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TECHNICAL REPORT CSMI/TR-84/01

Semi-Annual Technical Report

Support of the Design, Enhancement, and Demonstration of Multi-Node Video-Teleconferencing, and the Development of an M1 Tank Driver Simulator

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April 1984

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Under adverse conditions, command decisions require a high degree of interaction between command level personnel separated by extreme distances. Current "hands-on" training costs mandate improved training simluators to reduce those costs. The SGWS extension work will implement research efforts in shared telecommunications at two remote sites. Current M1 tank driver couch simulator efforts will produce effective audio and physical cues to augment training.

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SUMMARY

This Semi-Annual Technical Report covers the period from October 1, 1983 to March 31, 1984. The tasks/objectives and/or purposes of the overall project are connected with the design, development, demonstration and transfer of advanced computer-based command and control (C2) systems, video-teleconferencing, and of an M1 tank driver couch simulator. Work was performed in the area of video-based and microprocessor systems research, analysis, prototype development and installation; and in the development of advanced training and documentation aids. The work includes the further development of the Shared Graphics Work Space (SGWS), including the augmentation of the system by a menu-display, facsimile interface, and a satellite Earth station feasibility study. Work performed in the development of an M1 tank driver couch simulator included the development of a research prototype and the demonstration of this prototype.

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1.0 INTRODUCTION

This Semi-Annual Technical Report covers two key topics of effort: the continuing work on the design, development, demonstration and transfer of advanced computer-based command and control (C2) and video-teleconferencing systems; and the development of an M1 tank driver simulator.

1.1 Enhancements to Video-Teleconferencing

Previous technical reports covered the research, prototype development and installation of many of the components of the video-teleconferencing system as well as the novel idea of the Shared Graphic Workspace System (SGWS).

The current report covers the additional efforts performed in the extension of the SGWS effort. Work was done in the development of a satellite transmission system - network design and cost study as well as a program definition study for the development of low-cost KU-Band satellite Earth station. In addition, the SGWS system was extended by the capabilities of remote database access, the capability of presenting briefings from prepared "scripts" which are controlled by menu-driven software, and the capability of facsimile data input and retrieval. Efforts were expended in order to provide capabilities that ruggedized the system for operation by non-technical users.

The main body of this report discusses the technological achievements required to achieve these contract goals: investigation of the requirements necessary to provide better long range interactive communications; and efforts to improve the human interaction required for effective information sharing.

To fully understand those achievements some of the requirements of the undertaking will be discussed. Following this will be a brief survey on some of the work that preceded the current effort. After the main body of the report, which describes the success of the current effort, proposed enhancements will be briefly outlined.

1.2 M1 Driver Simulator

CSM undertook, at the direction of DARPA, the engineering and construction of a simulation testbed for certain components of the M1 battle tank driver's station. These investigations centered at first on the physical vibrations that the tank drivers experience, and later included the acoustic cues found at the driver's station. The extent of the realism of the simulation achieved was to be tempered by the cost and reliability factors of the system design.

2.0 TELECONFERENCING

The goal of providing interactive telecommunications has not changed. Consideration of the objective has refined and extended the concept of interactive communications separated by time and space. As new technology has become available, new ideas have been generated which have spawned newer technology, thus completing the cycle.

The engineering achievement, the software development and the general accomplishment discussed in this technical report are all based on one seemingly simple but extremely important idea: enhanced information sharing among individuals. Adding complexity to the idea and challenge to the task is that the information shared among individuals is spoken, "non verbal", illustrated and textual. And finally, the information sharing is placed in a "real-time" teleconferencing setting. The individuals may be scattered in a building, throughout a city, across the country or around the world.

The primary telecommunications task is that of connecting individuals located in different and often distant offices. Prior efforts had focused on teleconferences which where not greatly affected by the delays and synchronization problems incurred by distance. One of the key objectives of the current effort was examining the problems inherent in attempting distant telecommunications. Another key objective was consideration of the difficulty in creating an effective simulator for use in a network environment.

2.1 Information Sharing

The term "information sharing" is used for the conferencing situation, rather than communication, because communication tends to suggest only that which is spoken or expressed behaviorally in the conference setting. By information sharing we mean not only verbal and behavioral exchanges among the participants, but also textual, graphical, video and numerical exchanges. All of these attributes (verbal, non-verbal, textual, graphical video and numerical) of information sharing are subject to the same process in the conferencing situation.

Very simply, the information sharing process follows this general pattern: the information is presented; its reception is acknowledged; evaluation of the information begins, changes, corrections or eliminations are made. While this brief list appears straightforward, it presents considerable technical difficulties, especially when due consideration is given to the problems of synchronization of events separated by significant time delays, given the current state of telecommunications technology.

The SGWS has addressed the problem of how to share the same graphical information among the conferencing participants. It provides a common videodisc database consisting of maps of the world. It has the ability to change, correct or modify information that is the heart of sharing, not just the presentation of information. The SGWS provides a means to interactively share graphical information, coupled to the capability of spatial video.

Prior efforts in developing the SGWS as well as multiple demonstrations and evaluations of the systems had determined that many of the original assumptions of the system were valid, but needed to be revised and extended.

2.2 Information Sharing Requirements

One of the major requirements established at the beginning of the teleconferencing project was that the conferencing had to work during times of national emergency or crisis. It was the Defense Department's desire to have a communications network that would be operating during these potential episodes of chaos and uncertainty. These requirements meant that all communications, audio and video, had to take place over extremely low bandwidths (like those needed by telephones). Engineering and computing tasks followed this requirement.

Another requirement was that the conferencing situation had to be as natural or normal in operation as a standard meeting. This meant all participants in the conference had to be represented individually and that their automated representations or surrogates had to function like individuals. The idea behind this requirement was that in times of emergency, the teleconferencing process could be quickly and easily learned by the participants. The teleconference, in other words, would be an island of normalcy in a turbulent sea. Needless to say, engineering and computing efforts followed these guidelines.

