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THESIS

DISSEMINATION AND STORAGE OF TACTICAL UNMANNED AERIAL VEHICLE DIGITAL VIDEO IMAGERY AT THE ARMY BRIGADE LEVEL

by

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and
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September 1999

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The Department of Defense Joint Technical Architecture has mandated a migration from analog to digital technology in the Command, Control, Communication, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) community. The Tactical Unmanned Aerial Vehicle (TUAV) and Tactical Control System (TCS) are two brigade imagery intelligence systems that the Army will field within the next three years to achieve information superiority on the modern digital battlefield. These two systems provide the brigade commander with an imagery collection and processing capability never before deployed under brigade control. The deployment of the Warfighter Information Network (WIN), within three to five years, will ensure that a digital dissemination network is in place to handle the transmission bandwidth requirements of large digital video files.

This thesis examines the storage and dissemination capabilities of this future brigade imagery system. It calculates a minimum digital storage capacity requirement for the TCS Imagery Product Library, analyzes available storage media based on performance, and recommends a high-capacity storage architecture based on modern high technology fault tolerance and performance. A video streaming technique is also recommended that utilizes the digital interconnectivity of the WIN for dissemination of video imagery throughout the brigade.

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DISSEMINATION AND STORAGE OF TACTICAL UNMANNED AERIAL VEHICLE DIGITAL VIDEO IMAGERY AT THE ARMY BRIGADE LEVEL

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ABSTRACT

The Department of Defense Joint Technical Architecture has mandated a migration from analog to digital technology in the Command, Control, Communication, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) community. The Tactical Unmanned Aerial Vehicle (TUAV) and Tactical Control System (TCS) are two brigade imagery intelligence systems that the Army will field within the next three years to achieve information superiority on the modern digital battlefield. These two systems provide the brigade commander with an imagery collection and processing capability never before deployed under brigade control. The deployment of the Warfighter Information Network (WIN), within three to five years, will ensure that a digital dissemination network is in place to handle the transmission bandwidth requirements of large digital video files.

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We could not have finished this project without you!

I. INTRODUCTION

> Over the past several years, the Department of Defense (DOD) has invested significant resources in developing various Unmanned Aerial Vehicles (UAV) systems to meet our nation's 21st century surveillance and reconnaissance needs. While UAV programs have experienced difficulties, the compelling benefits, such as contributing to information superiority and the risk reduction of our pilot force, demand a strong, renewed, commitment.
>
> William Cohen, US Defense Secretary

A. PURPOSE

The purpose of this thesis is to provide the Army brigade intelligence infrastructure a technological solution for efficient storage and dissemination of digital motion imagery.

B. BACKGROUND

The Department of the Army is developing tactics, techniques, and procedures for the integration of UAV systems in the Army Force XXI brigade-level intelligence operation. Designated a *Tactical* UAV (TUAV), this airborne reconnaissance platform will provide the brigade commander with Real-time motion imagery intelligence with which to plan, execute, and assess tactical operations within his zone of influence. In recognition of the long outstanding need for a TUAV to support brigade commanders in combat operations, the Joint

Requirements Oversight Council considers the fielding of such a system its highest priority in the area of surveillance and reconnaissance (CBO, 1998).

The TUAV is but one component in the intended Force XXI Command, Control, Communications, Computers, and Intelligence network that will radically alter the processing of imagery intelligence (IMINT) within the brigade. In addition to the TUAV, the Tactical Control System and the Warfighter Information Network will play vital roles in storing and disseminating motion IMINT. All three of these components are currently under development and must be integrated in the near future as the Army prepares to digitize the modern battlefield.

C. ORGANIZATION

Figure 1.1 graphically portrays the brigade imagery processing function as the central key to providing the Army brigade, its subordinate battalions, and its division headquarters both Real-time and Non-real-time motion imagery. The first part of Chapter II uses a top-down methodology to describe the role of information in warfare and the role of the UAV as an information collector. The second part of Chapter II overviews the evolution of the UAV from World War I to OPERATION ALLIED FORCE in Yugoslavia.

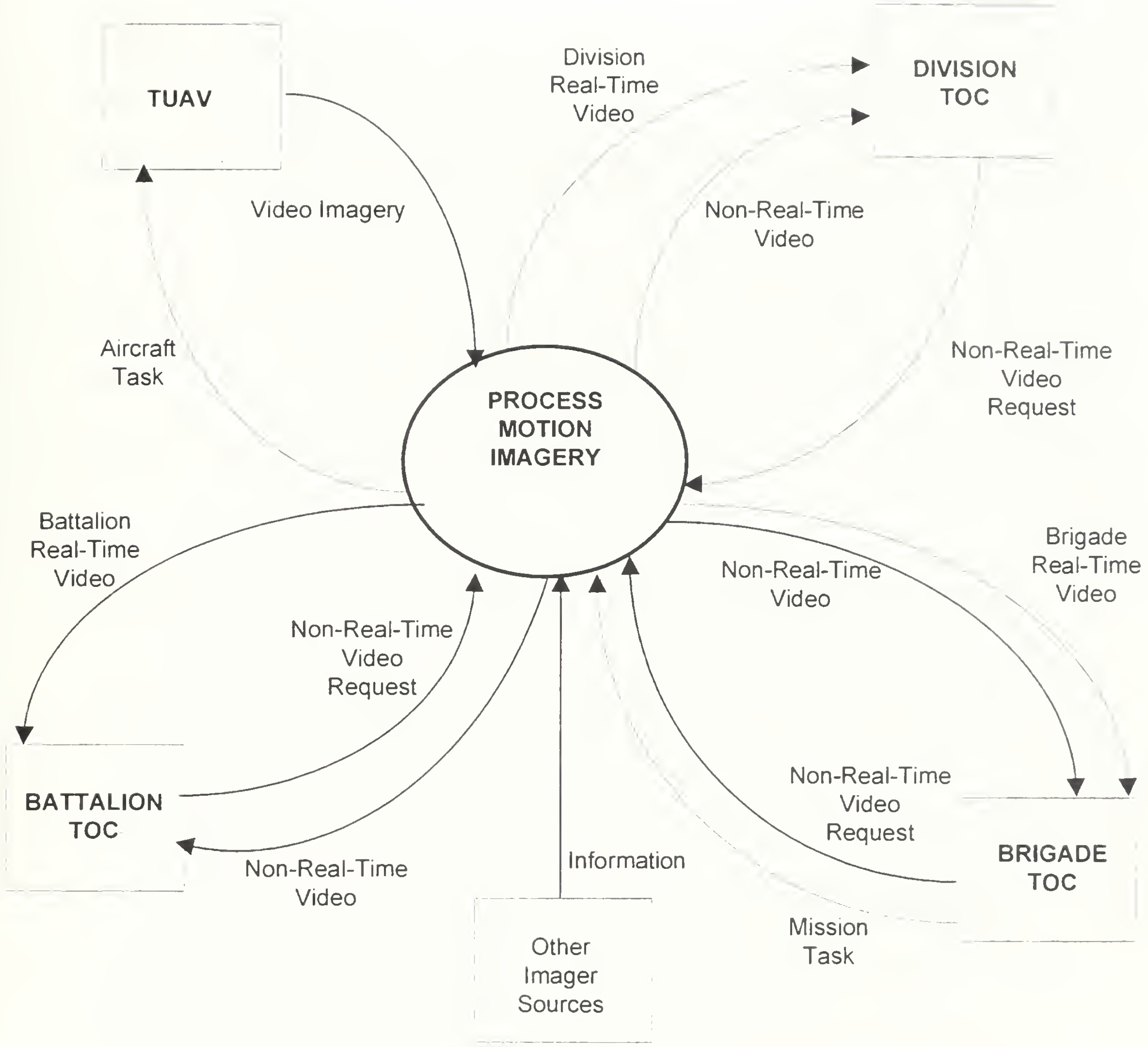

Figure 1.1. Context Diagram: Brigade Imagery System

Chapter III introduces the brigade stakeholders who stand to benefit from the availability of motion imagery. It also provides an overview of analog and digital video technologies as well as digital video capture technology.

Chapter IV calculates a minimum storage capacity requirement for the Force XXI brigade imagery system, compares storage media technology, and analyzes large capacity storage configurations based on the capacity calculation and media selection.

Chapter V provides an overview of the Army Warfighter Information Network (WIN). Upon deployment, the WIN establishes the digital conduit through which TUAV video will be transported in both Real-time and Non-real-time.

Chapter VI describes the technological factors involved in delivering intelligence video to requesting brigade stakeholders. Chapter VII analyzes video capture and storage hardware implementation alternatives and Chapter VIII concludes the thesis with a summary and recommendation.

D. RESEARCH QUESTIONS

1. Primary Research Questions

- What digital storage and dissemination technology is available to the brigade motion imagery system?
- How will digital imagery storage and dissemination technology be integrated into the brigade?

2. Secondary Research Questions

- Why does the tactical warfighter want motion imagery?
- What motion imagery technology is available for tactical operations?

- How does the brigade currently disseminate imagery intelligence?
- What imagery quality standards does the brigade require?
- What are the digital storage capacity requirements for motion imagery transmitted by a Tactical Unmanned Aerial Vehicle?
- What dissemination architecture will be in place in five years?
- How might the brigade implement digital hardware for the capture and storage of motion imagery?

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II. INFORMATION WARFARE AND THE ROLE OF THE UAV

A. THE ROLE OF INFORMATION IN WARFARE

The 21st century is marked with many inventions as well as innovations in all sciences and particular domains.

Three events changed the course of modern military history.

First, in the early 20th Century, the invention of the tank influenced the strategy and tactical decisions of commanders at all levels. Military strategists accepted the new technology as a decisive contributor to the success of future battles.

Second, at mid-century, ballistic missiles changed the strategy and tactics of battlefield commanders, by threatening to destroy whatever was found within their range of fire.

1. Information Age. A New View of War

The third invention that appeared in the early 1970s in the military and civilian domains: information technology. It is characterized by the growth of information, information sources and information dissemination capabilities.

In the first two cases the invention could be seen. It had volume, weight, physical dimensions, but in the third case information is an abstract concept, less tangible but extremely powerful. On the battlefield, information can become deadly power. Information is not something that can be felt, seen, or touched; it is an abstraction, but we are influenced by it. It can take the form of everything and can be used for different kinds of tasks. Information is limitless and can have various sources. It can be discovered, created, transformed and repeated, but its value is temporal.

2. Information is an Abstraction

In order to understand abstractions, human beings have always built models. This same principle, when applied to the information abstraction, provides the user an information model that facilitates comprehension and ultimately produces new knowledge for decision-making. Retrieving information is a main system process that consists of five processes: Collect Data, Organize Data, Analyze Information, Distribute and Apply the Knowledge, and Protect the Information.

a. Collect Data

The collection of data comes from lowest level of command and is accomplished through individual observations, experiments, human communications, text messages, newspapers, still and motion imagery, etc.

b. Organize Data

The organization of data in a useful way facilitates the analysis and produces information. The organizing process can be analyzed further to acquire the right data and then sort, classify, and link data.

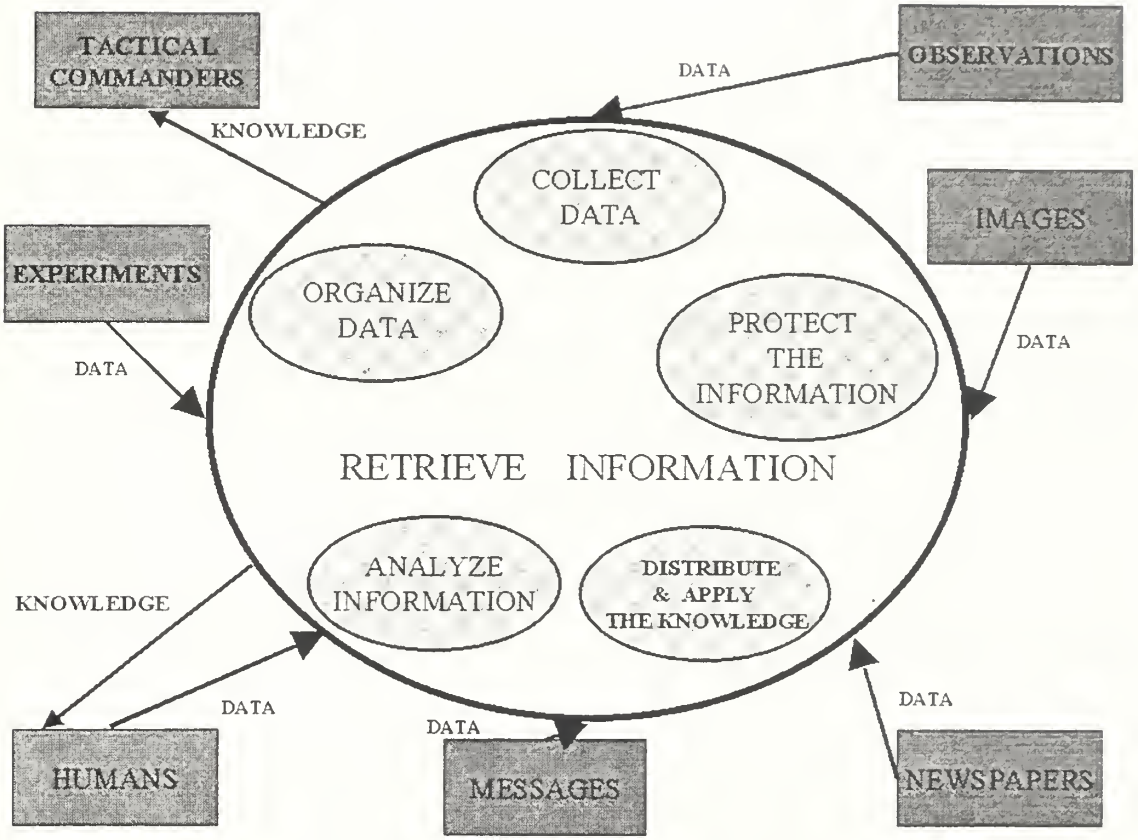

Figure 2.1. The Information System

c. *Analyze Information*

Analyze information in order to provide knowledge. Once information has been processed and analyzed, it becomes knowledge. In a conflict environment, knowledge combined with experience gives the advantage of "Knowing the enemy." Sun Tzu, the Chinese philosopher, said, "Know the enemy and know yourself; in a hundred battles you will never be in peril. When you are ignorant about the enemy but know yourself, your chances of winning and loosing are equal. If ignorant both your enemy and yourself, you are certain in every battle to be in peril."

d. Distribute and Apply Knowledge

Distribute and apply the knowledge in order to be efficient. The products of information must be delivered to users on time, in an understandable format, and in sufficient quantity to permit actions to be taken.

e. Protect the Information

Protect the information collection, processing and distribution channels from all forms of attack.

3. The Role of Information Technology in Information Warfare

Things that seemed futuristic a few years ago are commonly used today. In the last quarter of this century, an enormous expansion of electronic technology has occurred that continues still. As a result, electronically collected and managed information has became a very powerful weapon of both commercial and military sectors. Additionally, innovations in communications, electronic transmission, and automated processing of information have fueled the technology expansion. Commercial development, rather than classified military research and development, drive the technology of information warfare - unlike previous war forms. Current acquisition programs emphasize purchasing Commercial-Off-The-Shelf

(COTS) components as much as possible to avoid the expense of unique military performance specifications.

Key technology areas now in development include the following (Waltz, 1998):

- Intelligence, surveillance, reconnaissance (ISR) and command and control (C2) technologies provide rapid, accurate fusion of all-source data and mining of critical knowledge to present high-level intelligence to information warfare planners. These technologies are applied to understand geographic space (terrain, road networks, and physical features) as well as cyberspace (computer networks, nodes, and link features).

- Information security technologies include survivable networks, multilevel security, network and communication security, and digital signature and advance authentication technologies.

- Information technologies developed in the commercial sector and applicable to information warfare, include all areas of network computing, intelligent mobile agents, multimedia data warehousing and mining, and push-pull information dissemination.

- Electromagnetic weapon technologies, deny service to threat information networks with a non-lethal means of attack.

- Information creation technologies generate synthetic and deceptive virtual information (e.g., video, synthetic imagery, duplicated virtual realities).

In a conflict, both combatants intend to win by applying various strategies. Each one wants to identify enemy weak points and then exploit that information by attacking the weak point in order to gain an advantage. This advantage should contribute to victory by destroying the enemy with the least possible friendly casualties in personnel and equipment. Information Warfare includes actions taken to preserve the integrity of one's own information system from exploitation, corruption, or disruption, while at the same time trying exploit, corrupt, or disrupt enemy information systems.

To obtain a visualization of the enemy weak points, we apply surveillance, situation assessment, strategy development, and assessment of alternatives and finally, risks for decision making. Information is critical for all these processes because it is a common input.

In the Art of War, Sun Tzu describes the principles of war. Although these principles of war were written and applied before sixth century B.C., they are still applied today. Only the means of acquisition, processing, and dissemination of information has changed. Battlefield messages and reports that were once processed manually are now processed by automated electronic systems capable of acquiring and managing large volumes of information in a very short time. On the other hand, due to the continuous increase of dependency on electronic and computerized means, all information personnel, equipment, and installations have become both a significant target and a valuable weapon.

The steady increase of information technology forces the information to become more powerful in the warfare domain. Intelligence, as well as surveillance, and reconnaissance technologies have benefited by increasing their scope and range of operations. Now, instead of observing the objective "just over the hill", ten objectives can be seen "over the next 10 hills" with great accuracy.

In addition, communication and computer technologies support the decision-makers at all levels in the command and control process. Commanders and battle staff get the information very quickly and in near-real-time reducing their level of uncertainty and decreasing decision cycle time. They can now make the best possible decision.

Another area of continuous change is the integration of information technology into weapon systems and the subsequent "birth" of smart weapons that are more precise lethal, and capable of effectively operating in more environments (darkness, weather, obscurants.) This fact is easily evidenced by motion imagery segments recorded in the Persian Gulf, Bosnia and Kosovo.

4. Intelligence, Surveillance, and Reconnaissance

Intelligence, the information and knowledge about an adversary obtained through observation, investigation, analysis, or understanding, is the product that provides battlespace awareness [Waltz, 1998]. Depending on the established level of war, as well as on the amount of engaged forces, the levels of intelligence are strategic, operational, and tactical. The intelligence cycle as shown in Figure 2-2, delivers reports in response to specific requests and queries for knowledge to make decisions and set policies.

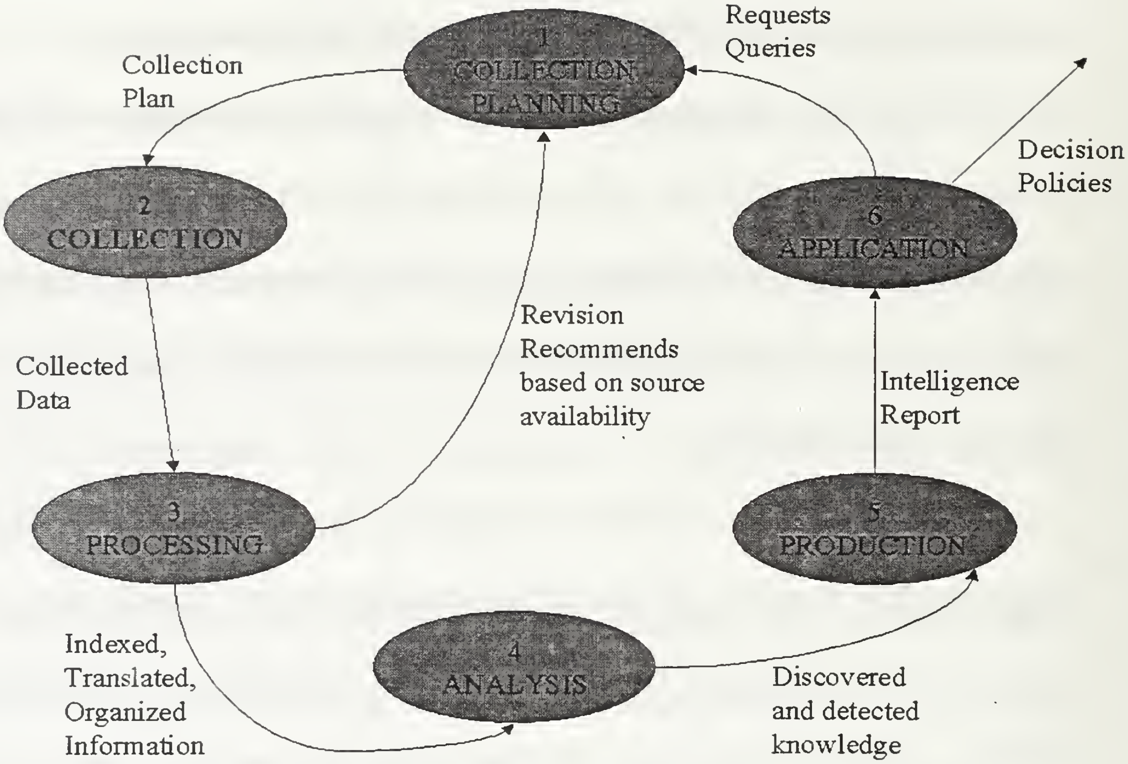

Figure 2.2. The Intelligence Cycle. From (Waltz, 1998)

Intelligence data sources can be distinguished as either open or closed. As expansion of electronic media access (telecommunications, video, and computer networks) continues. Open source intelligence (OSINT) is becoming the most important source of data collection. A good example of OSINT is the data collected from various DOD sources and publications for the purpose of this thesis. Table 2.1 shows the major intelligence categories and collection means.

