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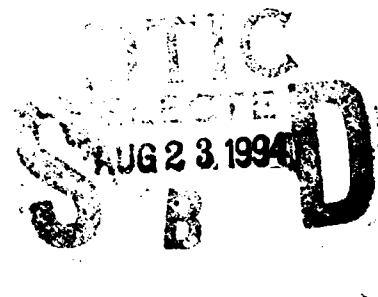
USACERL Technical Report FF-84/26
June 1984

Integrated Theater Construction Management Informational and Functional Requirements

by
Carol A. Subick
Dr. Francois Grobler

The Integrated Theater Construction Management (ITCM) research at USACERL focuses on identifying the future automated support requirements of the Army sustainment engineering mission and on developing software techniques for integrating the complex management processes associated with building the infrastructure required for military operations. The goal of ITCM is to bring together in one tightly integrated family of programs a state-of-the-art computer support system to aid in forecasting, planning, designing, and managing sustainment engineering operations both in peacetime and in war.

This report summarizes the informational and functional requirements for planning and managing sustainment engineering operations, outlines the current state of automated engineer systems and evolving software technologies, and identifies the research areas requiring the most intensive efforts to permit the development of an integrated system.



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FOREWORD

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INTEGRATED THEATER CONSTRUCTION MANAGEMENT INFORMATIONAL AND FUNCTIONAL REQUIREMENTS

1 INTRODUCTION

Background

Current U.S. warfighting scenarios focus on the strategy of projecting decisive combat power from the continental U.S. to remote regions of the world within a short time frame. Land combat forces deployed in such a rapidly unfolding situation will require a well-developed infrastructure—roads and bridges capable of supporting heavy equipment traffic, airports and seaports capable of handling large throughputs of men and materiel, secure facilities in which to work and live, storage facilities for fuel and ammunition, and more. This type of infrastructure presently does not exist in many regions of potential conflict. Combat engineers, under their sustainment engineering mission, are responsible for the design and construction of the facilities that make up the infrastructure required to support military operations. Under the evolving AirLand Battle doctrine and force structure, the successful accomplishment of sustainment engineering mission requirements will be critical to the ultimate success of a campaign but will be difficult to achieve.

Sustainment engineering activities span the entire operational spectrum, from the earliest planning stages to the final restoration efforts. Before the first troops are on the ground, the formulation of an initial strategy will depend on a rapid engineer estimate of the adequacy of a region's infrastructure and of the time and resources required to upgrade it. When forces are actually deployed, airlift and sealift capacities for transporting engineer equipment and supplies will be severely limited, particularly during the initial build-up period when they are most needed. More than ever before, engineer forces will rely heavily on civilian and host nation support. The timing, coordination, and control of all types of construction in a theater will be crucial, requiring excellent communications and constant adaptations to changing priorities and conditions.

Sustainment engineering is also a military mission with a large role in operations other than war. Recent experiences with the refugee problem in Iraq after Desert Storm and with relief work in Somalia—critical humanitarian efforts in hostile environments—highlight the importance of having a trained and ready construction engineering capability. Nation assistance and disaster relief efforts require quick, effective planning and efficient execution of facility construction and repair, often with the same types of time and cost constraints and shifting priorities encountered during combat. These types of activities are increasing in number and scope at the same time that force capabilities are being reduced.

In their future operations, the Army's sustainment engineering forces will be required to do more in less time with fewer resources and more coordination than ever before. Computer technology can help the engineer community meet this challenge by filling the gap created by limited time, resources, and expertise and linking engineer forces with the digital network that will be the future foundation of command and control. Computer systems already offer indispensable tools for managing data, multimedia information, projects, resources, communications, etc. As software development technologies improve and the use of networked desktop computers becomes commonplace, Army engineers will find that successful mission accomplishment is tied more and more to their ability to access and use sophisticated, well-integrated computer systems designed to meet their specific needs.

Integrated Theater Construction Management (ITCM) research focuses on identifying the automated support requirements of the sustainment engineering mission in the next century and on developing software techniques for integrating the complex management processes associated with building the infrastructure required for military operations. The goal of ITCM is to bring together in one tightly integrated family of programs a state-of-the-art computer support system to aid in forecasting, planning, designing, and managing sustainment engineering operations both in peacetime and in war.

Objective

The objective of the ITCM work units is to design and develop integrated planning and project management software tools to assist military engineers in executing sustainment engineering, disaster relief, and nation assistance missions. These tools will provide the capability to generate and track facility and resource requirements, to manage resources and projects in a dynamic environment, to do what-if analyses, to assist in determining priorities, and to provide consistent command and control interfaces between engineer units at different echelons.

This technical report summarizes the informational and functional requirements for planning and managing sustainment engineering operations, outlines the current state of automated engineer systems and evolving software technologies, and identifies the research areas requiring the most intensive efforts to permit the development of the ultimate integrated system.

Approach

ITCM research builds on the experiences of an earlier U.S. Army Construction Engineering Research Laboratories (USACERL) effort that produced the Theater Construction Management System (TCMS), Version 1.0. This software system linked commercial software packages (AutoCAD, Drawing Librarian, Project Scheduler 5, and PFS:First Choice) with the dBase-format database files of the Army Facilities Component System (AFCS) to produce a menu-driven operational planning and management tool for the engineering staffs at brigade, group, and engineer command (ENCOM) levels.

To identify the informational and functional capabilities required for ITCM, the researchers studied many written and oral reports from engineers deployed to the Persian Gulf and Somalia, to nation assistance activities around the world, and to disaster relief efforts in the United States. The relevant observations from these experiences are documented in Chapter 2 of this report and serve as the basis for establishing the vision for ITCM capabilities. Additionally, the researchers gathered valuable information from user feedback during the testing of TCMS at engineer exercises and from engineer unit experiences with an early prototype of TCMS during Desert Shield/Storm. Chapter 3 presents descriptions of AFCS and TCMS and summarizes the relevant limitations of the current system.

The areas to be explored in achieving the vision of what ITCM should be as an automated support tool lie in multiple disciplines: operations research, software development technologies, computer modeling, artificial intelligence, and information management. During the early 1990s, tremendous strides in computer hardware and software capabilities opened a number of avenues for expanding the basic functions of TCMS. Object-oriented design/programming offers a new approach to managing the complexity of large systems such as one that would be needed for sustainment engineering processes. New techniques for the design of graphical user interfaces will help reduce complexity for the end user. New database management and multimedia tools offer powerful mechanisms for placing information at the user's fingertips. Simulation and knowledge-based reasoning embedded in new software systems have the potential of providing powerful analytic capabilities. The major portion of the ITCM research is

devoted to leveraging these new technologies to produce a comprehensive sustainment engineering software system capable of supporting operations across staff positions and unit levels. Chapter 4 of this report provides a summary of the hierarchical nature of the problem area and of the evolving technologies and how they can be applied to achieve the vision of ITCM.

Several of the new technologies to be applied to ITCM are in their infancy and require further development. In addition, the sustainment engineering processes themselves must be analyzed from a software application perspective. These areas are the focus of future work units and are outlined in Chapter 5 of this report under conclusions and recommendations.

Mode of Technology Transfer

This technical report is the mode of technology transfer for the portion of ITCM completed in FY93. Given future funding, the researchers will be able to produce a pilot software system of integrated planning and management functions to demonstrate the design characteristics needed for the development of a fieldable system.

2 THE SUSTAINMENT ENGINEERING MISSION

Introduction

Integrated Theater Construction Management (ITCM) research will provide new capabilities for developing automated support for the planning and management of sustainment engineering operations in the next century. Those operations will be greatly affected by recent changes in the world order, in our armed forces, and in our technologies. The disintegration of the Soviet Union and the subsequent shifting of our national focus from global war to regional contingency have changed the shape of future military operations dramatically. The rush to capture the "peace dividend" has brought drastic reductions in the size of our armed services and left in its wake many questions about how best to structure and train the remaining force to meet a variety of possible contingencies. And our growing awareness of the fragile nature of our planet and our dependence on the political, economic, and social climates of other nations has forced us to consider more carefully what types of actions we are willing to take to defend our national interests. In this very dynamic and complex environment, combat engineers responsible for providing the infrastructure to support military operations must be prepared to respond to a greater variety of contingencies with fewer resources and more restrictions than ever before.

This chapter summarizes the sustainment engineering mission as it is specified in doctrine and as it is carried out in actual practice. What is outlined here for sustainment engineering in terms of mission, organizational structures, functional requirements, and recent experiences will be the basis for the content and structure of the ITCM system methodology.

The first two sections of this chapter describe sustainment engineering mission responsibilities and the organizational structures that are directly linked with mission performance. The third section discusses the operational continuum of the planning and management process and identifies the functional capabilities required in a theater of operations. The fourth section summarizes recent experiences of engineer units during the Gulf War and during several nation assistance and disaster relief efforts. These firsthand accounts of real-world mission requirements and the environments in which they were accomplished highlight specific problem areas that bear further examination. The concluding section identifies 12 key elements common to all the case studies and essential for defining a context for the capabilities to be developed under ITCM.

Sustainment Engineering Mission Requirements

According to U.S. Army engineer doctrine, the primary mission of sustainment engineering units and equipment is to assist combat units in performing their mission. They do this in a variety of ways, though the bulk of their activities consists of constructing, maintaining, repairing, and upgrading the roads, bridges, ports, airfields, storage facilities, camps, and bases required to support combat operations. Appendix A contains a complete mission essential task list (METL) for sustainment engineering. The list of mission responsibilities is divided into four categories:

- 1) lines of communication (upgrade, maintain, and construct lines of communication supporting movement of personnel, equipment, and material over land, air, and sea, including roads, railroads, ports, airfields, pipelines, and waterways);
- 2) facilities (upgrade, maintain, and construct facilities supporting personnel and equipment, including command and control (C²) and air defense artillery (ADA) facilities, supply depots, hospitals, billeting, and maintenance facilities);

3) area damage control (control and relieve both direct and indirect effects from natural and man-made disasters, including rapid runway repair, firefighting, decontamination, flood control, route clearance, and structure reinforcement);

4) production of construction materials (produce required materials and deliver to the construction site, including crushed rock, concrete, asphalt, and lumber).

Every division has some limited capability to perform sustainment engineering operations to increase their survivability and maintain their resupply routes to the brigade rear area. In the current Army force structure, some divisions have a considerable quantity of sustainment engineering capability for hasty construction of airfields, heliports, etc. The equipment used for sustainment engineering is not armored and consists primarily of camouflaged commercial construction equipment.

In the Corps rear area and communications zone, sustainment engineering operations may be planned and/or performed by Army troop units, by troop units of other services or nations, by Army Corps of Engineers civilians, by contractors, or by host nation engineers. The assumption is that sustainment engineering operations behind the division rear boundary do not normally come under enemy fire unless they involve construction or repair of high priority targets (airfields, ports, bridges, etc.). Though much of the work is performed by civilian contractors, U.S. Army sustainment engineering units provide a rapid response construction capability and must be prepared to perform all high priority missions if other means are unavailable because of dangerous conditions, security requirements, or timing and synchronization.

The Army currently maintains a large inventory of construction equipment, but the fleet is aging and not likely to be replaced. Recent budget constraints, the ready availability of commercial equipment, and the increased reliance on contracted construction have forced acquisition of new sustainment engineering systems to a low position on the Army's priority list. Because of the age and repair problems of the current fleet of equipment and the burden it places on airlift/sealift capacities, military construction units will generally deploy initially with minimum equipment and will rely heavily on the use of leased equipment during future contingency operations.

In a full deployment for a major contingency, the theater army is the central organizational framework for sustainment operations, and the ENCOM commands and controls the theater army engineer force. The number and type of echelon-above-corps (EAC) units in the engineer force structure is tailored to fit the theater requirements, and a variety of command and support relationships may be established. Federal Manual (FM) 5-116, *Engineer Operations: Echelons Above Corps* provides descriptions of the various organizational structures that might be used, and the reader is referred to that document for more details. Related to the design of ITCM, it is important to note from this FM that all EAC engineer units at the brigade level and above have missions which require them to plan, design, and manage the construction of facilities and lines of communication, to manage host nation and contract engineering, and to manage critical theater Class IV construction materials.

Army sustainment engineers have one of the few military missions that includes a large role in operations other than war, including operations conducted during peacetime. These operations include nation assistance to provide engineer advice and perform actual construction projects, and disaster relief to assist emergency management agencies and local authorities in the wake of large-scale disasters.

Under nation assistance, Army engineers provide general engineering advice and support to allied and friendly countries and to other U.S. agencies who are assisting those countries. The goals of nation assistance activities are to promote stability and enhance the growth of the host nation, to protect the host nation environment and public health during economic development, and to reduce poverty and hunger to promote self-sufficiency. The assistance may include training host nation personnel, supporting work

by U.S. Army Corps of Engineers (USACE), and performing actual construction and repair work. Army engineer troop units participate in construction, maintenance and repair efforts to improve host nation infrastructure (airfields, roads, bridges, canals, dams, etc.), civil facilities (schools, medical clinics, and governmental buildings), and utility services (power, water, and sewage treatment). Sustainment engineer units frequently operate alone in isolated regions, and their activities may be viewed as a threat by insurgent forces attempting to destabilize the government of the host nation. Engineer troops must be prepared to react if the situation should change from normal peacetime to conflict. These engineer units may be the only available units that are trained and equipped to fight as infantry.

Under disaster relief, Army engineers provide emergency assistance both in the United States and elsewhere in the wake of natural and manmade disasters: earthquakes, hurricanes, floods, fires, and contamination from chemical, biological, or nuclear releases. The typical response is to provide immediate assistance in restoring order and basic services. Army disaster relief efforts must be coordinated with a number of local and national agencies that have either direct or emergency management responsibilities in the affected area.

Organizational Structures

Army engineers have the bulk of the responsibility for planning sustainment engineering missions during a land-based contingency. At the theater level, the Army component sustainment engineering functions are managed by an ENCOM. The Army currently has two ENCOMs, the 412th ENCOM headquartered in Vicksburg, MS, and the 416th ENCOM in Chicago, IL. Figure 1, taken from FM 5-116, shows the organizational structure of a fully deployed ENCOM.

As an automated planning and management tool, the ITCM system will focus on the activities of the headquarters and headquarters company (HHC) at the ENCOM, Brigade/ Group, and Battalion levels.

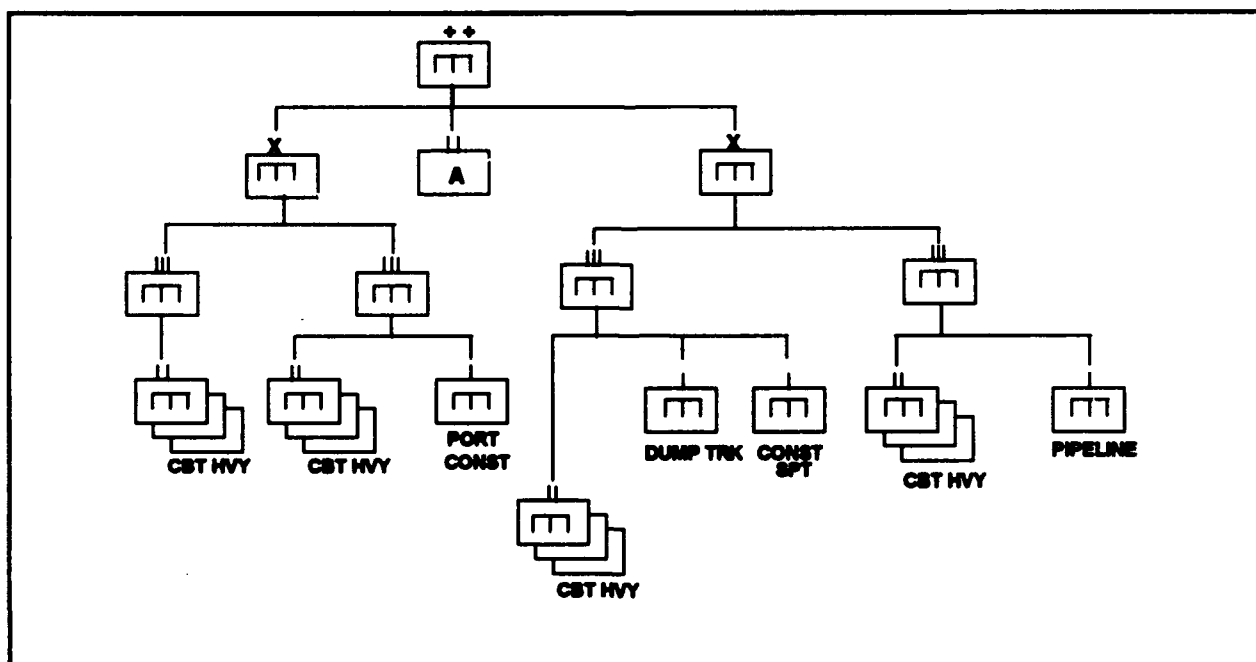


Figure 1. Typical Mature Theater ENCOM.

Each of these echelons looks at sustainment engineering missions and resources at different levels of detail over different time spans and for different purposes. The hierarchical breakdown in unit structure from the ENCOM to the Battalion follows the typical three-level view of projects and resources (Table 1). The ENCOM takes the long-range approach and concentrates on acquiring, positioning, and coordinating the correct number and type of resources to meet anticipated project requirements. The midlevel view of the Brigade and Group focuses on matching available resources with prioritized projects to achieve the most efficient and effective completion of known missions. The Battalion takes the most operational, short-term view of the three, concentrating on scheduling of resources to accomplish the specific tasks associated with assigned missions. One of the most difficult aspects of ITCM will be to design a system that can move consistently from level to level, providing the appropriate capabilities in an integrated fashion.

Within the Army, ENCOMs have the construction management lead, but the current emphasis on joint operations requires ITCM to consider the engineering organizational structures above the ENCOM level. A variety of structures are possible, each shaped to fit a given contingency's requirements. The engineering staffs at the joint and unified levels of a command focus on strategic planning; establishing priorities and monitoring operational costs at the macro level. These engineers are drawn from civil engineering resources of the Army, Navy, and Air Force, and in the Army's case would most naturally come from one of the ENCOMs. While ITCM focuses on construction management at the ENCOM level and below, it is important to note that ENCOM personnel are actively involved in macro-level construction planning activities. These activities have perhaps the most pressing need for automated support because of the complexity of the tasks and the time-sensitive nature of the work. Indeed, the current reliance on civilian contractor and host nation support for the actual construction of the facilities and lines of communication in a theater of operations indicates that, in the future, Army EAC engineers will probably require as much automated support for strategic planning and contract and funds management as for the planning and management of actual troop construction.