Although the current work has followed these guidelines, emphasis continues on the information sharing component of the teleconference. The current effort is primarily concerned with making the environment of a conference as natural as possible, while providing briefing aids that may be required by the participants. In addition, a certain amount of "ruggedization" and "automation" of the process had to be considered. This consideration was vital to achieve DARPA's mission of transferring research technology to an active military environment.

Two particular requirements determined the direction taken by both the engineering and computing efforts. Not unknown in the computing industry the two requirements, which are closely related, are that the information sharing must work in "real time" and "real motion".

"Real time," as is well-known, is simply that the computing system must work at the same speed or in the same time span as the actions of its users. For example, if a user is editing text with a stylus on a touch-screen, the computing must operate in the same time as the stylus---crossing out a word, inserting another and circling another. Similar to this and extending the example, is that the motion of the stylus as it crosses out, inserts or circles must also be replicated by the computer as the stylus is moved by the user. Real time represents the precise speed of a graphics movement and real motion represents the precise accuracy of the movement. Finally, real motion must work in real time.

It was determined from the active use of the participants of demonstrations of the SGWS that there was little contention for resources during a conference, since the usual demonstration consisted of a briefing where one participant was always the initiator of an action and the other was an observer. These roles might change repeatedly during the conference, but there were usually no "pen wars" in which both participants demanded immediate and total control. As a result, as long as the participant had total local control and if outstanding transactions from other participants were queued until computer resources became available, an effective conference using the SGWS could occur at extremely low bit rates. During the current transfer efforts, it will be determined if this is still true when the initiation and response of participants is separated by significant distances represented by more than a fraction of a second.

2.3 Previous Research

The current teleconferencing network had as its antecedents the work completed under the titles of Virtual Space and Shared Data. The evolution from these ideas to the current network is similar to most undertakings: ideas are adjusted and refined as the work progresses; and technical achievements proceed by experimentation and experience. A brief review of the previous technical effort is necessary to trace the evolution of the current work.

2.3.1 Virtual Space

Virtual space technology was designed to follow one of the requirements stated previously; namely, that teleconferencing should simulate as closely as possible the structure and process of a real meeting. Each individual should be able to interact with others as they would in a meeting. When one person is talking, the others face that person. When another person speaks, attention is shifted to that speaker. But each listener, if they look at other listeners, will see that the others are also facing the speaker and maintaining "eye contact" with the speaker.

Those familiar with video-conferencing will immediately recognize the novelty to the virtual space approach. Most video-conferencing systems do not permit this simulation of meetings. Indeed, most available video-conferencing systems show only groups of people to one another and miss altogether the nuances of intra-group interaction.

To achieve this effect of virtual space, rooms were designed for one person. Facing the desk in each room are four columns, each containing a TV monitor that displays a different individual, a camera and a loudspeaker. The first stage in virtual space was a four-station system with the video linked by ordinary coaxial cable, hardwired between each of the stations. The multi-node, low bandwidth video-teleconferencing system had five stations and is shown in Figure 1.