Source Type	Intelligence Category	Representative Sources
Open sources: Human and Tech. Means	OSINT: Open Source intelligence	• Foreign radio and TV sources • Foreign printed material: books, magazines, journals • Diplomatic and attaché reporting • Short-wave radio, telecom, Internet chat • Foreign computer network sources Gray literature (printed and electronic)
Closed sources: Human means	HUMINT: Human Intelligence	• Reports from agents in foreign nations • Discussions with personnel in foreign nations • Reports from defectors from foreign nations • Messages from friendly third-party sources
Closed source: Tech means	IMINT: Imagery intelligence	• Surveillance imagery (static air and space imagery of the Earth • Surveillance imagery (terrestrial static and video imagery)
	SIGINT: Signals intelligence	• ELINT electromagnetic signals monitoring (externals: events, activities, relationships, frequency of occurrence, modes, sequences, patterns, signatures; or internals: contents of messages) • Moving target indications (MTI) tracking data • COMINT communications traffic monitoring for externals and internals • FISINT foreign instrumentation signals intelligence(telemetry: TELINT, beacons, video links)
	NETINT: Network intelligence	• Network analysis and monitoring • Network message interception, traffic analysis • Computer intrusion, penetration, and exploitation
	MASINT: Measurements and signals intelligence	• Technically derived intelligence from all sources(parametric data) to support real-time operations (e.g. electronic support measures, combat identification, tactical intelligence analysis)

Table 2.1. Major Intelligence Categories. From (Waltz, 1998)

The intelligence category that is examined most often in this thesis is Imagery Intelligence (IMINT). Analysts produce intelligence from imagery delivered by radar, infrared, optical, and electro-optical sensors. IMINT, as well as imagery systems, increase the commander's ability to quickly and clearly understand his battle space and area of interest (AI) (FM 34-1, 1996). Some valuable IMINT contributions include:

- Helps in the intelligence preparation of the battlefield (IPB), as well as in terrain and environmental analysis.
- Reveals the location, composition, and characterization of resources.
- Facilitates the battle estimates, by identifying several facilities and lines of communications.
- Provides early indication and warning, as well as situation assessment and targeting.
- Provides battle damage assessment.

The cycle of collecting, processing, and disseminating IMINT is continuously executed before, during, and after the battle. In other words, IMINT never stops. In order to be as effective as possible, IMINT should be used to cue other collection systems or to verify information provided by other sources.

5. Intelligence Collection and Automated Processing

Some systems that provide IMINT include the U2R Advanced Synthetic Aperture Radar System (ASARS), Joint Surveillance Target Acquisition System

(JSTARS), and UAV systems (FM 34-1, 1996). These systems are placed in space, in the atmosphere, on the ground, and at sea, depending on the object of surveillance interest.

The technical collection process requires the development of a detailed collection plan, which follows the principle of the V-model (Figure 2.3). The collection plan

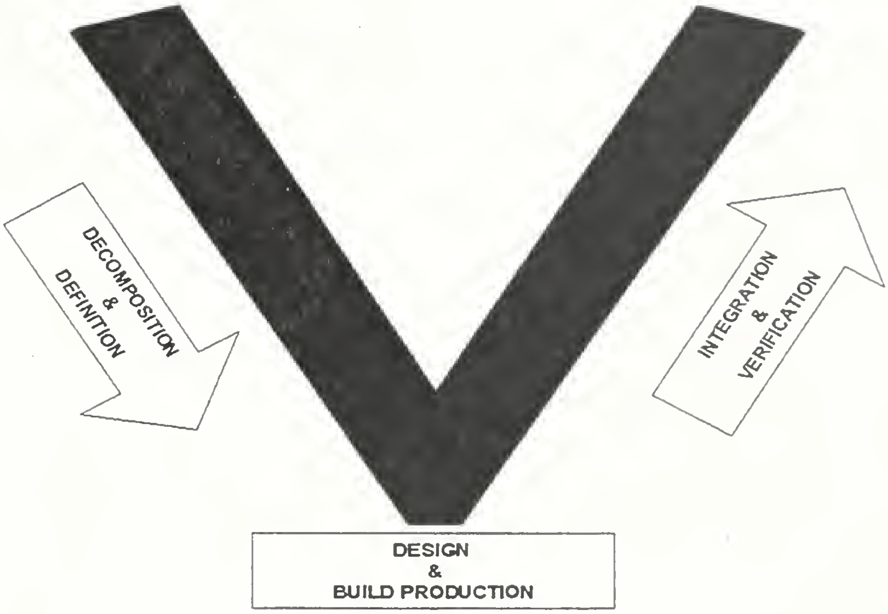

Figure 2.3. The Vee Model

begins with the decomposition of the subject target into activities, observables, and then collection requirements. From this plan, technical collectors are tasked and data is collected and fused to derive the desired intelligence about the target.

The intelligence process must deal with large volumes of source data, converting a wide range of text, imagery, video and other media types into processed products.

Information technology provides increased automation of the information indexing, discovery and retrieval (IIDR) functions for intelligence. The information flow in an automated or semi-automated facility requires digital archiving and analysis to ingest continuous streams of data and manage large volumes of analyzed data. The flow can be broken into three phases (Waltz, 1998):

1. Capture and compile,
2. Pre-analysis, and
3. Exploitation (analysis).

The capture and combine phase includes the acquisition of volumes of multimedia data and conversion to digital form for storage and analysis. During this phase, electronic data from network sources are directly formatted, while audio, video, and paper documents must be converted to digital form. This thesis will analyze how the video is converted to digital, in Chapter III.

The pre-analysis phase indexes each data item (e.g., article, message, news, image) by:

- Assigning a reference for storage,
- Generating an abstract that summarizes the content of the item and metadata describing the source, time, reliability-confidence, and relation to other items,
- Extracting critical keywords or meaning of the item for subsequent analysis.

The exploitation phase presents data to the human intelligence analyst for examination using visualization tools to bring to focus the most meaningful and relevant data items and their relationships.

6. Information Superiority, an Operational Advantage

The ultimate goal of information warfare is to achieve the assigned military tasks, using the most efficient application of all available information resources. Information superiority or information dominance, is a component of Information Warfare, an overall system of applied strategy, whose purpose is to eliminate the enemy power. This component is able to create an operational advantage to benefit the applied military force. For this reason Information superiority should be viewed in the same sense that air superiority is viewed as a precondition to achieve the advantage in military operations.

Information superiority is the enabling capability for four military operating concepts for advanced command and control warfare.

The technologies that are involved with information superiority can be formed into three categories, depending on their purpose. These categories are collection, processing, and dissemination.

The collection area includes the technical methods of sensing physical phenomena, as well as the platforms that carry the sensors to complete their mission. This category includes both direct and remote sensors, and the means of relaying the sensed data to users.

Some of the collection technologies are (Waltz, 1998):

- Unmanned Aerial Vehicles and High-Altitude Endurance UAVs,
- Intelligent Unattended Ground Sensors (UAGS),
- Commercial High-Resolution Imaging Satellites,
- Integrated Sensor Networks Ground-Air-Space,
- Integrated Precision Positioning, Telecommunications, Tracking,
- Micro UAVs,
- Micromachine Autonomous Ground Sensors and Nanomanipulators.

The processing area includes the hardware and software technologies that are used to automate the information. This area depends on the evolution of information technology. Some examples are the increase in processing power (measured in operations per second), the information storage capacity (measured in bits), the dissemination volumes (measured in bandwidth), as well as the compatibility of heterogeneous hardware systems.

Dissemination involves the communication technologies that increase the bandwidth and improve the effective use of it (e.g., the compression of transmitted data). All the concerned warfighters are provided with the same information simultaneously.

B. THE EVOLUTION OF UNMANNED AERIAL VEHICLES (UAV)

UAVs are not something new. The technology to develop and employ them has been available for many years. Its use is significant to force enhancer. When first introduced, the UAV was referred to as remotely piloted vehicle (RPV). An UAV is an aerial vehicle that has no onboard pilot and is capable of preprogrammed autonomous operation or operations received from a human operator located some distance (either on the ground or on a seaborne or airborne platform) from the vehicle. A RPV is considered as a subset of UAV and is capable of receiving continuous or intermittent commands from a human operator located at a ground, seaborne, or airborne station some distance from the vehicle. Another aerial vehicle that has no onboard pilot is the Drone. This vehicle is programmed prior to launch to accomplish a set of functions with no further human intervention or command. The drone may use onboard sensors to autonomously make mission adjustments. Drones are usually designed for such uses as expendable targets with relatively short operating distances and loiter times. (DTIC, 1998)

These remotely piloted or self-piloted aircraft, can carry cameras, sensors, communications equipment, or other payloads, and can collect different types of information, such as tactical intelligence and strategic intelligence.

An UAV is a platform that can have single or multiple sensors on board. It can be described as a directed collection sensor system gathering data as programmed by the ground or as a result of shared (cued) sensor data available to ground control or dictated by on-board sensor data. A successful mission is dependent on detailed geographic guidance (i.e., exact area to be surveyed) and collection requirements (i.e., mission statement to help determine the optimum UAV payload) from the higher headquarters' intelligence staff. (Joint Pub. 3-55-1, 1993)

> It is only the enlightened ruler and the wise general who will use the highest intelligence of the army for purposes of spying, and thereby they achieve great results. Spies are a most important element in war, because on them depends an army's ability to move.
>
> "Sun Tzu"

1. History of UAVs

a. W.W.I Era

Early in World War I, military planners realized that pilotless aircraft could have substantial advantages over the traditionally manned airplanes.

(Waller, 1996) Research began at the Ordnance College of Woolwich after the British sustained heavy pilot casualties from the German Fokker bi-plane. Professor A.M Low was tasked to design an unmanned aircraft capable of interception and ground attack. Unfortunately, numerous mishaps hampered the British attempt to demonstrate the effectiveness of unmanned aircraft.

The United States was also conducting experiments with unmanned aircraft. The Navy's efforts led to the first successful flight of a robot aircraft on March 6, 1918, when the Curtis flying bomb flew 1000 yards. (Waller, 1996) The Curtis bomb was guided by a preset gyroscope for direction and a barometer controlled the altitude. Once the aircraft had flown the prescribed distance, the engine would shut off and the bolts holding the wings in place would be mechanically removed. The fuselage and the bomb would then fall to the target.

The Army explored the possibilities of unmanned flight in a program that created a biplane called the Kettering Bug, a later version of a Wright flyer. Charles F. Kettering led this first successful effort to deliver an explosive to a target with an unmanned aircraft. The Kettering Bug, with a 15-foot wingspan and a 37-hp engine, carried a 180-pound bomb. On its forth flight it flew a specified distance before the controls directed the airplane into a nose-dive directly to the target. However the war ended less than a month after this flight, leaving little time to exploit its success. Military usage, however, waited for World War II. (Waller, 1996)

b. World War II Era

Germany developed the jet-powered UAV first with their V-1 Buzz bomb, named for the throaty sound of its engine. Even though only 2,500 out of 10,500 V-1s survived their own mechanical failures and the British air defenses, they caused 14,665 casualties. Consequently, the V-1 was one of the most notorious UAVs of World War II.

The U.S. Army Air Corps responded with a B-17 loaded with explosives. Manned for takeoff, the B-17 was placed on course and then abandoned by a parachute-equipped pilot. Joe Kennedy was killed flying such a mission. Ironically it would be his brothers Bobby as Attorney General, and John as president who would trigger the renaissance of the drone.

c. The Early and Cold War Years

In 1951, the U.S. Army Research and Development Command (ARDC) established a test project at the Holoman Air Development Center to develop reconnaissance versions of the Radio Control Aerial Target (RCAT), an earlier aircraft, as well as an armed terminal guidance drone. Radar returned signatures of the target were measured, providing data for stealth programs at Wright Air Development Center. These early tests, run during the urgency of the ongoing Korean War, defined three basic areas needing development: adequate stabilization of the platform, sufficient guidance and navigation accuracy, and long-range secure data links.

In 1954, Ryan Aeronautical Company was awarded the production contract for the Firebee UAV. Killing a Firebee was difficult, even with ample signature augmentation. Its small radar reflectivity prevented tracking systems from achieving lock-on. Ryan began to compile data on all service flights for reliability records and in 1960 it was this data that lead Ryan to establish a covert team to propose a reconnaissance version of the Firebee. The Lockheed Aquilla mini-RPV followed with a development program that spanned from 1965-77. (DTIC, 1998)

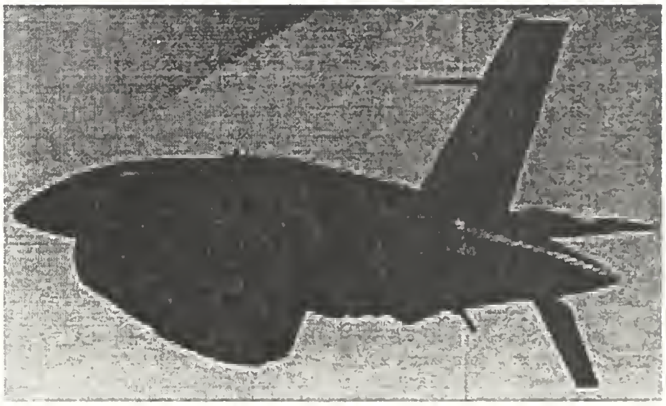

Figure 2.4. The Firebee

The genesis event for the UAV was the downing of Francis Gary Powers' U-2 spy plane over the Soviet Union on 1 May 1960 by a SA-2 missile.

Having promised to discontinue the U-2 flights, the U.S. found itself unable to collect intelligence of Soviet missile and bomber developments. It was 18 months before the first U.S. photo-reconnaissance satellites provided intelligence on Soviet missile sites. (DTIC, 1998)

Although some high-level Pentagon officials advocated funding the development of UAVs, neither Department of Defense (DoD) nor Central Intelligence Agency (CIA) provided any significant funding. This lack of financing for unmanned reconnaissance drones quickly subdued UAV support within the U.S. military. The first Recon-UAV effort by Ryan Aeronautical Company, code-named Project Red Wagon, started in July 1960 but terminated later that year under Air Force supervision. It is now evident that the Air Force's lessening interest in UAVs was because of the ongoing development of the SR-71 and spy satellite programs (e.g., CORONA). Also, because of President Eisenhower's commitment to end overflights of the Soviet Union, there appeared little need for reconnaissance drones. (DTIC, 1998)

Development activities for reconnaissance drones solidified again on 27 October 1962 after the downing of another U-2, which was flying over Cuba to determine the status of Soviet nuclear missile sites. A Soviet SAM protecting the ballistic missile sites destroyed the aircraft. The pilot died in the crash, again fueling a for unmanned reconnaissance. Classified work began rapidly on the AQM-34 Lightning Bug and the D-21 Tagboard. (DTIC, 1998)

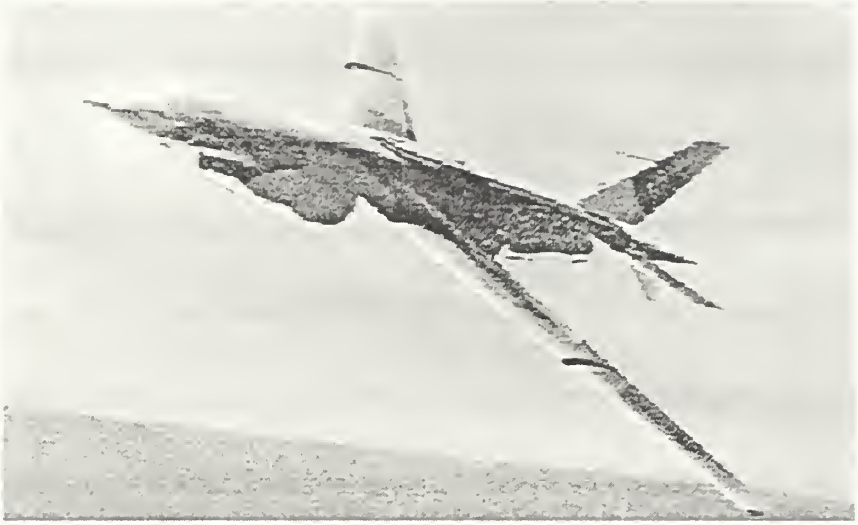

Figure 2.5. AQM-34 Lightning Bug. From (Ref. 24)

Lightning Bug was mostly employed in Southeast Asia. Most missions involved photography and real-time video, electronic intelligence (ELINT), and communications intelligence (COMINT). Some UAV missions, conducted at very low altitudes necessitated by poor weather conditions, provided battle damage assessments (BDA) to confirm that U.S. strike aircraft had hit their assigned targets. (DTIC, 1998)

Flights over China started in 1964, proceeding on to sorties over North Vietnam, Laos, and Cambodia. With aircraft flying initially from Bien Hoa AB, South Vietnam, and later from U-Tapao, the program was a huge success.

Not only did the UAVs provide photographs and ELINT on enemy MiG and SAM defenses, they also acted to determine the precise command codes used to detonate the enemy SAMs' warheads. This intelligence kept U.S. strike and bomber aircraft safe from all but the Soviet-supplied SAMs, affording U.S. aircraft the ability to jam the incoming missiles. (DTIC, 1998)

Lightning Bug employment commonly used throughout the war called for an air launch from a modified C-130. After flying the programmed (although sometimes remotely piloted) route, the drones recovered using a parachute system automatically deployed over a designated area, bringing the drone softly to earth. A helicopter would retrieve the drone and return it to the unit operating center for film retrieval and vehicle refurbishment. In 1966, a new mid-air retrieval system (MARS), initially developed to capture satellite photographic buckets, was adopted for the drones. A helicopter would snatch the drone's parachute and return to the recovery location with the drone hanging below the helicopter. The procedure was successful in Southeast Asia. (DTIC, 1998)

The intelligence community tasked the Lightning Bug under a classified operations order code-named Buffalo Hunter. The first operational flight for the Lightning Bug in Southeast Asia was 20 August 1964; the last flight was on 30 April 1975. In all, the Lightning Bug flew 3,435 operational sorties in Southeast Asia. (DTIC, 1998)

Mindful of the Gary Powers U-2 shoot down aftershocks and the inevitable political sensitivities concerning manned overflight of large expanses of denied territory, the Lockheed 'Skunk Works' designed a tri-sonic, air-launched, reconnaissance vehicle designated the D-21 (code-named Tagboard). Built primarily from titanium, the D-21 had a range of 1,250 nautical miles, cruised at Mach 3.3 and could reach an altitude of 90,000 feet. (DTIC, 1998)

The D-21 Inertial Navigation System (INS) was programmed to fly the desired track and flight profile and execute camera on and off operations, allowing it to satisfactorily execute the perfect photo-recce sortie. After completing its camera run, the drones' INS commanded the autopilot system to descend the vehicle to its 'feet-wet' film collection point. The entire palletized camera unit then ejected and parachuted towards the surface. As the drone continued it descent, barometrically activated explosive charges would destroy the vehicle. A C-130 equipped with a Mid-Air Recovery System (MARS) would retrieve the camera unit containing its valuable film and fly it to a base for processing and analysis. (DTIC, 1998)

d. Operation "ALLIED FORCE" in Yugoslavia

During the NATO air campaign in Yugoslavia, U.S., French, and German UAVs stationed in Albania, Bosnia, and Former Yugoslavian Republic of Macedonia (FYROM), acted as electronic scouts. Their tasks were focused in

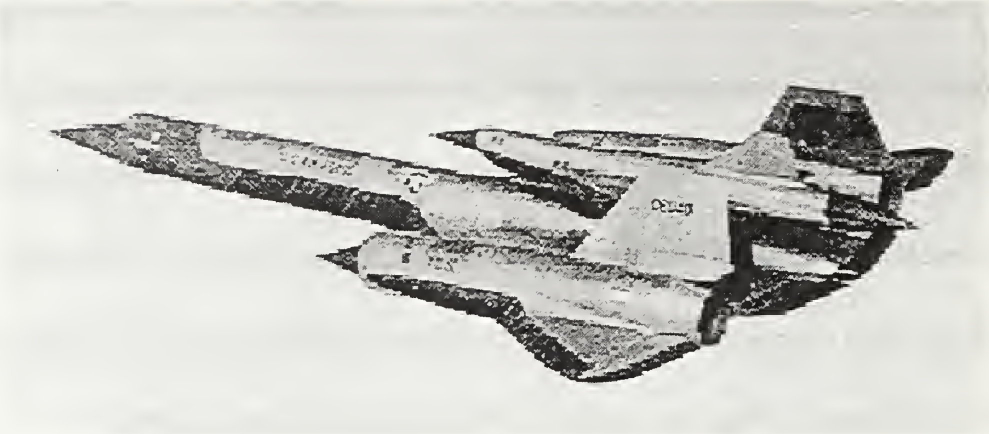

Figure 2.6. D-21 Drone Riding M-12. From DTIC, 1998

getting imagery of refugee movements, battle-damage assessments, and finding and filming targets, especially Serbian troops hidden in bunkers or woods. (Becker, New York Times, June 3, 1999)

Germany had seven batteries of the Canadian-built CL-289 UAVs. Each battery was consisted of 16 aircraft, but for operation "ALLIED FORCE" the German defense ministry decided to augment each battery with two additional aircraft. One of these batteries was flying missions out of Tetovo, FYROM. (Aviation Week, May 1999)

For the first 70 km. (44 miles) of its mission, the German UAV could provide live video imagery back to ground commanders (Aviation Week, May 1999). After the aircraft passed beyond its line-of-sight data link's range, the system switched to a line-scanner sensor that could use either regular or infrared film. The images were then stored for analysis after the aircraft's return to its base. The infrared film was generally used for night operations.

The usual altitude for German UAVs flying over Yugoslavia was 200-1,000 meters (660-3,300 feet). In the first month of Operation Allied Force, they completed about 90 missions. Average missions lasted 30-40 minutes and covered up to 400 kilometers (250 miles). (Aviation Week, May 1999)

The U.S. Army was operating the Hunter UAV out of FYROM. In addition, the U.S. Air Force was operating the longer-endurance Predator UAV out of Bosnia-Herzegovina.