Table 1. Hierarchical Breakdown of Sustainment Engineering Missions.

UNIT	MISSION
ENCOM HHC	Perform operational planning and supervision Coordinate activities of assigned or attached engineer brigades, groups, and other units engaged in construction
Brigade/Group HHC	Plan and coordinate operations of engineer units engaged in construction, maintenance, and rehabilitation of facilities and lines of communication (LOCs)
Battalion HHC	Perform construction, maintenance, and rehabilitation of facilities and LOCs

Functional Capabilities Requirements

The functional capabilities needed to support planning and managing the performance of sustainment engineering tasks must address the activities outlined in the following logical sequence of steps:

1. Provide engineer estimate
 - a. Analyze commander's intent
 - b. Forecast engineer mission requirements
 - c. Assess engineer capabilities
 - d. Report engineer estimate
2. Determine actual mission requirements
 - a. Determine facility/LOC requirements
 - (1) Identify facility/LOC specification parameters
 - (2) Establish size and operational capabilities
 - (3) Define life cycle expectations (build, maintain, destroy)
 - (4) Determine security/safety requirements
 - b. Identify operational constraints
 - (1) Set project milestones
 - (2) Determine spending limitations
 - (3) Identify geographical, climatological, political limitations
 - c. Establish priorities for meeting requirements
 - (1) Consider risks to mission success
 - (2) Determine impact of deployment schedule on resource availability
 - (3) Assess long-term effects on capability
 - d. Select methods for meeting requirements
 - (1) Locate existing facility/LOC
 - (a) Determine pertinent attributes of locally available facilities/LOCs
 - (b) Match facility/LOC requirements with available facilities/LOCs
 - or
 - (1) Plan construction of new facility/LOC
 - (a) Select and survey site
 - (b) Design facility/LOC
3. Accomplish mission
 - a. Procure site
 - b. Establish rights to use existing facility/LOC
 - or
 - b'. Construct new facility/LOC
 - (1) Contract with civilian/host nation
 - (2) Manage quality assurance for contract work
 - or
 - (1') Issue construction directive to subordinate unit
 - (2') Manage troop construction project
 - (a) Allocate resources
 - (b) Procure supplies
 - (c) Schedule work
 - (d) Monitor progress
 - c. Report progress
 - d. Adjust for contingencies

4. **Maintain ongoing capabilities**
 - a. **Monitor unit status**
 - b. **Maintain equipment**
 - c. **Update inventories**
 - d. **Gather operational statistics**
 - (1) **Perform cost accounting**
 - (2) **Study unit productivity/efficiency**
 - (3) **Analyze after-action reports**

Automated support for each of these activities is possible. Indeed, computer tools are already in use for many of them. The ITCM effort will concentrate on structuring the system in a way that provides consistency of information and integration of functions horizontally across staff positions and vertically between multiple echelons of command.

Recent Experiences

This section summarizes recent experiences of engineer units during the Gulf War and during several nation assistance and disaster relief efforts. These firsthand accounts of real-world mission requirements and the environments in which they were accomplished highlight specific problem areas and functional capabilities that bear further examination. What is reported here in anecdotal form and at the end of the chapter as "common threads" are the common elements that define the types and quantities of work involved in the sustainment engineering mission and the difficulties most often encountered in completing that work.

Desert Shield/Desert Storm (DS/DS)

20th Engineer Brigade (Airborne). The 20th Engineer Brigade (Airborne) deployed for Desert Shield on 21 August 1990 and was one of the first engineer units on the ground. Though their initial responsibilities included all engineer mission areas (mobility, countermobility, survivability, sustainment engineering, and topographic engineering), the unit's early efforts concentrated on sustainment.

The 20th's first lesson was one learned by Field Marshal Rommel during World War II: "Before you can defeat the enemy, you must defeat the desert." The unit expended a considerable amount of time and effort coping with climate and terrain. Problems with sand and dust during DS/DS are well documented. The area of operations covered more than 90,000 square miles of largely open and barren terrain. Competing priorities for cargo shipments caused significant delays in receiving Class IV material.

The 20th's efforts concentrated on assisting logistical resupply and protecting troops from the harsh environment. Among their accomplishments, the 20th listed construction of more than 1000 helicopter pads and approximately 1000 miles of newly cleared desert roads; preparation of ammunition supply points, petroleum terminals, and protective berms; and construction of six 2500-man base camps.

The unit used host nation contract construction equipment to ease the shortage of compactors, water distributors, and dump trucks. They also worked with host nation support engineers to learn local construction practices.

416th Engineer Command (ENCOM). MG Terrence D. Mulcahey documented the DS/DS experience of the 416th ENCOM in a 1992 article in *Military Review* ("Engineer Support in the COMMZ," March 1992). The 416th was activated in total and became operational in Saudi Arabia by 12 December 1990.

The primary mission of the 416th was command and control (C²) of EAC engineer units. Their C² responsibilities extended to an engineer brigade, three engineer groups, three combat heavy engineer battalions, a topographic battalion, nine engineer companies, and 10 specialized engineer detachments. MG Mulcahey states that the rule of thumb for planning task organization is one engineer brigade and one topographical battalion for each forward-deployed maneuver corps plus specialty engineer units as required (for example: port construction companies, dump truck companies, construction support companies, pipeline companies, and detachments to provide well drilling, prime power, and real estate expertise).

Before deploying, the 416th used the Civil Engineering Support Plan (CESP) at Central Command (CENTCOM) Headquarters in Florida to develop initial planning factors to project engineering requirements for the theater and to estimate the costs of supporting those requirements. In Saudi Arabia, the unit controlled the following major projects: the construction, repair, and maintenance of 2200 kilometers of roads; construction of 408 kilometers of fuel pipelines; construction of two 48,000-person prisoner-of-war camps; construction of helipads and aircraft beddown sites; management of theater Class IV materials, including procurement of more than \$64 million in Class IV supplies (500,000 cubic meters of gravel, 170,000 metric tons of asphalt, 93,000 cubic meters of ready-mix concrete, 68,000 metric tons of construction steel, and electrical and plumbing materials); building of defensive positions for rear area troop compounds; construction of temporary storage buildings; drilling and rehabilitation of wells; real property maintenance; real estate acquisition; and environmental engineering support. The ENCOM was responsible for keeping track of existing projects, anticipating new projects as the war progressed, and planning tasks for incoming engineer units. The ENCOM even prepared a hazardous waste policy for CENTCOM and developed a theater plan for environmental cleanup.

The 416th served as the Army theater engineer, interfacing with the host nation, the other U.S. services, Middle East/Africa Projects Office (MEAPO), and the engineer brigades of the two Corps. The unit also contracted for engineer troops to operate civilian quarry sites and asphalt plants when business owners could not find civilian workers to continue work after fighting began and procured 154 major items of engineering equipment within Saudi Arabia. Finally, the ENCOM served as consultant to determine the engineer effort required to provide a minimum life support structure for Kuwait and to provide engineer support for the relocation of refugees, including planning to support redeployment of U.S. troops.

In another DS/DS article, Chief of Engineers LTG Henry J. Hatch reported on the role of USACE and, indirectly, about the role of engineer units ("Corps of Engineers: Laying the Groundwork for Theater Operations," *Military Review*, March 1992):

There were few engineers in theater when the first corps representatives arrived, in part because CENTCOM had reduced the number of engineer units in the initial deployment to allow for the transport of maneuver units. No engineer command had yet arrived to manage construction requirements. Yet, the requirements for contract construction and real estate support were, as CENTCOM engineer Colonel Jay W. Braden described, "immediate and massive." The first elements of the 82nd Airborne Division were arriving in Dhahran with no logistic structure to support them, no shelter in 120 degree heat and no sanitation facilities.

On 12 September 1990, the SUPCOM reported that real estate leasing was the predominant engineer activity. Officials were finalizing an average of four leases a week with private landowners and businesses, and the average lease provided housing for 500 people. ...By early November, there were 97 leases totaling about \$94 million.

We were trying to get our troops out of the sun, out of the sand, and into some air conditioning... (Units identified requirements and sent them through channels to the SUPCOM, which established priorities.) SUPCOM priorities changed daily, sometimes hourly.

Efforts to meet the construction and real estate requirements of U.S. forces, however, would not have been as successful if the troops had not deployed to a part of the world that had an existing supply of contractors, materials and facilities. Without that supply of fuel, equipment and contractors, the engineers' ability to support the troops would have been significantly curtailed.

18th Engineer Brigade. The 18th participated in Operation Provide Comfort, the coalition effort to provide humanitarian relief to the Kurdish people of northern Iraq in the wake of the Gulf War. The brigade's experiences were reported in COL Stephen A. Winsor and MAJ Stephen D. Austin's article "The Engineer Role in Helping the Kurdish People" (*Engineer*, October 1991). The brigade had responsibility for all engineering in the region and coordinated the efforts of about 2000 personnel from three coalition countries, including the U.S. 94th Engineer Combat Battalion (Heavy), the U.S. 133rd Naval Mobile Construction Battalion, the 51st Field Squadron from the United Kingdom, the 11th Engineer Relief Battalion from the Netherlands, and elements from the USAF 564th Civil Engineering Squadron.

The tactical area of operations for Provide Comfort was quite large: 250 thousand by 80 thousand. Besides managing the engineering activities of the primary relief mission, the brigade was also responsible for providing the sustainment engineering support required by the joint task force (a division-sized force with over 15,000 troops from six countries) and for providing mobility, countermobility, and survivability engineering support should the Iraqi Army attack from the south.

The brigade planned and managed the construction of ten transient camps, four of which were completed. The brigade also repaired and maintained a coalition-damaged runway at Sirsenk Airfield to allow C130 airlift operations and managed work by the Seabees in repairing 25 kilometers of a critical roadway needed to facilitate movement of 130,000 refugees back into Iraq from camps in Turkey. Each relief camp was designed to handle 21,000 refugees. Tents provided the facilities for housing, food storage, health care, administration, security, and logistics. Soldiers constructed streets (9 kilometers per camp), erected tents, and put up fencing and lighting. Latrines, the water system, and food warehouse facilities were contracted through the U.S. Army Engineer Group (TUSEG) of the Corps of Engineers' Europe District. The brigade worked with TUSEG to provide quality assurance of contractor operations. The heavy influx of refugees overwhelmed contractor efforts, however, and troops were used to expedite latrine construction to avert life-threatening sanitation problems.

The command established several guidelines for infrastructure and construction. To be accepted and used by the Kurdish people, the relief camps had to be designed to accommodate important cultural and religious considerations and had to be easily taken over by civilian relief organizations. In that regard, the brigade coordinated with the United Nations High Commission for Refugees and the International Relief Commission, which eventually took over relief camp operations. Other guidelines followed standard doctrine that all construction be temporary in nature and be designed to be economical and easily constructed.

Lessons learned during Operation Provide Comfort were:

- Engineers need to deploy early and in sufficient strength to do the job,
- Better contingency engineer packages need to be developed to allow for quick tailoring to specific needs and rapid deployment,
- An efficient, onsite contracting capability is very important,
- Class IV materials should be centrally managed to ensure that highest priority needs for scarce resources are met.

Peace Time Activities

Army engineer units have deployed several times recently to help with cleanup operations following major storms, including hurricanes in South Carolina, Florida, and Hawaii. Many of their experiences have been reported in *Engineer* magazine. From the command and control perspective, these experiences are strikingly similar to those of engineers deployed for Operation Desert Storm.

Hurricane Hugo (reported by MAJ Jeffrey R. Sommerville, "After the Storm: Military Engineers and Hurricane Hugo," *Engineer*, July 1990):

In the wake of Hurricane Hugo in 1990, 1500 engineers from the South Carolina National Guard and Army Reserve, active duty soldiers, and Corps of Engineers worked as a team in area damage control operations. The engineers had to clear their own way into the region, arriving before local command and control was established. They had no communications network, the extent of damage was unknown, and work priorities had not been outlined. In the most extensively damaged areas, military engineers performed the following tasks: clearance of trees, especially on power lines and roadways; clearance of rubble, especially roofing material and damaged vehicles; removal of sand deposits on roads; repair of erosion breaches around bridges and culverts; and support of landfill operations. Work was assigned to the military through county emergency operations centers. The engineers worked day and night shifts, scheduling use of some of the equipment around the clock but limiting others such as chainsaw operations to daylight hours for safety reasons.

Engineers working inland where damage was more sporadic had a problem keeping their platoons busy and had to do a great deal of reconnaissance. Because power had not been turned off in the inland regions, power lines could not be cleared until power companies inspected the area to make sure live wires did not endanger work crews. The engineer relief effort was also hampered by the lack of maps containing sufficient detail to support operations and by the difficulty of moving around in the devastated area, first because of the damage and later when local traffic was heavy and traffic control measures had not been returned to service.

Hurricane Andrew (reported by LTC Peter Madsen and MAJ Wayne Whiteman, "Responding to Hurricane Andrew: The 10th Mountain Deploys to Florida," *Engineer*, February 1993, and by MAJ Robert M. Ralston and LTC Douglas L. Horn, "Engineers Respond to Operations Other Than War," *Engineer*, April 1993):

Shortly after Hurricane Andrew struck south of Miami in August 1992, the 10th Mountain Division, Fort Drum, NY, received a "be-prepared" mission and immediately began analyzing the situation as it unfolded. One of their leading problems was deciding how large a force to deploy and what kinds and numbers of equipment to send.

Ultimately, a large number of engineer units deployed for disaster relief in the wake of Hurricane Andrew. They coordinated their efforts with USACE, Jacksonville District, with Federal Emergency Management Agency (FEMA), and with state and county officials. Initially their work involved clearing debris from roadways, and then clearing areas to establish and operate disaster assistance centers, life support centers, feeding sites, and relief camps. They also addressed the support of basic infrastructure operations: restoring power, helping to manage overburdened landfill operations, and inspecting facilities for structural damage. Those tasks were eventually replaced by the need to clear debris from schools and prepare them for opening day, requiring extensive electrical and interior work.

Damage to the area and the large number of homeless made finding living space for the units deployed in the region very difficult. Delays in construction of relief camps were caused by indecision of local officials regarding which building codes to follow and by a lack of key engineer equipment left behind during deployment.

Hurricane Relief Lessons Learned (reported by MAJ James R. Brannon, "Lessons Learned: Disaster Assistance Missions," *Engineer*, February 1993):

Engineer experiences in hurricane relief efforts during the early 1990s all indicated a need to pay attention to three important problems areas:

- The difficulty of tailoring the right combination of forces and equipment to respond quickly,
- The scarcity of building supplies and construction materials in a disaster area, mainly because of the high demand and because many of the commercial suppliers (lumberyards and hardware stores) may be closed or destroyed,
- The complexity of coordinating with multiple, overlapping governmental and regulatory agencies in a particular geographic region during a disaster, including public utilities, police and fire jurisdictions, and hospital districts.

Nation Assistance

Operation Restore Hope (reported by MAJ James R. Brannon and Mr. Vernon Lowrey, "Lessons Learned: Somalia and Operation Restore Hope," *Engineer*, April 1993):

The 41st Engineer Battalion (Light) was among several engineer units involved in Somalia when American forces were deployed to provide a secure environment for nonmilitary relief efforts. Engineer missions included base camp construction, road and airfield repair, and utilities support. Host nation resources were severely limited and long lead times were required to establish an adequate flow of Class IV materials. Unlike relief efforts in the United States, special measures were required because of the extreme poverty of the host nation. Crowd control at feeding centers was a major concern, and special construction methods were required to prevent theft of component materials, such as welding bridge decking into place. In addition, military unit waste and trash was often seen as valuable by local inhabitants, presenting safety and health problems. Waste management procedures also had to address environmental issues related to spill prevention and the proper disposal of hazardous materials.

536th Engineer Battalion (reported by Specialist Bob Blocher and CPT Louis Herrera in "Army Engineers in Bolivia," *Engineer*, March 1990):

The 536th Engineer Battalion deployed in June 1989 to Potosi, Bolivia, as part of the Joint Chief of Staff exercise Fuerzas Unidas 89 on a 90-day nation-assistance mission to expand the use of Potosi airport to commercial airliners. The mission involved removing the top of a mountain near the airport to improve the glide path to the landing strip. The engineer task force also included Seabees from the Naval Mobile Construction Battalion 40 and an Illinois National Guard medical team as well as a Bolivian engineer company and infantry company. While Army and host nation engineers set about the task of removing the top of the mountain, the Navy Seabees conducted civic action projects in the region, including construction of a school house and repair of community buildings.

As with Operation Desert Storm in which the desert itself was a major enemy to overcome, troops working in the austere mountain environment had much to learn about coping with the terrain and climate.

The high altitude of the worksite forced adjustments in work schedules, and four of the 350 soldiers deployed to Potosi had to be evacuated because of altitude sickness. Mission planners underestimated the effect of the rocky terrain on work schedules, especially the impact of having to dig out and haul many large boulders. The boulders caused shifts in dump truck loads that could break the drive shaft, and dozer end bits had to be replaced frequently. The supply line for repair parts for the equipment was "painfully long." Maintenance crews were forced to cannibalize parts from one broken piece of equipment to repair another and to weld broken parts back together instead of replacing them. At one point, the fleet strength dropped as low as 60 percent.

To meet the original schedule, a second work shift was added to the task force, and the schedule was altered to include a night shift whose work improved the efficiency of daytime operations. The mission was completed on schedule, but, in the process, the original construction plan was completely reworked, including major changes in labor and equipment, in scheduling, and in construction procedures.

84th Engineer Battalion (reported by CPT Kevin S. Porter in "Building to Last in the Tropics," *Engineer*, January 1991):

In 1990 a vertical construction team from B Company, 84th Engineer Battalion, deployed to Mirpur, Bangladesh, to build three school buildings for the town. Though the mission was a relatively simple one, the construction team experienced many of the same difficulties of a major deployment: coping with austere terrain and climate, using inadequate, unfamiliar equipment, having to change original construction plans to overcome deficiencies in equipment and supplies, facing the difficulties of inferior contractor workmanship, coordinating closely with the host nation, and being prepared to deal with the impact of local cultural requirements.