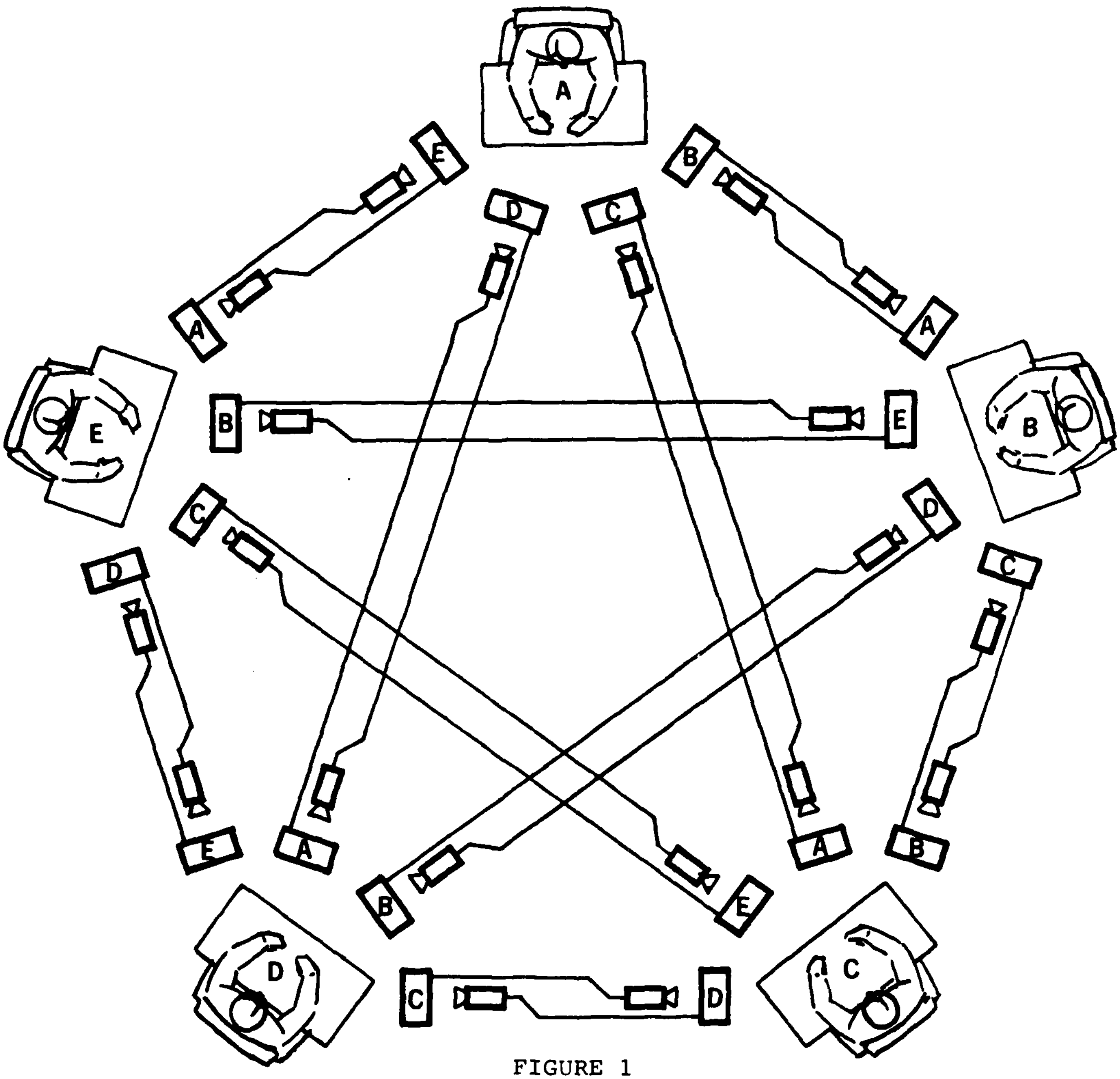

FIGURE 1

VIRTUAL SPACE
TELECONFERENCING
NETWORK

The physical design and appearance of the virtual space videoconferencing system differs substantially from conventional systems. Instead of placing all monitors (one for each station of the network), on a wall, the virtual space design isolates each monitor in its own column or cabinet. In conjunction with the camera and loudspeaker, the columns become the "conferee surrogate". Another advantage of this approach, in addition to the visual perspective just mentioned, is that audio is localized to the individual columns. This permits each conferee to hear the voice of the individual who is talking, and associate the location of the audio with the location of the video.

A major task of the system was to present to each conferee the nonverbal communications of the others. Since most nonverbal communications are presented by facial expressions, cameras were mounted in a permanent position focusing on the face of the conferee. While this meant that camera operators were not required, the significance of this effort (to represent the facial expressions of the conferees), was the transmission of the facial image over a very small bandwidth: 19.2 kilobits per second or about 1/4700th of the full bandwidth.

To compress the information content of the image to such a small (and incidentally a much, much lower cost) bandwidth required the use of one of the new codecs (coder-decoders). The codecs in the system are built by Compression Labs, Inc. and use two dimensional run-length encoding to reorganize the information in the signal.

The result of this information manipulation is an image that corresponds to a pencil "sketch" of the individual. The "sketch" also "lives" as long as the actions of the individual are not too sudden or dramatic. To capture the individuals' actions, the transmission rate of frames is approximately seven to ten frames a second. And the display quality is high; the image is stored digitally and refreshed at a rate of about 60 frames per second. Figure 2 offers a comparison of a "sketch" and a photograph.

One of the important developments that took place elsewhere during the current contract interval was the development of the WIDCOM, Inc. 56Kbps Color Video-Codec which was also funded by DARPA. One of the most frequent comments by users of the Spatial Video Teleconference was that color would greatly enhance the effectiveness of the conference. People expressed this comment very strongly and most were even willing to incur the substantial additional costs in bandwidth and hardware to achieve this requirement. The WIDCOM codec is expected to be delivered at CSM very shortly and the existing in-house operation of the Video Teleconference will be enhanced by this feature.

The audio portion of virtual space has two components. One component permits verbal communication from each individual to all other conferees. This "global" component consists of a shotgun mike placed in an unobtrusive position and the signals are transmitted over standard leased lines. The second component permits private conversation between any two of the conferees. This "local" component consists of an ordinary telephone and autodialer wired with a cutoff switch to the shotgun mike so that all "local" conversations are private. Obviously, this component permits private conversation, that, in a traditional conference setting would be confined to the disruptive practice of subdued secondary conversing.

A

SOURCE IMAGE

B

DECODED IMAGE

FIGURE 2

COMPARISON OF SOURCE IMAGE AND DECODED IMAGE

After numerous demonstrations and constant evaluation, it is clear that the strength of the virtual space aspect of the teleconferencing project is its remarkably small bandwidth. Recall that the bandwidth is only 19.2 kilobits per second (kbps) for the CLI sketch encoder and 56Kbs for the WIDCOM color codec. This means that even when four simultaneous images are transmitted out of the room, the total required bandwidth is less than 150 kpbs. And this includes telephone quality audio that is also compressed to 16 kbps. Because a small bandwidth means substantially less cost, the bandwidth alone makes this system very appealing; but when the small bandwidth is combined with the audio and video components of virtual space---and all this is added to the capability of sharing data---this teleconferencing system becomes truly exciting.

2.3.2 Shared Data

Shared data, the second key element of the teleconferencing system, evolved through experimentation and experience. The original telegraphics system, called Telepad, consisted of five Apple computers communicating with one another in a ring network. The system provided a menu of options, including five "ink" color selections, selections of a common graphics database and utility functions such as "clear screen."

The SGWS was modelled on this earlier effort initially, and additional features were added that augmented this concept. This included an extended menu control system, video underlays, remote database access, and a graphical facsimile interface.

2.4 Current Efforts

2.4.1 Menus

The final software improvement to the existing SGWS was the implementation of menu driven software to permit the user of the system to have local control of briefings. The original design of the SGWS was planned to have a staff station at every teleconferencing site. This would have permitted users to have the support of trained technical staff to aid in the preparation and the presentation of briefings.

It was determined after countless briefings, that the users did not require extensive staff support, but did require extensive local control of the teleconference. To provide the capabilities required by the participants of the teleconference, without requiring extensive technical training, it was determined by CSM, that a highly interactive menu environment would be most appropriate. Figure 3 shows the currently active primary presentation menu of the teleconferencing system.

Figure 3 - SGWS primary presentation menu

```
              S H A R E D   G R A P H I C S   W O R K S P A C E

V i d e o   C o n t r o l s:                      F i l e   C o n t r o l s:

A) Go to Page Number                              L) Get Text File

B) Turn Off Video Underlay                        M) Next Text Page

C) Clear the Video Screen                         N) Previous Text Page

                                                  O) Get Graphics File

V i d e o d i s c   C o n t r o l s               S Y S T E M   C O N T R O L

D) Get Videodisc Frame Number                     P) Enter UNIX Command

E) Get Underlay of Geographical Location          Q) Virtual Terminal

F) Zoom In

G) Zoom Out

H) Move North

I) Move South

J) Move East

K) Move West


Make a selection or press ESC key to escape...
```

2.4.2 Network

With the completion of the applications work for each node of the network, the task was to make the entire network function. The basic problem was to take the information coming in from any node of the network and then sending it out to all the other nodes of the network. Most of the work for the network had been completed during earlier phases of this project, so the current effort was allocated to simply making sure the network operated correctly. Several caveats are in order, however.