Programmed to fly as low as 1,000 feet, the Hunter UAVs capture on camera what they see on the ground and immediately relay the pictures to forward aircraft like A-10 and F-16's, whose pilots call in strikers to bomb the targets. (Becker, New York times, June 3, 1999)

The information and photographs were sent first to UAV controllers and then to NATO headquarters in Italy or Belgium. The information relayed through the Hunter planes was processed through the Apache task force in Albania, and much of the video from the Hunters and Predators was sent to the Pentagon. (Becker, New York times, June 3, 1999)

According to NATO and Pentagon officials, during operation "ALLIED FORCE", at least 21 UAVs had been lost due to gunfire or mechanical problems. (Becker, New York Times, June 3, 1999)

2. Modern UAV Class Categories

In order to achieve maximum flexibility and mission success, the UAVs are divided in the following categories:

a. The Tactical UAV (TUAV)

This category supports Army divisions, including detached battalion and brigade task forces and corps, Navy and Air Force combatants and Marine Air-Ground Task Forces, meeting the need to monitor enemy activities out to a range of 200 Kilometers (Km) or more beyond the Forward Line of Own Troops (FLOT) or launch platform (in naval operations), with a flight endurance requirement of four hours on station. The UAV systems in this category are more sophisticated, can carry a wider variety of payloads, can consist of more than one air vehicle and perform more kinds of missions than the close-range systems (Joint Pub. 3-55-1, 1993).

The TUAV is composed of a baseline system that can be adjusted by the addition or removal of personnel and equipment to meet operational needs. The baseline system consists of a mission planning station (MPS), two ground control stations (GCS), two ground data terminals, eight air vehicles (AVs), eight

EO/FLIR payloads, four data relay payloads, a launch and recovery system (LRS), four remote video terminals (RVTs) and a mobile maintenance facility. It provides day or night imagery intelligence (IMINT) in addition to radio relay. (Joint Pub. 3-55-1, 1993)

The increased range and endurance allows for the system to operate over a significant area. Payload capacity allows for the UAV to carry multiple payloads, executing several missions on a given flight. The ability to analyze the payload product is resident within the system ground or ship component equipment. During preprogrammed autonomous flight, several hours of data can be recorded, stored and then retrieved and interpreted. The UAV maintains a constant link with GCS to provide real-time coverage. RVTs can be supplied to provide downlink information during mission execution to selected agencies such as the command centers or joint intelligence centers. (Joint Pub. 3-55-1, 1993)

The UAV size necessitates ground and shipboard considerations which limits the opportunity to operate from small clearings or unprepared areas and can impact routine afloat flight operations without prior flight plan integration. (Joint Pub. 3-55-1, 1993)

(1) The Pioneer Tactical UAV was the primary UAV employed by the U.S during DESERT SHIELD and DESERT STORM.

Figure 2.7. Pioneer Tactical UAV

Israel originally developed the Pioneer system. Because of the Israeli success with UAVs and identified U.S. military needs for an unmanned penetrating reconnaissance platform, the Navy started the Pioneer Program in 1985. Israel Aircraft Industries teamed with the U.S. company AAI to form Pioneer UAV, Inc. and produce the Pioneer for the U.S. military. The Army also procured Pioneer systems from the Navy and received its first Pioneer system in 1990. The U.S. deployed forty-three Pioneers to the theater that flew 330 sorties, completing over 1,000 flight hours. In ten years, the U.S. Pioneer system has flown nearly 14,000 flight hours and supported every major U.S. contingency operation to date. Since 1994, it has flown over Bosnia, Haiti, and Somalia. Currently, there are nine systems in the active force: five Navy, three Marine Corps, and one assigned to the Joint UAV Training Center at Ft. Huachuca, AZ. The Pioneer system will begin drawdown and phase-out in FY2000 as its replacement, the Outrider Tactical UAV, enters the inventory. (DTIC, 1998)

(2) The Hunter Tactical UAV provide both ground and maritime forces with near-real time imagery within a 200-km radius of action, extendible to 300+ km by using another Hunter as an airborne relay. This system is a derivation of a UAV developed by Israel Aircraft Industries able to operate from unimproved airfields to support the ground tactical force commanders at the FLOT. The Army is operating the Hunter systems in the Continental United States (CONUS) to support contingency operations, UAV doctrine and concept development, and exercises and training. (DTIC, 1998)

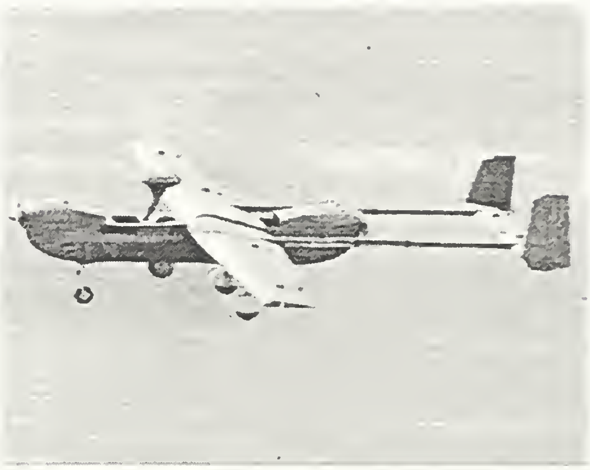

Figure 2.8. Hunter Tactical UAV

(3) The Outrider UAV was the intended replace-ment for the Pioneer UAV with a maximum range of 200 Kilometers, and a duration of operation of 4.9 hours or 7.2 hours at 50 Kilometers. The Outrider initially carried a day and night electro-optical and infrared sensor. In time, it might carry a

moving target indicator (MTI) and synthetic aperture radar (SAR), electronic warfare, and communications and data relay capabilities. (DTIC, 1998)

Figure 2.9. Outrider Tactical UAV

b. The Vertical Takeoff and Landing UAV (VTOL-UAV)

This category, formerly referred to as Maritime or VIPER (vertical takeoff and landing integrated platform for extended reconnaissance), will be

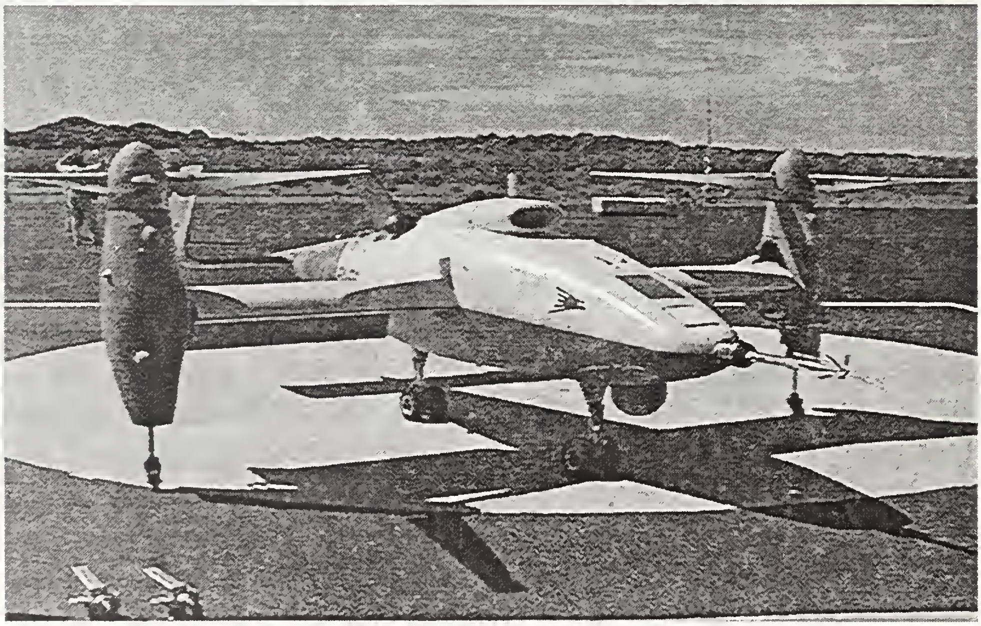

Figure 2.10. Eagle Eye. Vertical Take Off and Landing UAV

designed to complement the TUAV inventory with a VTOL-capable vehicle and provide a low cost extension of warship sensors, enhance maritime warfighting capabilities, thereby increasing the security of high value naval assets. (Joint Pub. 3-55-1, 1993)

c. *The Medium-Range UAV (MR-UAV)*

This category addresses the need to provide prestrike and poststrike reconnaissance of heavily defended targets at significant ranges and augment manned reconnaissance platforms by providing high quality, near-real-time imagery. MR-UAV systems differ from other UAV systems in that they are designed to fly at high subsonic speeds and spend relatively small amounts of time over target areas. (Joint Pub. 3-55-1, 1993)

The Predator Medium Altitude Endurance UAV was used during the Bosnia-Herzegovena operation (JOINT ENDEAVOR) conflict. It is also identified as the Medium Altitude Endurance (MAE) or Tier II UAV, and is a derivative of the Gnat 750 (Tier I) UAV used by the Central Intelligence Agency.

Predator appeared in the acquisition arena in July 1996. It consists of three parts: The air vehicle with its associated sensors and communications equipment, the ground control station, and the product or data dissemination system. The air vehicle carries EO (still frame and video), IR (still frame) and SAR (still frame) sensors which enable the system to acquire and pass imagery to

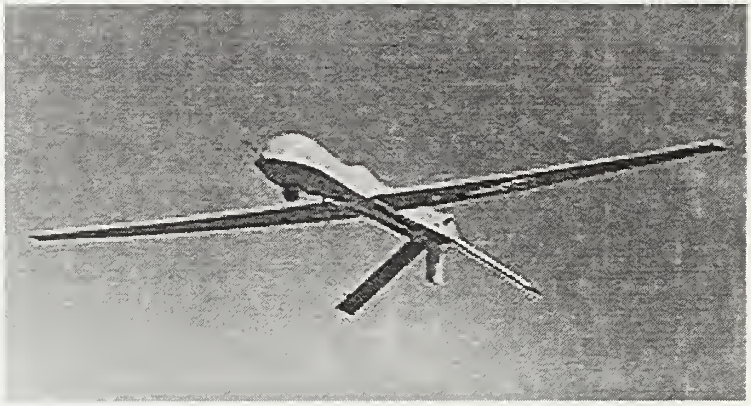

Figure 2.11. Predator Tactical UAV

ground stations for beyond-line-of-sight use by tactical commanders. The command link to the vehicle from the ground station allows the operator to dynamically retask the sensors and vehicle as requested by the field commander. Recent addition of de-icing equipment now allows transit and operation in adverse weather conditions. The commercial off-the-shelf (COTS) sensor hardware does not compromise sensitive technology if lost over enemy territory. The notional system, to maintain continuous 24-hour coverage, comprises three or four air vehicles, one GCS, and 28 personnel.

d. The High Altitude Endurance UAV (HAE-UAV)

This category provides heavy payload, multimission, and surrogate satellite support across all mission areas with flight duration in excess of 24 hours. HAE-UAV systems are capable of employing the widest variety of sensors and payloads in support of joint forces. (Joint Pub. 3-55-1, 1993)

These systems operate as a stand-off system behind friendly lines and also penetrate deeply into enemy territory for selected missions. The HAE-UAV operates night and day, in near-all-weather conditions, for extended periods of time. Its radius of operation can be up to 1200 Km from the controlling GCS, using either a UAV or satellite relay, with an endurance of more than 24 hours on-station. A baseline consists of 16 AV, all payloads, 4 GCS/GDT and support equipment.

The DarkStar and Global Hawk air vehicles, with their Common Ground Segment (CGS), form the HAE UAV system. The two air vehicles are complementary: DarkStar would provide a capability to penetrate and survive in areas of highly defended, denied airspace, while Global Hawk's even greater range, endurance and multi-sensor payload will provide broad battlefield awareness to senior command echelons. The CGS will ensure interoperability between the air vehicles and transmission of their sensor products to the C4I infrastructure, as well as provide common launch and recovery and mission control elements (LRE and MCE). The systems are being designed for pre- and post-strike, standoff and penetrating reconnaissance missions, cost effectively complementing other reconnaissance assets.

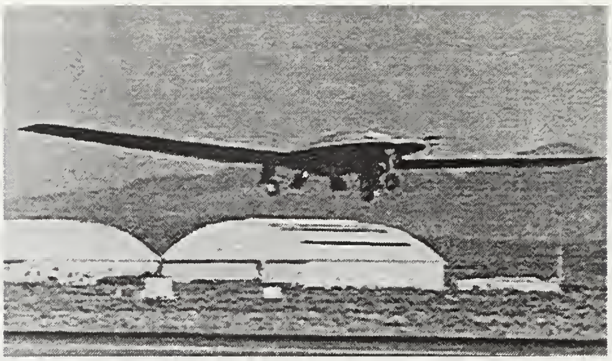

Figure 2.12. DarkStar HAE-UAV

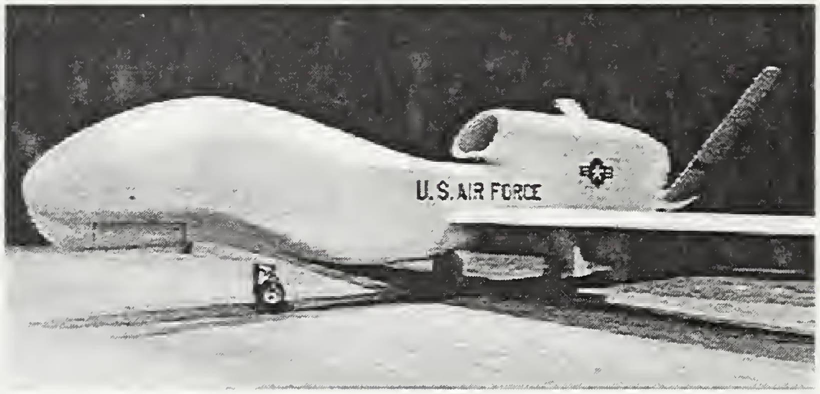

Figure 2.13. Global Hawk HAE-UAV

In January 1999 the Defense Department had terminated the DarkStar unmanned aerial vehicle program.

e. Micro Air Vehicles

Defense Airborne Reconnaissance Office (DARO) is supporting a Defense Advanced Research Projects Agency (DARPA) initiative to develop a micro-air vehicle (MAV), defined as UAV measuring less than 15 centimeters (6 inches) in any dimension while carrying a miniaturized payload, simple avionics and a communication link. This new class of UAV would be ideal for employment by small, mobile units operating in environments such as urban areas or unconventional operations anywhere. At the same time, the MAV presents a combination of technical challenges, as the sub-15-centimeters regime involves changes in the way things fly in terms of the physics of aerodynamics and flight control. Modern materials, microsensors, and study of the flying techniques of small birds and insects will all contribute to MAV development. (DTIC, 1998)

3. Employment of UAVs

a. Mission

The primary mission of UAV units is to support their respective service component commands as a tactical reconnaissance surveillance and target acquisition (RSTA) system, providing the commander a capability to gather near-real-time data on opposing force position, composition, and state of readiness without risking the lives of an aircrew. The categories of missions are the same as those for normal air support, preplanned or immediate.

Military analysts and planners, as the warfare is becoming more information-based, believe that UAVs can play a key role by providing their users with sustained, nearly instantaneous video of target information, weapon designation capabilities, and radar images of an area, without putting human lives at risk. They also provide fire support agencies an ability to target and adjust supporting arms at significantly greater distances and at reduced risk when compared to current forward observer, forward air controller procedures.

Missions of UAVs may also include surveillance for search and rescue, deception operations, electronic warfare (including electronic attack), signals intelligence, and directed energy sensor reconnaissance. By having the proper payload, they can provide nuclear, biological, and chemical reconnaissance as well as:

- Special and psychological operations, such as resupply for special operations and psychological operations teams (scheduled and emergency), and leaflet delivery and broadcast.
- Meteorology missions.
- Route and landing zone reconnaissance support.
- Rear area security support.
- Battle damage assessment.
- Radio and data relay. (Joint Pub. 3-55-1, 1993)

Eventually, UAVs may also be used in combat operations, such as the suppression of enemy air defenses and strike missions, developments that are still in testing.

At the tactical level, they are the capability that the commanders have not had before. At the strategic level, UAVs have some advantages over reconnaissance satellites, such as being able to watch one area for an extended period of time.

b. UAV Product Exploitation

The UAV product exploitation can be accomplished at various command levels, depending on the UAV system sophistication, the payloads used, the specific collection requirements to be satisfied, and the UAV unit expertise. Considerations for determining who will do exploitation are:

- Urgency between product receipt and exploitation.
- Type and sophistication of payload used.
- Security levels required to exploit the product.
- Mission
- Dissemination channels (i.e., desired communications flow from the UAV payload to end-user, to include any inter-mediate processing facilities)
- Data format, method and rate of transmission, and type of exploitation equipment. (Joint Pub. 3-55-1, 1993)

c. Dissemination

Dissemination is the conveyance of intelligence from the uav payload to end-user, to include any intermediate processing facilities, in a suitable form and timely manner. Dissemination formats include video, freeze-frame, voice communications, recorded message traffic, and digital data. The primary concerns of end-user are interoperability and commonality. Prior planning should identify types and numbers of communications paths to be used, the load requirements, and the level of security.

C. SUMMARY

UAVs are the smallest and potentially, the most effective sensor platforms. The variety of implementation will increase as their sophistication and strength improves. As an intelligence platform, they provide rapid and accurate intelligence and promise greater achievement over the next twenty to thirty years. Relatively inexpensive, their loss does not become a political or military disaster. They can shift position, and are able to carry multiple sensors and even weapons.

The UAVs and mainly the tactical UAVs, are deadly force in the tactical commander's hands. The key to success in every battle, is time. In tactical combat, minutes, even seconds, matter. Knowing that an enemy tank company is approaching from beyond a hill is vital information, but only if it is delivered in time to effect adequate counter-action. Information arriving even minutes late is useless. Information arriving in a format that requires detailed analysis beyond the ability of commanders operating in a stressful battlefield environment is also worthless. The closer the contact with the enemy, the more urgent the need for instant information.

A theater commander is interested in threats that develop over the course of several days or even weeks. A division commander is concerned about hours and days; the brigade and battalion commander deals with minutes and hours. For a company commander and platoon leader seconds only count. And wars are fought by squads and platoons.

Conventional tactical warfare requires the rapid processing and delivery of intelligence to every platoon in the army. Data management has become the pivot of tactical land combat. The problem is no longer gathering sufficient intelligence, but it has become screening and distributing what has become an unmanageable amount of data.

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III. MOTION IMAGERY: THE STAKEHOLDERS AND THE TECHNOLOGY

A. INTRODUCTION

Motion Imagery is captured on the modern battlefield in several ways. Aircraft gun cameras record air-to-air and air-to-ground engagements for post-flight operational analysis and damage assessment. Cameras mounted in the nose cones of smart missiles and smart bombs transmit motion imagery until the point of impact to verify target acquisition. Even if CNN removes camera crews from a hostile environment, the U.S. Army can collect ground-based motion imagery via the Lightweight Video Reconnaissance System - a hand held video camera deployed with ground forces.

Though multiple motion imagery sources are available to the battalion and brigade warfighter, this thesis will only address the motion imagery collected by electro-optical or infrared motion imagery camera payloads of a Tactical Unmanned Aerial Vehicle (TUAV). The extended duration of TUAV missions (4 hours) provides a worst-case scenario to calculate motion imagery storage requirements. Analog imagery technology has been successfully integrated into UAV systems, but digital imagery technology is currently replacing analog systems. DoD acquisition reform guidelines recommended commercial technology to eliminate the high cost of unique military requirements and performance specifications. (JTA, 1998) Commercial industry is migrating toward digital technology for several reasons that will be reviewed in this chapter.

B. DEFINITIONS

On September 17, 1997 the National Imagery & Mapping Agency (NIMA) released the Preliminary Draft of the Motion Imagery Archive and Distribution Concept (MIADC). In response to the tactical warfighters' request for more imagery intelligence products in a more timely manner, NIMA developed the MIADC to stimulate dialog within the community of users, collectors, exploiters, operators and system developers of motion imagery archive and dissemination systems (MIADC, 1997). The MIADC established three important definitions that this thesis adopts for any future reference to imagery:

1. Still Imagery

An individual image or image set which is managed a discrete object and displayed as a static image.

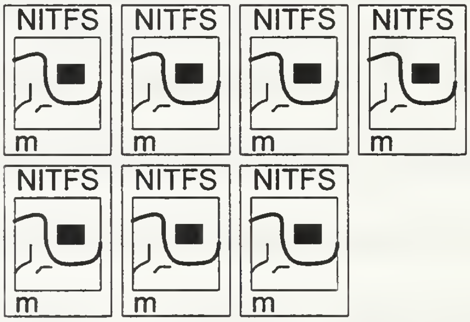

Figure 3.1. Set of Still Images (MIADC, 1997)

2. Motion Imagery

A sequence of images that are managed as a discrete object and displayed as a time sequence of images.

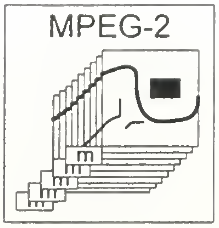

Figure 3.2. Sequence of Images (MIADC, 1997)

3. Video Imagery

A sequence of images which is collected as a time sequence of images, managed as a discrete object, and displayed as a time sequence of images.

C. STAKEHOLDERS

The United States Army doctrine requires seven Battlefield Operating Systems (BOS) as a framework for planning and executing military operations: Intelligence, Maneuver, Fire Support, Air Defense, Mobility and Survivability, Combat Service Support, and Command and Control (FM 100-5, 1993). The primary battle staff officers of both brigade and battalion use these BOS to coordinate the operations of subordinate maneuver units and to de-conflict common goals and objectives. Every BOS stands to gain from the information provided by TUAV motion imagery, since both the planning and execution phases of an operation suffer from identified "gaps" in the intelligence base. In addition to the tactical BOS, several federal agencies have claimed a stake in developing an imagery intelligence architecture to support the tactical warfighter.