Though brick is the most plentiful building material in the Mirpur area, local bricks cannot endure the rains and floods of the monsoon season. So concrete was chosen as the main building material, and crushed bricks were used in the place of aggregate, which is not available in the region. Only a small mixer was available to prepare the concrete, so the building design was altered to use precast slabs which could be hand emplaced. The roof slabs were positioned with a Chinese-made crane.

A local contractor fabricated the precast concrete components. His inexperience with the techniques required by the design specifications led to the delivery of inferior products that could not pass the load-bearing requirements of the structure. The engineers had to adjust their design to use steel plates to reinforce the purlins supporting the roof. In addition, other design changes were made to lower the cost of the structures because of the high expense of building materials in the country and limited funds for the project.

The climate presented other problems. The 100-degree heat caused the concrete to dry too quickly, requiring many extra manhours to carry water by bucket to keep the new concrete wet. The extreme heat also forced changes in the schedule because of the decreased ability of workers to sustain their efforts for an entire work day. To add to the schedule problems, planners had not taken into account the impact of Ramadan, a religious fast observed by the Moslem soldiers in the Bangladesh platoon. Productivity was hampered by the effects of the required religious fast.

412th ENCOM in Central and South America (reported by MAJ Robert Bottin and Major Jimmy Fowler, "Reserve Engineer Command: Helping Latin America," *Engineer*, November 1992):

The 412th ENCOM supports U.S. Southern Command (SOUTHCOM) operations in Central and South America. The goals of nation assistance efforts in this theater include preservation of stable, nonrepressive, democratic national governments and cessation of illicit drug trafficking. The 412th acts

as an extension of the SOUTHCOM engineer staff, assisting with the development of engineer work estimates, engineer annexes to ambassador country plans, engineer construction management plans, and engineer force structure plans. Since 1990, teams have deployed to 11 countries in the SOUTHCOM region and have evaluated construction projects for airfields, roads, bridges, water supply/sanitation facilities, ferry dock terminal and river port facilities, well drilling, and water supply quality control.

Country deployment teams consisting of two or three officers and one NCO conduct site inspections and prepare work estimates for potential nation assistance and counter-drug projects. The work estimates include a description of the project, scope of work required, the general priority of the project from the perspectives of the host nation and the country team, descriptions of how the project relates to the ambassador's goals, and general construction specifications. An example of one of these work estimates is included at Appendix B. Engineer Construction Management Plans (ECMPs) are being developed to summarize engineer requirements specific to a host nation or SOUTHCOM campaign area. The ENCOM will recommend engineer force structure requirements for each ECMP, including assessment of host nation capabilities as well as U.S. military and civilian capabilities. To do this, the 412th works closely with SOUTHCOM's engineer office in Panama, Forces Command, the host nation, and Mobile District, Corps of Engineers.

Nation Assistance in Honduras (reported by CPT Neal T. Lovell in "Lessons Learned," *Engineer*, July 1990, and by CPT William J. Penny and CPT Paul D. Cramer, "Living with Foreign Commercial Construction Equipment," *Engineer*, November 1992):

Military engineer units have been involved in humanitarian construction projects in Honduras for several years. They have discovered that determining the right mix of equipment for the mission is a complicated task. Terrain plays a big role in limiting the choices in the type of equipment that can be used. For example, hairpin curves, steep grades, and the general condition of the roads impact both speed, safety, and vehicle maintenance for cargo trucks and tactical tractors.

Foreign equipment is now being leased by engineer units in Honduras, Bolivia, and elsewhere, and the use of foreign equipment appears to be an increasingly viable method of augmenting table of equipment (TOE) equipment in some circumstances. Problems have arisen with the use of leased equipment: operators are not as proficient in using unfamiliar equipment with nonstandard controls as they are with the TOE equipment on which they have trained; operator and maintenance manuals are not usually supplied with the equipment; equipment capability and reliability are generally not up to military standards; replacement parts for equipment repair may be difficult and time-consuming to obtain. These problems may have a potentially large impact on military construction planning and point to the need for more adaptive planning methods than are currently available.

As with other engineer operations in third world countries, procurement and control of materials is a major problem. Poor contractor reliability in meeting delivery schedules and poor construction material quality caused many project delays. Standard materials may be in scarce supply, and theft and population control around base camps, work sites, and equipment parks are major problems.

Common Elements in Recent Experiences

The recent experiences of military engineers involved with theater construction, disaster relief, and nation assistance have a number of common threads running through them. These common threads shape the context in which sustainment engineering missions must be planned, managed, and performed. As

such, they are key factors in determining how the ITCM system will be designed and, ultimately, how it can be used. They are:

1. The requirement to respond with little prior warning to a crisis situation.
2. Uncertainty about the possible mission requirements and the engineer force needed to meet them.
3. Chaotic initial conditions leading to uncertainty about what must be done and by whom.
4. Coordination required between multiple command levels and with many nonmilitary organizations.
5. Operations involving large numbers of equipment and personnel and a variety of technically complex tasks.
6. Designs, schedules, and priorities greatly affected by local conditions, especially terrain, weather and climate, regional infrastructure, and enemy.
7. Dependence on the use of contracted equipment that has not been trained on or maintained to military standards.
8. Inability to obtain quality Class IV supplies in sufficient quantities and in a timely fashion from local suppliers.
9. Difficulty in prioritizing and controlling the use of scarce supplies across a large area of operations.
10. Many unexpected hindrances to and changes in planned operations.
11. Missions accomplished in austere and frequently dangerous environments.
12. Operations frequently constrained by legal, cultural, and environmental concerns.

These factors and their influence on the ITCM design will be elaborated in later chapters.

Summary

This chapter described the tasks that fall under the sustainment engineering mission, including a summary of the types of tasks that doctrine identifies as being in the mission area and the functional capabilities required to plan and manage the performance of those tasks in a theater of operations. Recent experiences in the field were cited to indicate the range of tasks that are actually performed, the size, number, and type of tasks that are typical of certain deployments, and the circumstances under which the work is done. This information is the foundation for determining the functional capabilities that will make ITCM most useful to the military engineers who plan and manage sustainment engineering operations.

3 CURRENT AUTOMATED SYSTEMS

Introduction

Current commercial software packages support many of the functional capabilities required to plan and manage sustainment engineering operations. Among these are relational database management systems, computer-aided design and drafting, project management systems, communications software, and simple spreadsheet and word-processing tools. In addition, information about standard Army designs for facilities and the labor, equipment, and materials required to build them is available in electronic format in the Army Facilities Component System (AFCS). An earlier USACERL product, TCMS, combines a broad set of this type of commercial software with the AFCS databases to form a single, user-friendly software package that provides powerful new capabilities for the engineering staffs of EAC units.

Though powerful by the standards of software products of the early 1990s, the current versions of AFCS and TCMS do not provide the type of automated sustainment engineering support that is possible in the present environment of software technologies. They also do not provide the type of automated support that is compelled by the ever-increasing reliance of the military on the seamless flow of information between networked desktop computers. Desert Storm proved that warfare has changed dramatically in the wake of the digital revolution. Smart weapons and sensors, automated command and control, wargaming in synthetic environments, and other electronic wonders will have increasing impacts on battlefield pace and tactics. To succeed in this environment, military engineers need more sophisticated software systems.

AFCS and TCMS represent the first step in the ITCM journey toward more powerful automated support of sustainment engineering. This chapter describes the structures of AFCS and TCMS, the capabilities they provide, and the limitations of these current systems that highlight the need for the continued ITCM research and development.

Army Facilities Components System (AFCS)

The processes used in the design and construction of facilities needed to support military operations have a different emphasis than those used by the commercial world. Facilities are simple and austere, designed to provide the needed functionality for 2 years or less, to use expedient construction methods, and to require only easily procured, standard materials. The Army's theater construction follows the principle of minimality: use the least time, resources, and expense possible to accomplish the mission. What makes theater construction so complex is not the difficulty of any single project, but the sheer number of projects and the dynamic environment of shifting priorities, uncertain resources, and limited time in which projects must be accomplished.

In the environment of a theater of operations, the construction planning and management process works best when applied to a set of standard facilities with designs, labor/equipment/material requirements, and work breakdowns planned and resourced well in advance. The system which makes this possible is the Army Facilities Component System (AFCS).

AFCS provides design information for the standard facilities required to support operations in a theater of war. It includes the elementary construction, logistics, and planning data commonly needed by military planners, supply agencies, and construction personnel at all levels, from strategic to operational. AFCS provides facility designs and data for four different climates (temperate, tropical, frigid, and desert) and two building standards (initial and temporary). Each facility in AFCS has a set of data associated

with it: AutoCAD designs; a list of subfacility components down to the bill of materials (BOM) required for construction, labor and equipment estimates (LEE) in terms of military occupational specialty (MOS), horizontal equipment, and general manhours; and a list of the theater-oriented guide specifications (TOGS) associated with its construction. AFCS also includes tables for linking specific Army units with their facility requirements by their TOE type.

The AFCS data is structured in a building block approach, using items, subfacilities, facilities, and installations. Items are generally construction materials with national stock numbers (NSN) that can be procured through the Army supply system. AFCS has a table of items by NSN that includes the item description, quantity and unit of issue, and weight, volume, and cost per unit. An AFCS item is anything that can be ordered under a single number through the supply system. It may be as complex as a pre-engineered building or as simple as a nut and bolt. A facility is a group of items designed to provide a service, such as an administration building or an airport runway. An installation is a group of facilities designed to provide a specific service or support to a military function, such as a base camp or a supply depot. Subfacilities are treated as facilities but are usually non-standalone components that are aggregates of assemblies common to many different facilities. Subfacilities aid the hierarchical decomposition of more complex structures and are used to simplify the repetitive nature of the data. An example of a subfacility is an end bay used for a number of warehouses of different lengths. Each such warehouse lists only the subfacility (one record) for the end bay instead of the component items (doors, windows, framing, etc., which would require many records repeated for each warehouse).

Huntsville Division, USACE, is responsible for building and maintaining the required AFCS design documents and supporting databases, which are published in Technical Manuals 5-301, 5-302, and 5-303. In recent years, this data has been digitized for use on a personal computer with commercial software packages (e.g., AutoCAD for the designs and the dBase Database Management System for the associated data). To assist with the use of the dBase files, Huntsville Division produced a program called Theater Army Construction Automated Planning System (TACAPS). This program provides a look-up capability in electronic form that overcomes the unwieldiness of the hardcover versions of the databases. TACAPS, however, does not provide mechanisms for dealing with the hierarchical structure of the databases. For example, it is not capable of rollups of bills of material or of combining facilities to form new types of installations.

Huntsville Division updates their electronic files on a yearly basis and works continuously to ensure that the facilities in AFCS represent the current doctrine, operational requirements, and construction practices of the military engineering community. The existence of AFCS and the continuing support for the maintenance of its data are key to ITCM research. Not many large system developments for the Army have such a well-established source for input data.

Theater Construction Management System (TCMS)

In the late 1980s, USACERL began a project to capitalize on emerging software technologies to support EAC engineer staffs in the complex processes of planning and managing theater construction. The product of the research effort was the prototype computer application TCMS.

In the early days of TCMS work, personal computer (PC) applications such as relational database management systems and computer-aided design and drafting (CADD) were making great strides. The speed, memory size, and storage capacity of PCs were beginning to grow at increasing rates, and access to computers in the workplace became less and less of a problem as PCs began appearing on every desk. Indeed, there was no doubt that the time had come to produce a user-friendly PC application for theater construction management.

The goal of the TCMS work was to demonstrate how a multifunction engineer planning and management tool could be constructed by linking independent off-the-shelf software packages using a shell program to manage the common data files and the user interface. The AFCS files were the source for basic facility designs and data. Unlike TACAPS, which was designed primarily to ease access to the AFCS facility data, TCMS was designed as a working tool to assist the entire process of designing and managing the construction of actual facilities. With TCMS, an engineer staff could:

- Retrieve designs and dBase records for a facility from an AFCS reference library
- Associate a copy of an AFCS facility data set with an actual project
- Create new or modify retrieved facility designs, BOM, LEE, and TOGS
- Group projects together and roll up BOM and LEE data
- Print a BOM for a facility, a group of facilities, or an installation
- Produce a construction directive and a hard-copy of design documents for a project
- Import projects into a project management system for scheduling and tracking, including using CPM and Gantt charts
- Assign labor and equipment resources to a project
- Commit and level the use of resources across multiple projects
- Exchange data for projects with another unit via modem or floppy disk.

The functionality of TCMS was provided by commercial software: AutoCAD and Drawing Librarian for the designs, Project Scheduler 5 for project management, PFS: First Choice for the construction directive and other word processing, Close-Up for communications, and a library of dBase utilities for the database management functions. The TCMS shell, which was the focus of the USACERL effort, provided the user interface and managed the storage, retrieval, and formatting of data as it passed from one application to another. For a complete presentation of the structure and features of TCMS, see USACERL ADP Reports FF-93/13 and FF-94/13 (1993). Responsibility for maintaining and distributing TCMS was transferred to the AFCS team at Huntsville Division in July 1993.

When it was completed in 1993, TCMS provided many valuable capabilities previously unavailable to the engineer planner. But those capabilities only whet the appetite for what has evolved through the hardware and software environments during the years TCMS was being developed. The ITCM work must proceed in the promised potential of these new tools (graphical user interfaces, software compatibility and extensibility, database management, and computer modeling). Some of these tools directly address limitations of TCMS and other tools (i.e., object-oriented programming, embedded simulation, artificial intelligence, hypermedia information management, etc.) reach well beyond the basic functions of TCMS. The latter is addressed in Chapter 4. The recent advances directly applicable to limitations of TCMS are addressed in the following sections.

Graphical user interfaces. When the original design decisions for TCMS were made, Microsoft® Windows™ had only begun its climb to the level of popularity it enjoys today. MS Windows' growing capabilities in the areas of object linking and embedding (OLE), dynamic link libraries (DLL), and dynamic data exchange (DDE) will be discussed under *Software compatibility* below and in Chapter 4.

The discussion here is limited to the graphical user interface (GUI) used for most new PC applications designed for MS Windows.

The TCMS shell is a DOS-based program using a text display. As such, it is severely limited in the amount and type of data that it can display on one screen. Use of a GUI would allow multiple resizable windows, scalable fonts, and menu icons. Within one of these windows, it is possible, for example, to display a map of the theater and to overlay icons showing the location of units, projects, supply depots, land features, etc. A mouse click on an icon provides a natural way to access data about the item represented by that icon, and the display of the spatial relationships provides much more information than a multitude of textual records. In addition, menu interactions are much easier for a system user to understand when they are presented in the form of icons and dialog boxes instead of as text-based commands.

Software compatibility. TCMS uses commercial software to achieve much of its functionality. It makes sense economically not to have "reinvented the wheel," but the approach has definite drawbacks. For one, the commercial software available in 1990 was not designed to work with other software as Windows applications are now being designed to do. This means that the TCMS shell must constantly translate data from one application to another instead of relying on software standards for data exchange between applications. If a TCMS commercial application is upgraded in a way that changes the format of what is used for its imported data, TCMS will require code changes to maintain its compatibility. Indeed, the original choice of the commercial software was limited by the ability of candidate packages to import data structured by the TCMS shell. TCMS users are required to use the specific commercial software originally chosen for TCMS, even though they might be more familiar with a similar package from another vendor. Changes in the way software is designed today eliminate many of these problems.

Software extensibility. The architecture of TCMS makes expanding its capabilities difficult. The TCMS development process was constantly haunted by the 640K DOS limit on memory—a problem that MS Windows and its pending successors (Cairo, Chicago, NT) overcome. Even if memory were not a problem, managing the complexity that comes from adding functions would be an extremely difficult task because the architecture itself cannot support expansion easily. An example of a much needed new capability would be the management of resources, whether personnel and equipment or supplies. Expansion of the system to include this capability would necessarily require linking the facility data and the project schedules with a new database for resources. These three functions would be extremely difficult to integrate because the linking of the data is tightly connected with the inner workings of the project management software over which TCMS has little control.

Database management. TCMS was designed to proceed through the facility design and construction processes in a forward direction. As a planning tool, TCMS leaves too much off-line calculation to the user to answer some fairly common questions. Examples:

- What will be a unit's demand for a specified material/job skill/piece of equipment within a specified time frame?
- What materials may be in extremely short supply?
- What labor and equipment mix best corresponds to a given unit workload?
- What is the impact of delayed material resupply on the construction schedule?
- Is the project schedule consistent with established priorities?

These types of questions require an ability to query the database in ways unavailable in the present system. Even more basic questions cannot be answered because key data is not in AFCS nor is it added in TCMS. An example of this is a data field that states how long it should take to construct each facility under ideal conditions. The labor and equipment hours give an approximation but cannot account for concurrent/sequential efforts. Having an ideal construction time associated with each facility is the first step in moving toward an automated process for adjusting the construction time to account for the impacts of weather, terrain, equipment shortages, and the like.

The AFCS databases are complex enough in their structures to make general querying by an end user difficult to accommodate. A typical query of AFCS's relational databases requires recursive accessing within a single table and the linking of records from one table to another—not an easy task. Restructured data that accommodates the hierarchical decomposition of the installations and facilities and uses common, inherited methods to process queries has a much better chance of being accessible to an end user.

Such a structure is possible in object-oriented programming (OOP). With the OOP paradigm, the software closely models the attributes, relationships, and behaviors of the entities of the system itself and simplifies the representation of hierarchical structures and inherited behaviors. OOP methods could add new perspectives to the current "elemental" representation of facilities, materials, labor, and equipment. For example, structures could be added to represent an entire engineer unit and to link its resource capabilities, workload, and schedule to the more elemental-level objects (e.g., project, occupational specialties, pieces of equipment). This ability is particularly important to modeling the strategic, long-range view of higher level units where details blur and a lower resolution perspective is required.