First is that the network is low-speed. While this appears initially to be a disadvantage, the network is highly configurable and will work anywhere where there are telephones. This means that the entire network can work with computers and modems with auto-dialing capabilities. Second, the current network has been tested using five nodes, but it will function with a total of eight nodes. And finally, the typical configuration is a local-area network or a network that is "hard wired" together. Advantages of the local-area network is that it by-passes modems with auto-dialers and can be used in the same building or in offices of close proximity. But this typical system is not as configuable as the wide area low-bandwidth network.

2.5 Future Enhancements

A major characteristic of research and development work is that it continues: new ideas emerge from the experience; refinements are made as insight accumulates; and enhancements extend the utility of the product. The Shared Graphics Workspace and its low-bandwidth network are not immune from this trait of technological innovation and production. The enhancements to be discussed briefly continue the effort and hopefully will make the entire telecommunications system even more useful.

2.5.1 The Future of SGWS

Work continues on the ruggedization and automation of the SGWS to permit easier startup, execution and maintenance of the existing system. This effort will be vital once completion of the transfer of the prototype system occurs.

Currently, efforts include converting some of the Shared Graphic Workspace (SGWS) software to execute on IBM-PC/XT microprocessors, replacing less efficient DEC LSI-11/23 hardware. Technology has continued to move quickly in the computer field with costs dropping quickly and hardware capabilities continuing to expand. As technology becomes available to CSM, it will be used in effective ways to increase the versatility of telecommunications while continuing efforts to reduce costs.

CSM has been tasked to begin the development of the "fast fax" capability which will provide for the rapid transmission of hardcopy along with the color video images produced by the WIDCOM codecs. This will allow compatibility with an existing technology base while adding additional speed to operations. This will result in an overall improved operational capability while lowering the cost/bit transfer rates.

It is anticipated that transfer of the enhanced prototype system will be made of a two-node version of the teleconferencing system to the Air Force, and is scheduled for completion by the end of the second quarter of 1984.

3.0 SATELLITE FEASIBILITY STUDY

Another transfer of the DARPA video teleconferencing system is planned to begin in the second quarter of 1984. This transfer will incorporate the new Widcom 56Kbps codec and the latest version of the SGWS including the "fast fax" feature. This transfer will link two Naval command centers, one on the East coast and the other in Hawaii. This transfer will further test the capabilities of the system through the greater distances involved.

Through earlier studies it has been determined that leased "land lines" would be cost prohibitive and that satellite communications would be more appropriate. The result of studies conducted by CSM consultant Brig.Gen. H.R. Johnson (USAF Ret.) describe the feasibility of using satellite communications..

3.1 Site Evaluation

The earth stations which are to be installed at Suitland, Maryland and Kailua, Hawaii were designed to transmsit digital data on two channels at 112 Kb each. The two data streams are composed of 56 Kb from each of two video codecs plus stereo voice channels, graphics, and facsimile added to each codec output.

A bit error was established of 10-7 for data transmission. If the video codec divides a frame into 1000 blocks fo 256 pixels each, and half of the clocks only need an 8-bit value transmitted and the other half require 18 bits per block, then an encoded frame requires about 13,000 bits. The stated bit error rate means far less than one bit per frame in error due to the transmission medium.

It is assumed that at least a 6 meter antenna will be needed to meet the FCC 2 degree spacing requirement. The low power requirement of the system indicated that a five watt solid state amplifier would be adequate.

The purpose of the network design and cost study was to devise the most cost-effective approach for a three-node network using technology available in 1983-1984. Both C-Band and Ku-Band alternatives were considered, but the cost of the earth station at Ku-Band was determined to be higher in most cases than a C-Band. One alternative at Ku-Band was determined to be slightly lower in cost for the earth stations, but the cost of the space segment was determined to be much higher at Ku-Band then at C-Band.

The overall requirements for this system were reduced reliability/availability numbers plus bit error rates, and these in turn were translated into antenna size, HPA power, and station G/T parameters. Beyond this point the most cost effective approach was determined to be having companies in the business of supplying and installing earth stations bid on the requirements. Therefore, the actual hardware design approach would be that offered by the company whose overall proposal accomplishes the objective in the most economical way.

The ultimate network would be a three-node full-mesh type with each station able to transmit and receive to/from all of the others. The initial demonstration network would be a single two-node link between the West Coast and East Coast. Each station would transmit on a given set of frequencies and each station would have an IF power splitter at the output of the downconverter so that the transmissions fromthe other two stations are separated according to frequency and directed to separate demodulators. Each station, then would have demodulators dedicated to receiving the transmissions from each of the remote stations. Although the demonstration would have used only one set of demodulators since it would only be receiving from one remote, a four-way IF splitter would have been used at the outset so that transmission frequencies from up to four remotes could be separated and directed to separate demodulators that would be installed later.

The network would thus be a full-mesh, full-duplex type that allows all nodes to receive data streams from two cameras at each of the other nodes.

3.2 Conclusion

The conclusion of the satellite study recommended the purchase of two Vitalink 6.1 meter, five watt earth stations with space segment plus network monitoring and maintenance provided by Vitalink. This recommendation was based on technical advantages, such as packaging, all solid-state construction, and a unique dual channel design, as well as the price advantage. The mantenance program plus the 24 hour network monitoring provided through the Vitalink space segent charge made it an an arrangement for a small initial network that is expected to grow over the new few years. The system as designed would have been flexible and would lend itself to a growing network with changing traffic requirements.