1. Intelligence

An intelligence officer (S2) provides an Enemy Situation Template (SITEMP) for the planning process. This SITEMP composes a picture of the battlefield that includes terrain information, enemy force locations (known and suspected), and probable movement corridors for both friendly and enemy forces. TUAV motion imagery improves the quality of the plan by updating terrain information for a map that may have been printed several years before. For example, rivers and streams change course, bridges collapse or are washed away by flooding, forested areas succumb to timbering which removes a natural form of concealment for troops and equipment.

2. Maneuver

A battalion operations officer (S3) relies on the accuracy of the S2 SITEMP to derive alternative friendly courses of action. A TUAV can reconnoiter several locations of suspected enemy units by air in less than half the time required by ground-based reconnaissance. TUAV motion imagery can then be reviewed to gain a video of enemy activity information. A S3 can also visually inspect how well friendly battalion units have camouflaged their own positions. TUAV motion imagery can provide quick coverage of the battalion's subordinate units to display what information enemy aerial observation might obtain if corrective action is not ordered.

3. Fire Support

The fire support officer manages the commander's High Pay-off Target List (HPTL) for organic artillery, supporting artillery and Close Air Support. TUAV motion imagery permits real-time observation of these High Pay-off Targets to direct and adjust artillery fire and provides an immediate damage assessment of the engagement. The TUAV, equipped with Global Positioning System capability, transmits accurate target grid coordinates with the motion imagery. Accurate engagement of targets provides that more High Pay-off Targets are suppressed and/or destroyed with less ammunition expended and fewer ammunition restocks.

4. Air Defense

An air defense officer must analyze a commander's assigned Area of Operations (AO) in order to determine what avenues of approach are most likely to be used by an enemy reconnaissance or attack aircraft. When no elevated terrain feature permits the air defense officer a view of the entire AO, TUAV imagery can help confirm or deny possible enemy approach routes that are usually derived from a topographical map.

5. Mobility and Survivability

A combat engineer contributes to the planning process by advising the S3 how best to distribute engineering assets. After observing motion imagery of planned axes of advance, an engineer can more accurately position bridging and obstacle-reducing equipment for use in the most demanding areas. This was done in The Gulf War to bridge minefields. A TUAV flight over enemy territory can capture motion imagery of the planned routes to inform the engineer exactly which sections of the proposed routes require what quantity of material, equipment, and labor.

6. Combat Service Support

A logistics officer (S4) must designate a main and alternate supply route from the supply trains to the forward positions (approximately 25 kilometers). A TUAV overflight of this route provides motion imagery that can identify feasible logistics release points, potential enemy ambush sites, and possible lateral routes that will link forward movement and separate return routes. These routes could be reconnoitered by wheeled vehicles requiring considerably more time. A S4 can use TUAV information for designating future supply routes as part of any attack plan expecting to advance into enemy-held territory.

A division logistics officer also holds a stake in the motion imagery collected by the brigade. In the event of forward movement, division logistical support units will travel the same routes that forward brigades used. Video collected by brigade for the purpose of route analysis should be sent to division headquarters for use by the division staff to prevent duplication of effort.

7. Command and Control

A maneuver commander relies on his or her staff to collect, analyze and apply all information from every available source toward a comprehensive operations plan. A TUAV equipped with motion imagery capability provides a commander with a tool that supports multiple users with imagery intelligence. TUAV motion imagery is an intelligence source that provides every primary officer with up-to-date, visually confirmed battlefield information.

8. Federal Agencies

At least six federal agencies concern themselves with the standards, technology, and policy of motion imagery collection, storage, and dissemination:

1. National Imagery and Mapping Agency (NIMA),
2. Department of Defense/Intelligence Community/ US Imagery and Geospatial Systems (DoD/IC/USIGS),
3. Video Working Group (VWG),
4. Video Archive and Distribution Subworking Group (VAD),
5. Video Imagery Quality Committee (VIQC),
6. Video Exploitation Research and Development Committee (VERAD).

The mere existence of these organizations at the federal level attests to the significance of motion imagery intelligence as viewed by high level DoD decision-makers. An excellent summary of top-down demand is found in the VWG mission statement:

> Whereas, video imagery has been recognized by the DoD/IC/ USIGS as a fundamentally important source of imagery intelligence, and whereas, improved battlespace awareness using video sensors has been identified as a key developing technology area in policy documents such as DoD Joint Vision 2010, the mission of VWG is

> to ensure the development, application, and implementation of standards that maintain interoperability and quality for video imagery associated metadata, audio, and other related systems in the DoD/IC/USIGS. (VISP, 1998)

D. MOTION IMAGERY TECHNOLOGY

Motion imagery, once recorded, is more commonly referred to as "video." The capture and storage technology may be either analog or digital, or a combination of the two.

1. Analog Video

Analog video refers to images that are reproduced using a continuously varying electronic signal. Light is converted to electrical frequencies (waveforms) that are recorded on magnetic tape. A lightsensor (example Charged Coupled Device (CCD)) converts light frequencies into electrical frequencies which are subsequently routed to a recording head that transfers the signal to tape. (Cunningham, 1996) VHS, VHS-C, Super-VHS, and Hi-8 are all analog magnetic tape recording formats in common use today.

A Hunter UAV system records mission imagery on three 8-mm tape recorders. One recorder is located in a Ground Control Station (GCS) which transmits flight control signals to an air vehicle. A GCS feeds a parallel signal to a remote video terminal (RVT) equipped with a display and the second recorder. A RVT is placed in a Tactical Operations Center (TOC) for use by the TOC battle staff. A third recorder is mounted on the UAV and records mission video as a backup system. Should the motion imagery transmission link between UAV and GCS fail, a UAV recorder provides mission video for post-landing review.

Figure 3.3. Hunter Unmanned Aerial Vehicle

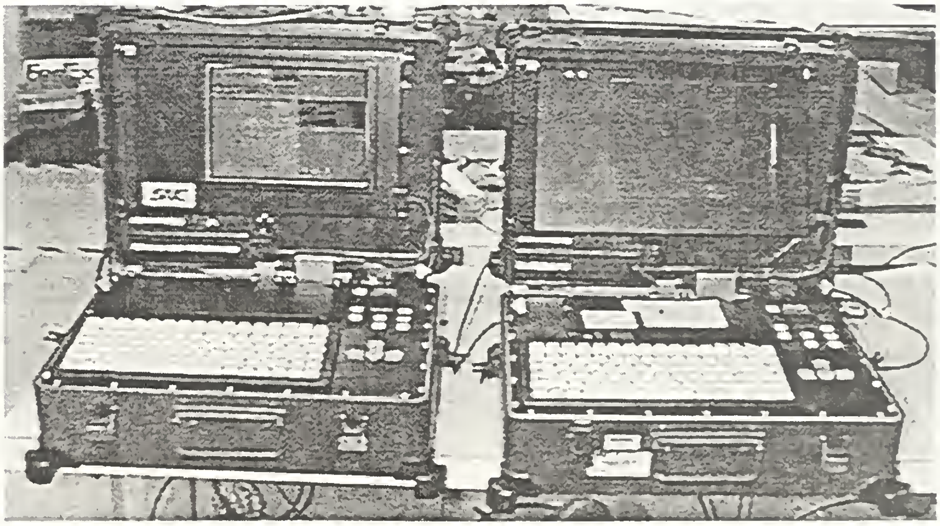

Figure 3.4. UAV Remote Video Terminals

a. Advantages

Analog technology has been on the market for many years and the cost is low. Massive commercial use and large production volumes result in lower prices for all analog equipment. Analog video is a forgiving medium that allows some damage to occur to the tape, yet still shows the original recorded information with little or no noticeable distortion (Cunningham, 1996).

b. Disadvantages

TUAV analog video suffers two major disadvantages: (1) copy degradation and (2) sequential access. In order to view the imagery on a magnetic tape, a tape must come in contact with the playback head of an analog video deck. This physical contact actually removes small amounts of adhesive that hold microscopic metallic particles onto the tape. Subsequent to the original, every copy of a magnetic tape loses viewing quality and the quality of any tape degrades with each use. Making multiple copies of a two-hour tape requires either a lot of time or multiple recorders – a major disadvantage in the battle field.

Locating a particular video segment requires shuttling the tape forward and backward (sequential access) until a desired scene can be recognized. This time-consuming process impedes rapid dissemination of time-sensitive information. Additionally, special equipment must be available to edit the tape with secondary markings that draw the untrained eye to an item of tactical interest.

2. Digital Video

Light can be transformed into digital signals by two methods. The first method uses an analog camera to capture imagery and then transform the continuous imagery waveform to a digital signal with an Analog-to-Digital Converter (ADC). The ADC takes thousands of "samples" per second of the analog signal at discrete points in time. Each sample is subsequently assigned a unique binary code representing sequence, frequency, and amplitude. This large population of samples represents a statistically accurate analog signal that can now be saved in a primary digital storage device, such as Random Access Memory (RAM), or in a secondary digital storage device such as a hard disk drive.

The second method is to use a digital camera. Digital cameras contain both a photosensitive CCD and an ADC so that motion imagery is stored digitally within the camera or rapidly transferred to an external storage device or visual display. Regardless of where the imagery signal becomes digital, some degree of computational processing is required to display, manipulate, and store the digital signal. This processing capability may be found in the function-specific computer chip of a digital camera or in a multi-function central processing unit of a multi-media computer.

On 26 May 1998 the Department of Defense published the Joint Technical Architecture (JTA), Version 2.0. In the Annex for Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR), the JTA documents the following two statements:

> **C4ISR.AR.3.1.2.1.1.1 Video Cameras**
>
> Commercial industry is currently migrating away from analog video components to all-digital systems. Airborne Reconnaissance systems will leverage advances in commercial television technology that provide the standards for interoperability for commercial broadcast and military video systems. Airborne Reconnaissance systems should provide a clear migration path toward an all-digital system, conforming to the mandated standards of the JTA Core.
>
> **C4ISR.AR.3.1.2.5 Mission Recorder Mandates**
>
> In conjunction with the migration to all-digital systems, mission recorder standards will be re-evaluated to emphasize digital and de-emphasize analog.

In a 30 November 1998 memorandum, the Under Secretary of Defense (Acquisition and Technology) stated that "Implementation of JTA, that is the use of applicable JTA mandated standards, <u>is required</u> for all emerging capabilities, or changes to an existing capability that produces, uses, or exchanges information in any form electronically."

a. Advantages

Copies of digital imagery files experience no quality degradation because no physical contact occurs at the point of transfer from electrical signal to storage medium. Digital files can be copied and transferred to portable media instantaneously. Any single frame of a digital motion imagery file can be accessed instantaneously by means of a program so that no time is wasted searching for a particular video segment. Digital error correction techniques ensure that digital files can be transmitted without loss of signal integrity. Commerical RAM, hard disks, video capture cards, and editing software can easily be added to the tactical computers found in the brigade TOC today. Also, intelligence analysts can produce secondary imagery without the need for specialized equipment.

b. Disadvantages

The use of binary coding to represent motion imagery information produces large digital files. Storage of large digital files requires expensive digital equipment and point-to-point wireless transmission of large digital files requires complex compression algorithms.

E. SUMMARY

The US Navy flew the Pioneer UAV over Kuwait City to monitor Republican Guard occupation activity after the Iraqi invasion. Pioneer also provided forward observation motion imagery for naval gunfire upon execution of OPERATION DESERT STORM (CBO, 1998). The US Air Force flew the Predator UAV over Bosnia-Herzegovina to monitor compliance with the Dayton Accord. When Serbian military officials vehemently denied removing weapons and ammunition from designated cantonment sites, a NATO Implementation Force commander played a Predator video of easily identifiable and unsuspecting

Serbian troops entering a storage site in violation of the Dayton Accord. The illegal activity at that site ceased completely. (CBO, 1998)

Still imagery of an intelligence target may well depict information of a static nature such as quantity and type of troops or equipment, but motion imagery more adequately portrays "activity" information. This "activity" information is in high demand from tactical warfighters. Even as this thesis is being drafted, the Predator and Hunter UAV systems are collecting motion imagery intelligence over Kosovo searching for evidence of Serbian genocide.

With motion imagery in such high demand and with digital technology replacing analog systems, the maneuver brigade now requires a digital storage capability to store large digital imagery files.

IV. ANALYSIS OF STORAGE ALTERNATIVES

A. INTRODUCTION

Anticipating a need for battlefield storage and dissemination of digital motion imagery, the National Imagery and Mapping Agency (NIMA) prepared the Motion Imagery Archive and Dissemination Concept (MIADC) to define the approach used to estimate the performance requirements for the NIMA Library Program and the Image Product Library (IPL) (MIADC, 97). The brigade IPL is a subsystem of the Tactical Control System (TCS), which both controls tactical unmanned aerial vehicle (TUAV) flight operations and receives motion imagery directly from the TUAV on-board camera (Figure 4.1).

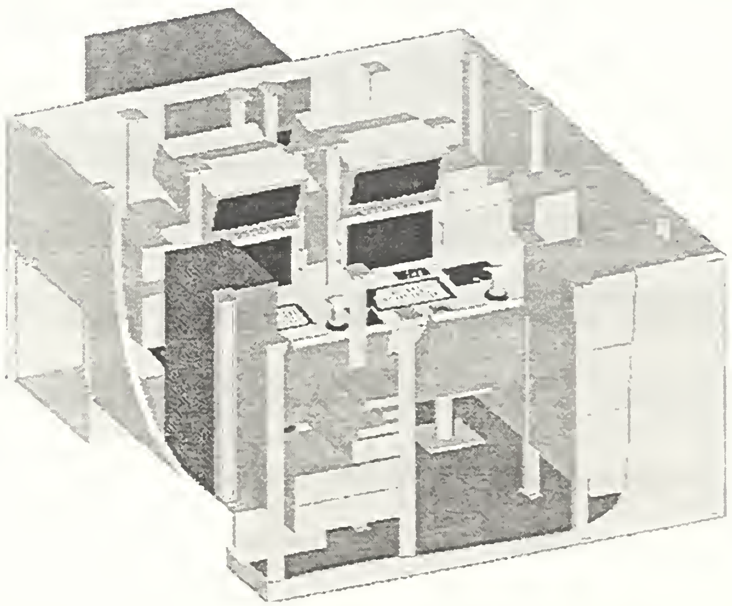

Figure 4.1. TCS Shelter (TCS CONOPS, 1998)

This chapter will calculate a storage capacity basis for the brigade IPL by combining motion imagery broadcast standards with TUAV operational requirements. Commercial off the shelf (COTS) storage media technology will then be evaluated for compatibility with data-intensive motion imagery files. Finally, seven multi-disk storage configurations are evaluated to determine which configuration or configurations provide an acceptable IPL storage device for the tactical environment.

B. IMAGERY PRODUCT LIBRARY

The IPL supports lower level echelon UAV operating sites, imagery exploitation sites, and tactical operation centers. The IPL stores and manages both still and motion imagery in a single, unitary domain - primarily in support of near-term tactical requirements. The TCS site IPL serves as a short-term imagery storage buffer and supports distribution of motion imagery segments to designated users of every TUAV mission video.

A quantitative definition of "short-term" has yet to be established, but estimations range from 12 to 24 hours. After this short-term period, the storage buffer purges imagery by erasure and/or transport to a higher echelon IPL via digital tape. (MIADC, 1997)

The term "archive" will be used in this thesis only when referring to hardware that stores motion imagery for periods greater than 24 hours.

C. STORAGE CAPACITY BASIS CALCULATION

The respective TUAV and Tactical Control System Operational Requirements Documents (ORD) established performance requirements that define two constants in the storage size equation. Concurrently, the Video Imagery Standards Profile (VISP) establishes video broadcast standards in terms of quality that define three constants in the storage size equation.

1. TUAV and TCS Performance Requirements

The Training and Doctrine Command (TRADOC) Systems Management-UAV office published the TUAV ORD on 11 March 1999. The TUAV is required to provide a video collection capability of no less than four hours per mission at a range of 50 kilometers (TUAV ORD, 1999). For future reference, this collection constant shall be labeled "MISSION."

The MIADC estimates IPL capacity based on a UAV groundsite supporting *one* UAV collection at a time. Within the System Performance subsection of "Capabilities Required," the TCS ORD stipulates that the TCS "allow operators to have simultaneous flight and payload control of at least *two* air vehicles." This imagery sensor requirement shall be labeled "SOURCE."

2. Video Imagery Standards Profile (VISP)

The VISP introduced the concept of Video Systems Matrix (VSM) to standardize motion imagery quality characteristics. Different levels of quality are represented by a specific VSM level which includes the characteristics listed in Table 4.1.

Characteristic	**Description**
Spatial Resolution	Number of Horizontal & Vertical Pixels (Frame)
Temporal Resolution	Number of Frames Transmitted per Second (fps)
Image Depth	Bit Representation per Pixel
Compression	Algorithm and Ratio

Table 4.1. VSM Characteristics

The VISP distributes ten VSM levels among four Subdivisions based on the image resolution required. Table 4.2 displays this distribution:

Level	Subdivision
9	**High Definition Video**
8	
7	
6	**Standard Definition Video**
5	
4	
3	
2	**Low Spatial Definition Motion Imagery**
1	
0	**Low Temporal Definition Motion Imagery**

Table 4.2. VSM Levels and Subdivisions

Mid-term projections (3-5 years) for TUAV motion imagery quality fall to Standard Definition Video, VSM Level 5 (MIADC, 1997). The quantitative measures that define VSM 5 are adopted by this thesis for capacity calculations and are listed in Table 4.3.

SPATIAL RESOLUTION		IMAGE DEPTH	TEMPORAL RESOLUTION	COMPRESSION
Horizontal pixels	Vertical pixels	Bits	Frame Rate (fps)	Type (ratio)
720	576	10	30	MPEG-2 (5.5:1)

Table 4.3. VSM 5 Quantitative Measures

VSM 5 permits a frame rate from 24fps to 60fps. In anticipation of international systems that will contribute video for dissemination, a frame rate of 30fps is used with regard to Mid-term Motion Imagery Systems estimations (MIADC, 1997). The VISP allows both 8 and 10 bit representations for image depth, but 10 bit implementations are preferred (VISP, 1998). With these discrete constants identified, a pre-compression storage basis can be calculated.

3. Calculation

If

M = Mission
S = Source
SR = Spatial Resolution
ID = Image Depth
TR = Temporal Resolution

Then

Uncompressed Storage Basis = M x S x SR x ID x TR

$$= \frac{4\ \text{hrs}}{\text{UAV}} \times 2\ \text{UAVs} \times \frac{(\text{Horz. pixels} \times \text{Vrt. pixels})}{\text{frame}} \times \frac{10\ \text{bits}}{\text{pixel}} \times \frac{30\ \text{frames}}{\text{second}}$$

$$= \frac{4\ \text{hrs}}{\cancel{\text{UAV}}} \times 2\ \cancel{\text{UAVs}} \times \frac{(720 \times 576)\ \cancel{\text{pixels}}}{\cancel{\text{frame}}} \times \frac{10\ \text{bits}}{\cancel{\text{pixel}}} \times \frac{30\ \cancel{\text{frames}}}{\text{second}}$$

$$= 8\ \text{hrs} \times 414{,}720 \times 300\ \text{bits/ second}$$

$$= 8\ \cancel{\text{hrs}} \times 414{,}720 \times 1{,}080{,}000\ \text{bits/}\ \cancel{\text{hr}}$$

$$= 3.58 \times 10^{12}\ \text{bits} = 4.48 \times 10^{11}\text{bytes} = \mathbf{448\ GB}$$

The 448GB figure approximates the actual digital imagery information transmitted by two TUAVs over an eight-hour period. If two, four-hour missions are executed by each TUAV in a 12-hour period (very likely for a non-linear battlefield), the uncompressed storage basis increases to **896GB**. Supporting digital information, known as metadata, is added to this imagery stream in the form of geo-coordinates, sensor model, sensor roll angle, collection time, mission start time, and sensor altitude.

The Video Working Group (VWG), chaired by the Central Imagery Office, created the Video Metadata Group to develop and coordinate a community-wide common set of video metadata (CVMP, 1997). This effort involves a complicated attempt to incorporate metadata specifications within the appropriate national and international standards. Since a common metadata metric is not yet available, the conservative estimate of 896GB will serve as the uncompressed storage capacity requirement for the TCS 1PL.

4. Compression

The VISP establishes MPEG-2 (Motion Picture Expert Group) as the compression standard for motion imagery broadcast to conserve transmission bandwidth. MPEG-2 also permits compression of motion imagery data for storage. MPEG compression exploits redundant data within an image frame (spatial) and redundant data within sequential frames (temporal) to economize bit quantities.

Unfortunately, a fixed MPEG compression ratio cannot be applied to a video segment to precisely calculate a compressed capacity. Panning or zooming a camera for a specific time period creates constant movement of all adjacent frames during that period and subsequently decreases frame data redundancy. Though MPEG-2 provides motion compensation techniques to limit this problem, different segments of the same video may compress at different ratios depending on the degree of frame movement.

In order to estimate the compressed storage capacity requirement, the nominal compression ratio of 5.5:1 is utilized (VISP, 1998):

$$\textbf{Compressed Storage Basis} = \frac{896\text{GB}}{5.5} = \textbf{162.9GB}$$

D. STORAGE MEDIA

There are three major types of storage media technology available for analysis: magnetic, optical, and magneto-optical. Each type uses a different method of writing and reading data from a storage surface. Each type is also capable of unlimited rewrites as demanded by recurring TUAV operations.

