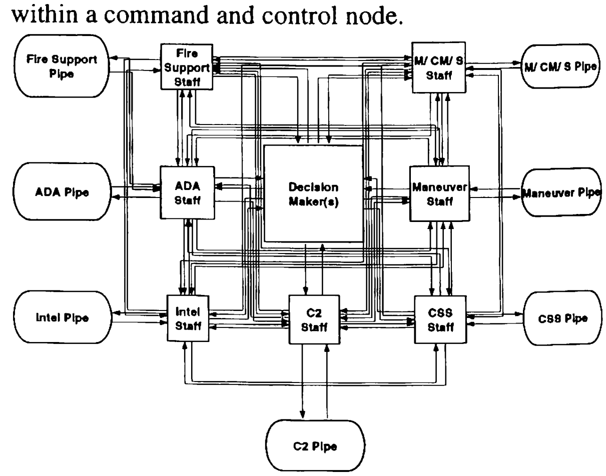

Figure 7. C^2 Node Information Flow

If we assume a Poisson arrival process for information that enters the C^2 node and exponentially distributed information processing times by each staff sections (i.e., server), then this C^2 node may be modeled as a Jackson Network. $\lambda_j = r_i + \sum_{i=1}^{k} P_{ij}\lambda_i$, $i \neq j$, describes the systems conservation of flow equations for information, where j represents either any battlefield operating system staff section or the military commander. For this system, we do not allow for the case where $P_{ij} = 0$. The only external arrival of information permitted is that designated for the commander. Stability of the C^2 system requires that $\mu_j > \lambda_j$ otherwise queue j would grow out of control although this is a fairly common occurrence in real-world situations.

Figure 8 depicts one representation of a future C^2 node reengineered for information operations. In this system, we require $\mu_j > \lambda_j$ for all functions except the military decision making cycle where human processors may be in the loop. Using a discrete-event process simulation, this C^2 system representation can be analyzed in terms of making tradeoffs between human and computer-based methods for processing information. The system can also be used to study the effects of information overload on humans or to determine acceptable arrival rates of information for human processors.

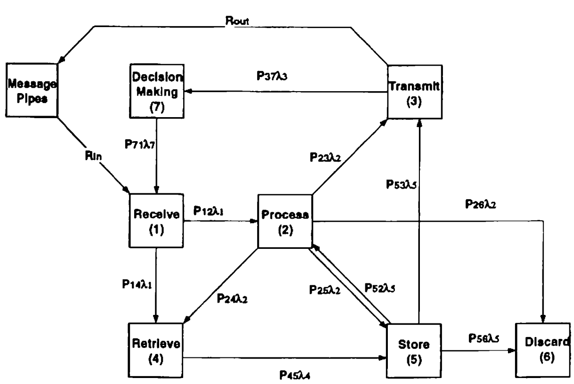

Figure 8. Framework for Analyzing Future C^2 System Information Flow Rates

Modeling either of the systems as a Poisson process assumes both exponential interarrivals and service times. However, there are no validated data sets that would to confirm this assumption. One experiment that will attempt to do this is called Prairie Warrior 1996 conducted at Fort Leavenworth. This experiment will study alternatives for organizing staff sections manned by students from the Army's Command and General Staff College and equipped with advanced computer and information technology. The Battle Command Battle Laboratory of Fort Gordon is designing experiments to record network traffic data during the exercise. It is expected that this data can then be used to determine interarrival and service time distributions for the staffs and staff functions under consideration. These distributions can then be used in the discrete event simulation model being developed for studying the C^2 system.

Figure 9 illustrated how the discrete event process model fits within the existing hierarchy of data and process models. Arrival and service rate estimates are taken from the C^4RDP and C^2NET respectively.

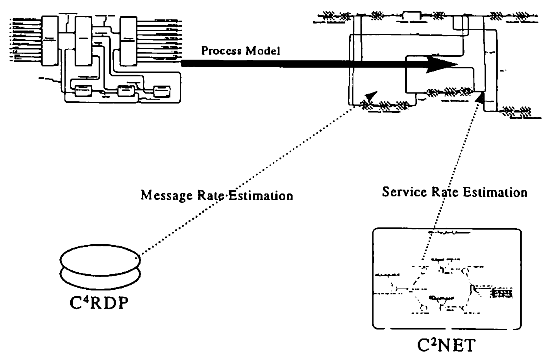

Figure 9. Linking the Discrete Even Process Simulation Model to Existing Data and Process Models

Currently, information message arrival and processing rates used for the discrete event process simulation model were obtained from the C^4RDP. The data reflects the flow of information to and from a "typical" division tactical operations center. The information exchanges were cross-referenced with the first level functional decomposition of the battlefield as defined by TRADOC's blueprint of the battlefield (TRADOC, 1993). Two important measures of information exchange provided by the C^4RDP that are also used as performance measure in the discrete event simulation are *speed of service* and *cost of failure*.