4.0 M1 TANK DRIVER COUCH SIMULATOR

4.1 General Problem

Current and projected military strategies rely more on complex, sophisticated hardware systems spread over large battle theaters acting in unison with allied forces. The goal is to achieve and sustain a technologically superior fighting force capable of engaging and overwhelming a potentially larger but technologically inferior enemy. These goals, however, carry a heavy price. The costs to procure and support high-tech military systems along with the concurrent costs of training and maintaining battle ready troops is rapidly escalating beyond the current abilities of the participating nations to pay. Digital computers interconnected over high-speed communications networks are now being enlisted to reduce the costs of troop readiness training programs by providing accurate simulations of battlefield conditions. The Defense Advanced Research Projects Agency is currently investigating the feasibility of creating a world-wide military strategies simulation network, SIMNET, to support large-scale battle simulations until now considered prohibitive both logistically and financially. SIMNET is targeted toward providing a real-time interactive networking system capable of linking physically separate computer controlled simulator modules in a cost effective manner. This approach is designed to provide improved tactical training facilities while reducing the necessity of committing the actual battle material.

To achieve convincing simulations of battle conditions the participants must be provided with the sensory cues ordinarily encountered under actual battle situations. These sensory cues must be provided at or above certain threshhold levels necessary to sustain the trainee in a positive learning role while he is using the simulator.

CSM undertook, at the direction of DARPA, efforts toward defining certain of these sensory thresholds. This involved engineering and construction of a simulation testbed for certain components of the M1 battle tank driver's station. These investigations centered at first on the physical vibrations that the tank drivers experience, and later included the acoustic cues found at the driver's station. The extent of the realism of the simulation achieved was to be tempered by the cost and reliability factors of the system design.

4.2 Physical Cues

DARPA and U.S. Army Armored personnel provided the first direction for investigation. They noted that physical vibration was present and obvious at the M1 driver's station. These vibrations are due to the tank drive mechanisms and to the impact of the tank tread pads with the ground as the tank moves about the terrain.

A previous DARPA sponsored experiment coupled the energy of an acoustic driver into a rigid seat to simulate the conditions of an M60 tank but were found to be inadequate as a simulation cue due to the low levels of power transmitted through the seat surface into the trainee. CSM continued this line of investigation due to its inherent simplicity and reliability. The majority of the acoustic driver energy was found being absorbed in heating the enclosure trapped air mass while transmitting little of the remaining energy through the rigidly attached seat surface. Modifications to this produced a loosely coupled seat surface mounted directly over the acoustic driver. The design of the existing driver enclosure was altered to increase the overall system efficiency using current high fidelity speaker enclosure design theory. This arrangement significantly increased the amount of transmitted energy which in turn allowed the reduction of the power amplifier requirement from the initial 100 electrical watts to 10 watts.

The reduced power requirement allowed CSM to experiment with several commercially available drivers for equal performance at lower costs. The original seat structure incorporated a high-power 12" driver as it's transducer. Medium power 8" drivers were substituted and found to be of equal performance providing that the driving power was increased approximatly 20% to compensate for the reduced piston volume of the new driver. The increased driving power caused increased piston excursion, however this remained under the maximum limit set by the equipment manufacturers.

The original source for the 'rumble' drive signal was a digitally synthesized tape recording based on a field recording of M60 tanks. This format limited the control possible over the source signal to volume and tone adjustments available at the system preamplifier. This simulation technique was deemed inadequate due to the lack of fine sensory cues felt necessary for good simulation of the M1 tank.

The next level of development was to achieve greater control over the 'rumble' source signal by electronically synthesizing the signal in real-time under control of a user operated throttle. Thus CSM designed and built circuitry which generates an electrical pulse train which when mixed with two additional fixed frequency oscillators produces an appropriate drive signal. The pulse train frequency can be controlled remotely to approximate the rising and falling tread pad 'rumble' as the tank accelerates over the surrounding terrain. This was an immediate improvement over the fixed 'rumble' speed of the taped version.

4.3 Seat to Couch Conversion

All tests to this point had used the modified upright seat. The M1 tank driver, however, lies on a specially designed couch in either a partially or fully reclining position dependent upon whether he is under 'hatch up' or 'hatch down' driving conditions. Figures 4 and 5 show the tank driver in profile in the 'hatch up' and 'hatch down' driving positions. A wood mock-up couch was constructed based on dimensions provided by Perceptronics, Incorporated. The couch mock-up design is shown in figure 6.

These dimensions closely model the 'hatch down' condition for the tank driver station. In this position the majority of the tank driver's weight is supported by his back and shoulders while a smaller proportion is supported by the driver's buttocks. Two 8" speakers were mounted in tuned enclosures which were in turn attached to the mock-up panels directly under the driver's back and buttocks. This arrangement is shown in figure 7.