This section will first provide a brief description and initial screening of the media common to the three types of storage technology. Evaluation criteria are then defined and, finally, a comparative analysis will be implemented to facilitate the identification of a superior media.

1. Magnetic Media

The hard disk and digital tape are two magnetic media used extensively within the digital storage arena. Hard disks are rigid platters made of aluminum alloy or a mixture of glass and ceramic, covered with a magnetic coating. The platters are hermetically sealed in a case to prevent contamination. Two or more platters are stacked on top of each other with a common spindle that turns the whole assembly at several thousand revolutions per minute. A gap between each platter makes room for a control arm that mounts a set of read/write heads for each platter surface. (PCTechGuide, 1999) Minute crystalline grains embedded in the magnetic coating act as tiny magnets capable of holding an electrical charge. The hard disk write head polarizes the crystalline magnets according to the one or zero bit that is presented for storage. The read head can recognize a negative or positive charge and recreate the corresponding one or zero bit. (Glatzer, 1998)

Magnetic tape enjoys a good reputation as a data back-up archive media, but it's sequential access and imagery quality degradation preclude it from consideration as a viable on-line storage media.

2. Optical Media

Rewritable versions of the Compact Disk (CD-RW) and the Digital Versatile Disk (DVD-RAM) are the two optical media offering high-volume digital storage capacity. This particular disk is a polycarbonate plastic blank coated with a thin aluminum film on one side, for CD-ROM, and on both sides for DVD-RAM. The film is then coated with a translucent lacquer, which protects the film from debris and scratch damage. Both disks store binary data as a series of small pits along a single spiral path running from the center of the disk to the outside edge. Data is written to the disk by a laser beam that passes through the lacquer and burns pits into the aluminum film. DVD-RAM differentiates itself in this regard by being able to burn smaller pits than CD-RW (0.4 microns versus 0.83 microns) (PCTechGuide, 1999). A read laser is focused on the data layer where pits alternate with land (the smooth area between pits). The reflected light reflects back through a prism onto a photosensor that varies its voltage output based on the amount of light it receives.

The pits and land do not directly represent data ones and zeros. The transitions between pits and land contain the data. When light hits a pit, it is more diffused than when it hits land. The read head is able to detect these transitions and thus recreate the data. One DVD-RAM disk, with data stored on both sides, is expected to reach a capacity of 17 GB by using two data layers. (Poor, 1999)

3. Magneto-optical Media

Magneto-optical technology (MO) uses a combination of magnetic fields and laser beams to record and write information. To store data, each disk sector must be erased; all data bits must be reset to zero before new data can be written to the sector. The process subjects the sectors to a strong magnetic field in one direction. A laser beam then heats the data layer (similar to CD and DVD) and the whole segment is changed to the same magnetic orientation.

To write, a reversed magnetic field is imposed and only the non-zero bits are heated. To read, a laser beam is focused on the data layer, which reflects light differently, depending on the magnetic orientation. (McCormick, 1998)

4. Evaluation Criteria

The evaluation criteria defined below are based on the large storage capacity requirement for TUAV video and on the time-sensitive, data retrieval performance for TUAV video dissemination. The performance criteria, *access*, *read*, and *write*, refer to measurements of internal data transfer from the media disk to the disk drive cache. It is assumed that system engineers will make allowance for an external data transfer capability (disk drive to CPU) equal to or greater than the minimum transfer rate of the media selected.

a. Capacity

- Measured in Giga-bytes (GB).
- Maximum capacity available for one media drive mechanism.

b. Access

- Measured in milliseconds (ms).
- Speed at which the media drive moves the read/write head to target sector.

c. Read

- Measured in Mega-bytes per second (MBps).
- Speed at which media read head can move data from disk to drive cache.

d. Write

- Measured in MBps.
- Speed at which media write head can record data from drive cache to disk.

5. Results

Table 4.4 profiles the best capacity and performance data for each media type. The magnetic hard disk drive (HDD) clearly dominates both capacity and performance measurements.

MEDIA	CAPACITY (GB)	ACCESS (ms)	READ (MBps)	WRITE (MBps)
HDD	50	4.2	66	66
DVD-RAM	17	120	1.35	0.5
MO	5.2	21	2.05	2.05

Table 4.4. Storage Media Profile

E. STORAGE MEDIA CONFIGURATION SYSTEM - RAID

Because a single HDD (50GB) cannot meet the compressed storage basis requirement (163GB), a multiple disk storage configuration is necessary. The only multiple HDD configuration currently in production is known as Redundant Array of Independent Disks (RAID). RAID was originally developed to add storage capacity for computer network systems by spreading data across no less than three connected hard disk drives. The array configuration offers advantages in the form of greater capacity, speed, and reliability.

RAID can be implemented by both software and hardware. Software implementation increases the workload of the host CPU by tasking it to manage all application input/output requests (e.g., editing) as well as storage input/output (I/O). A hardware implementation incorporates a dedicated I/O processor that reduces CPU workload and a hardware implementation is assumed for this analysis.

1. Definitions

Definitions are provided below to allow understanding of RAID descriptors.

- **Striping.** Data is divided into blocks or bytes, generally in a consecutive string, and distributed evenly over multiple connected disk drives.

- **Mirroring.** Primary disk drive data is copied in its entirety to a designated secondary disk.

- **Parity.** Error correction technique that permits recovery of binary data in the event of a disk drive failure.

- **Parallel.** Hardware configuration that allows multiple read/write heads and/or disk drives to contribute increased speed to data transfer.

2. RAID Levels

RAID is characterized by different configurations commonly referred to as *Levels*. Seven RAID Levels are presented for comparative analysis: Levels 0, 1, 10, 3, 5, 53, and 6. Each Level utilizes a different data distribution scheme. RAID 10 and RAID 53 each combine two distribution schemes. A brief description of each Level follows:

a. Level 0

- Block striping
- No Fault tolerance
- No Parity calculation

Figure 4.2. RAID Level 0 (AC & NC, 1999)

b. Level 1

- Mirroring
- 100% data redundancy
- Double the space requirement for hardware

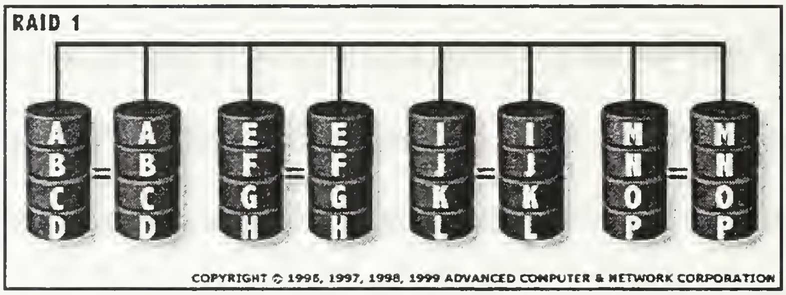

Figure 4.3. RAID Level 1 (AC & NC, 1999)

c. Level 10

- Striping and Mirroring
- Parallel Read/Write head actuation

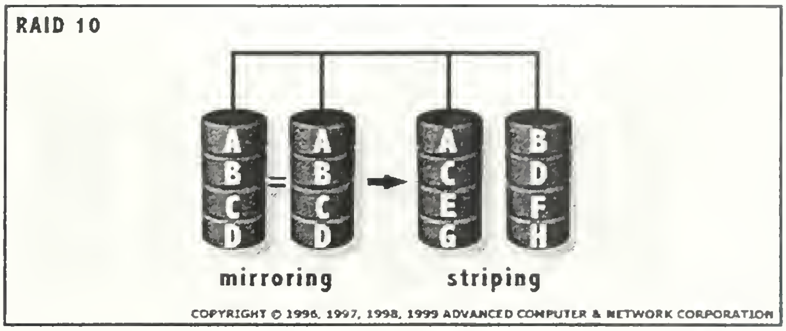

Figure 4.4. RAID Level 10 (AC & NC, 1999)

d. Level 3

- Byte striping
- Parallel Read/Write head actuation
- Dedicated parity disk

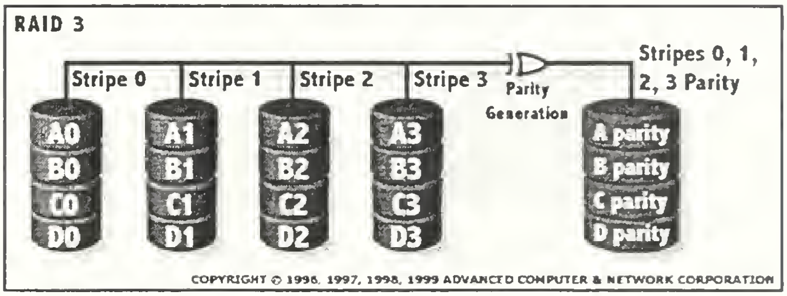

Figure 4.5. RAID Level 3 (AC & NC, 1999)

e. Level 5

- Block striping
- Independent Read/Write head actuation
- One parity set distributed across array disks

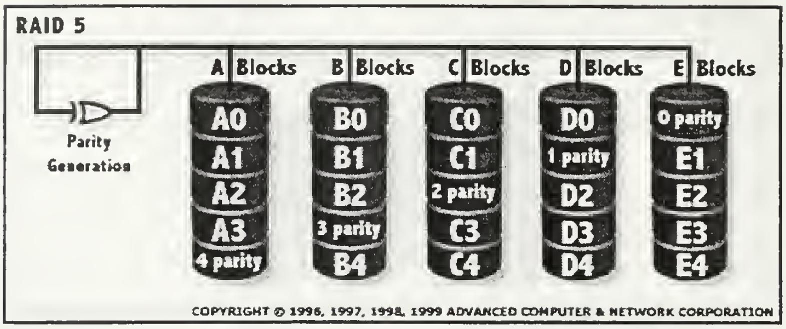

Figure 4.6. RAID Level 5 (AC & NC, 1999)

f. *Level 53*

- Byte striping of RAID 3 array segments
- Dedicated parity disk

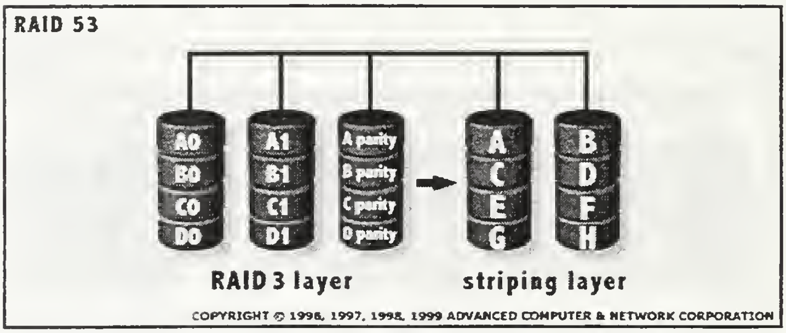

Figure 4.7. RAID Level 53 (AC & NC, 1999)

g. *Level 6*

- Block striping
- Independent Read/Write head actuation
- Two parity sets distributed across array disks

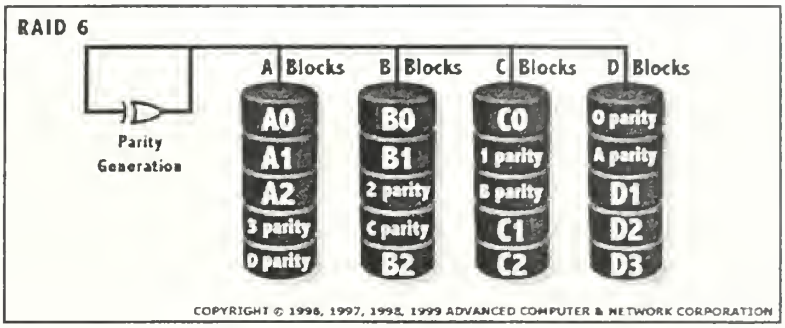

Figure 4.8. RAID Level 6

3. Fault Tolerance

RAID provides data protection in the form of fault tolerance. Given a multiple-disk storage configuration, different RAID Levels compensate for the mechanical failure of one disk drive with different implementations of redundancy and data recovery schemes where redundancy is the degree to which each RAID Level copies or represents a duplicate set or sets of primary data; and fault recovery is the degree and level of difficulty with which each RAID Level provides reconstruction of data lost to disk failure.

4. Accessibility

The necessity for timely battlefield intelligence dictates that imagery is available immediately upon request. Accessibility defines the degree to which a RAID Level provides access to stored data, despite the failure of a disk drive. Particular RAID configurations provide access to lost data only after the time required to reconstruct data from parity information.

5. Transfer Performance

- Read is the speed at which a RAID Level retrieves data from its array - measured in Mega-bytes per second (MBps);

- Write is the speed at which a RAID Level records data to its array - measured in MBps.

6. Transaction Performance

- Read I/O is the number of read I/O requests handled by a RAID Level - single or multiple;

- Write I/O is the number of write I/O requests handled by a RAID Level - single or multiple.

7. Evaluation Criteria Assumptions

a. Unit Price

The aggressively competitive nature of commercial information technology development renders hardware price information both unpredictable and extremely perishable. This analysis precludes cost as an evaluation criterion to prevent dating this thesis before it is distributed.

b. Criterion Weight

Storage and dissemination of digital motion imagery cannot occur without a performance-oriented system. For the purpose of comparative analysis, all performance-related criterion are considered twice as important as fault tolerance criterion. The access criterion is directly related to fault tolerance and is considered to be of equal importance.

8. Maintenance Assumption

Hot-swappable components allow RAID systems to suffer a power supply, cooling fan, or hard drive failure with only a few minutes required for replacement of the failed component. Since hot-swappable RAID systems are available from the commercial sector, the selection of any RAID configuration for the purpose of motion imagery storage assumes the inclusion of this hardware maintenance option.

9. Results

Subjective metrics are used to analyze fault tolerance, accessibility, and performance:

Fault Tolerance/Accessibility	Performance
VH - Very High	VF - Very Fast
H - High	F - Fast
G - Good	A - Average
P - Poor	S - Slow
VP - Very Poor	VS - Very Slow

Table 4.5 consolidates evaluation criteria and rating information by RAID Configuration.

RAID Level	Data Distrib.	Parity	Fault Tolerance		Access	Performance			
						Transfer		Transaction	
			Redundancy	Recovery		Read	Write	Read	Write
0	Block Striping	N/A	None	None	VP	VF	VF	G	F
1	Mirroring	N/A	VH	VH	VH	S	S	F	S
10	Strp. & Mirr.	N/A	VH	VH	VH	A	A	F	F
3	Byte Striping	Ded. Disk	G	G	G	F	F	S	S
5	Block Striping	1 set DD	G	H	G	A	A	VF	A
53	Byte Striping	Ded. Disk	H	H	H	F	F	F	F
6	Block Striping	2 sets DD	H	H	H	A	VS	VF	VS

Legend: Ded. = Dedicated
DD = Distributed Disks

Table 4.5. RAID Configuration Comparison

An initial screening of Table 4.5 immediately disqualifies RAID 0 from consideration as either an IPL storage device or an imagery server due to the lack of any fault tolerance. If one drive fails, all data is lost without possibility of recovery. The millions of dollars invested in TUAV, TCS, and IPL development warrant the guarantee that no motion imagery is forfeited to the failure of a single disk drive.

Inspection of the data transfer comparisons reveals RAID 3 and RAID 53 sharing dominance of both read and write speeds. RAID 53, however, only produced fast data transfer speeds for requests of small files. RAID 3 byte striping permits fast data transfer of large contiguous files, which is characteristic of eight-hour TUAV mission video. Only RAID 3 meets the performance requirements of a large-scale imagery storage buffer necessary for recording and editing operations.

The brigade imagery server must accommodate multiple requests from brigade users. Both RAID 5 and RAID 6 support multiple user requests with the fastest read transaction rates. RAID 6, implementing two sets of distributed parity, provides the only fault tolerance configuration that can recover data from the failure of *two* disk drives. This data protection enhancement all but guarantees that denial of access to imagery intelligence will result from a system failure other than a disk drive.

The slow write transaction performance of RAID 6 does not create a significant obstacle. Only two TCS imagery analysts who exploit motion imagery segments write video files to the imagery server. This low write I/O request rate should not over-burden even the slow write I/O capability of RAID 6.

Therefore, RAID 6 best supports the brigade with an imagery server hardware configuration that provides the fastest read I/O data rates combined with superior data protection.

10. Proprietary Technology

The Advanced Computer and Network Corporation advertises a RAID 7© configuration that appears to provide both high data transfer rates as well as high I/O rates. RAID 7© could provide a single solution for the IPL storage buffer and imagery server. Unfortunately, RAID 7© is not currently user serviceable; but should be considered in the future.

F. SUMMARY

The TCS IPL stoppage buffer must store 163GB of MPEG-2 compressed TUAV motion imagery. Seven different magnetic RAID configurations supply this capacity with varying degrees of additional fault tolerance, accessibility, and performance. Video exploitation and dissemination functions require high-speed performance capability in terms of data-intensive transfer rates (storage buffer) and read-intensive transaction rates (imagery server). No individual RAID Configuration adequately satisfies both performance requirements. RAID 3 best performs the IPL storage buffer function and RAID 6 best performs the imagery server function.

V. VIDEO DISSEMINATION NETWORK

A. INTRODUCTION

The existing intelligence infrastructure of the maneuver Army Brigade has no organic imagery capture capability. Requests for imagery intelligence (IMINT) from battalion commanders may travel up the chain of command quickly via voice radio or tactical telephone, but the Brigade and Battalion S2 depends on Division assets to collect all IMINT. If the division intelligence database does not contain the requested imagery, the Division aerial exploitation battalion must be tasked to collect it. Still imagery is transmitted from division to brigade via the WARRIOR intelligence Local Area Network (LAN). Motion imagery is collected on VHS or 8mm video tape and distributed to battalions by courier.

This process is time consuming. Current UAV systems can record mission video on analog tape, but this tape must be copied several times before Brigade-wide distribution is attempted. In addition, copying degrades analog tape resolution original color. The courier's traveling time must also be considered. The recorded information loses intelligence value the longer it remains out of the hands of its intended audience.

The dissemination of digital video imagery to Brigade stakeholders is something new. It is not included in the current Warfighter Information System (WIN) Master Plan of November 1998. According to WIN master plan, its programmatic and implementation is scheduled to be accomplished in three phases (architectures):

1. Near-Term architecture (FY 97 through FY 99).
2. Mid-Term architecture (FY 00 through FY 02).
3. Far-Term architecture (FY 03 through FY 10).

Based on the provided information by WIN master plan of November 1998, concerning the scheduled implementation of Asynchronous Transfer Mode (ATM) technology, as well as the scheduled completion progress of the transmission media infrastructure (Fiber Optic cable, upgraded switches and routers), that were designed to support other services than Tactical UAV (TUAV) video, like Battlefield Video teleconference (BVTC), but could be implemented to transmit the video imagery from the TUAV to the user's computer terminal, this thesis proposes that the TUAV video imagery should be part of the Information Services component of WIN and could be start incorporated in it during its mid-term architecture (FY 00 through FY 02).

Due to increasing battlefield requirements, digital video imagery should be rapidly exchanged vertically (without following the traditional hierarchical structure) and horizontally (units at the same level), in a common operating environment when battlefield functional areas are interoperable.

This chapter briefly describes the Warfighter Information Network and its subsystems, as well as the communications backbone for video imagery dissemination. This backbone will be essential for carrying real time quality video from the TUAV to Brigade and Battalion warfighters.

B. WARFIGHTER INFORMATION NETWORK (WIN) OVERVIEW

1. Today's Information Network

Today's information system support infrastructure was designed and built to accommodate the requirements for voice and low speed data. As warfighter C4I requirements grow, network services and throughput requirements continue to increase (Figure 5.1). The currently fielded signal support infrastructure is incapable of fulfilling these growing C4I requirements. (WIN Master Plan, 1998)

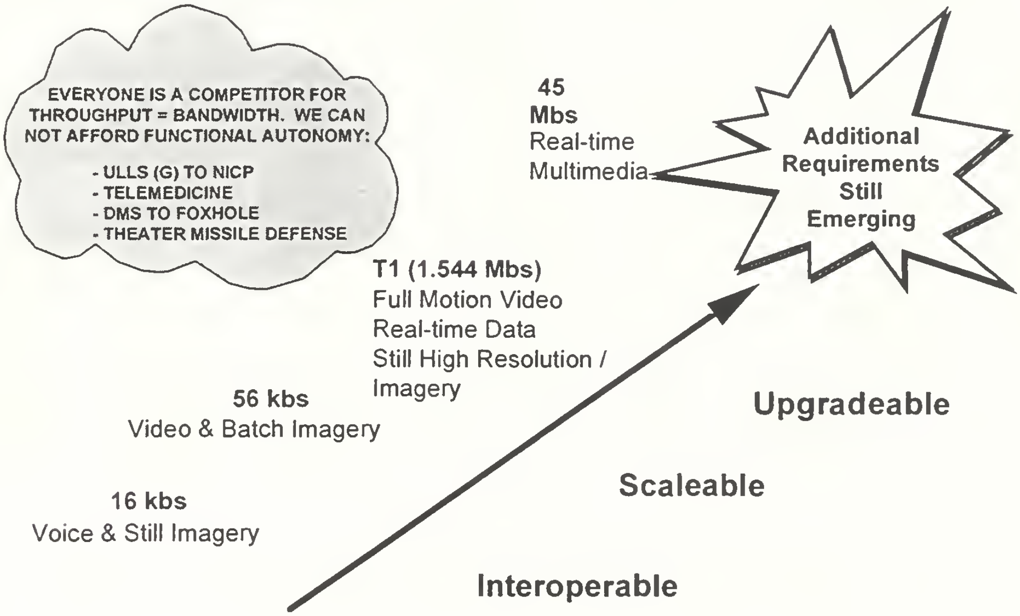

Figure 5.1. Increasing Requirements and Competition for Throughput. From (WIN Master Plan, 1998)

2. Future Warfighter Information Network (WIN)

A non-digitized division employs about 1300 computers. Considering requirements described in The Army Modernization Plan, the Army's Enterprise Plan and Force XXI Advanced Warfighting Experiments, a fully digitized heavy division will employ over 5000 computers (Figure 5.2). Additional requirements will continue to emerge and demands on existing bandwidth will increase.