Computer modeling. An earlier paper (Appendix C) considers the appropriateness of the methods of CPM/PERT in managing theater construction projects. CPM/PERT methods are the standard project management approach, and PS5 uses such a method for that aspect of TCMS. The CPM/PERT objective is to determine the scheduling and resource requirements for a project to achieve a desired project completion time, and the methodology does not adapt well to changes after the original schedule is set. The case studies cited in Chapter 2, however, clearly indicate that theater construction is an extremely dynamic process where effective use of resources may take more priority as an objective than the well-timed completion of a task and where changes in mission and priorities are the only constants. As indicated in Appendix C, a new methodology that proceeds from goal decomposition to alternative courses of action and identifies the conditions for choosing a particular course of action in an evolving situation is a key ingredient to the automated support tools of ITCM. Appendix C contains excerpts of a study performed by CPT Clarence C. Turner for his master's thesis, which shows that even the units below platoon level involved in construction will benefit from better planning support in an integrated modeling system allowing controlled communication up and down the chain of command.

4 ITCM INFORMATIONAL AND FUNCTIONAL REQUIREMENTS

Introduction

This chapter discusses the implications of the key elements of sustainment engineering operations identified in Chapter 2 and how those elements not only help to define the informational and functional requirements of ITCM but also indicate that the conventional methods for providing some of this functionality are inadequate. Later sections identify the emerging technologies that will provide the tools to construct software modules to provide the required capabilities for a full ITCM system.

Key Elements of Sustainment Engineering Operations

The 12 key elements characteristic of sustainment engineering operations that were identified at the end of Chapter 2 can be summarized briefly: The sustainment engineering mission requires that a great many independent, complex tasks must be planned and performed quickly under extremely uncertain conditions and unpredictable resource levels and must be coordinated with a large number of organizations both within and outside of the military engineering community.

Even though a single theater construction project is generally simple by commercial construction standards, sustainment engineering is a very complex endeavor taken across a support area comprised of numerous projects. Planners require considerable amounts of information to support the development of project details not typically considered in commercial construction. This includes regional information regarding infrastructure, climate, terrain, enemy posture, host nation resources, and relevant treaties, laws, and regulations. It includes engineering, geographic, and technical data. It includes force structure data, operations schedules, and standard procedures. The information may be in the form of text, electronic databases, tables, charts, graphs, maps, pictures, videos, etc. A large portion of the planning process involves simply gathering and digesting the necessary information. High speed data storage devices and hypermedia information management technologies are available to help process online information. The scope and quality of online information itself is expanding rapidly in all directions.

As stated in Chapter 3, the information included in AFCS is an invaluable source of facility data. While AFCS provides a standard set of facilities from which to begin a facility planning process, adjustments must be made to account for local conditions, time constraints, and the availability of resources. Currently these adjustments are made by hand calculations as the need for them arises. These adjustments have information requirements regarding regional conditions, resources, and the sensitivity of the LEE and BOM data to the impact of climate and terrain. The adjustments to the original data and the assumptions involved in making them tend to be lost since planners lack an easy-to-use mechanism to record them. Engineer staffs also lack a good way to record the alternative courses of action considered as the project proceeds from planning to execution.

The requirement for carefully recording as many details about each project as possible is needed to support the more difficult tasks of managing a large number of simultaneous projects with multiple levels of dependencies and of coordinating the use of limited resources to accomplish them in an environment of constantly changing priorities and resource levels. Good planning requires that the project objectives and assumptions be known and checked frequently against evolving conditions. In the typical wartime situation, project responsibility will move along the chain of command through the hands of many decisionmakers, and no single person will know or remember all of the details. An automated system should support documenting these project details in a noncumbersome way so that decisions are made with full knowledge of what has been decided previously. Ultimately, the system itself should be able to detect

inconsistencies. At the very least, projects should be linked to the top-level objectives they were designed to meet so that changes in top-level objectives rapidly filter down to project decisions and progress on individual projects rolls up to a measure of progress on the overall objective. This is far more than current project management systems are capable of doing.

Project management systems using CPM/PERT methodologies are not adequate for the dynamic conditions of theater construction. CPM/PERT methods were created to manage single large projects having multiple parallel streams of development. The original uses of CPM/PERT were to coordinate work being done by independent contractors. The method concentrates on identifying tasks critical to the completion of the overall project within a predetermined time and treats resources secondarily. Also, it assumes that all tasks are required and does not provide any way to represent alternative courses of action and the conditions under which a specific course of action might be taken. Tasks have only a predecessor/successor relationship, which is not flexible enough to represent tasks which are spatially related (order of performance is inconsequential, but work cannot be done simultaneously because crews interfere with each other); tasks that are scheduled on the basis of safety and/or efficiency (for example, pouring concrete or blasting only at certain times of day); or alternative tasks from which one is chosen according to a stated condition at the time of performance. Finally, CPM/PERT methods do not handle change well; any change in the original plan requires that the entire network be reworked.

The CPM approach to project management is so prevalent that the idea of integrating resource management as an equal function seems almost unnatural. Yet the case histories cited in Chapter 2 indicate that resource planning and management are primary functions of EAC staffs. Determining the engineer force structure required for meeting mission requirements is one of the most difficult tasks in the predeployment stage. Arranging for transportation, leasing of equipment, scheduling maintenance and repair, and adjusting project schedules to account for equipment limitations are all activities which rely as much or more on resource management functions as on project management functions. Limited supply inventories and unpredictable supply deliveries through local procurements are major reasons for adjusting facility designs and schedules. At some point in the supply cycle, engineers assume responsibility for managing material inventories. Indeed, the extreme limitations on Class IV supplies are frequently the deciding factor in determining whether a project is even scheduled or not. In theater construction, determining what must be done is so intimately connected with what is available to do it that any good model of the process must treat project management and resource management as one integrated whole.

The processes of project and resource management at any specific unit level could be handled, though perhaps not without a great deal of human effort, by traditional methods. But the requirement to communicate project and resource information across multiple command levels places stringent conditions on the structures used and the consistency of the functions that operate on them. In a given theater each level of the command hierarchy uses data relevant to the same assigned mission, but that data varies in its resolution and use at each level of the hierarchy. The hierarchical decomposition of the entities, attributes, and functions related to EAC operations is the key to the structural design of ITCM. These issues will be discussed in the following section.

The Hierarchical Structure of the Problem Area

The sustainment engineering effort in a theater is inherently an effort of many contributors at various echelon levels. The actions take place within a time continuum, adapting to respond to a continuously changing environment. This section will focus on the hierarchical nature of the activities, and the fact that they change as the effort matures. For the purposes of this study three generic task levels were identified: strategic, operational, and project.

While many aspects of the Army organization and warfighting doctrine may change over time, the generic requirements of performing fundamental tasks from the strategic, operational, and project perspective will remain, regardless of who will be charged with responsibility for them. The functionality of ITCM should allow for the reassignment of generic tasks to the relevant unit (which may change over time).

The focal areas of the hierarchical levels, which are shown in Figure 2, are now compared and contrasted without descending to a level of unnecessary detail. At the strategic level, plans are initially developed about goals and mission requirements for sustainment engineering based on directives of the Theater Commander. To satisfy the goal and mission requirements (which contain many temporal constraints) plans about force organization and resource acquisition and allocation must be made within an assumed scenario (set of assumptions and knowledge about the theater infrastructure, terrain, and environment) while making priority trade-offs, based on limited resources. From the resource plans follow the logistical requirements. Schedules and timetables are further derived taking into account the temporal mission constraints.

At the operational level the focus is on the sustainment engineering activities required to support the strategic goals. The emphasis is on the list of facilities to be provided (at carefully selected locations) and other tasks to be performed, given the timetables derived from the higher level requirements. Specific resources have to be identified and assigned to specific tasks. Supply inventories have to be projected and monitored. Overall progress of the work and the productivity and well-being of the performing units must be monitored. The local weather, geography, and other relevant conditions must be taken into account for making projections of future requirements and work.

Project level concerns include the design of facilities, or adaptation of designs and specifications to local conditions, and an estimate of required materials and labor. Once assigned to the performing unit, its leader must make an analysis of the required work, usually in terms of a work breakdown structure, and schedule the tasks to comply with required timelines. Tasks are assigned to individuals, or groups of individuals, who are responsible for performing the work.

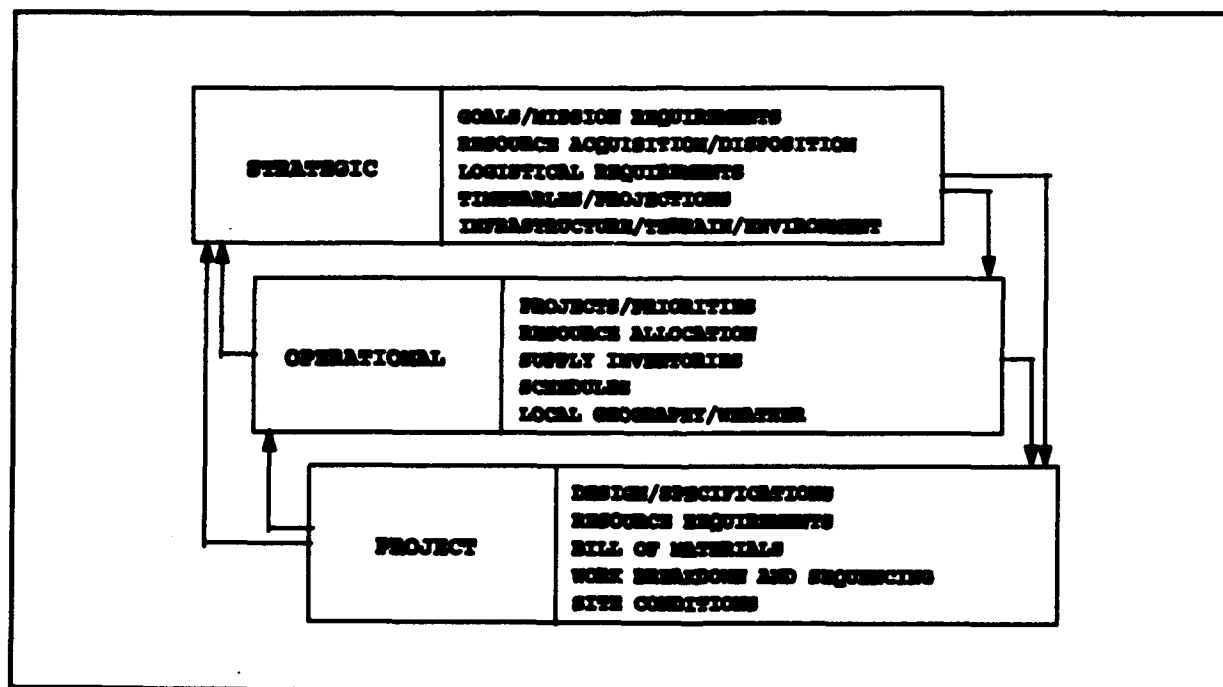


Figure 2. Levels of Planning/Management.

This brief description of the three hierarchical levels highlights the distinct differences in the focus of each level. Yet, from the theater point of view, it is a unified process serving to accomplish the sustainment engineering mission. To provide the needed unification of the support provided at the various levels, a consistency of data is required across the hierarchical levels.

Data Consistency

Different levels in the hierarchy must be connected by a consistency of data. For example, uncertainty about the amount of Class IV material at the strategic level may be reduced by a more detailed analysis of the number and type of facilities needed at the operational level. Uncertainty about the quantity of material needed for a site-adapted facility must be determined at the project level. The roll-up of information from one level to the next must be effortless and correct.

Data consistency is required for a number of different capabilities. First, during initial strategic planning, it is desirable to use roll-ups of historical data to make the high level plans more accurate. It may also be necessary to perform recursions to arrive at the final plan. Second, once the strategic plan is finalized, the high-level plan should be decomposed into lower level goals in a manner that would allow roll-up of the subgoal data to the original one. This capability will enable more timely and accurate progress control. Third, data consistency is required to use the system as a wargaming simulator.

Taking initial strategic planning as an example, much of the information used in the planning process, as well as assumptions incorporated into the plans, are uncertain. Some of the uncertainty is due to inherent uncertainty about future theater conditions or occurrences, but a significant proportion of uncertainty is a result of the high-level information view used at the strategic phase. The latter type of uncertainty can be alleviated by moving down successive levels into a more detailed view of the information, through analysis, or historical information. Once historical information is available in a compatible format, the planner can accept historical data as the default, or check the analysis against historical data.

Consistency is similarly required for comparisons of initial plans with what is actually transpiring. Any significant discrepancy must be explained satisfactorily as to the cause, which typically will require analysis at levels more detailed than the discrepancy. To provide the needed detail, the fundamental input for the system must be at the lowest level performing unit. This assertion may be obvious to some readers, but since this is a drastic break with past practice, we offer the following discussion in its support.

Support for Performing Units

Current information systems used to support sustainment engineering, whether manual or automated, are primarily designed as upward reporting systems. In some cases there are numerous reporting systems, requiring a duplication of input. Also in many cases, by the very nature of the system, the person performing the input views the use of the information with suspicion, not knowing who will be using it or for what purpose. Our premise is that systems which are designed solely as upward reporting systems will fail in the long run, since the input will not be consistently reliable.

The solution is to design a system that will span the hierarchy levels and specifically provide planning and management support to the performing units. Only if the system is a tool to help the performing units perform their own tasks better will it be used in a manner resulting in consistently reliable data. The question then is: Does the performing unit need automated support in planning and managing tasks? Through a study performed by CPT Clarence Turner as part of the requirements for a

Master of Science degree in industrial engineering, ample evidence was found showing that performing units do indeed need automated support in planning and managing tasks. Appendix C contains excerpts from CPT Turner's study.

Evolving Hardware/Software Technologies

A big force driving the development of automated support for sustainment engineering is the potential for improved operations offered by the sheer number and power of new hardware and software technologies currently available or promised in the near future. Those current or emerging technologies expected to have an impact on ITCM are outlined below:

Hardware. A number of new products are currently on the market that greatly improve the speed, memory capacity, long-term data storage volume, high-speed communications, and portability of personal computers. These include 486-based notebook computers with 20 MB RAM memory and high-resolution color display, high-capacity removable hard drives, portable triple speed CD-ROM drives and optical disk drives with removable high-capacity disks, portable laser printers, GPS devices which link directly with mapping software, color digital cameras capable of direct image downloading, and high-speed modems. An entire set of these items could be packed in one small, lightweight case and easily transported. All of these items have come on the market within the past 5 years, and it is probably safe to say that they will be overtaken by more sophisticated equipment in a very short time. This trend of ever-improving and ever-expanding hardware options indicates that PCs offer a sound software platform upon which to build the ITCM application. While workstations may currently offer more computing power, they also come with an overhead of more complicated administration and training requirements. Experience with introducing the original TCMS into engineer units indicates that the simpler, more familiar PC is the more acceptable option.

Operating systems. The eventual victor in the operating systems war cannot be predicted as of this writing. Microsoft DOS™ has clearly failed to meet the memory demands of many current applications and the multiprocessing requirements of many users. Microsoft DOS™ with Windows 3.1 overcomes some of these limitations but cannot compete with the power and growing acceptance of UNIX. Microsoft Windows NT has been released only recently but appears to compete favorably with UNIX. In choosing an operating system at this point, technology will not be the deciding factor. The choice must be the system that has the most solid corporate backing. Microsoft's dominance of the software market and the almost universal acceptance of Windows 3.1 indicate that Windows NT and its still unreleased companions (Cairo and Chicago) will eventually claim the lead.

Applications development environments. Without a doubt, OOP is the only acceptable approach for new software development. OOP was designed to ease the development of large scale systems. One of its biggest advantages is the possibility for software reuse. Because of the availability of a large number of commercial C++ class libraries to support many of the functions required for the ITCM system, C++ has been selected as the programming language. Several strong C++ contenders include Borland and Microsoft. Indications are that Microsoft Visual C++ will be well supported by vendors producing C++ class libraries. It should also be the easiest to use in building applications for Microsoft's Windows-based operating systems.

Commercial C++ Class Libraries. The following packages offer capabilities that could be added to the ITCM system without the requirement for extensive programming. They are currently available for Windows 3.1 and will soon support Windows NT. Part of the ITCM research involves studying the degree of difficulty encountered in attempting to integrate all of these packages into one application.

Microsoft Visual Control Pack by Microsoft Corp., released 1993, offers 19 programming shortcuts for Windows including access to 3D interfaces, charting, and serial communications; allows the user to add multimedia or Windows for Pen Computing functionality by adding custom controls to Visual C++ or Visual Basic Toolbox.

Essential Graphics Chart (V.4.0) by South Mountain Software, Inc., released in 1992, provides DLL for adding 2D and 3D charts to Windows applications and allows use of chart library from any Windows API compatible language including C and C++.

TerraView for Windows by TerraLogics, Inc., released in 1991, provides object-oriented cartographic display tools designed to link to information in existing databases and to create new map-based systems; allows users to treat maps and data as objects and integrate mapping functionality into current applications.

ObjectStore for Windows (V.2.1) by Object Design, Inc., released in 1993, is an object-oriented, C++-based DBMS for implementing large-scale, data-intensive design applications.

Style for C++ for Windows by Software Ingenuities, Inc., released in 1992, provides a class library that manages all associations and links between C++ objects and facilitates building C++ applications; includes consistent paradigm, traversal functions, built-in traversal cycle protection and built-in integrity checking; supports object sequencing, multiple inheritance, recursive structures, user-defined condition handling and dynamic memory management.

Meijin++ (V.3.0) by Network Integrated Services, Inc., released in 1993, provides a C++ modeling and simulation class library that reduces complex models to collections of interacting entities to study behavior through simulation runs.

ObjectEngineering for Windows by ImageSoft, Inc., released in 1993, provides a C++ scientific class library, including numerical analysis, semi-persistent containers, discrete-event simulation, exception handling, signal processing and time series, statistical tests and random generators.

Rete++ by Haley Enterprise, Inc., released in 1993, uses the Rete Algorithm and C++ to integrate rules and objects. Rete++ extends the international object-oriented programming standard to support production-rule programming syntax. C++ applications can use Rete++ generated classes directly or can further subclass them as needed.

ImageMan (V.1.06) by Data Techniques, Inc., released in 1993, provides an object-oriented Windows library that allows developers to add advanced image display and print capabilities to Windows applications; allows applications to access all types of images with the same set of standard function calls; supports TIFF, PCX, EPS, Windows Metafile and bitmap formats.

The ITCM Concept

The ITCM system must serve a number of end users and therefore must be able to function in a distributed mode. Users with different staff positions at different locations on a network must be able to access ITCM functions as they require and share data effortlessly with other users. ITCM users must also be able to interface with other automated systems, especially for command and control and for logistics.