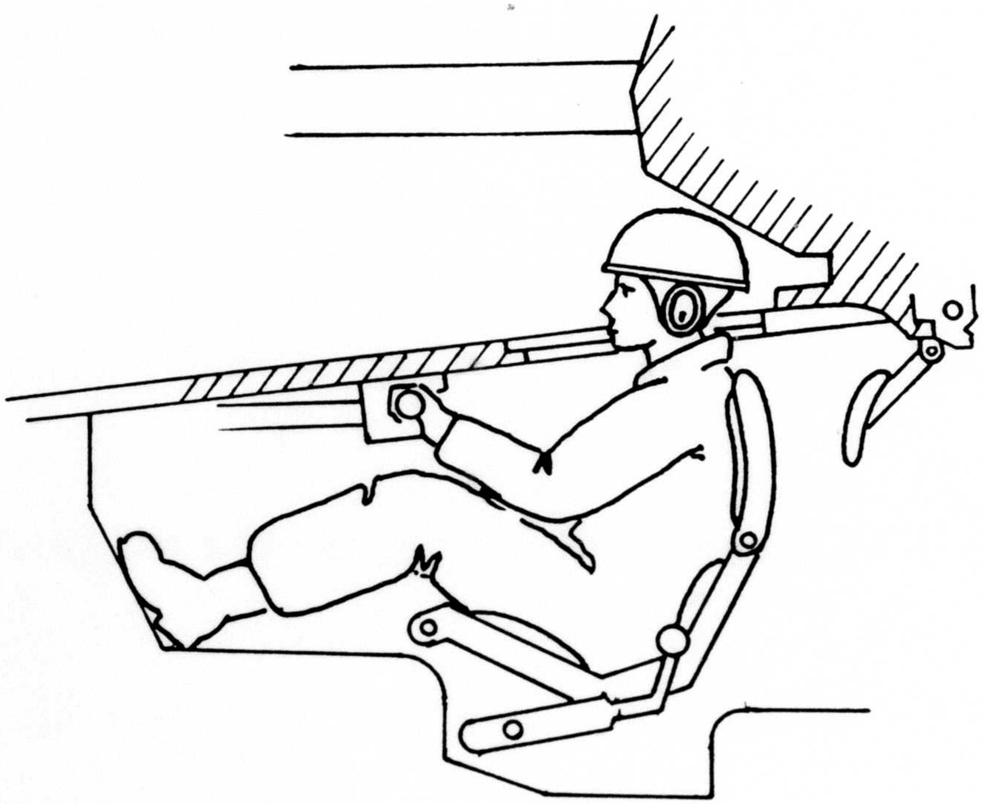

FIGURE 4

HATCH UP
DRIVING POSITION

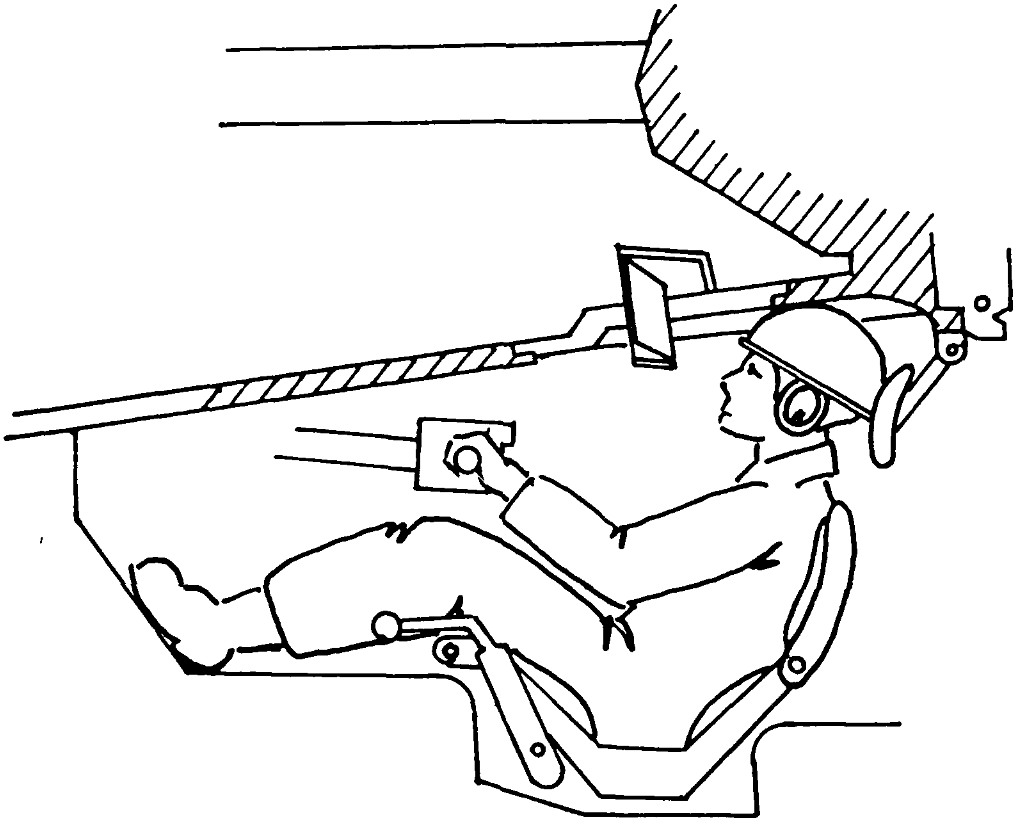

FIGURE 5

HATCH DOWN
DRIVING POSITION

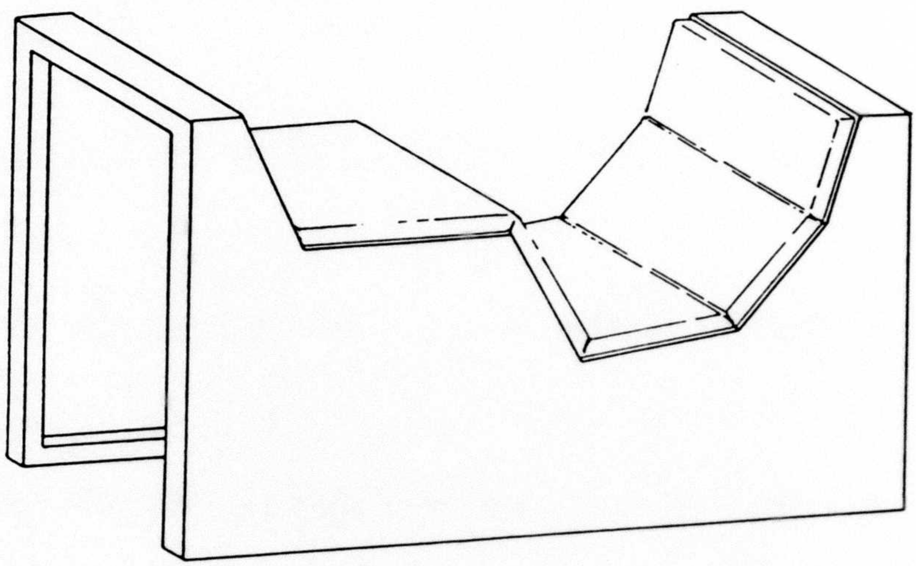

FIGURE 6

COUCH MOCK-UP

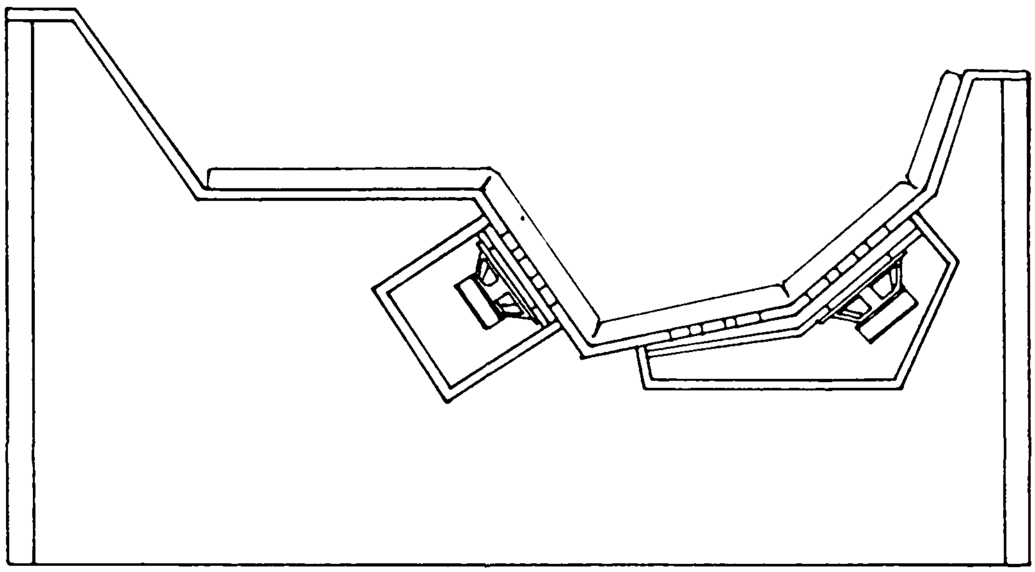

FIGURE 7

SPEAKER PLACEMENT

Holes bored in these panels coupled the 'rumble' vibration energy through a 0.5" low density foam pad into the trainee. Our tests demonstrated this to be adequate at a maximum power level of 10 watts. The effect at higher power levels was bothersome to the user. Tests using isolated single acoustic drivers demonstrated that the 'rumble' effect could be adequately sustained using only the speaker mounted under the tank driver's back. This was apparently due to a coupled sympathetic resonance established in the trainee's chest cavity.

An additional feature of this arrangement was that some of the 'rumble' driver energy escaped past the foam pad into the surrounding area creating a 'rumble' sound. This made originally planned additional 'rumble' drivers unnecessary.

4.4 Audio Cues

The next area of investigation was the audio cues within the tank driver station. The M1 battle tank is powered by a turbine engine rather than the more familiar diesel engines in earlier tanks. Tape recordings made in the drivers compartment of an M1 tank were provided by Dr. Jack Thorpe, Program Manager at DARPA. These recordings demonstrated that the sounds of the M1 are radically different from those of a diesel powered tank. Spectral analysis of isolated tape segments yielded the fundamental signal frequency range along with the accompanying overtone series in the turbine whine. The analysis also demonstrated a noise component in the whine. This was later found to be an important and necessary component of the turbine simulation.

The turbine whine was synthesized using three variable frequency oscillators, one fixed frequency oscillator, and a pseudo-random white noise generator. These signals, mixed together, create the fundamental, overtones, sum and difference components, and broad band noise components close to the original sound recorded inside the M1 tank driver compartment. The fundamental frequency is controlled by one potentiometer setting. This potentiometer was mounted in a housing modelled after that in the M1 and is controlled by a throttle bar also mounted in the housing. The throttle housing, shown in figure 8, was mounted on the couch from a swing arm facilitating entry and exit. The trainee, laying on the couch as shown in figure 9, operates the throttle bar just as he would in the M1 tank.