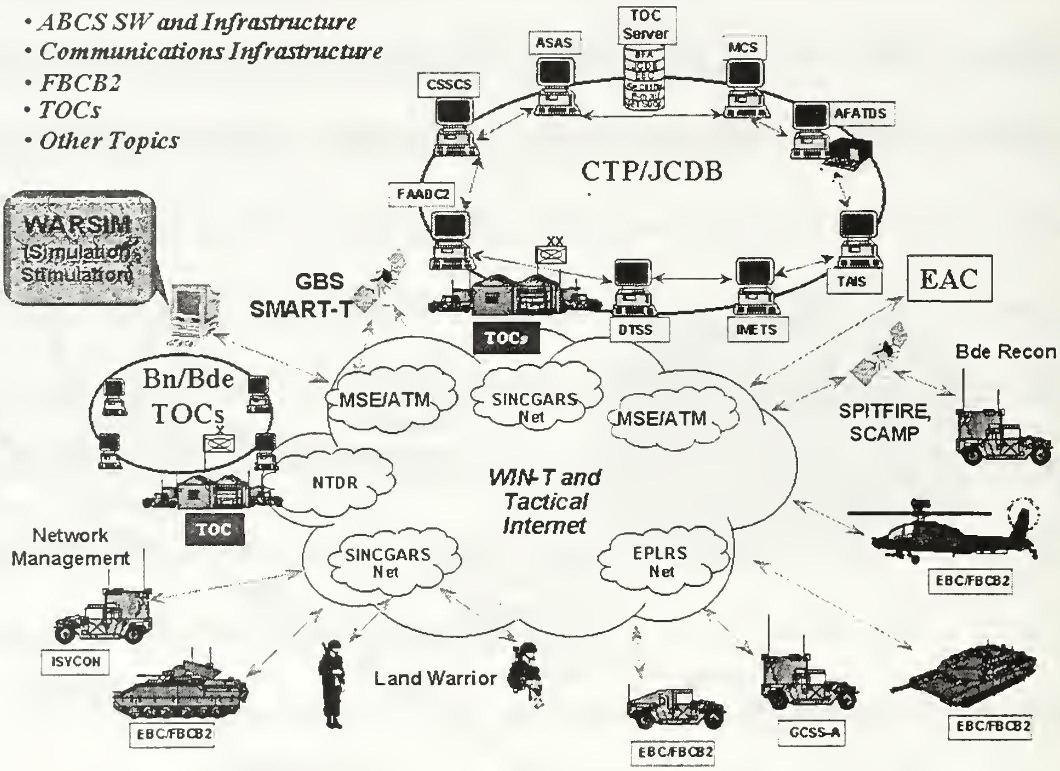

Figure 5.2. Key Components of a Digitized Division

WIN components are designed to increase the security, capacity, and throughput of information distribution throughout the battlespace in order to gain information dominance. (WIN Master Plan, 1998)

WIN is composed of seven interrelated subsystems that consist of their own components (Figure 5.3), and it was designed using Object-Oriented development. It is a terrestrial transport communications and information system, based on commercial technology, which will provide simultaneous voice, data, and video services, like video teleconference, on one transmission path. All WIN systems

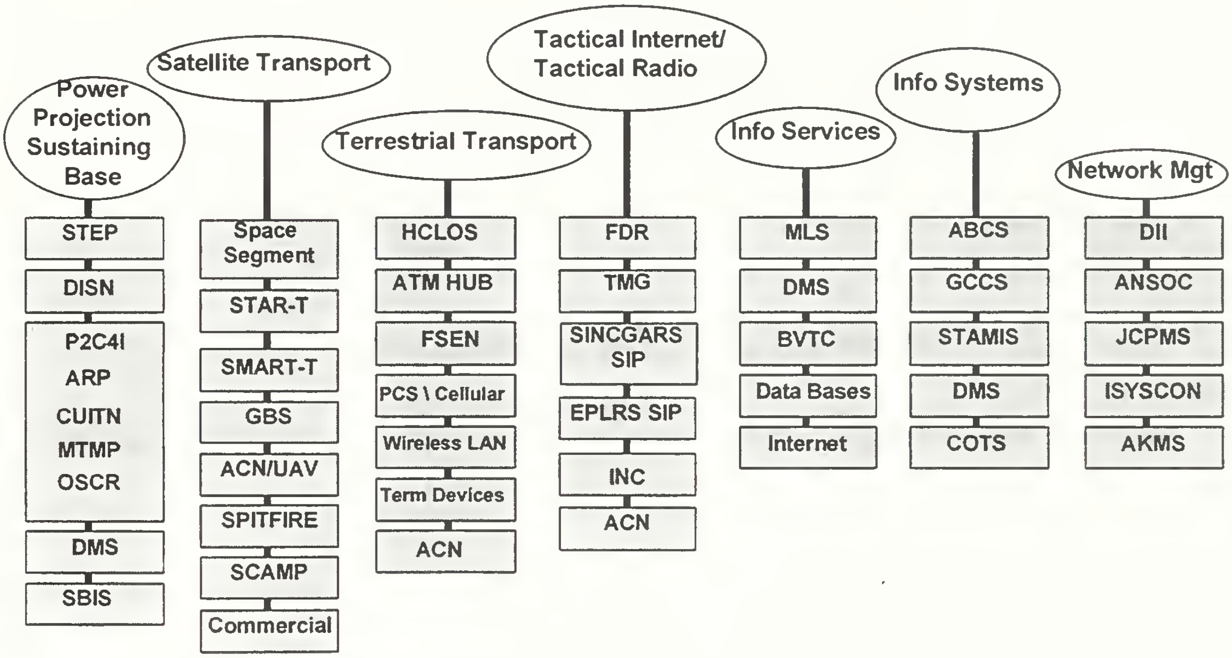

Figure 5.3. WIN Subsystems. From (WIN Master Plan, 1998)

will be modular in design to allow the flexibility to insert technological improvements as they become available. High capacity line-of-sight (HCLOS) radios and fiber optic cable will provide the throughput necessary to support transmission of imagery information required by Force XXI warfighters.

C. WIN OPERATIONAL PERSPECTIVE

The Army Battle Command System (ABCS) is a component of the WIN Information Systems subsystem (Figure 5.4). It integrates Army battlespace

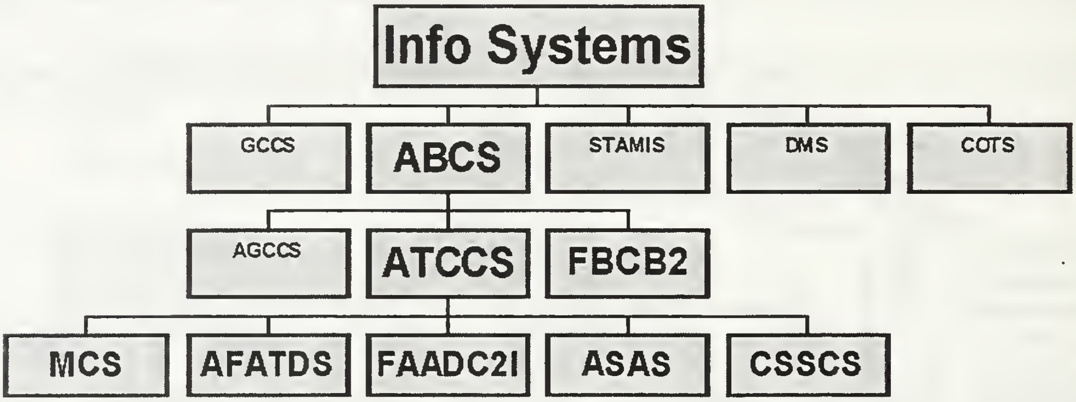

Figure 5.4. Army Battle Command System Structure

systems and communications to functionally link strategic, operational, and tactical headquarters.

The components of ABCS are (WIN Master Plan, 1998):

1. (AGCCS) Army Global Command and Control System

AGCCS provides the link to Global Command and Control System (GCCS). It is inter-operable with the theater, joint, and multinational command and control systems across the full range of battlefield operating system functions, and is vertically and horizontally integrated at the tactical and operational levels.

2. (FBCB2) Force XXI Battle Command Brigade and Below System

BCB2 will provide the command and control capability at brigade and below.

3. (ATCCS) Army Tactical Command and Control System

ATCCS interfaces directly to AGCCS and provides the framework for seamless connectivity from brigade to corps. ATCCS is composed of the following five tactical command and control systems:

a. (MCS) Maneuver Control System

MCS is a system for use by commanders and staffs of tactical units. It integrates information from other C2 systems to provide the common picture of the battlefield. It also allows rapid dissemination of direction and orders.

b. (AFATDS) Advanced Field Artillery Tactical Data System

AFATDS is a totally integrated fire support command and control system. AFATDS is a digitized and integrated battlefield management and decision support system that will function from firing platoon through echelons above corps, as the Fire Support (FS) node of the ABCS. It will enhance survivability and continuity of operations for the commander.

c. (FAADC2I) Forward Air Defense Command Control and Intelligence System

FAADC2I protects warfighters from low altitude air attacks. It provides a real time common air picture to counter low altitude air threats including rotary wing and UAV, (2) air defense C2 and airspace situational awareness to reduce fratricide within division, brigade, and battalion area.

d. (ASAS) All Source Analysis System

ASAS is a ground-based, mobile, automated intelligence processing and dissemination system designed to provide timely and accurate intelligence and targeting support to battle commanders. It is the Intelligence-Electronic Warfare (IEW) sub-element of ABCS.

e. (CSSCS) Combat Service Support Control System

CSSCS will consolidate and collate the vast quantities of data required to integrate situational awareness within combat service support mission areas. It collects, stores, analyzes, and disseminates critical logistics, medical, transportation, and personnel information.

f. The principal ATCCS communication components of the ABCS are:

1. Enhanced Position Location Reporting System (EPLRS).
2. Near-Term Digital Radio (NTDR).
3. Combat Net Radio (CNR)Single Channel Ground and Airborne Radio System (SINCGARS) System Improvement Program (SIP).
4. Mobile Subscriber Equipment Tactical packet Network (MSE TPN).

D. WIN'S NON-VIDEO COMPONENTS

1. The Tactical Internet

The Tactical Internet (TI) subsystem is integrated with the total ABCS through an interface with the ATCCS (Figure 5.5). The subsystem is named "Tactical" because it provides data communications infrastructure at Corps and below, as well as gateways to strategic levels, situational awareness and command and control. It is also named "Internet" because it uses the Internet Protocol (IP) suite for seamless communications. TI uses commercial network standards and products to dynamically route data to hosts. TI also facilitates technology insertion.

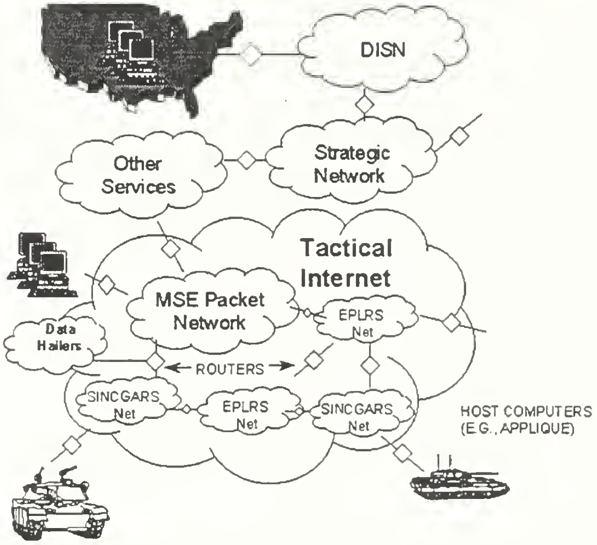

Figure 5.5. The Tactical Internet Architecture

Its primary function is to provide a more responsive information exchange necessary for battle command at brigade and below. FBCB2 devices of the TI are integrated into the tactical operation center (TOC) local area networks (LANs) at battalion and brigade echelons, thus enabling information flow between the soldier/platform level and the division echelon and throughout the ABCS (Figure 5.6). The near-term digital radio (NTDR) also links the TI to the ABCS at the division, brigade, and battalion TOCs. The NTDR network provides the primary data and still imagery communication transmission system at these echelons. (FM 24-32, 1997)

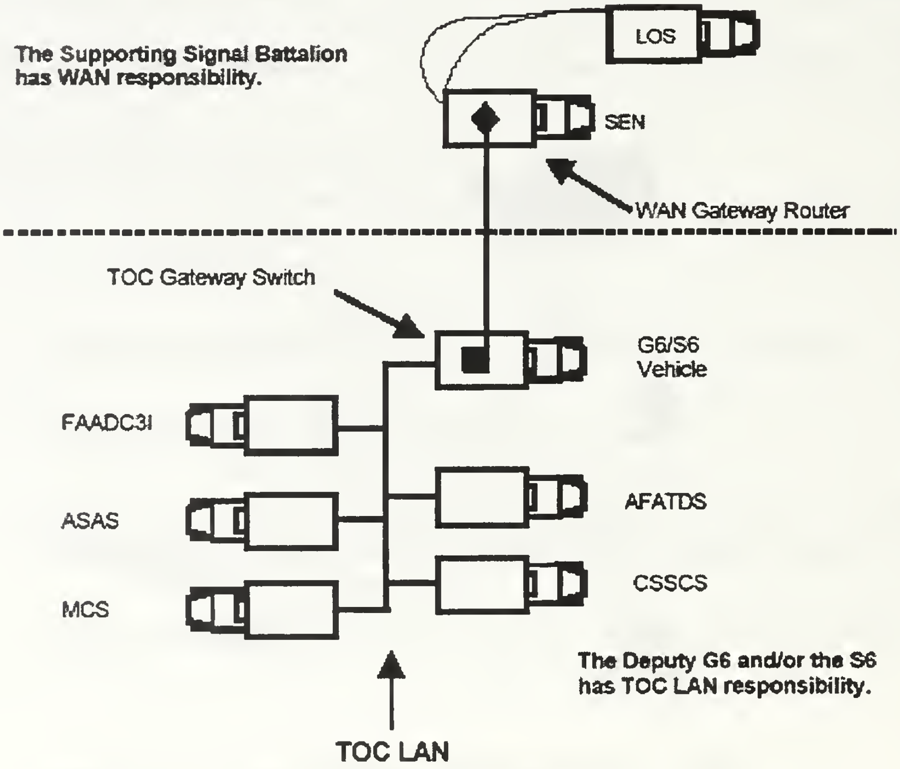

Figure 5.6. The Brigade LAN. From (FM 24-7, 1998)

The TI employs the following communications systems (Figure 5.7) that link the five Battlefield Functional Areas (BFA) of maneuver, fire support, air defense, intelligence and electronic protect, and combat service support (FM 24-32, 1997):

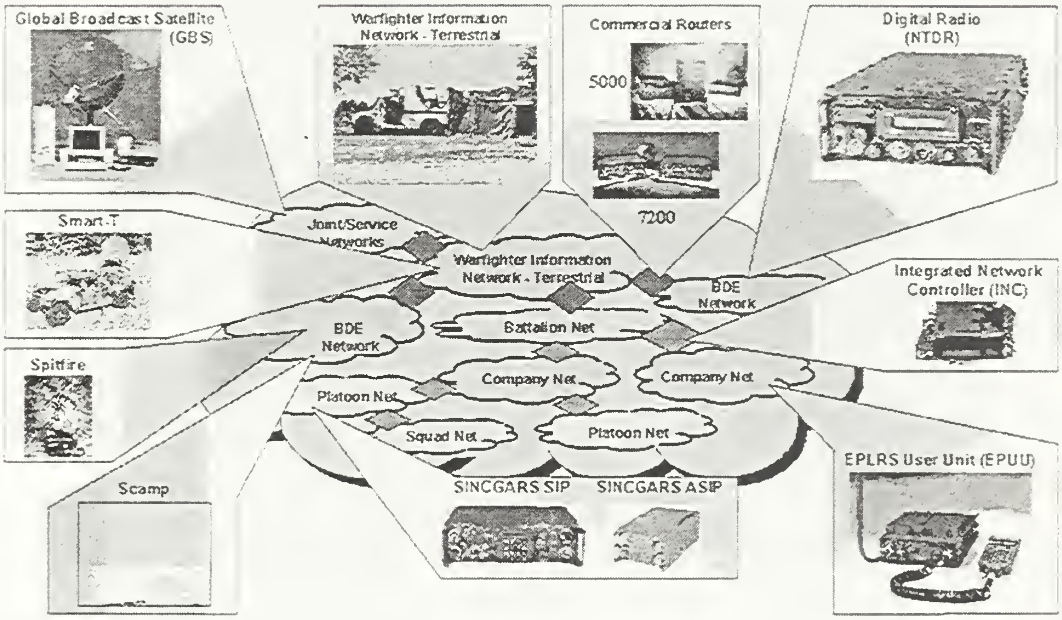

Figure 5.7. The Communication Systems of Tactical Internet

1. FBCB2 computers.
2. EPLRS Very High Speed Integrated Circuit (VHSIC).
3. NTDR.
4. MSE TPN SINCGARS with SIP and Internet Controller (INC).

5. Small Extension Node (SEN) and Node Center (NC) switches enabled for Asynchronous Transfer Mode (ATM).

TI is an automated, router-based communications network using commercial internet standard protocols to move data vertically and horizontally throughout the brigade area, and to higher-level echelons using the MSE TPN. Figure 5.8 graphically shows the complexity of the TI architecture required at brigade and below to provide its capabilities to the supported operational areas in terms of the deployment of host FBCB2s, supporting communications, networks, and integrated management at each echelon. (FM 24-32, 1997)

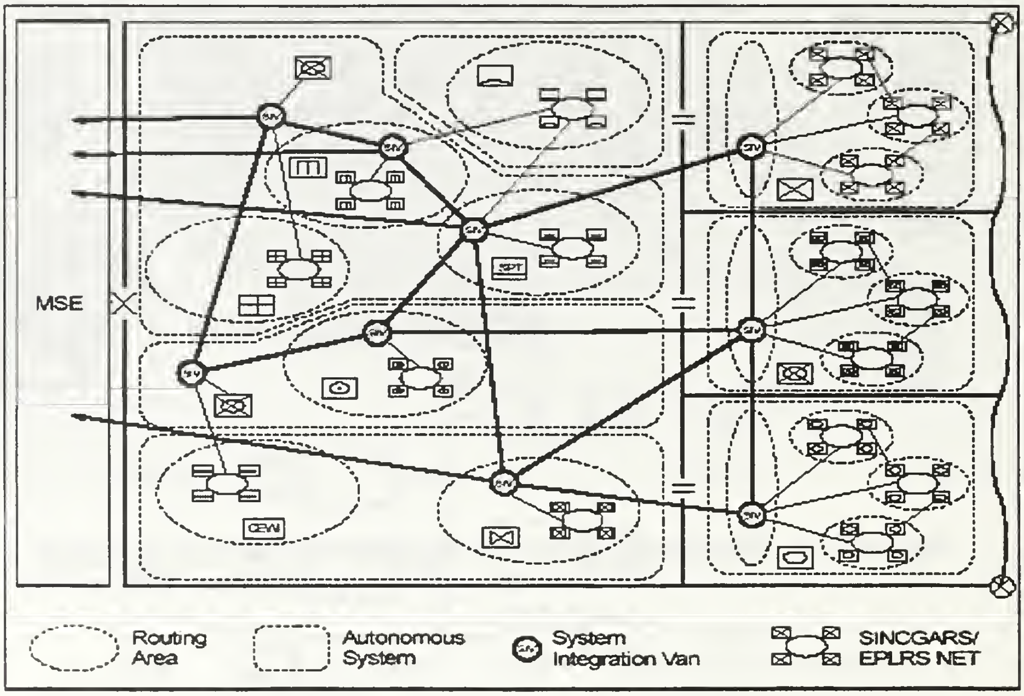

Figure 5.8. The TI at Brigade and Below. From (FM 24-32, 1997)

Figure 5.9 shows how the TI enhances the sharing of Command and control (C2) data by commanders, staffs, units, soldiers and weapon platforms, and results in improved force lethality, operational tempo, and survivability, while providing near real-time Situational Awareness (SA). (FM 24-32, 1997)