The complexity of the envisioned system would be difficult to manage using traditional software development techniques. The object-oriented paradigm, however, is well-suited for this type of problem.

While traditional programming methods treat functions and data as separate pieces, the object-oriented approach brings the two together to model the real-world system as closely as possible. The entities of the system are represented by objects with attributes (data) and behaviors (functions). The system itself is modeled by its collection of objects and their interactions with each other, represented as messages sent, received, and acted on. OOP features include inheritance, encapsulation, and polymorphism, all of which allow the system developer to build evermore complex classes of objects from simpler ones.

The object-oriented approach offers a solution to managing the multiple perspectives of the theater construction process. Each staff position and each level of the command chain looks at what is happening from its own unique point of view. From mission generation to project design, from force structuring to the assignment of labor and equipment to a project, from the management of supply inventories to the delivery of project materials, the object-oriented approach offers the potential of managing the complex interactions and relationships with relative ease.

The ease with which the object-oriented approach handles complex structures and behaviors means that the ITCM system can be designed so that users will be able to access the project and resource databases in ways that are not possible with relational databases. Difficult database queries that could not be handled in TCMS should be easy to implement in ITCM. An object-oriented database management system such as Objectstore provides the tools to build a persistent model of the sustainment engineering world and to access the data in powerful ways.

A key ingredient to simplifying the role of the end user is to build an intuitively natural interface with great reliance on graphical representation of the data. The use of C++ class libraries for building the graphical user interface will speed the system development process. As has already been suggested, displaying the "state of the world" with maps and using that mechanism to select objects of interest from the database should greatly simplify the user's interactions with the system. Unlike geographic information systems (GIS), which provide a shell in which databases may be embedded, the geographic functions of ITCM will be designed as a subordinate module, working with but not dominating the database functions.

The informational requirements of ITCM have already been mentioned above. High-volume storage devices, hypermedia information management technologies, and the growing base of electronic information all point to the possibility of adding online reference libraries to ITCM. In addition to gathering and storing data from other electronic sources, end users will be able to use digital cameras and photo CDs to build an online library of pictures that could be rapidly accessible.

Engineer teams regularly gather data about countries of interest. While visiting the country, they check the availability and condition of roads, bridges, and ports, determine host nation capabilities and material resources, and locate facilities that might be used to support military operations. With ITCM, the information gathered during these trips, even photos, could be stored electronically and linked with map positions, work plans, and supply inventories. ECMP under nation assistance programs could also be stored in a more comprehensive, organized way using ITCM's hypermedia information management. Appendix B contains a sample ECMP and illustrates how difficult it is to organize the information in a text-based format. With a portable computer system, outfitted with digital camera and Global Positioning System (GPS) device, an engineer team could build a comprehensive plan incorporating maps, photos, and preliminary designs and estimates. Collection and distribution of planning data could be done electronically, providing instant copies of pertinent information formatted for immediate implementation in the management portion of ITCM.

Facility designs are as important to ITCM as they are to the current TCMS. AFCS is the Army standard for theater of war facilities. It will remain the source for standard facility designs and data for

ITCM. The CADD functions required of ITCM will probably be provided by the MS-Windows version of AutoCAD. ITCM must have functions to display AutoCAD drawings, overlay redlining, and manage the storage and retrieval of files and their linkage with projects. Experience with TCMS indicated that the project design process is so time and labor intensive that a separate machine must be available to accommodate it. The ITCM system will be built on the premise that basic project data will be either imported from AFCS standard facilities or created externally and imported.

Commercial software such as CADD packages, presentation managers, word processors, or any other application that performs a function required for ITCM should be usable with ITCM if the standards for object linking and embedding are followed. Future software will be designed so integration with other systems is easier to accomplish than was possible with the software that was available for TCMS. ITCM will leverage commercial offerings wherever possible. But the tools in ITCM will move well beyond the database, hypermedia management, and graphical interfaces mentioned thus far.

The most difficult problem for ITCM revolves around the need to manage large numbers of both projects and resources in a dynamic environment. The standard CPM approach fails in that it subordinates resources to projects, and it cannot handle even the simplest change. A new methodology must be developed that models the human decisionmaking process. This will require adding intelligence to the object base of ITCM. It will also require adding simulation capabilities. The premise is that the objects of ITCM must be able to explore their evolutionary possibilities. Commercial C++ libraries exist to add simulation and expert system capabilities. The methods for structuring these tools to work together consistently have yet to be devised.

Envisioning the Future ITCM System

In 1990, Bill Gates, chairman of Microsoft, suggested that computers could place "information at your fingertips." He said that PC users should be able to access information "anywhere at anytime" through an icon-based graphical user interface. He demonstrated applications that used OLE, DDE, handwriting recognition, cellular communications, and multimedia. Those technologies are now in widespread use. Today, efforts focus on voice recognition, "smart assistant" professional workbenches, pocket-sized personal information managers, a nationwide information highway, and more.

With such rapid advances being made, it is difficult to imagine a function that a military engineer would perform that could not be assisted by the use of a computer. In the future, each soldier on the battlefield will have a PC, perhaps mounted in a helmet or in specially designed goggles. In the future, each commander will have a real-time view of the battlefield. And communications between command levels will be limited in speed only by the human beings at the receiving end of the transmissions. In this future world, military engineers will not be able to keep up with the pace of operations without their own set of computer tools. Those computer tools must be designed to serve as individualized systems capable of assisting each user with appropriate information and functions and of transmitting information to and from others.

Though each user will see the ITCM system from an individual perspective, all such views will have the same basic structure and differ only in emphasis, resolution, and scope. The structure of the typical ITCM tool set for the general end user is illustrated in Figure 3. Each user's system consists of a reconfigurable tool set that is organizationally integrated but addresses operations from the individual user's perspective. Some examples will help to illustrate the concept.

For example, the system will track a heavy equipment operator's schedule, provide GPS data for information about current location and destination, list instructions for each task with animated illustrations

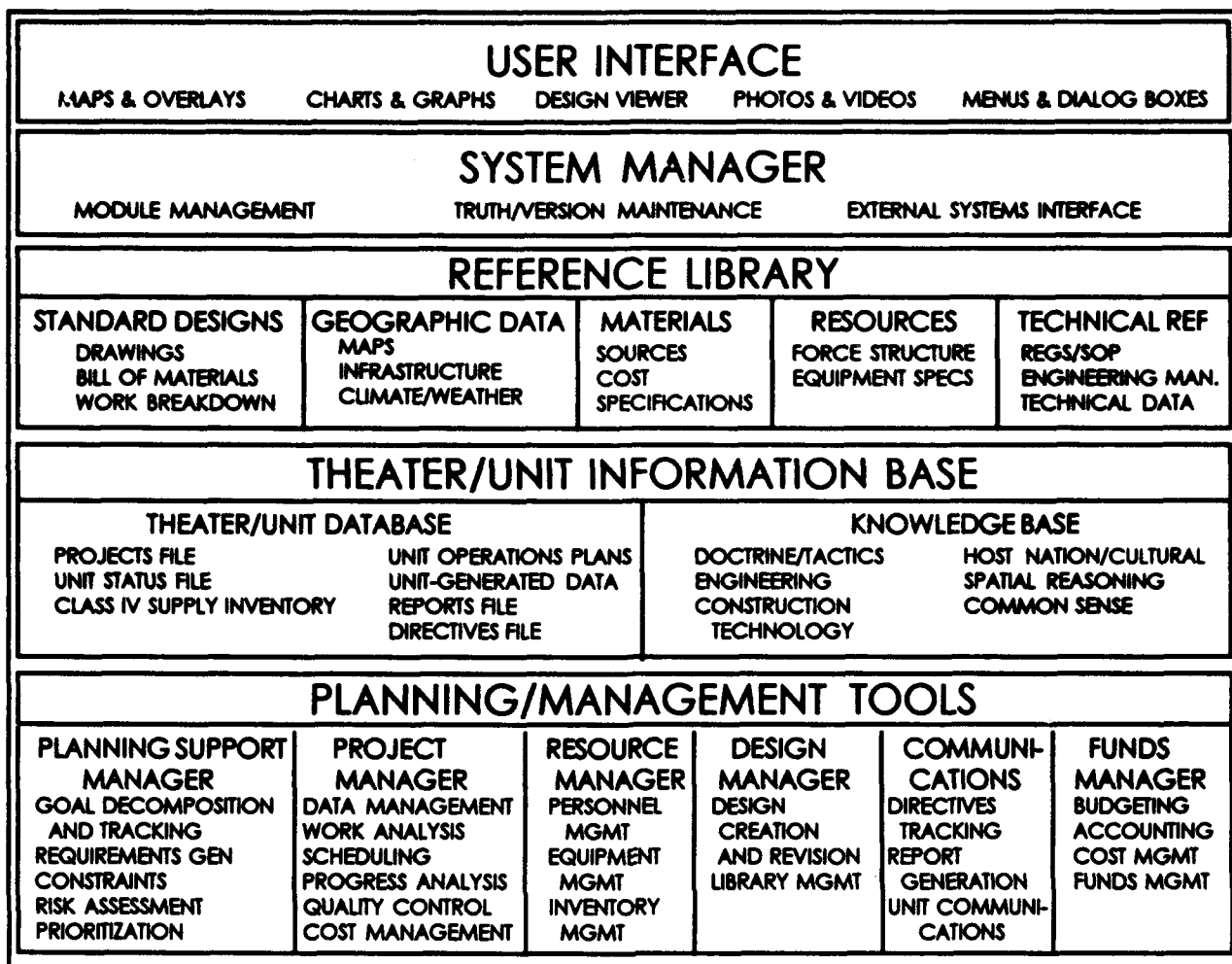


Figure 3. The ITCM System Concept.

available to resolve technical issues, provide information about equipment specifications and condition, and transmit status reports to appropriate headquarters staff members monitoring projects, personnel, equipment, and materials.

For a battalion commander, the system will track projects planned and in progress, report status of subordinate units, display the location of all pertinent entities on a digitized map, warn of projects that deviate from planned activities or progress, track inventories of Class IV materials and predict shortfalls, estimate future workloads, and permit wargaming of plans to identify potential trouble spots.

If the individual is the S4 in an ENCOM, the system will track supply requirements and inventories, predict future supply requirements, provide information for locating and procuring supplies in country, provide an interface with appropriate supply and transportation systems, and track supply transportation and delivery.

For the Army component representative on a joint engineer planning staff, the system will provide quick access to needed planning information (theater infrastructure, force capabilities, equipment specifications, facility requirements, etc.), allow strawman plans to be set up, documented, and wargamed, track fund allocations and civilian and host nation contracting, and adapt plans automatically to adjust to changing scenario requirements.

These examples are not exhaustive of the activities or responsibilities of the individuals cited, but they do indicate the wide range of functional capabilities that are still to be explored if ITCM is to accomplish its goal of providing an automated support system for EAC engineers in the next century.

These examples only hint at the problems to be overcome. While the examples indicate that each system would have the ability to communicate with other systems, they do not touch on the difficulties of the type of seamless integration that is envisioned for the ultimate ITCM system. While these examples indicate that tremendous amounts of information can be available to each user, they do not address the challenge of devising a user interface that does not overwhelm and confuse the individual. While the examples indicate that the system will provide functionality at all levels of command, they do not touch on the problems associated with the requirements for data consistency across multiple resolutions. All of these areas and more require further research if the ITCM system is to become a reality.

5 CONCLUSIONS AND RECOMMENDATIONS

This report has examined the organizations, functions, and working environment of sustainment engineering and has described how computers could be used to assist the planning and management of its operations. Sustainment engineering operations have several characteristics that determine the types of tools needed:

- Operations involve large numbers of equipment and personnel and a variety of technically complex tasks,
- Operations take place in a very dynamic environment, with frequent changes in missions, resources, and external conditions,
- The effective structuring and use of resources (i.e., personnel, equipment, materials, and funds) is a prime objective, on a par with the timely completion of missions,
- Coordination of activities and resources across multiple command levels and with nonmilitary organizations is crucial.

Current commercial software applications—database management systems, project management tools, CADD, electronic spreadsheets, wordprocessing, etc.—can assist with specific functions. But standalone applications generally do not work well with each other and place too much of a burden on the user to structure the information and manage its flow. USACERL's TCMS overcomes some of these problems by linking a set of commercial software packages with the AFCS databases to form a single menu-driven system that provides basic theater construction planning and management capabilities. As powerful as those capabilities are, TCMS has serious limitations (user interface, database accessibility, fragile architecture, CPM-based project management) and does not provide the type of automated support needed for the next century.

The automated support system that will result from the ITCM effort will be designed to have the following features:

- Graphical user interface, with extensive use of maps, charts, diagrams, photos, animation, and 3-D rendering
- Easy database access and manipulation
- Hypermedia information storage and retrieval
- An online reference library, including the AFCS databases, geographic information, and technical references
- A host of integrated tools to support mission planning, project design and management, and resource management
- Reconfigurable tool sets that are organizationally integrated but which address operations from the individual user's perspective.

Some of the developmental capabilities required for the ITCM system can be based on current software technologies. Others can be added as they mature through the efforts of academic and commercial researchers. These capabilities include:

- Computer networking
- Distributed object-oriented database management
- CADD and three-dimensional walk-through systems
- GIS
- Multimedia information management
- Computer visualization techniques.

The research required to make the ITCM system possible falls into several broad categories:

- The design of a suitable object base to meet the specific needs of the sustainment engineering mission area
- The design of the system's user interface and the investigation of methods for placing information at the fingertips without overwhelming the user with complexity
- The development of new project planning and management algorithms that are resource-based, adaptive, constraint sensitive, and hierarchically consistent
- The application of decision support theory, expert system methodologies, and simulation to assist in:
 - forming and documenting comprehensive operational plans
 - transitioning from long-range planning to crisis action C²
 - adapting plans to meet changing conditions
 - assessing alternatives and risks
 - forecasting future requirements
 - collecting and analyzing "lessons learned" data
- The exploration of new concepts for managing the time/reality continuum in automated management systems to permit the comparison of alternative futures and the analysis of variations between planned and actual operations.

Through expansion of knowledge in the areas identified in this report, the ITCM research will provide the software methods and tools to build the automated support that will be required by the fast pace of future combat and the demands that the increased tempo will place on the theater infrastructure that supports the warfighter.

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APPENDIX A: Mission Essential Task List

Introduction

Several documents from the U.S. Army Engineer School address the sustainment engineering mission essential task list (METL), which varies tremendously for each type of deployment. This appendix contains task lists for conventional warfare during a major regional contingency, for disaster relief efforts, and for nation assistance.

Major Regional Contingency

During a major regional contingency, the sustainment mission of combat engineers is divided into four categories: lines of communication, facilities, area damage control, and production of construction material. The entire METL for these four categories is outlined below. This list was developed by the U.S. Army Engineer School and was published in their *Master Plan for Sustainment Engineering Equipment* (February 1993).

1. Lines of communication (LOC): Responsibilities include the upgrade, maintenance and, when necessary, construction of LOC supporting the movement of personnel, equipment, and material over land, air, and water routes.
 - a. Construct and maintain road nets
 - (1) Upgrade and maintain existing road nets
 - (a) Evaluate existing roads
 - (b) Design road net improvements
 - (c) Upgrade existing roads
 - (d) Maintain existing roads
 - (2) Upgrade or construct new bridges
 - (a) Evaluate existing bridges
 - (b) Design bridge reinforcements
 - (c) Reinforce existing bridges
 - (d) Design standard fixed bridge replacement
 - (e) Construct standard fixed bridges
 - (f) Design nonstandard fixed bridge replacement
 - (g) Construct nonstandard fixed bridge
 - (h) Design bridge protective devices
 - (i) Construct bridge protective devices
 - (3) Construct new roads
 - (a) Conduct preliminary reconnaissance
 - (b) Conduct detailed survey and soils study
 - (c) Design new road
 - (d) Construct T/O road
 - (e) Surface the road as required
 - b. Upgrade, maintain, and construct airbases, airfields, and heliports
 - (1) Develop requirements for airbases, airfields, and heliports
 - (2) Runways, taxiways, and aprons
 - (a) Extend or construct
 - (b) Stabilize surface
 - (c) Install expedient surface

- (d) Pave critical areas
 - (e) Apply dust palliatives
 - (f) Provide drainage
 - (g) Provide clear zones and approaches
 - (h) Aircraft revetments
 - (i) Install aircraft arresting gear
 - (j) Install lighting
 - (k) Install electric power
 - (l) Mark runways
- (3) Airport and heliport facilities
 - (a) Flight operations facilities
 - (b) Navigational aids
 - (c) Refueling facilities
 - (d) Rearming facilities
 - (e) Maintenance facilities
 - (f) Cargo handling facilities
- (4) Airbase support facilities
 - (a) Air defense firing positions
 - (b) Personnel protective structures
 - (c) Billeting facilities
 - (d) Mess facilities
 - (e) Medical facilities
 - (f) Base security structures
 - (g) Base electrical system
 - (h) Base water system
 - (i) Base sewerage system
 - (j) Chemical, biological, and radiological decontamination structures
- c. Construct and maintain Over-The-Shore support facilities (part of logistics over the shore)
- d. Upgrade, maintain, and construct ports
 - (1) Harbor structures
 - (a) Channel improvements: Includes harbor bottom surveys, clearance of underwater obstacles, and dredging
 - (b) Piers and wharves
 - (c) Breakwaters, jetties, and headwalls
 - (d) Navigation aids
 - (e) Floating and underwater protective structures
 - (2) Shore structures
 - (a) Port operations facilities
 - (b) Bulk cargo handling facilities
 - (c) Container handling facilities
 - (d) Fuel storage and distribution
 - (e) Ship refueling and resupply
 - (f) Defensive structures
 - (g) Electric power
 - (h) Transportation marshalling areas
 - (3) Underwater structures
- e. Upgrade, maintain, and construct crosscountry pipelines including aboveground, underground, and underwater pipelines.
 - (1) System (storage and distribution) design
 - (2) Pipeline construction
 - (3) Pump station construction

- (4) Tank farm construction
 - (5) Protective structure construction
 - (6) Fire fighting systems installation
 - (7) Communication system installation
 - f. Upgrade and maintain inland waterways
 - (1) Bottom surveys
 - (2) Clearance of underwater obstacles
 - (3) Dredging
 - (4) Locks and dams
 - g. Assist in camouflage, concealment, and deception operations regarding LOC facilities.
 - h. Maintain railroads
 - (1) Track ballast
 - (2) Track ties
 - (3) Rail sections
 - (4) Rail bridges
2. **Facilities:** Responsibilities include the upgrade, maintenance, and, when necessary, construction of facilities supporting the sustainment of personnel and equipment. Included are the locating and development of water sources and the provisioning of electric power beyond that from tactical generators.
- a. Acquire, administer, and dispose of real estate
 - b. Upgrade, maintain, install electric power
 - (1) Provide power when not available
 - (2) Augment existing commercial power
 - (3) Repair, maintain, and operate fixed facility
 - c. Upgrade, maintain, construct supply facilities
 - (1) Covered storage
 - (a) Dry storage
 - (b) Cold storage
 - (2) Open storage
 - (a) Class III packaged products
 - (b) Class V
 - (c) All other classes
 - (3) Material handling/cargo transfer
 - (a) Break-bulk
 - (b) Trailer transfer
 - (4) Bulk petroleum storage and distribution
 - (a) System design
 - (b) Construction of storage tanks
 - (c) Construction of pumping facilities
 - (d) Construction of connecting pipes
 - (e) Construction of protective structures and fire fighting systems
 - d. Upgrade, maintain, construct maintenance facilities
 - (1) Covered structures
 - (a) Climate controlled
 - (b) Repair parts storage
 - (c) All others
 - (2) Hardstand facilities
 - e. Upgrade, maintain, construct medical facilities
 - (1) Hospital core (surgical, lab, etc.)