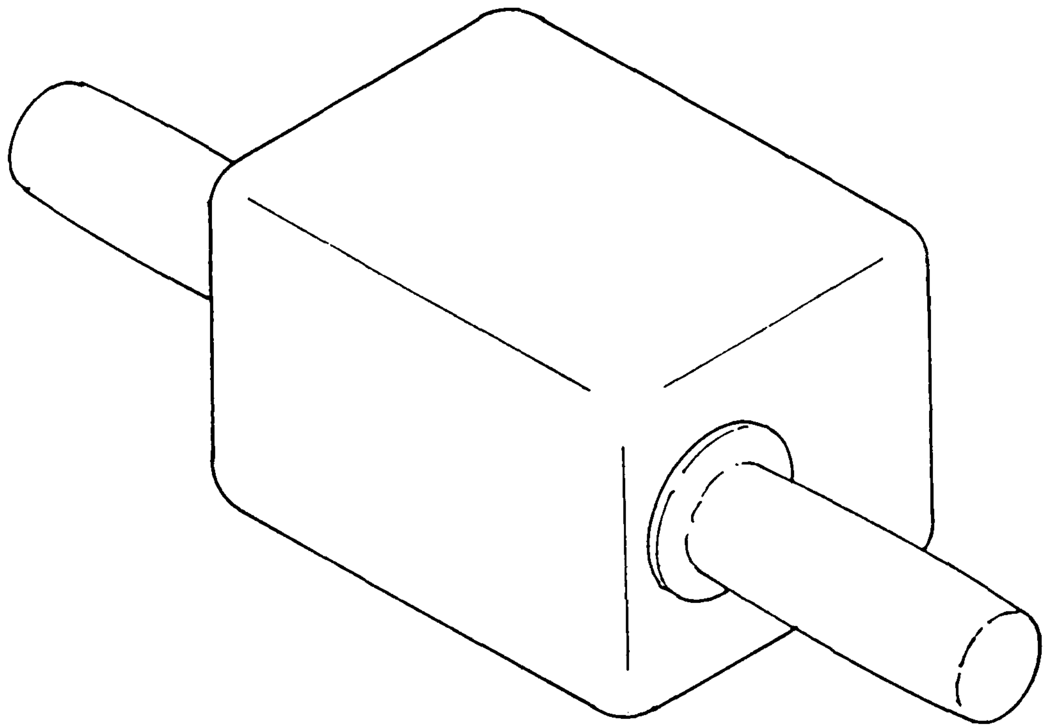

FIGURE 8

THROTTLE HOUSING

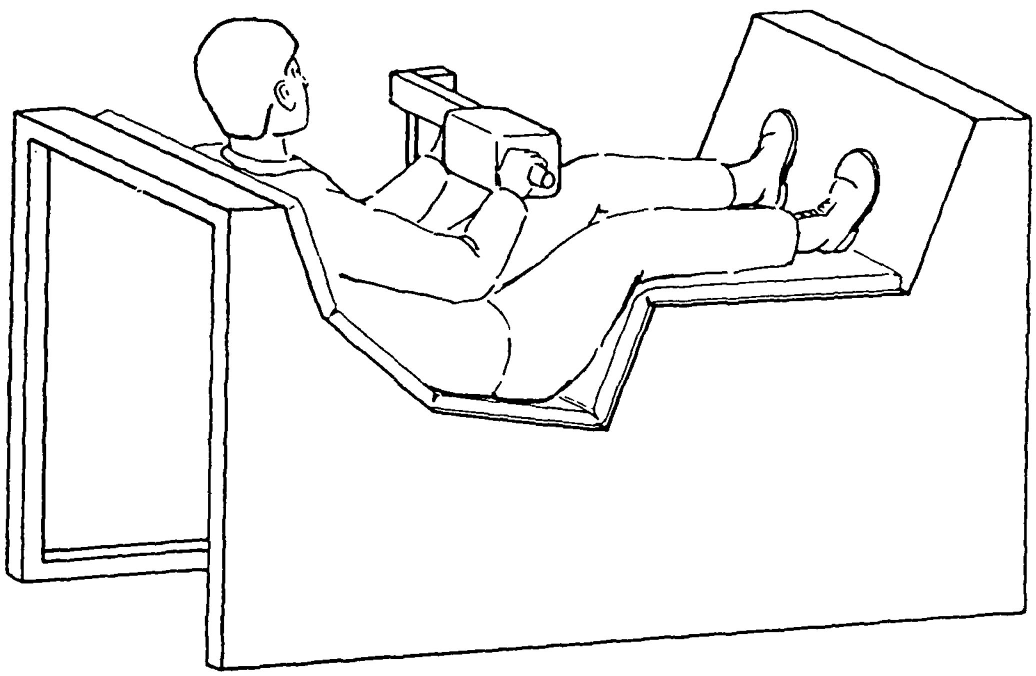

FIGURE 9

TRAINEE OPERATING POSITION

In addition to the tank rumble, tank treads squeak noticably and almost constantly while in motion. This is not a result of maladjustment, but is indicative of normal operating conditions and was considered to be an essential auditory cue for the trainee. The tape recordings were analyzed for the spectral content of the tread squeak. The squeak was surprisingly simple and was synthesized in hardware using a frequency and amplitude modulated 2700 Hz sine wave. The modulation signal was derived from the rumble generator and was synchronized with the tread rumble signal just as in the M1 tank.

4.5 Cue Coordination

The synthesized signal at this point was still only an approximation of the time invariant components of the tank recordings. An essential element was found to be the time dependent signals on the tapes. Tread rumble and squeak are direct functions of the tank's ground speed, which is a function of the turbine engine speed and time. Turbine engine speed is, in turn, a function of throttle position and time. There is a distinct and significant time lag involved in the operation of a turbine engine under load. The turbine speed always lags behind the operator's throttle commands. Tread rumble and squeak, in turn, lag behind the turbine engine speed because drive power in the M1 tank is coupled to the treads through an automatic transmission. Circuitry was devised to simulate these lag times. The lags are variable from two to six seconds dependant upon internal circuit adjustments. Electronically operated signal attenuators coordinate the relative loudness of the individual signal components to complete the signal simulation.

4.6 Spatial Cues

The rumble, squeak, and whine sounds were tested through the main couch mounted speakers. Low frequency components were omnidirectional in nature and were located solely for optimal energy transfer into the trainee. Two auxillary speakers mounted behind the trainee's head were used to provide more accurate spatially perceived information cues. Turbine whine and tread squeak are directed to these speakers.

4.7 Results

The simulator was tested by CSM personnel, DARPA representatives, and most importantly U.S. Army Armored personnel. The synthesized sounds were found to be sufficiently close to those recorded in and experienced at the M1 tank drivers station. The inclusion of the time and spatially correct cues were felt to be necessary for the accurate simulation of the M1 environment.

4.8 Future Directions

The current circuit operates strictly in a stand-alone mode. Interface circuitry must be designed to communicate with the local node CPU regarding system status conditions and to accept new commands as they are issued by the node CPU in response to SIMNET network status.

In addition, the current methods of signal generation must be implemented fully in digital circuitry for improved reliability and repeatability so that what is generated locally accurately reflects the commands issued from the local CPU.

5.0 CONCLUSION

The main intent of this report has been to outline the technical achievments of, primarily, the Shared Graphics Workspace (SGWS) and the M1 tank simulator. Recall that the major requirement of the SGWS was that it resemble as closely as possible traditional work tools such as pen and paper. This requirement meant that all engineering and computing capabilities had to work in real time and real motion. Given existing hardware and software constraints, the engineering and computing efforts met the goal of working in real time and motion. In this sense, therefore, the technological work on the SGWS must be termed successful. But the success of this work extends beyond the technological achievement.

The Satellite Feasibility Studies established that relatively low cost alternatives were available for implementation of extremely long distance teleconferencing.

The real success of these technological achievements is the close adherence to the true purpose of a conference. Information is shared, work is done, and decisions can be made---just as in a traditional conference. The technology permits face-to-face contact, verbal and non-verbal communications and the presentation of text and graphics. The structure and process of a conference are represented by the concept of virtual space, and the function of a conference (to exchange and correct information) is made possible by the Shared Graphics Workspace.

The tank simulator was tested by CSM personnel, DARPA representatives, and most importantly U.S. Army Armored personnel. The synthesized sounds were found to be sufficiently close to those recorded in and experienced at the M1 tank drivers station. The inclusion of the time and spatially correct cues were felt to be necessary for the accurate simulation of the M1 environment.

It is no small accomplishment to replicate via state-of-the-art technology human interaction and behavior. It is an even greater accomplishment to use technology to promote human interaction. The real value of this technology, therefore, is its capability for promoting the work necessary for the completion of group tasks and decisions.

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