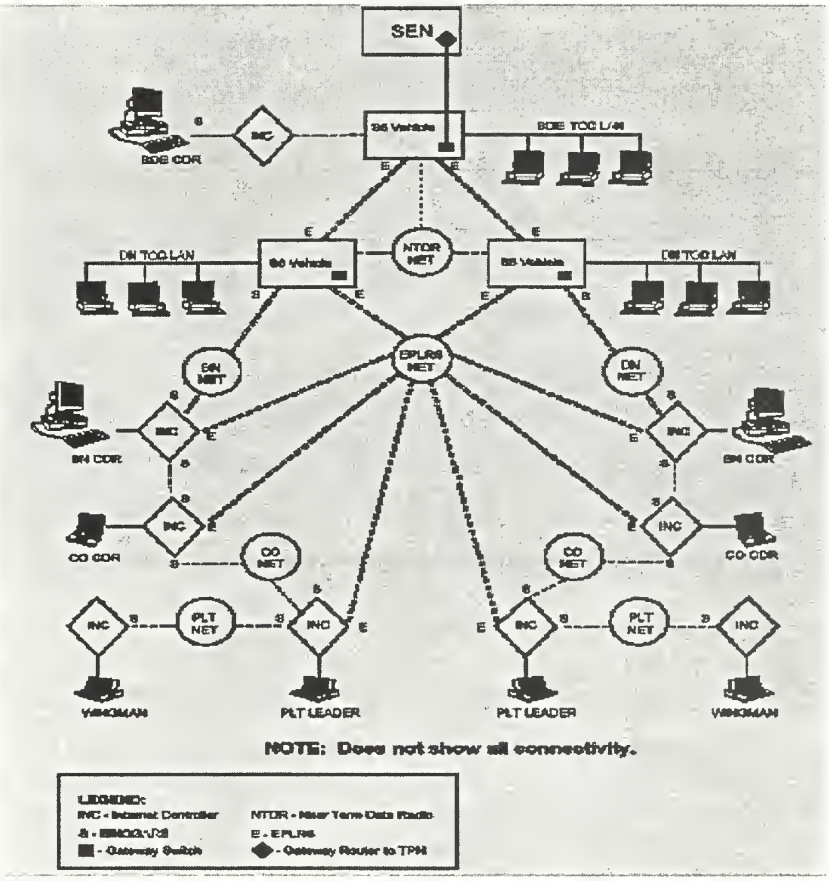

Figure 5.9. TI at Brigade and Below. From (FM 24-7, 1998)

2. Force XXI Battle Command Brigade and Below (FBCB2) System

The Force XXI battle command brigade and below is both a system and a concept to be used by combat, CS, and CSS units across all Battlefield Operating

Systems (BOS) while performing missions through the operational continuum at the tactical level (Figure 5.10). It is a battle command information support system

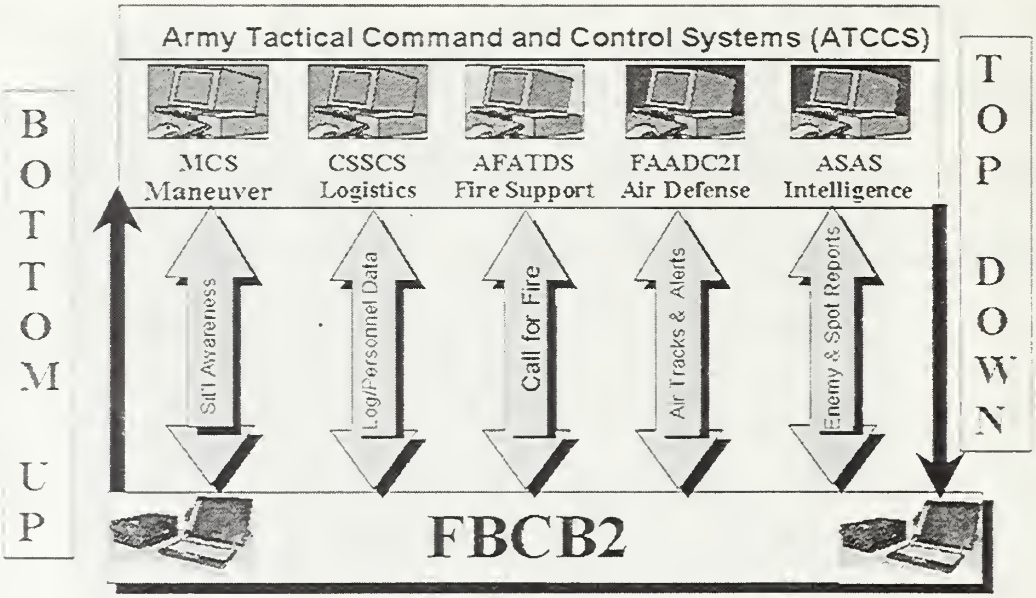

Figure 5.10. FBCB2 Interoperates with ATCCS

supported by existing and emerging communications, sensors, and electrical power sources. It will interoperate with battlefield automated systems (BAS) in compliance with GCCS and all appropriate BASs in common operating systems as specified by GCCS. FBCB2 must interoperate and exchange information with all ABCS battlefield functional areas (BFA) (Figure 5.11). (FM 71-3, 1997)

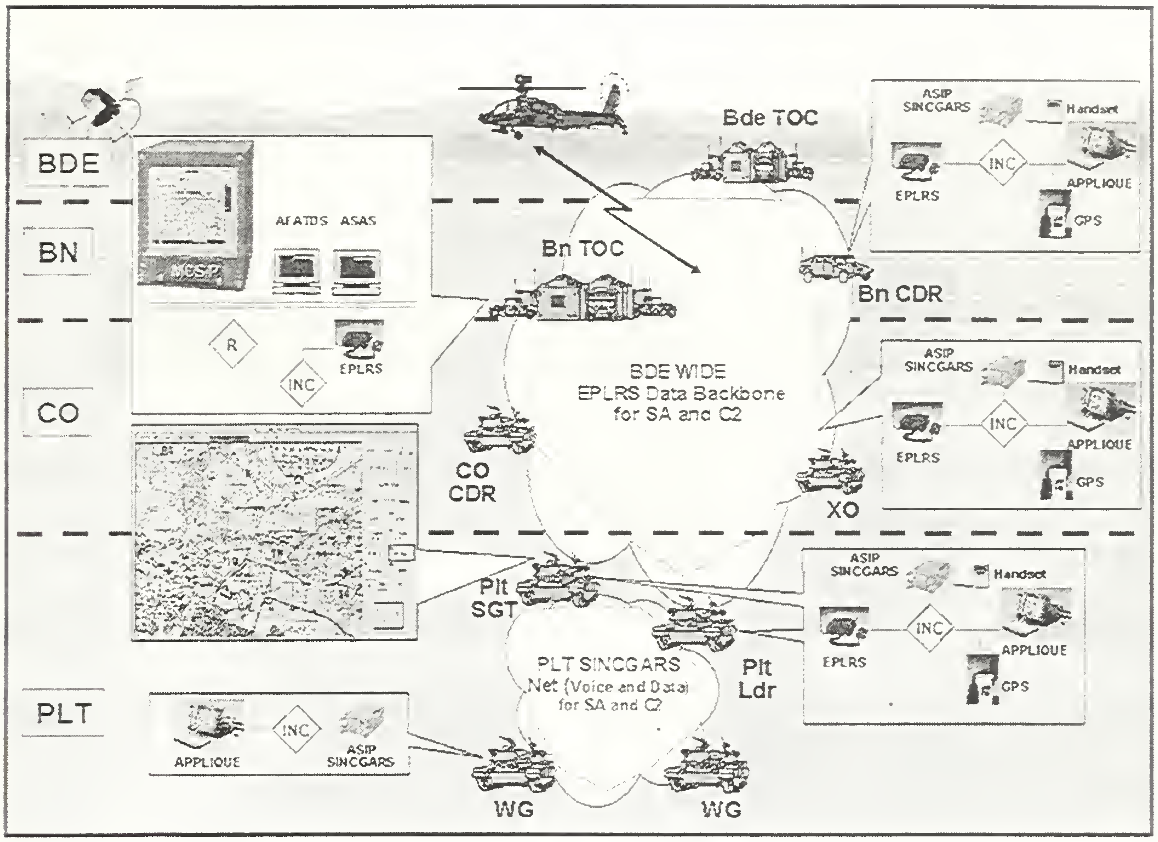

Figure 5.11. The FBCB2 from Brigade to Platoon Level

The FBCB2 system (Figure 5.12) consists of:

1. Five versions of computing hardware (Commercial V1, Ruggedized V2, Militarized V3, Position/Navigation Device (PND), and Dismounted Soldier System Unit (DSSU)) depending on the type of the user. It is linked to a network by tactical radio systems and uses the variable message format (VMF) to send or receive messages, both horizontally and vertically in near-real time.

2. System and application software, which is the same for all the versions of hardware, and is designed for common operating environment. It provides menu-driven screens of command and control, and situation awareness.

3. Installation kits

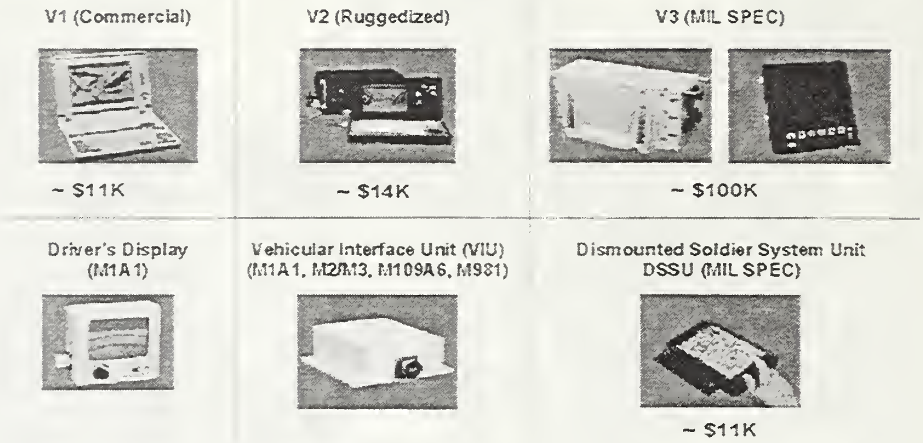

Figure 5.12. The FBCB2 Hardware

The FBCB2 system: (FM 24-7, 1998)

- Provides monitor for viewing video imagery
- Is user-owned and-operated.
- Improves combat effectiveness of the force.
- Provides up-to-date combat situation data such as friendly and enemy, air/ground unit position, and map / terrain /elevation data, based on echelon and location.
- Generates and disseminates messages and message acknowledgments such as orders and requests, fires and alerts, and reports.
- Generates and disseminates overlays on the situation posture such as intelligence, obstacle, operations, and control measures, and geometry data.

- Exchanges selected mission-critical data between FBCB2 and the other information systems semi-automatically.

E. WIN'S VIDEO COMPONENTS

1. The Satellite Transport of Video Imagery

The digitization of the battlefield requires communication pipes that are able to handle large amount of data, such as maps, overlays, audio, and video imagery. TI cannot support all the types of information that are generated within the digitized battlefield because of their large volume. The solution to this problem is the Global Broadcast Service/Battlefield Awareness and Data Dissemination (GBS/BADD) that uses the GBS satellite technology to provide wide band communications and asynchronous transfer mode (ATM) technology to provide efficient multimedia switching.

The GBS/BADD deployment architecture is depicted in Figure 5.13. GBS is used primarily to transport the information that is required by the brigade task force (TF) commanders and staffs. Warfighter Associate (WFA) terminals function as the receivers at the division, brigade, and battalion TOCs.

Data sources are generated at the brigade TOC for broadcast down to the battalions over GBS. The information generated by these sources is too large to be passed over the Near Term Data Radio (NTDR) network which is the only other link to the battalions. The sources are intelligence related such as Joint Surveillance Attack Radar System (JSTARS) Moving Target Indicators (MTI), UAV video and telemetry, Longbow Apache targeting messages, MCS overlays, battlefield videoteleconferencing (VTC), and whiteboard. The information is passed over the brigade local area network (LAN) to the reachback utilizing in-theater assets including a satellite system and a land line to the Information Dissemination Server (IDS) located in the Washington, DC area. (FM 24-32, 1997)

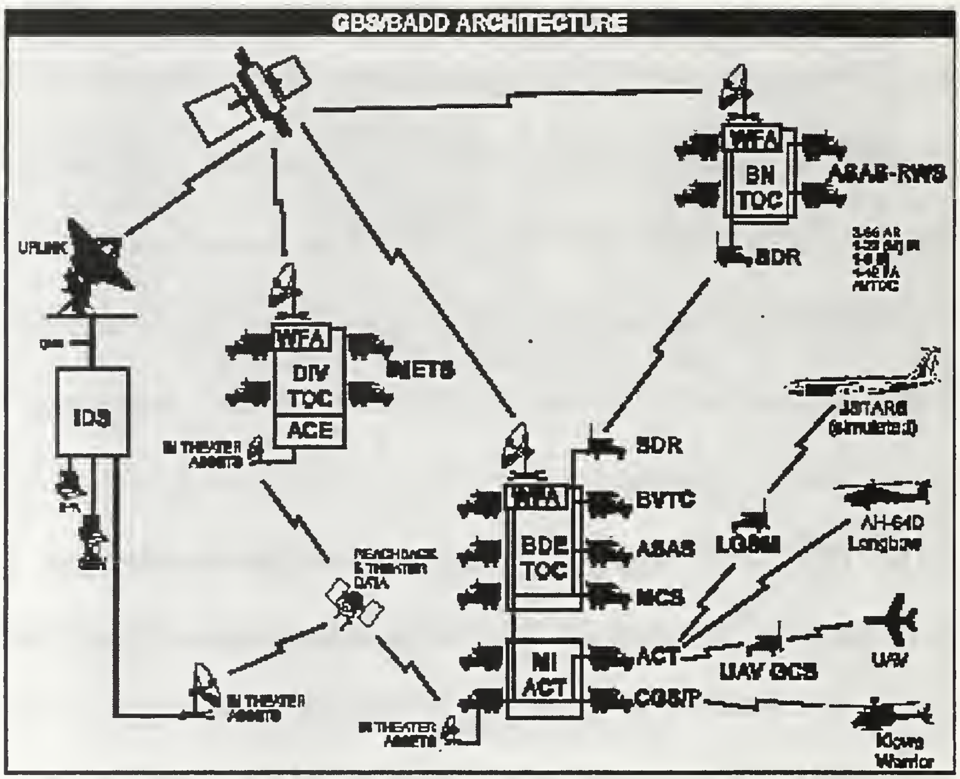

Figure 5.13. GBS/BADD Deployment Architecture. From (FM 24-32, 1997)

The information requirements that approved by any commander will become WFA profiles, so as imagery information enters the system from any source it will be sent to the commanders that need it. For example, if a unit is moving into a corridor in the next two hours, a profile would be set for the appropriate area for the next two hours and the commander would ask for intelligence information. If a UAV flew over that area, an icon would appear on the WFA terminal screen display, and the commander would be able to watch the UAV fly in near real-time. (FM 24-32, 1997)

2. The Terrestrial Transport

WIN Terrestrial transport (WIN-T) is a communications system, based on commercial technology, which will provide simultaneous voice, data, and video communication services at all levels of security. WIN-T includes the component of information services, in which this thesis proposes that the TUAV video imagery should be part of. All WIN-T systems will be modular in design to allow the flexibility to insert technological improvements, as they become available. WIN-T includes the following systems (WIN Master Plan, 1998):

1. **Switching System:** WIN-T will utilize state-of-the-art commercial technologies, like ATM, for information transport that provide dynamic bandwidth management. This will allow efficient utilization of network bandwidth by providing the capability to mix together on one transmission path different types of information with different characteristics (i.e., voice, data, and video on one physical link) and to efficiently allocate bandwidth dynamically.

2. **Transmission Systems:** High capacity line-of-sight (HCLOS) radios and fiber optic cable will provide the velocity and throughput necessary to support transmission of information required by Force XXI warfighters. The HCLOS radios will provide connectivity between WIN-T nodes and will replace current low bandwidth line-of-sight (LOS) radios.

3. **Subscriber Services:** The WIN-T will provide support for all tactical voice, data, and video users. It will support secure wireless Command Posts (CP), and integrated voice, data, and video communications services.

4. **Information Services:** The WIN will provide vital information services throughout the battlespace. These services include multilevel security, seamless messaging, battlefield video teleconferencing, and data replication and warehousing.

Although the transmission of video is an objective of WIN and the technologies that support it have been scheduled to implement from FY 98 through FY 10, TUAV video imagery which could be implemented through the same technology, is not included. Table 5.1 shows the WIN Terrestrial transport implementation schedule (only for the components that could be involved in the transmission of TUAV video imagery) based on information from WIN Master Plan, November 1998.

The U.S. Army has already funded many of the Near-Term modifications and enhancements. Funding for the Mid-Term and Far-Term have been included in the 1998-2003 Program Objective Memorandum (POM). The first Army ATM switches at the Joint Task Force should be fielded by the 4th quarter of FY 1999. Plus-ups to the 1998-2003 POM build are expected to meet the CSA's goal of equipping a digitized corps in FY 2004. The Army should fully transition to the objective architecture by FY 2006. (WIN Master Plan, 1998)

	Switching System	Transmission Systems	Information Services
Near-Term architecture (FY 97 through FY 99)	**ATM** work groups should be installed in Joint Task Force (JTF) switches during FY 98. This change will allow ATM transmission links from 1.544 Mb/s up to 8 Mb/s.	**HCLOS Radio:** Radio modification feasibility study and frequency .	**Video Teleconference** (VTC): The FCC-100 multiplexer will be fielded to some tactical units to provide a limited (VTC capability. **UAV/ Airborne Communications Node (UAV/CAN):** Validate during Advanced Warfighting Experiment
Mid-Term architecture (FY 00 through FY 02),	The **Switch Multiplexer Unit** will connect to the ATM work group at the Standardized Tactical Entry Point (STEP) and provide strategic connectivity for the digital transmission groups from the tactical switches. It will allow up to four T1 (1.544 Mb/s) digital transmission systems between tactical and strategic links **Fiber optic** connectivity between the JTF switch will accommodate 622 Mb/s links.	**HCLOS Radio:** High Capacity Line of Sight (HCLOS) radio will be fielded to the Joint Communications Support Element (JCSE) and to selected units typically supporting the JTF and will provide fiber optic like data rates initially starting at 8 Mb/s. **HCLOS (minus)** fielded to provide inter-operability between units.	**Battlefield VTC (BVTC):** WIN Switches **UAV/ACN:** Predator UAV with limited payload
Far-Term architecture (FY 03 through FY10)	The Multimedia Conference Unit (MCU/VTC) server will be installed in the WIN Switch to handle all automatic multi-point video conferencing and dedicated video conferencing requests. The multi-service platform will provide all frame based signal conversion to cell based signaling required by ATM.	**HCLOS Radio:** Field	**BVTC:** Fully integrated digital WIN switches.

Table 5.1. WIN Terrestrial Transport Implementation Schedule (Only For Components that Could be Involved in Transmission of the TUAV Video Imagery)

3. Asynchronous Transfer Mode (ATM)

ATM is connection-oriented (Making a call requires first sending a message to set up the connection), and divides all data into 53-byte fixed-length packets called cells. The 53-byte consists of 48 bytes of data and 5 bytes of routing information (Header). ATM has no clock in or associated with the transmitted digital data stream, but it has start and stop bits that delimit the characters transmitted.

An ATM network uses switches instead of routers. All ATM switches must switch all cells with as low a discard rate as possible and never reorder the cells on a virtual circuit. The ATM network consists of one or more sets of ATM switches connected by point-to-point interfaces of two types:[Goncalves, 1999]

- User network interfaces (UNIs) that connect ATM end systems such as hosts and routers to an ATM switch.

- Network-node interfaces (NNIs) that connect two ATM switches and are the physical or logical links across which ATM switches exchange protocol information.

To carry high data rates, the connection between a computer and an ATM switch often uses optical fiber instead of copper cable. In fact, because a single optical fiber cannot easily carry data in two directions simultaneously (Full duplex), each connection uses a pair of fibers. (Comer, 1997)

In addition, in order to provide more network bandwidth, the bandwidth-on-demand technique can be implemented. This technique is used by CISCO experimentally in WAN multimedia networking. Bandwidth on demand enables a router to bring in additional bandwidth when the traffic requires. (www. cisco.com)

4. Brigade's Networks

In order to reach the end user, video imagery transmitted by the TUAV should travel through the following networks and pipes:

a. Brigade's WAN

The WAN for the Brigade uses ATM technology over satellite, that simultaneously transmits data, voice and video traffic, over high bandwidth circuits (155 Megabits per second and 622 Mbps (Four 155-Mbps channels)). (WIN Master Plan, 1998) ATM over satellites that are located 36,000 Km above the earth with a view of approximately one-half of the earth's surface, provide service to geographically diverse areas, many of which terrestrial fiber cannot economically serve (McDysan, 1999).

b. Brigade's Backbone

The backbone connects multiple LANs at a single location. Fiber Distributed Data Interface (FDDI) or Ethernet, provides 100 Mbps, high-speed backbone connectivity.

Adding an ATM switch could build more bandwidth into the Brigade's backbone. Because ATM switches are sensitive to congestion and cell loss, the backbone must be sized appropriately and use traffic shaping techniques (www.cisco.com). High-speed servers and specialized applications can take advantage of 155-Mbps ATM today through use of products such as Cisco HyperSwitch A100 or Cisco LightStream 2020 ATM switches (www.cisco.com).

c. *Brigade's LANs*

Workgroup switches can provide higher bandwidth to desktops by reconfiguring the network without rewiring or replacing network interface cards (NICs) at every Brigade desktop. Employing LAN segmentation and micro-segmentation and using LAN switches, enables network managers to provide individual users with bandwidths of 1 megabit per second (Mbps), 10 Mbps, and 100 Mbps (High-speed Ethernet). Two high-speed mechanisms will soon be available: 100 megabits-per-second (Mbps) Ethernet (known as Fast Ethernet) and 100BaseVG (a demand priority mechanism). Both of these technologies could provide 100-Mbps performance to the Brigade's desktops. In addition, future generations of Ethernet switches will support both 10-Mbps and 100-Mbps ports simultaneously. (www.cisco.com)

In addition, ATM technology is able to multiplex many lower speed legacies onto a single, common configuration, higher-speed ATM uplink, connected to a LAN backbone. Savings are realized through upgrading only as needs grow without investing in high-bandwidth networks up front; when equipment is upgraded or changed, the change takes place only in the wiring closet without recabling or making changes on every desktop (www.cisco.com). Figure

5.14 shows the proposed wiring collection and segmentation of the Brigade network, in order to support the TUAV video imagery.