- (2) Patient wards
 - (3) Electrical system
 - (4) Potable water system
 - (5) Waste disposal systems
 - (a) Sanitary water
 - (b) Nonmedical solid waste
 - (c) Medical waste
 - f. Upgrade, maintain, construct billeting facilities
 - (1) U.S. forces
 - (a) Security fencing
 - (b) Antivehicular obstacles
 - (c) Guard towers
 - (d) Protective structures
 - (2) Prisoner of war
 - (a) Security fencing
 - (b) Antivehicular obstacles
 - (c) Guard towers
 - (d) Protective structures
 - (3) Displaced persons
 - (a) Security fencing
 - (b) Antivehicular obstacles
 - (c) Guard towers
 - (d) Protective structures
 - g. Upgrade, maintain, construct militarily significant facilities
 - (1) C² facilities
 - (2) Communication centers/nodes
 - (3) Air defense positions
 - h. Assist in camouflage, concealment, and deception operations regarding facilities
 - i. Assist in providing field services
 - (1) Surface water location and source development
 - (2) Subsurface water location and well drilling
 - (3) Laundry and bath facilities
 - (4) Ice production and storage
 - (5) Mortuary and temporary internment
 - (6) Establish and operate sanitary landfills
 - (7) Snow removal
 - (8) Decontamination sites
3. Area damage control: Responsibilities include the control and relief of both direct and indirect effects from natural and manmade disasters including war-related damage. Control includes those proactive measures taken to minimize damage. Relief includes emergency restoration of minimal services and operating capabilities.
- a. Structure reinforcement
 - b. Route opening and clearance
 - c. Structure opening and clearance
 - d. Casualty extraction and personnel rescue, especially from structures
 - e. Firefighting
 - (1) Structures
 - (2) Areas (petroleum and munitions storage, forests, etc.)
 - (3) Aircraft and vehicles

- f. Control of flooding
 - g. Assist in control of decontamination
 - h. Airbase battle damage repair
4. Production of construction material. Responsibilities include the production of construction materials from raw materials and delivery to the construction site.
- a. Crushed rock and aggregate
 - b. Construction water
 - c. Concrete
 - d. Lumber
 - e. Asphalt
 - f. Salvaged construction materials from existing, damaged, and destroyed structures.

Disaster Relief Mission Task List

FM 5-114, *Engineer Operations Short of War*, presents lists of the most likely tasks for military engineer units under a variety of disasters (flood, earthquake, tornado or hurricane, volcano, tidal wave, snowstorm, and forest fire)[pp 3-10-12]. While FM 5-114 presents a list for each disaster type, all tasks are included in the following general list:

1. Assist in evacuating threatened areas
2. Assess damage to roads, bridges, structure, utilities
3. Support search-and-rescue operations with personnel and equipment
4. Open roadways for emergency and medical traffic
5. Conduct topographic surveys for the extent of damage
6. Overprint maps to depict damage, key facilities, and relief activity locations
7. Construct temporary bridges
8. Provide emergency power
9. Clear debris
10. Demolish unsafe structures
11. Restore critical facilities, services, and utilities
12. Provide power to critical facilities
13. Provide expedient repair of critical distribution systems
14. Construct base camps
15. Transport critical supplies
16. Fight fires.

Nation Assistance Mission Task List

According to FM 5-114, nation assistance includes "all cooperative actions taken by the U.S. government and governments of other nations to promote internal development and the growth of institutions within those nations." (p 2-1) Exercise deployments and civic action projects are two nation assistance activities in which engineer troops are actually involved with planning and executing construction projects. Tasks associated with these activities are quite varied but generally fall into the following list:

1. Construct roads and bridges
2. Control damage from natural or man-made disasters

3. Produce construction materials (i.e., crushed rock, lumber, asphalt, and concrete)
4. Locate potable water sources
5. Construct and upgrade airfields
6. Drill wells
7. Provide diving teams for all types of operations
8. Design and manage construction of pipelines
9. Operate and maintain power plants
10. Manage forestry operations
11. Develop, rehabilitate, and maintain port facilities
12. Train host nation personnel in construction, operation, and maintenance of utilities
13. Train host nation personnel in firefighting
14. Provide topographic engineering support.

APPENDIX B: Sample 412th ENCOM Project Summary

The 412th ENCOM serves as an extension of the SOUTHCOM engineer staff and has participated in a number of country deployment teams working throughout Central and South America in nation assistance activities. A major part of the engineer effort involves conducting site inspections and preparing estimates for engineering projects. An example of an engineer estimate for one such project is cited below (quoted from "Reserve Engineer Command: Helping Latin America," by MAJ Robert Bottin and MAJ Jimmy Fowler, *Engineer*, November 1992, pp 5-10).

The sample report is thorough in specifying what must be done and why. As a narrative description, the report is well organized and comprehensive in providing project details. The sequential text presentation of this plan, however, necessarily mixes information about project goals, environment, equipment and materials, work breakdown, and operational procedures so that a complete reading of the report is required to gather all the information about any particular aspect of the project. The topics discussed in each section of the report are listed below in the right-hand column. This demonstrates how difficult it is to know and keep track of all of the information pertinent to any one aspect of the project. Important information about each topic is sprinkled throughout more than five pages of text. This information will tend to be lost or overlooked during the life of the project. In addition, the text of the report cannot supply the vast quantity of information that can be supplied by maps, photos, diagrams, and charts. A hypermedia approach to organizing and storing the information overcomes many limitations of the narrative approach and helps to express the information in a way that facilitates automating portions of the planning process.

Cano Blanco Road (Costa Rica) Project Summary

Topics within each section

1. Project Statement

a. Location. The project, which includes the improvement and construction of a road between Maryland and Parismina, is located in the Limon Province. Equipment could be shipped via sea transport to the Port of Limon. The equipment would then be hauled or conveyed along Highway 32 to Siquirres. At Siquirres, the convoy would take a gravel road to the site. This road is capable of supporting the maximum loads presented by the equipment. It should be noted that Del Monte has a large banana plantation located near the project, and uses the same route for large tractor-trailer units loaded with bananas.

Map data
Equipment transportation
Planning assumptions
Planning factors
Scheduling factors

b. Scope of Work

(1) The gravel road from Siquirres to Maryland has been improved to the point that it can support relatively large loads (approximately 84,000 pounds). The road has a wearing surface and is approximately 16 feet wide and capable of passing two large trucks. The road from Maryland to Cano Blanco is basically 7 kilometers (km) long and has a base 12 feet wide with no wearing surface. It is impossible to maintain. The project in this area requires adding a wearing surface and widening the road to 16 feet. The construction of 5 km of road from Cano Blanco to Parismina will entail clearing and constructing the roadway. This part of the project will need filter fabric placed prior to fill material.

Planning factors
Materials requirements
Design specifications
Work breakdown

(2) The road is important to the country because it opens a route to the Atlantic Ocean. According to Mr. Jose Chacundo, Assistant Director of the Ministry of Public Works and Transportation, construction of the road would:

Goal decomposition
Point of Contact

(a) Facilitate the construction of a small port on the Rio Parismina. This would provide a much closer and cost effective route for the shipment of agricultural products.

Goal decomposition

(b) Provide access to families living in the region. During the site visit, it was noted that many families live in the area, especially along the Rio Parismina. Mr. Chacundo stated that these people have to rely on horses and canoes for transportation.

Goal decomposition
Cultural information

(c) Open access to the town of Parismina. The town of Parismina is a tourist community, catering to tarpon and snook fishermen. The only access to the two is water taxi or small airplane.

Goal decomposition
Cultural information

(3) Mr. Chacundo stated that this road project is the number one priority for his country. It was determined that the local citizens desperately want this project. Several local residents met with the country team, expressed their desire for the project, and stayed with the team during the site investigation. The local people provided canoes, horses, and a power boat to visit the site.

Cultural information
Planning factors

c. Background. The project supports the ambassador's goal of strengthening people-to-people relations by providing economic development and modernization. The strategic objective of democratization and economic modernization would be supported, and the country would be favorably disposed to U.S. interests. These projects are supported by the local people and will modernize the infrastructure in the region as well as promote economic development.

Goal decomposition

2. Terrain and Weather

a. Site Characteristics

(1) **Geotechnical.** The area soils generally consist of clayey silts to sandy silts. The top 6 to 8 inches have a high organic content. It was noted during the investigation that, during the wet season, the top organic layer gets extremely muddy, making transportation very difficult. The soil approximately 8 inches below the surface is usually not permeated by the moisture and is capable of supporting light loads. Mr. Chacundo stated that in the dry season this silt dries out and will support extremely large loads.

Site conditions
Weather
Planning factors
Scheduling factors
Topographic information

(2) **Topographical.** The project is located on the coastal plain. Only minor variations in elevation are evident. The project will cross one manmade canal.

Map data
Planning factors
Scheduling factors
Topographic information

b. Weather

(1) **Temperature Variations.** The Caribbean region of Costa Rica is characterized by moderately high temperatures that vary only slightly throughout the year. Daytime temperatures range from 81 to 88 degrees Fahrenheit.

Weather
Planning factors

(2) **Expected Rainfall.** The mountain ranges that bisect the country block the rain-bearing northeast trade winds, causing heavy and continual rainfall in the Caribbean coastal area during the rainy season. Annual precipitation ranges from 35 to 60 inches. The wet season occurs from May through October and the dry season from January through April.

Weather
Planning factors
Climate

3. Execution

The project should be constructed in at least two phases. The first phase will be the improvement of 7 km of road between Maryland and Cano Blanco. The only borrow pit for this project is a river site located approximately 15 km from the beginning of the project. The first phase should be completed before the second phase is started because the road probably would not support the continual hauling of fill material and aggregate and would not allow the passage of two dump trucks (the road is approximately 12 feet wide). To adequately improve the roadway in phase one, 12 inches of loose aggregate (9 inches compacted) should be applied, and the roadway increased to 16 feet in width. When the roadway is expanded, the new base should be compacted with a pneumatic tire roller to 95 percent standard proctor. The aggregate for the wearing surface should be applied in 6-inch lifts and compacted with four passes of a vibratory roller. Once the aggregate surfacing is completed, the roadway should be final graded, and compacted with four passes of the pneumatic tire roller. The borrow area material is large river-run rock and will need to be crushed. The rock-crusher should probably be onsite at least one month prior to the heavy equipment.

The second phase of the project will involve the construction of a road between Cano Blanco and Parismina. The project will require the clearing of small vegetation (vines and grass) and large trees. The roadway will be constructed over several swampy areas ranging in size from 50 to 200 meters (m). Filter fabric should be used in these areas. A borrow pit about 5 km from Maryland will produce sand fill needed to construct the base. Approximately 24 inches of this fill will be required to raise the road above the natural ground. The sand fill should also be placed in 6-inch lifts and compacted with four passes of the vibratory roller. After four lifts have been placed, aggregate surfacing can commence. A crushed stone wearing surface of 15 inches loose (12 inches compacted) should be applied, as describe above.

Work breakdown
Map data
Materials acquisition
Materials requirements
Planning assumptions
Scheduling factors
Design specifications
Equipment requirements

Map data
Work breakdown
Planning factors
Topographic information
Materials requirements

4. Materials

a. General Bill of Materials

(1) First Phase. 13,000 cubic yards (cy) of aggregate will be needed to complete this phase. It is assumed that an additional 8000 cy of material will be needed to maintain the haul road, for a total of 21,000 cy. The aggregate should have a gradation of:

Total Percent by Weight, Passing Sieves					
2"	1-1/2"	3/4"	No. 4	No. 16	No. 100
100%	95-100%	65-95%	35-95%	35-55%	4-15%

A 10-foot section of 60-inch corrugated metal culvert is also needed to extend one culvert.

(2) Second Phase: 18,500 cy of fill material will be needed to construct the road base, and a total of 11,500 cy will be needed for the wearing surface. Approximately 11,500 cy of aggregate will also be needed to maintain the haul road, since hauling will be over the road constructed on the new base and some settling is anticipated. Total aggregate required is 23,000 cy, with the same gradation as in the first phase. A 40-meter bridge designed and acquired by the Costa Rican Government should be onsite. Approximately 1500 m of filter fabric, 24 feet wide, will be needed for construction through the swamps.

b. Source. All aggregate will come from a river borrow pit approximately 15 km from the start of the project. A small sand hill approximately 5 km from Maryland will provide all earth fill for the project. The culvert, bridge, and filter fabric will be provided by the Costa Rican government.

Materials requirements
Planning factors
Materials specifications

Materials requirements
Planning factors
Coordination requirements
Map data
Topographic information

Materials acquisition
Map data
Planning assumptions
Coordination requirements

5. Equipment

a. Military Inventory

(1) First Phase

<u>Type</u>	<u>Amount</u>	<u>Time Estimate</u> (Days)
Rock crusher	1	90
Front-end loader (5 cy)	3	60
D7E dozer	2	75
Motor grader	3	75
Tractor trailer	4	90
5-ton wrecker	1	90
Contact truck	1	90
Pneumatic tire roller	1	75
Vibratory roller	1	60
5-ton dump trucks	20	60

Work breakdown
Equipment requirements
Scheduling factors

(2) Second Phase

<u>Type</u>	<u>Amount</u>	<u>Time Estimate</u> (Days)
Rock-crusher	1	145
5-ton dump truck	20	120
Front-end loader (5 cy)	3	120
D7E dozer	4	145
Motor graders	4	145
RTO crane (20-ton)	1	30
Tractor trailers	5	160
5-ton wrecker	1	145
Contact truck	1	145
Concrete mixer	1	30
Pneumatic trailer and tools	1	30
Vibratory roller	1	145
Pneumatic tire roller	1	145

Work breakdown
Equipment requirements
Scheduling factors

(Note: Twenty dump trucks are projected and it is anticipated that at least 15 will be operational at all times. The time estimate is based on using 15 trucks.)

Planning assumptions

b. Nonmilitary Inventory. None.

c. *Fuel and Repair Parts.* Fuel can be obtained in Siquirres. Repair parts can be air delivered to San Jose and then delivered via truck to the project site.

Supply acquisition
Planning assumptions
Scheduling factors

6. Manpower.

a. Detailed Site Exploration/Project Design. No further site exploration is needed. The project design detailed in this report is sufficient to construct the project.

b. Type of Construction Skills. The project can be constructed by either a combat construction or combat construction heavy unit. The construction unit should be company size, augmented with additional heavy equipment operators from the battalion. The construction can be performed by Active, Guard, or Reserve units on 2- or 3-week rotations (preferably 3 week). Total time required from deployment through redeployment is 90 days for phase 1, and 145 days for phase 2. Key officers and noncommissioned officers should overlap rotations by at least 3 days for continuity of operations.

c. Types of Support Skills. The construction troops should be augmented by organic maintenance and mess personnel. The company should have personnel with local purchase order authority, and the battalion's maintenance section should be added. A Costa Rican security force should be assigned for base security operations. A water purification team with a reverse osmosis water purification unit must be onsite to provide potable water.

7. Time.

a. Project Design. No further project design is required for the first phase. The second phase will require that the Costa Rican government design a bridge to span the manmade canal.

b. Material Acquisition. The rock crusher should operate from December through April so that adequate supplies of rock are available. The rock crusher should be onsite approximately 1 month prior to the arrival of construction troops in order to have a stockpile of aggregate at the start of construction. The crusher should operate continually through construction so that a stockpile of material can be left for the local maintenance crews. The Costa Rican government will need sufficient time to design and procure a bridge.

c. Equipment Acquisition. Equipment can be shipped via sea to the Port of Limon and then transported overland to the project site.

d. Support Facilities Construction. A basecamp should be constructed by the battalion's vertical section, with construction taking approximately 7 days.

Planning assumptions
Design specifications

Planning assumptions
Planning factors
Scheduling information
Personnel requirements
Unit support information

Planning factors
Personnel requirements
Unit support information

Coordination requirements
Design specifications

Equipment requirements
Scheduling factors
Work breakdown
Materials acquisition
Coordination requirements

Equipment transportation
Map data
Scheduling factors
Unit support
Scheduling factors

8. Summary/conclusions.

a. The first phase of the project lends itself to troop construction. Equipment can be easily transported to the project. The project is not complicated and could be constructed by almost any engineer unit.

Planning assumption
Equipment transportation

b. The second phase of the project lends itself to troop construction; however, this phase of the project should be ended at the man-made canal. As stated in the time estimate, this entire phase should take approximately 145 days to complete. By stopping the phase at the canal, the time estimate is decreased to approximately 80 days.