Speed of service reflects the amount of time that can be allowed to pass from when the information is sent to when it is received. This time varies from less than one second to over eight hours.

Cost of failure describes the impact on mission accomplishment from the originator's viewpoint if the transmission of the information is not completed. Categories of cost of failure are given in Table 1.

Table 1. *Cost of Failure* Categories

Indispensable	Causes complete mission failure if not satisfied 100% at any time
Critical	Causes complete mission failure if not satisfied over 75% over extended time periods
Essential	Has a negative impact on the mission if not satisfied over 75% over extended time periods

The next three tables give examples of the type of data available from the C^{4}RDP. For example, this includes mean interarrival times for messages arriving or leaving the fire support section. The Network Assessment Model uses similar data to estimate arrival rates and assumes exponential interarrivals.

Table 2. Division In-Flow Mean Time (hours/message)

System	Speed of Service	Critical	Essential	Indispensable
Fire Support	5-10 Sec	6.00		0.50
Fire Support	25-59 Sec	0.06		24.00
Fire Support	1-10 Min	0.22	0.41	0.17
Fire Support	10-60 Min	4.80	1.20	0.20
Fire Support	1-2 Hrs	24.00	0.32	2.40
Fire Support	2-3 Hrs	12.00		
Fire Support	4-8 Hrs	24.00		

Table 3. Division Internal Information Flow Mean Time (hours/message)

System	Speed of Service	Critical	Essential	Indispensable
Fire Support	5-10 Sec	8.00		
Fire Support	25-59 Sec	0.03		
Fire Support	1-10 Min	0.73		0.28
Fire Support	10-60 Min		0.47	2.67
Fire Support	1-2 Hrs		6.00	
Fire Support	2-3 Hrs		0.75	
Fire Support	4-8 Hrs			1.33

Table 4. Division Information Out-Flow Mean Time (hours/message)

System	Speed of Service	Critical	Essential	Indispensable
Fire Support	5-10 Sec	2.67		0.10
Fire Support	25-59 Sec	0.01		
Fire Support	1-10 Min	0.01	0.43	0.44
Fire Support	10-60 Min	0.50	0.63	6
Fire Support	1-2 Hrs		6	6

The data presented here, among other data, is used to estimate the internal flow rates and routing probabilities for the internal Jackson network. It has also been useful in the development of performance measures. However, more effort is required in this area. For example, the US Army Training and Doctrine Command (TRADOC) Headquarters is currently spending considerable effort to estimate the times that tactical units routinely spend to perform doctrinally approved command and control tasks with tactical operation centers from brigade to corps level for the C^{2}NET model.

The simulation package selected for the discrete event model is *SIMPROCESS*. This simulation software is currently being beta tested. The simulation software is a process oriented and permits dynamic modeling for simulating the stochastic flow of items through user defined processes. Figure 10 depicts a sample screen created for a future C^2 system using *SIMPROCESS*.

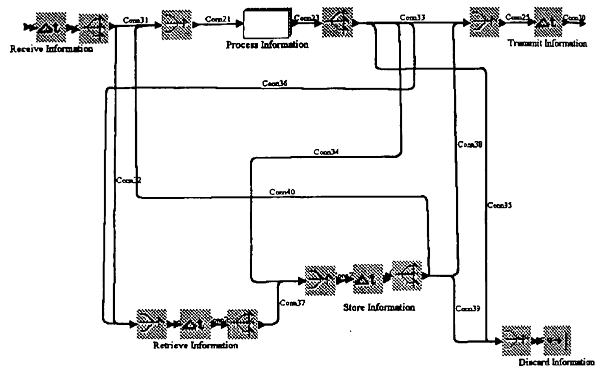

Figure 10. *SIMPROCESS* representation of a C^2 System

8 FUTURE WORK

Future work will focus on completing those tasks required to analyze different staff alternatives. The first is incorporating IDEF0 process models under development by TRADOC into the simulation model. The second is the incorporation of a data network simulation focusing on the internal movement of information. The third major area involves devising and incorporating an analytical memory model to refine the storage of information function.

Future operations may involve situations where commanders and their staffs are not physically collocated. A supporting data network will be constructed to pass information between systems and locations. The network topology and the physical medium will directly influence information flows. A network simulation model will be overlaid onto the process model.

Information storage and retrieval will also play a major factor in the development of both tactical situational awareness and the supporting data network's performance. For the Force XXI Army, it is imperative that each staff section use the most current and up to date data. Many of the problems facing our future systems are strikingly similar to today's parallel computing platforms. Raw and processed data may be stored in some central location or at each of the workstations. During our model development, we plan to apply current analytical parallel computing performance models to ascertain the impact of various data storage alternatives.

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