Scheduling factors
Planning assumptions

APPENDIX C: Adaptive, Multi-resolution Modeling of Construction Plan

Francois Grobler, Carol Subick*

Abstract

The process of developing a construction plan is complex, taking many considerations and constraints into account. In contrast, the CPM paradigm of planning allows only the results of the planning process to be recorded from an activity-duration point of view. Any change in the numerous factors that can impact the plan virtually nullifies the intelligence embedded in the CPM network, forcing a reconstruction of the plan based only on human recollection of the original considerations. CPM's inherent activity-duration orientation provides weak support for the construction manager's most vexing problem: how to coordinate resources effectively. The approach proposed here is intended to provide a richer means of recording planning considerations, in a planning and tracking system based on a resource-task orientation, and aimed at multiproject, multilevel management.

Introduction

The proposition that the use of formal planning techniques in construction produces numerous advantages is almost universally accepted. How the planning should be performed, and what planning tools to use, are questions with a variety of answers, depending on who is asked. While CPM has been recognized as the dominant planning tool, its limitations have been all too obvious. We believe that a quantum leap can be made in planning and control capability with adaptive, multiresolution modeling of construction plans.

Limitations of the CPM Planning Approach

In the dynamics of real-world construction, even the best laid plans change continually during the course of a project. Construction managers may be faced with choosing from alternative courses of action at any point in time. The choices to be made depend on a large number of factors including not only those that affect the day-to-day schedule of activities of the original plan (weather, material availability, interference with other crews, temporary labor or equipment shortages, etc.) but also those that arise from evolutionary shifts in the goals and priorities of the project itself and of the organization responsible for its completion. The ability to assess and manage these alternatives and to incorporate them into an ongoing planning and control process plays an essential role in accomplishing the multiple objectives of the construction manager, especially in optimizing the use of labor and equipment resources, completing projects on time, controlling costs, and assuring quality.

Network-based tools using CPM/PERT methodologies have been the traditional starting point for computerized systems designed to support the construction management process. Such systems focus primarily on the sequencing and duration of the subtasks of a project with the goal of scheduling resources and controlling costs to meet a certain completion date. The limitations of CPM/PERT as a planning tool—indeed, even its suitability as a model of the construction process—have long been realized and widely discussed in the literature (Arditi 1983), (Birrell 1980), (Davis 1974), (Levitt, et al., 1988).

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From its earliest uses in a manual form, CPM has been criticized for being too rigid in its requirements to identify a single breakdown of tasks for a project and to determine their logical sequencing and duration times. The CPM model is not robust enough to handle multiple alternatives in the task breakdown and sequencing or to adequately account for variations in task duration that result from unpredictable external factors. And even though the CPM network provides a simpler approach to representing the project structure than one that would take these uncertainties into account, the benefits of modifying a CPM network to adapt to changing conditions tend to be outweighed by the level of time, effort, and expert knowledge required. As a result, CPM tools do not move naturally into the control phase of a project and are frequently abandoned after initial planning.

Computerized CPM-based management tools have eased some of the mechanics of preparation and update, but limitations still abound and expectations have increased. As a single project planning tool, the CPM framework fails to capture the knowledge used to build the initial network or to adjust it as conditions change. This is a fundamental flaw if the computer-based tools are to meet the construction industry's expectations that they will ultimately be able to support the generation of project plans, to move seamlessly from planning to control, and to reuse past knowledge and experience to improve present operations.

Perhaps a more fundamental question, however, is whether the CPM network analysis methodology provides a suitable framework upon which to build an automated model of the construction management process. First, CPM focuses on a single project and does not readily scale up to handle multiple projects in a single framework. Second, CPM's goal of meeting a project completion deadline takes precedence over the construction management goals of using resources efficiently and controlling costs. Third, CPM network sequencing, being task related rather than resource related, is extremely limited in the dependency relationships that can be represented and manipulated in an automated fashion.

Adaptive, Multi-Resolution Model

A new conceptual approach was developed to fit the real-world construction model better. The main features of the model are introduced here, and further discussed in the following sections. We propose that projects are decomposed in successive hierarchies of tasks and attached abstract resources, with the tracking of performance metrics and constraints between levels, and between tasks in one level—thus providing consistent methods to aggregate control data at different levels of resolution. At the leaf level of the breakdown structure, dynamic task sequencing is performed from an individual resource perspective, based on a survey of the existing environment, and active constraints, in an inherently adaptive system. The constraints may include temporal, spatial, and resource constraints, and preferences, priorities, etc. Step-wise simulation can be performed directly on the project model to analyze the effects of actual, or anticipated conditions, or alternative actions. This approach is made possible by a unified model underlying the views of the project available to the manager, and others.

The fundamental differences between this approach and existing ones, is that it not only records activity logic, but also other important considerations, and constraints, in a hierarchical fashion, and that task sequencing is performed at the resource level, from a resource perspective in compliance with the relevant current constraints rather than from an activity logic basis only. It also handles multiple projects elegantly, since the list of tasks to be sequenced for each resource may include tasks from multiple projects.

Whereas the approach will use elements of knowledge-based system support, our philosophy is to let the computer "remember," and track, rather than attempt to supplant the human user in the more creative aspects of planning. Our approach will aid the user in planning, by recording and retrieving

relevant information during the planning process, and lighten the burden of adapting plans as the project unfolds—even propose regenerated schedules, based on the previously recorded planning considerations.

The concepts of the model are now addressed under the headings of: elements of plans, decomposition of goals; multi-level plans; task sequencing; plan adaptation.

Elements of Plans

For the purposes of this discussion, plans are represented by sets of tasks (the completion of which will produce effects which in turn will realize a goal) that are mapped to sets of resources (sourced from an appropriate resource pool, organizational structure, etc.). The mappings imply a specific method, or technique, which in turn results in a specific duration, cost, quality, and safety of the effort. The mappings further take place within a specific environment. These concepts are depicted in Figure C1.

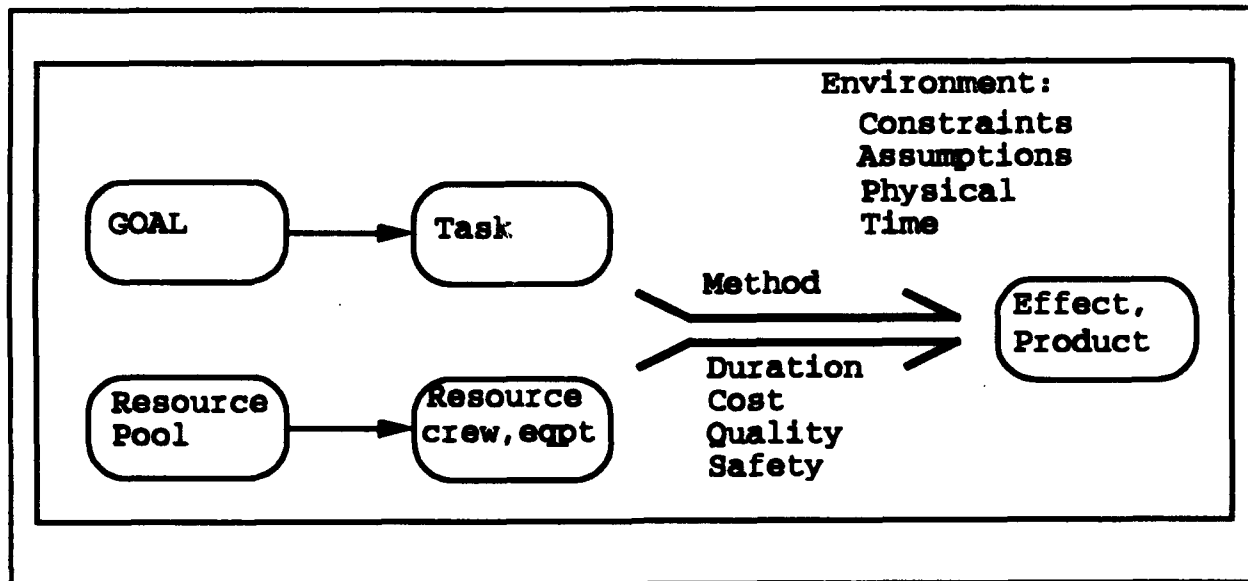


Figure C1. Elements of Plans.

Decomposition of Goals

In planning in general, a decomposition of the original goal takes place to create a hierarchy of subgoals. The decomposition continues to a level where the leaf subgoals can be mapped to a resource, as described above. It should be noted that the "leaf level" is arbitrary, and dictated by custom and preference. In construction practical considerations determine that the leaf level is at the crew level. A consequence of considering the crew level is that the duration of a union of task and resource can be predicted if a reliable productivity rate is available. Since the single resource performs the tasks assigned to it sequentially, these durations can be simply summed. To determine duration of subgoals at higher levels in the hierarchy, such simple summations cannot be performed because of concurrency in the execution of tasks.

The question of evaluation of subgoals in terms of criteria for performance set for the goal can not be fully dealt with in the scope of this paper. It will form the topic of a future paper. But it can be

briefly stated that we propose in the process of decomposition to explicitly record the metrics to evaluate subgoals in terms of the performance criteria for the goal.

The process of decomposition is currently practiced in construction in the creation of a work breakdown structure (WBS). We consider it a very important process, where many of the key construction decisions are made. Unfortunately, the considerations that caused a particular WBS to be adopted, as well as the constraints and assumptions that led to it, are not recorded.

These considerations, constraints, and assumptions exist in each level of decomposition, as well as between peer subgoals within a level. The logic constraints of traditional CPM models are of the latter nature. Indeed, if no other constraints are recorded, our model has the appearance of a CPM network, at a given level in the hierarchy.

The process of decomposition is depicted in Figure C2.

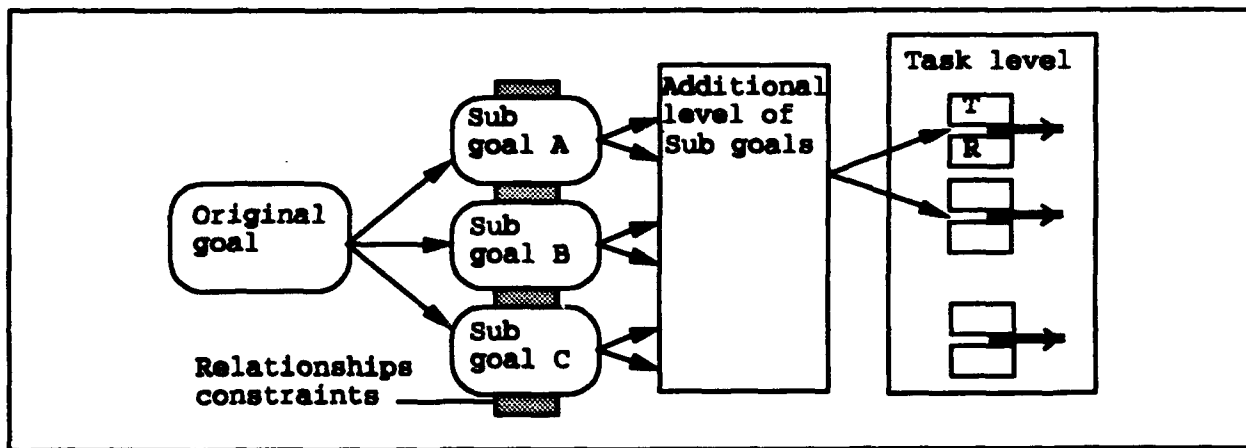


Figure C2. Decomposition.

Multi-level Plans

Our model envisions a hierarchy of goals and a hierarchy of resources that contain the considerations, constraints, and assumptions discussed above. In the planning mode, higher level (conceptual) resources are assigned to subgoals at the appropriate level. Figure C3 shows the multilevel plan concept, and illustrates the mapping of subgoal 3,1 to the resource 3,3. This is analogous to assigning all masonry work to a subcontractor. Eventually tasks are to be assigned (mapped) to individual resources at the leaf level. In Figure C3 tasks at the leaf level, n1 and n2, are both mapped to the resource n3. Performance at the leaf level can be rolled up in a pre-established manner and evaluated in terms of the pre-established metrics, thus making possible consistent, multiresolution modeling of the project.

The multilevel plan exists within a set of project assumptions and constraints, and must conform to project resource capacities. It is also subject to numerous environmental factors, as shown in Figure C3. To the degree the influence of these factors is recorded in the other elements of the plan, they can be taken into account in the dynamic resequencing of tasks. This scheduling process is based on the Deck-of-Cards (DOC) paradigm, and will be explained further in the next section.

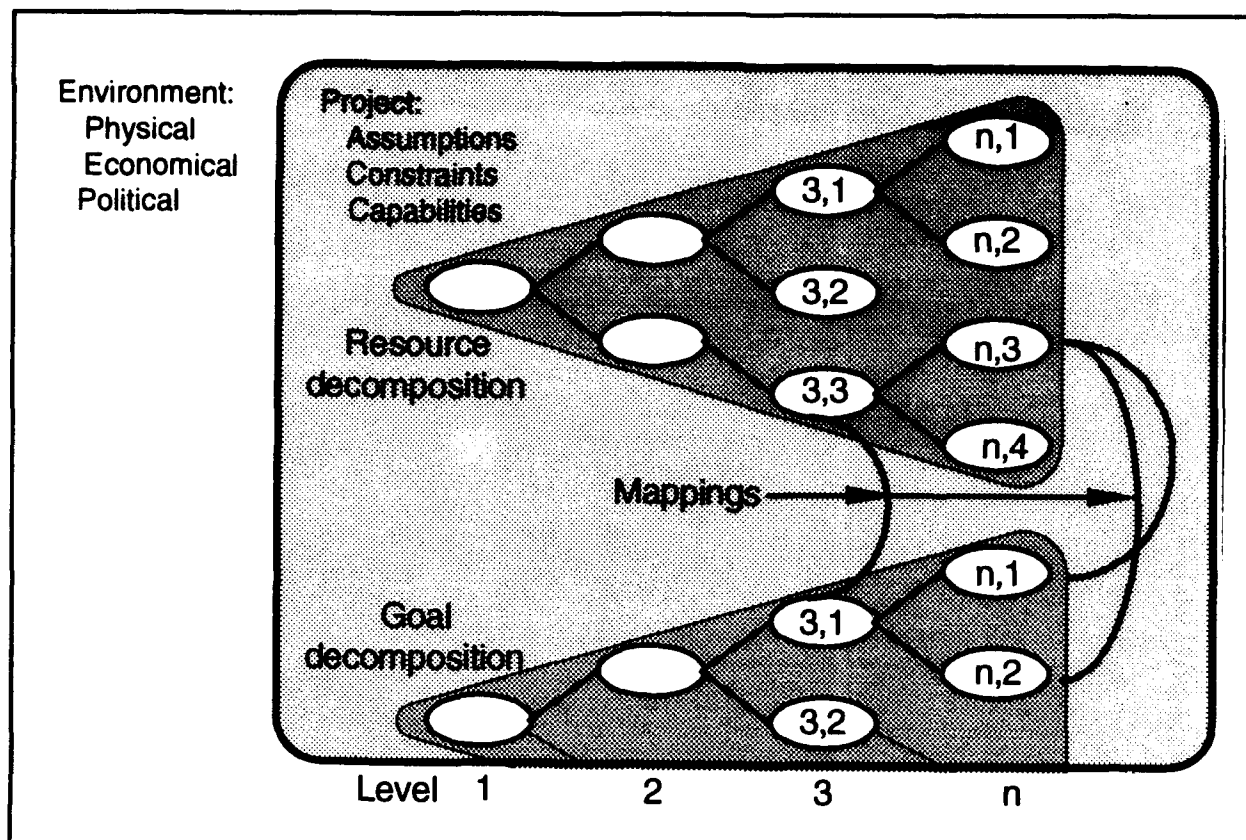


Figure C3. Multi-level Plan.

This multilevel approach allows for the rather convenient accommodation of multiple projects, where multiple projects are represented by branches of the hierarchy, while recording the cross-project constraints in the same manner other constraints are handled. These multiple projects are intended to reside within a geographic context (being represented in a geographical information system [GIS]) in order to allow for reasoning about questions such as the effort and time required to move a piece of equipment from one site to another.

Sequencing of Tasks

The simple but useful DOC paradigm is depicted by Figure C4. All the tasks assigned to an individual crew must comply with the constraints set by earlier assignments, i.e., in this example the subcontracted masonry work is now further decomposed into individual tasks by the subcontractor, as assigned to its individual crews. Figure C4 shows that mason crew C is instantiated for the conceptual crew n3 in Figure C3, and that crew C has tasks Y1 through Y5 in its "deck of cards."

In card games, there are rules of how the deck in hand may be ordered. Analogously, the list of tasks assigned to crew C may be reordered only within the constraints attached to each task. (It was alluded to earlier that if activity logic constraints are attached to tasks, and none of the other important constraints, this approach will generate the equivalent of a CPM schedule.) The effect of the DOC approach is that resources have the autonomy to sequence the tasks from the resource point of view, while complying with the constraints linking their tasks with other tasks, resources, and other constraints. Although not shown, resources may have certain constraints attached, too, such as policy considerations to guide how a resource should sequence its tasks.

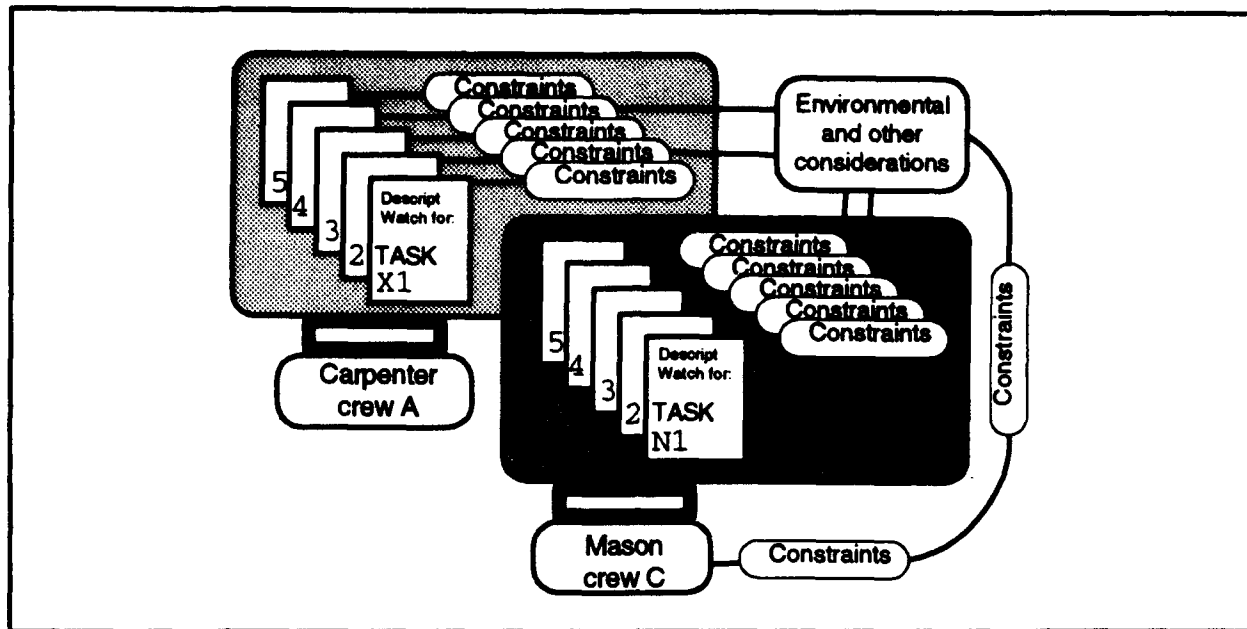


Figure C4. Deck-of-Cards Paradigm.

This approach is fundamentally different from other knowledge-based approaches to scheduling in that no activity logic network is created. Except for the Ghost system, all other research prototypes reduce their considerations to a logic network that is then processed by what is often called a CPM-kernel. An example of such a system is described by Echeverry (1991).

Recent developments in personal information management (PIF) software are beginning to provide the capability to consider a list of "to-do's" that are linked to other elements of concern. Packrat™ and ManagePro™ are examples of such systems. Our prototype is planned to function in some ways like a PIF for each of the members of the construction team, allowing each member (down to the crew level) to take control of sequencing its own responsibilities, yet to do so in a manner compatible with the requirements of other members. It is expected that with the value this system will add to the job, each member will have an incentive to use it productively rather than seeing it as an upward reporting burden.

Project progress and cost control can be significantly enhanced if crew members directly report progress at the task level, described by Grobler (1988). The crew rhythm problem (Melin 1989) can be solved easily.

Adaptation of Plans

The environment in which the project is performed, the project itself, and the resources to perform it are continuously changing. Since these considerations are reflected, to some extent, in the constraints attached to the tasks and recorded elsewhere, the system can dynamically resequence the tasks for each resource when conditions change. If rain prevents a crew from performing a certain task, that task is simply shoved further back in the deck, and the crew continues with what can be done next, as determined in compliance with the relevant constraints.

Conclusion

This paper first reviewed the limitations of CPM as a paradigm for planning and control of real world projects, and then proposed a new approach to overcome these limitations. The main part of the paper described the concepts of adaptive, multiresolution modeling of construction plans and how such plans are used in project control. It also briefly described our plans with our prototype system, which is currently being implemented.

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APPENDIX D: Excerpts From a Study of Factors That Affect Troop Construction Tasks Below Platoon Level

This appendix contain excerpts from a study performed by CPT Clarence D. Turner as part of the requirements for a Master of Science degree in Industrial Engineering at Wichita State University, Wichita, KS. CPT Turner has gained considerable experience through his leadership of troop construction all over the world. Based on personal experience with the perceived shortcomings in the available tools, he chose to study the effectiveness of current planning techniques as applied below platoon level.

The significance of this study from the perspective of this technical report lies in his conclusions that even the relatively simple tasks at the leaf level of the goal decomposition trees can benefit from planning support. Respondents do not always understand how their tasks fit into the "big picture," and therefore have difficulty in making appropriate tradeoffs.

Abstract

AN ANALYSIS OF FACTORS THAT AFFECT THE ADAPTATION OF TROOP CONSTRUCTION TASKS BELOW PLATOON LEVEL

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The Wichita State University, 1993

The purpose of this study was to document the factors that affect the adaptation of Troop Construction Tasks (TCTs) below platoon level and to determine if the current project management techniques used by troop construction units are effective below platoon level. A sample of 38 junior engineer noncommissioned officers from 20 U.S. Army Installations worldwide participated in this study. A survey response rate of 97.3 percent was achieved.

A 20-item survey instrument indicated that constraints and conditions did affect the adaptation of troop construction tasks below platoon level. The constraints and conditions that accounted for 50.7 percent of the adaptation of troop construction tasks were: weather, material availability, equipment availability, and manpower availability, in that order. An analysis of variance did not denote any significant difference among the 51 and 62 series military occupational specialties evaluations of the 18 variables (factors) derived in this study. A t-test measured differences in group means on the 18 dependent variables (factors) used in this study for the groups 51 and 62 series military occupational specialties. A significant difference exists in one variable (material splitting) with a $p=0.029$.

The study showed that the current project management technique is not effective below platoon level and a need exists for a project management tool that can plan and control tasks based on the factors associated with the resource that is responsible for the tasks.

INTRODUCTION

Military troop construction leaders use the critical path method (CPM) paradigm as a planning tool. This paradigm was developed during the late fifties. This network-based planning tool is used to schedule

troop construction tasks based primarily on task-dependency. There is a need for a project management tool that will schedule troop construction tasks (TCTs) below platoon level (BPL) based not only on task dependency but environmental constraints and considerations as well. Additionally, this tool must be able to reschedule tasks based on the same criteria.

Once tasks are assigned to crews, the order of performing these tasks could be cast as a constraint satisfaction problem. The environmental factors force the planning and controlling of tasks from a resource point of view, while acknowledging the constraints, conditions, and priorities which link tasks with other tasks, resources, constraints, and conditions. The behavioral aspects of these factors in most cases are not available and must be sought out. This research will focus on developing this information. Throughout this research, resources will be classified as: crews or teams, squads, sections, and platoons. For example, a typical vertical engineering squad consists of carpenters/masons, electricians, plumbers, a five-ton dump truck, tools, and accessories.

CPM does not provide troop construction leaders below platoon level solutions on how to plan and control resources effectively. There is a need for a construction management tool that can plan and track tasks from a resource point of view. This tool must inherently consider the constraints associated with each resource.

This research will examine CPM's applicability for planning and controlling tasks in the real world troop construction environment BPL. CPM does not allow troop construction managers BPL the latitude to plan and track. Therefore, it offers little support during the control phase of the project.

The forward and backward pass scheduling of tasks with CPM is useful for a single project, with unlimited resources, in a controllable environment. Military troop construction leaders are often responsible for many projects, are faced with limited resources, and have little control over environmental factors. Therefore, this research will examine why the classical planning technique "CPM" is quickly abandoned when constraints or conditions such as weather or priority shifts occur during the control phase of a task. Troop construction managers usually refer to an isolated informal rescheduling of tasks at a resource level, when such a situation occurs. The rescheduling of a task often stems from a constrained resource or a change in environmental conditions.

Grobler and Subick (1993) discuss the limitations of CPM planning and proposed an Adaptive, Multi-Resolution Modeling of Construction Plans, which are addressed under the headings of: elements of plans; decomposition of goals; multilevel plans; task sequencing; and plan adaptation.

This research will consist of a thorough study of factors that impact the adaptation of troop construction tasks BPL, designed to complement the ongoing research of Grobler and Subick (1993). The overall goal of this research is to investigate the effects current constraints and conditions impose on the adaptation of troop construction tasks BPL.

Literature Review Summary

Military engineering construction during peace and wartime consists of horizontal and vertical construction of hardened facilities. This study will focus on troop construction scenarios where tasks mapped to resources at the leaf level (crew or team) are subject to constrained conditions.

Several mathematical techniques have been developed over the years to generate optimal project schedules where the minimization of the project length is desired (Badiru, 1988; Sisson, 1961; Conway, et. al., 1967; Muth and Thompson, 1963). These techniques are not practical because of the computational intractability of generalized formulations. Heuristics are used to handle such complex scheduling problems.

A heuristic technique must be developed to take us into the new generation of troop construction scheduling that will give project managers the tools to plan tasks from a resource point of view as opposed to an activity dependency point of view. Therefore, we must use heuristics that are capable of handling the diversities found in project scheduling such as constrained resources. This research will focus on the constraints and considerations this heuristic must adhere to. Additionally, this research will validate that the current project management technique is not effective below platoon level.

Rationale and Objective

It is known that troop construction is confronted with multiple projects, constrained resources, and several levels of management. This makes it one of the most complex scheduling problems facing construction managers.

It is also known that the research in this area has centered around the formulation of heuristics restricted to the case in which each job may be performed in only one predefined way. In general, the research focused on reducing project duration and not the assignment of resources to tasks.

The scheduling and rescheduling of tasks occurs based on constraints associated with the shared resource. Troop construction managers need a planning and control tool that can formally schedule and reschedule tasks based on constraints associated with the resource. First of all, it should be stressed that in the presence of time and resource restrictions, there seems to be no way of successfully using conventional scheduling rules (Kurtulus and Davis, 1982; Kurtulus and Narula, 1985; Russell, 1986; Drexel, 1991).

The purpose of this study was to document the factors that affect the adaptation of TCTs below platoon level and to determine if the current project management techniques used by troop construction units are effective below platoon level. The study investigated the behavior of constraints and conditions on real-world TCTs. A survey instrument was developed and the collected data analyzed to determine the following specific research questions:

1. Identify and validate the factors that affect the adaptation of TCTs below platoon level.
 - a. H_0 : Determine if there is a significant difference among the factors.
 - b. H_0 : Determine if there is a significant difference in the factors that affect vertical and horizontal TCTs.
2. Determine if the current project management technique considered factors associated with the planning and controlling of tasks BPL.
3. Assess the attitude of using a computer system designed to plan and control tasks BPL.
4. Determine if the CPM is effective BPL.
 - a. Determine if project planning is required BPL.
 - b. Determine if project leaders BPL consider the factors associated with project planning when constructing their project networks.
 - c. Identify how tasks are assigned to resources BPL.
 - d. Determine if the assignment of these tasks are understood by noncommissioned officers (NCOs) below platoon level.
 - e. Identify the level where TCTs are performed in sequential order.
5. Assess the attitude of having a system that will advise junior NCOs on how to perform some of the more complicated tasks.

METHODOLOGY

For the purpose of answering the research questions, a survey instrument was designed and implemented following the design suggested by Wilson and Corlett (1990). The survey instrument elicited demographic data on each subject, which consisted of six items: rank, MOS, years experience, unit, duty location, and duty position.

A 5-point Likert scale was used to access the level of agreement or disagreement respondents expressed to survey questions 1-4, 6-15, and 17. Survey questions 18-20 allowed the respondents to provide more than one answer. Question 16 was open-ended.

Population and Sample Size

The targeted subjects in this study consisted of at least one representative (crew, team, or squad leader) from each of the active duty troop construction combat heavy engineering battalions in the U.S. Army. Eighty percent of the active duty units were represented in this study. Along with the combat engineering battalions, two support battalions, one transportation company, and two reserve units that were not targeted provided valuable feedback to this study.

The subjects were junior NCOs attending their basic professional development course for the 51 and 62 series MOSs. These courses are conducted at the Libby noncommissioned officer academy (NCOA) at Fort Leonard Wood, Missouri.

Data Collection

The researcher administered the survey to a class of twenty 51 series students on May 27, 1993 at the Libby NCOA, Fort Leonard, MO. An additional 18 surveys were administered to the 62 series students. The 20 surveys administered to the 51 series MOS were useable and 17 of the 18 surveys administered to the 62 series MOS were useable.

Statistical Treatment and Analysis

The coded data were entered into a text file using WordPerfect and later downloaded into a data base file using SYSTAT. Responses to the open-ended question were coded by hand and a content analysis was performed. The demographic data were tabulated and summarized in Table 1.

Limitations of Study

The targeted population for this study (junior NCOs from combat heavy engineering battalions) limits the ability to generalize to other groups which may share certain characteristics. For example, senior NCOs, company and field grade officers have traditionally exhibited a more assiduous attitude toward project management and could well express divergent perceptions from the junior NCOs who participated in this survey.

RESULTS AND ANALYSIS

Overview

To answer the proposed research questions, it was necessary to collect and analyze information from junior NCOs throughout the Army. The data was collected in a questionnaire developed by the researcher.

The 20-item questionnaire was administered to 38 junior NCOs worldwide. One survey (62 series junior NCO) was partially completed and could not be used in this study. Only 18 of the 51 series responses to question 19 were useable and 14 of the 62 series responses to question 19 were useable. Only 18 of the 51 series responses to question 20 were useable and 9 of the 62 series responses to question 20 were useable.

The junior NCOs are stationed at 18 active duty installations and two reserve installations, which included the continental United States, Alaska, Hawaii and Germany. The leadership positions held by the NCOs included 15 team leaders, 18 squad leaders, 1 platoon sergeant, 1 section leader, 1 repair and utility sergeant, and 1 instructor. The following results in this study pertain to TCTs below platoon level:

Table 1: Demographics

Level	Subjects	Average Experience	51 MOS	62 MOS
Team	15	6.1	7	8
Squad	18	6.1	10	8
Other	4	8.8	3	1

This study tested 18 factors that affected the adaptation of TCTs below platoon level and validated 16 of those. The results of these factors are presented in Table 2. For example, the factor "WEATHER" was ranked the number 1 (most often) factor to force the adaptation of construction plans at the troop construction level. The significance of the results is that they demonstrate the need for a planning tool that can easily incorporate these factors in the planning process, as well as in the adaptation of plans.

Table 2: Factors Affecting Construction Plans

FACTORS	Number	n	Percent	Cum Per
Weather	1	26	16.3	16.3
Material Availability	2	20	12.5	28.8
Manpower Availability	3	18	11.3	40.1
Equipment Availability	4	17	10.6	50.7
Mandatory Training	1	4	8.7	59.4
Time	6	14	8.7	68.1
Cost	7	10	6.2	74.3
Interference With Other Tasks	8	10	6.2	80.5
Goal Change	9	9	5.6	86.1
Manpower Splitting	10	5	3.1	89.2
Task Splitting	11	4	2.5	91.7
Administration	12	3	1.9	93.6
Other	13	3	1.9	95.5
Preference	14	2	1.3	96.8
Policy	15	2	1.3	98.1
Equipment Splitting	16	2	1.3	99.4
Material Splitting	17	1	0.6	100
Situational	18	0	0	100
Substitution of Resources	19	0	0	100

The results also strongly indicated three additional variables:

1. Lack of Experience
2. Lack of Knowledge
3. Lack of Training

These additional variables were not in the original questionnaire, but were added to the study based on the subjects' response to the questionnaire. (Please refer to the full text of Turner's thesis, where the effects these variables had on the adaptation of TCTs is fully discussed.)

Conclusions

The following conclusions were drawn from the results of this study:

1. The current project management technique CPM is not effective below platoon level. This technique does not consider the factors associated with the planning and controlling of TCTs below platoon level. There was overwhelming support among respondents in this study for a project management tool that can plan and control TCTs based on the factors associated with the resource that is responsible for the tasks.
2. This study derived and validated 18 factors that affected the adaptation of TCTs below platoon level. The factors that had 50.7 percent of the impact on the adaptation of TCTs were: weather, material availability, equipment availability, and manpower availability, respectively. The study solicited optional comments in question nineteen. The three additional factors were write-ins from three of the respondents. These factors are: experienced personnel, lack of knowledge by planners "at or above platoon level" about the factors associated with the planning of TCTs, and lack of training. An independent t-test measured a significant difference in means for material splitting. An ANOVA tested the effect among the 51 and 62 series MOSs evaluation of the 18 variables. The ANOVA test was not significant.
3. Junior NCOs below platoon level are concerned about leaders above them, particularly, 2LT and 1LT, not taking into account the factors that affect the adaptation of TCTs at their level.
4. There was strong support among respondents about having a system that will assist them on how to perform some of the more complicated TCTs.
5. This study showed that 51.4 percent of the tasks are performed in sequential order at the crew or team level.
6. Project planning is required BPL and junior NCOs need to be more involved in this planning.
7. Tasks are assigned to elements BPL by verbal order, operation order, tasking list, and training schedules. The project planning paradigm discussed in question one above must include the assignment of tasks to the resource that is responsible for the TCTs.

Recommendation for further research

Based on the results and the conclusions of this study, the following recommendations for future research are made:

1. Conduct a study on the analysis of the factors that affect the adaptation of troop construction plans (1) at platoon level and (2) above platoon level.

2. Quantify the list of constraints used in this study.
3. An investigation on designing a data base using object oriented programming C++ or expert systems "knowledge based" that has the ability to use past information to make future decisions.
4. Develop a system that will advise troop construction leaders on how to perform some of the more complicated TCTs.

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LIST OF ACRONYMS

ADA	air defense artillery
AFCS	Army Facilities Component System
ASCE	American Society of Civil Engineers
BOM	bill of materials
BPL	below platoon level
C ²	command and control
CADD	computer-aided design and drafting
CBR	chemical, biological, and radiological
CENTCOM	Central Command
CESP	Civil Engineering Support Plan
COMMZ	communications zone
CPM	critical path method
DBMS	database management system
DDE	dynamic data exchange
DLL	dynamic link library
DOC	Deck-of-Cards (paradigm)
DS/DS	Desert Shield/Desert Storm
EAC	echelons above Corps
ECMP	Engineer Construction Management Plan
ENCOM	engineer command
FEMA	Federal Emergency Management Agency
GIS	geographic information system
GPS	Global Positioning System
GUI	graphical user interface
HHC	headquarters and headquarters company
ITCM	Integrated Theater Construction Management
LEE	labor and equipment estimate
LOC	lines of communication
LOTS	logistics over the shore
MEAPO	Middle East/Africa Projects Office
METL	mission essential task list
MOS	military occupational specialty

NCO	noncommissioned officer
NCOA	noncommissioned officer academy
NSN	national stock number
OLE	object linking and embedding
OOP	object-oriented programming
PERT	Program Evaluation and Review Technique
PIF	personal information management
SOUTHCOM	U.S. Southern Command
SUPCOM	Support Command
TACAPS	Theater Army Construction Automated Planning System
TCMS	Theater Construction Management System
TCT	troop construction task
TOE	table of equipment
TOGS	theater-oriented guide specification
TUSEG	the U.S. Army Engineer Group
USACE	U.S. Army Corps of Engineers
USACERL	U.S. Army Construction Engineering Research Laboratories
WBS	work breakdown structure

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