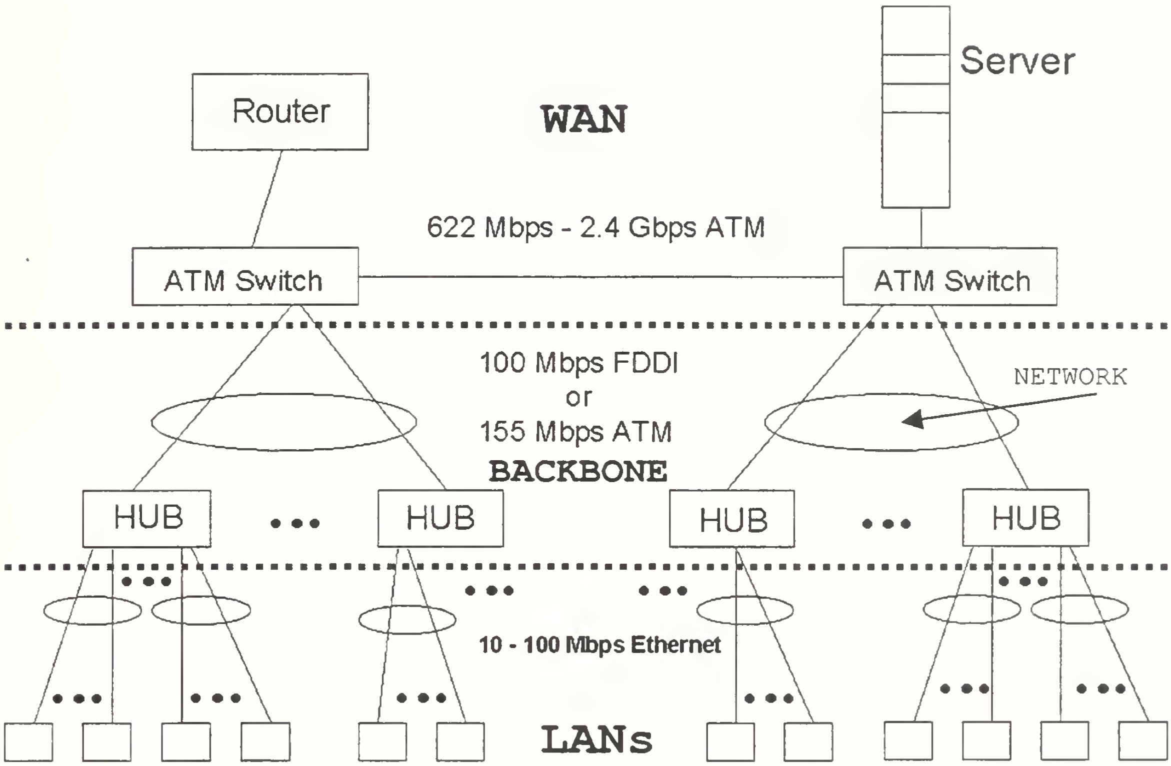

Figure 5.14. Proposed Wiring Collection and Segmentation of the Brigade Network

F. SUMMARY

WIN capitalizes on systems such as Tactical Internet, Satellite and Terrestrial Transport, and FBCB2 to provide the Brigade warfighter with real and near real time video of the battlefield, in order to attain situational awareness. It implements the latest advances of Information Age technologies form the commercial factor. Video imagery will enable the Brigade Task Force to share a common picture of the battlefield while communicating and targeting in real or near-real time.

The TUAV video imagery could be added as a component of WIN information services, because according to WIN Master Plan of November 1998 the scheduled network infrastructure will support video's large bandwidth requirements through the use of ATM technology.

VI. DIGITAL VIDEO DISSEMINATION VIA THE STREAMING VIDEO TECHNIQUE

A. INTRODUCTION

> *...Airborne Reconnaissance systems should provide a clear migration path toward an all-digital system, conforming to the mandated standards of the JTA Core.*
>
> *DoD Joint Technical Architecture, May 1998*

Taking this technology mandate as input in conjunction with the preference of video imagery by the Brigade stakeholders, the pretext of this chapter assumes that the demand for networked digital video imagery will increase exponentially over the next few years. With networked digital video imagery, the brigade and battalion commanders and staff will be able to watch simultaneously:

- Real-time video imagery, by implementing streaming and multicast video technology, in conjunction with the installation of a buffer for that purpose.
- Non-real-time video imagery (Video on Demand (VOD)), by implementing the same technology as for real time video imagery, after the installation of a video server into the existing network.

B. THE PROBLEM

The management, as well as the dissemination of digital video imagery, adds two major and particularly difficult challenges to the network and the server:

1. Dealing with large amounts of data, and
2. Handling the time-dependent demands of video.

The existing Brigade Local Area Network (LAN) was not designed to handle this quantity of data. For example, if the Brigade TOC has 20 computer desktops and each one requires a rate of 1.5 Mbps per video stream, the video server must handle 20 streams or 30 Mbps simultaneously. The Tactical Internet (TI) will experience many problems, such as traffic congestion and access denial, if it uses for video traffic the same client-server hardware and software that it uses to handle text based data.

The major problem is that video requires large, continuously flowing streams of data to successfully play back clear, full screen smoothly moving pictures. For this reason, the amount of data that is required by a server to store and transmit a digital video file must be compressed, while retaining the original quality. The network bit rate and the compression method are factors that influence the transmission of video files, as well as its reception, decompression, and storage. There is a tradeoff between bandwidth, compression, and video quality. The U.S. Army has adopted the International Standards Organization (ISO) Moving Pictures Expert Group 2 (MPEG-2) compression/de-compression (CODEC) standard solution (VISP, 1998). So, what can we do using this standard?

C. THREE SOLUTIONS

There are three strategies that offer a range of solutions:

1. Update the existing Brigade hardware and software, so it can handle more data. This strategy improves the general performance of the

network and the servers, but it does not address the different processing requirements for video.

2. Replace the existing hardware in order to transmit the data faster with fiber optic cable instead of copper wire. This strategy, although expensive, may not solve the resource-sharing and time-dependent needs for video.

3. Install a parallel system that implements streaming video technology and provides either real-time video with the addition of a real time buffer, or non-real-time video with the addition of a video server depending on the user request. The new system will use the same physical network and the same desktops. This solution should easily integrate video and non-video information within the same environment (FBCB2).

Strategy number 3 is the most efficient. It expands the current system in order to implement the new digital video imagery technology. The streaming video technology, as well as the installation of the buffer and the video server, will not influence the existing network structure, architecture, services, and operating system. On the other hand, it will provoke a change on the network protocols and hardware, the transmission media, and it will require new application software, as well as additional funds.

D. DEVELOPMENT OF DIGITAL VIDEO NETWORK REQUIREMENTS

Albert Einstein said that the questions are more important than the answers. A key to success in adopting a network dissemination technique is that the dissemination requirements have to be sized in the beginning of the process. In order to determine the dissemination requirements for the Brigade digital video network, the following questions have to be answered:

1. What is the required daily data volume through the network, what quality is required and what bandwidth is necessary? An uncompressed motion-video stream segment amounts to width X height X bit depth X frames per second. According to the Video System Matrix (VSM) discussed in chapter 4, VSM 5 has a resolution of 720 X 576 pixels, and a bit depth equal to 10 bits/pixel. So 720 X 576 X 10 X 30 = 124,416,000 bits per second, or 15.5 Mb/s (1 Byte = 8 Bits).

2. How fast must the data arrive at the intended destination? Are data going to be live, recorded or both? The video has to be delivered real-time as well as non-real-time and upon demand by the brigade network users.

3. How much of the data received by each destination, are actually used by that site and what level of interactivity is required? Each user must be able to store and analyze the segment(s) of the video he is interested in and discard the rest.

4. Is the data transmission steady throughout the day? The TUAV will fly with a maximum of sixteen hours a day, and the network should be accessible by all users, any time, regardless of TUAV operations.

Figure 6.1 shows the functional decomposition and analysis of the video dissemination process, using the Hatley-Pirbhai Hierarchical Input Process Output (HIPO) method. The video dissemination process belongs to the 2nd level of the overall digital video imagery system analysis, which is described in Chapter I.

The process "DISTRIBUTE" has the following three outputs (dataflows):

1. Real-Time Video Imagery.

2. Non-Real-Time Video Imagery (Video-on-Demand).

3. Decision-Critical-Information.

This thesis addresses only the dissemination of Real-Time Video Imagery, and Video-on-Demand.

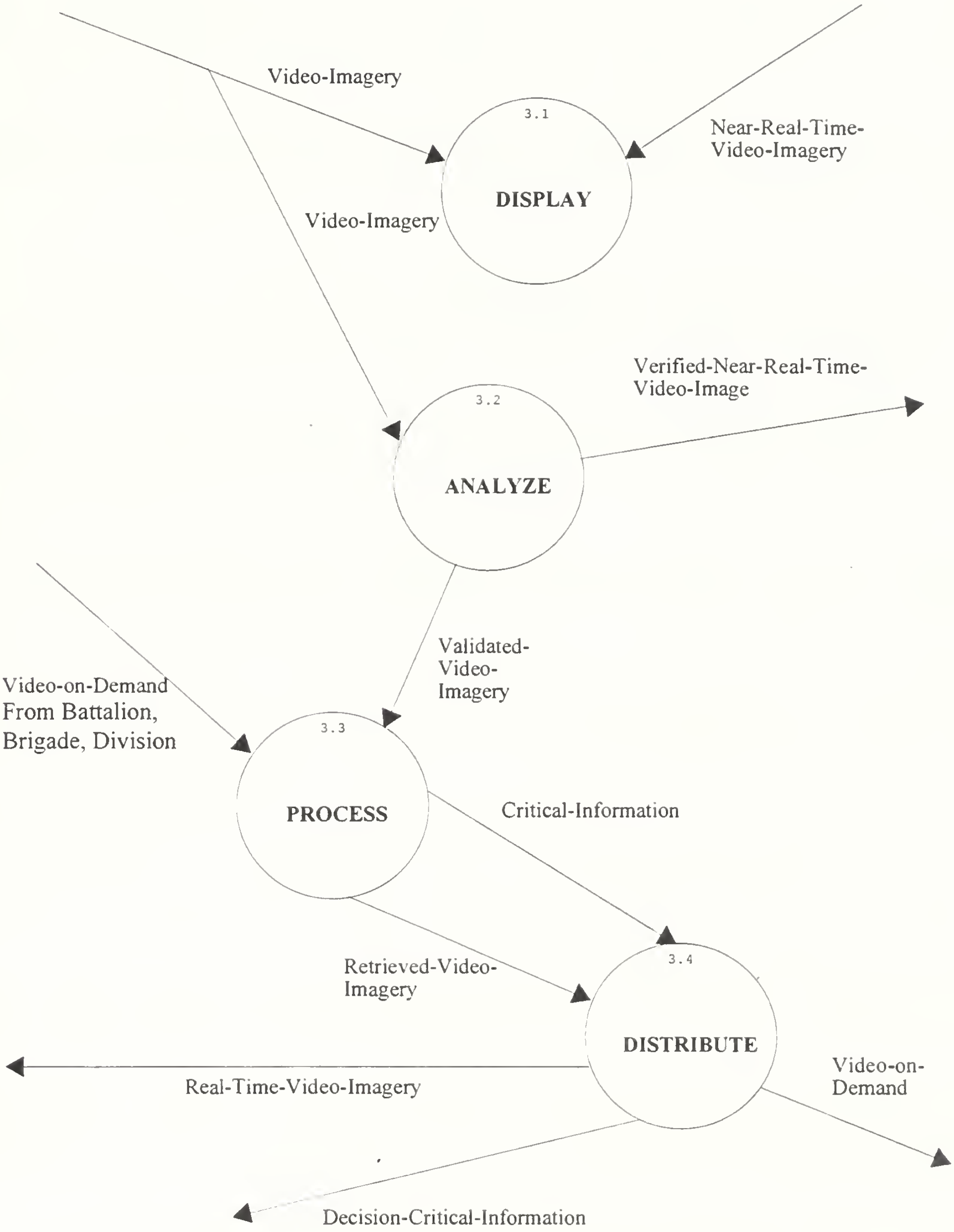

Figure 6.1. Functional Decomposition and Analysis of the Video Dissemination Process

E. DISSEMINATION OF REAL-TIME-VIDEO-IMAGERY

The ability to continually deliver new video imagery information to the Brigade stakeholders is critical for the success of tactical operations. If one picture is worth a thousand words, then 30 pictures per second (operation of television) that are distributed simultaneously to a group of hosts, will be a treasure of information.

1. Streaming Video Technique

This section explains the Streaming Video Technique that could be used to provide the brigade users with real-time and non-real-time video. The following five streaming video factors that play a key role in streaming video segments through network pipes apply to both real-time and non-real-time environments.

1. Bandwidth
2. CODEC MPEG-2
3. Quality of Service
4. Streaming Protocol
5. Multipoint Packet Delivery

Streaming video solves a long-standing problem of sending video signals across a network by combining the characteristics of a buffer, compression-decompression algorithm, and a client-server architecture. It allows playing broadcast-quality video over a computer network in real and near-real time, after the implementation of a video server.

Video files consume a large portion of available bandwidth (26 Mbytes/s) because they have so much information packed into them. Streaming video solves this problem in two ways. First, it compresses the video file in order to be able to transmit it over the network. Secondly, it lets the receiving computer start displaying the video, with the aid of viewer software, while the file is being transmitted, without waiting for the entire file to download. The bytes of video travel over the network as they are played, without being copied to the client's hard disk. Real-time video is viewed in a simultaneous time of broadcasting by the TUAV camera. Non-real-time video is viewed upon request some time after the TUAV mission has been completed.

In order to deliver both types of video imagery from the server to multiple clients, the Brigade network must provide adequate bandwidth through MPEG-2 compression, quality of service through use of a streaming protocol, and multipoint packet delivery.

a. Bandwidth

The size and the rate of the frame, as well as the quality of image affect the bandwidth. The use of MPEG-2 video encoding scheme affects all these factors too. The bandwidth that will transmit the video should be able to support transmissions at 3 to 15 Mbits/sec, to satisfy the MPEG-2 encoding compression.

To deliver acceptable video-imagery performance to the users, the transmission media of the areas below must support adequate bandwidth at: The wide Area Network (WAN) in which the Brigade belongs, in order to transmit the video to higher echelon (Division).

- The Brigade's workgroup backbone, and
- The Local Area Networks (LANs) (Battalions and Brigade Staff) that link the workstations and the various devices.

b. CODEC MPEG-2

MPEG-2 is a set of international computer and broadcast industry standard formats for digital video and audio compression and playback. MPEG technology merges broadcast television quality video with the interactivity of a computer. It requires special hardware to encode and decode (encoder and decoder respectively.) It offers interoperability, high image quality, and full-screen video resolution 720 X 576 at 30 frames per second, somewhat better than a laser disk. [After www.sigmadesigns.com/faq]

MPEG-2 eliminates the redundant information between frames over time (temporary redundancy), and encodes only the differences. This type of compression is called lossy. Lossy compression eliminates the transmission of indistinguishable pixel-to-pixel differences within one frame or successive frames (that is, it eliminates data that can not be reproduced because of the resolution or frame-rate limits of the equipment), and it eliminates color and intensity information that the human eye can not detect. (Gaston, "Spread Spectrum Techniques for Video Transmission," 1996 IEEE Northcon)

A compression process, called encoding, creates MPEG-2. During this process, the number of bytes per second the MPEG video will use can be selected. This is the bitrate of the MPEG video. The more bytes per second, the less compressed the video and the better the quality. MPEG-2 bitrates from 4 to 24 Mb/s, but commonly used rates range from 4 to 10 Mb/s, (image quality improves only slightly at transmission rates above 8 to 10 Mbps) without sacrificing quality for bandwidth. Because MPEG-2 rates range so widely, there is a type of second-pass compression available which called the Variable-Bitrate (VBR). This second-pass scans through the MPEG for scenes with little motion and compresses them further from 0.5 to 2 Mb/s. There are also other variants of the MPEG-2 format, such as MPEG-2 Half D1 and MPEG-2 2/3 D1, for lower band applications. Compression ratios of 200:1 are common with good image quality. [After www.sigmadesigns.com/faq]

When compressed, the digital video is transmitted with the implementation of streaming video technology, to the brigade users where it is decompressed and viewed in place. The requirement to view the video fps, is dependent on the amount of motion present on the video. For example, for a "Talking Head" clip, 8 to 12 fps may be adequate and 15 fps is virtually indistinguishable from a 30 fps. In addition, the displayed fps can double or even quadruple the transmission fps. An interpolation technique is used that enable the creation of additional frames at the receiver, in between regularly transmitted frames. Those additional frames are called "B" frames since a Bi-directional interpolation is used for their creation, require very little, if any, additional information to be added to the bitstream, and thus virtually double or even quadruple the fps performance of the CODEC [www.crystalnet.com /compare. html]. Figure 6.2 shows MPEG 2 running over ATM (LightStream 2020 is an ATM switch). (Cisco Systems, 1998)

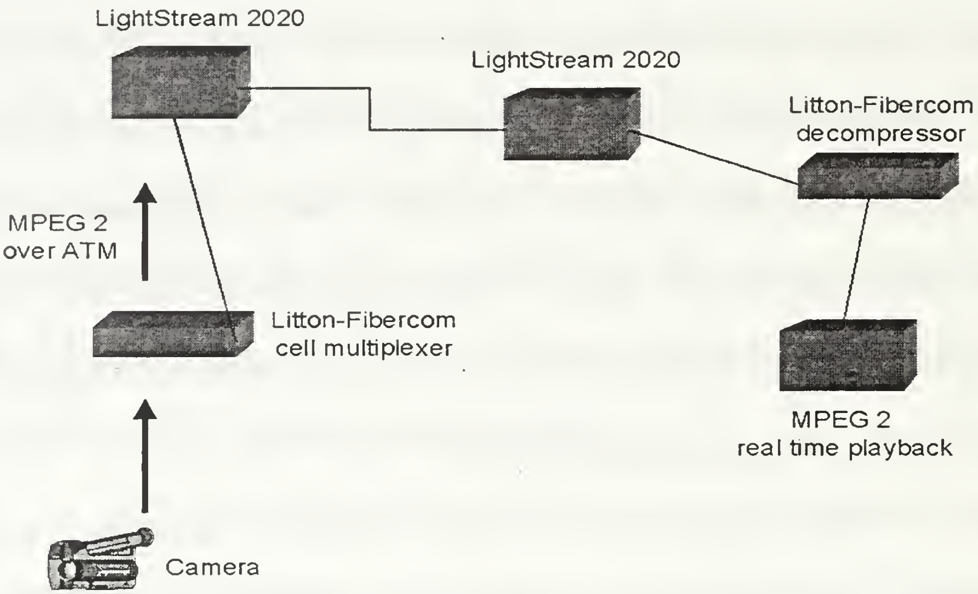

Figure 6.2. MPEG-2 over ATM

c. Quality of Service (QoS)

With the addition of video to Brigade LANs, providing service quality and consistency become more critical concerns than they are for network traffic consisting of data only. A user expects a flow of video information to be presented in a continuous, smooth fashion. A lack of continuity or excessive loss results in a loss of quality. Any delay above a few hundred milliseconds becomes noticeable and annoying (Stallings, 1998).

Video imagery produces traffic that must be delivered on a certain schedule or it becomes useless. In order to achieve accurate bandwidth and delay control, quality of service is critical in a networked multimedia environment in reference to parameters such as latency, delay, and minimum variance in delay (jitter) that characterize traffic flow [www.cisco.com].

Critical performance metrics for QoS are throughput, latency, and jitter (Figure 6.3). Throughput is the number of user data bits communicated per second. As network throughput has improved, attention has shifted to latency and jitter.

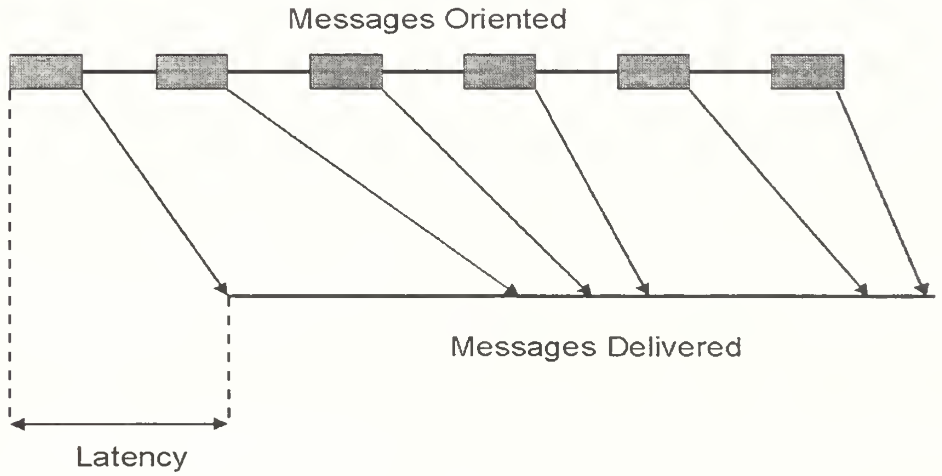

Figure 6.3. Latency and Jitter

(1) **Latency**. Real-time video is sensitive to long latency (accumulated delay), which is undesirable. Latency is the time from message origination at the source to message delivery at the destination. Considering that telephone networks are engineered to provide less than 400 milliseconds round-trip latency, multimedia networks that support audio/video also need to be engineered with a latency budget that is less than 400 ms round-trip. Approximately 100 ms latency for video is adequate. The sender, the network, and the receiving computer consume the round-trip latency budget. The network contributes to latency in several ways, including propagation delay, transmission delay, store-and-forward delay, and processing delay. (Cisco Systems, 1998)

Propagation delay is the length of time it takes information to travel the distance of the circuit. This is essentially controlled by the speed of light and is independent of the networking technology used. As a rule of thumb, it takes approximately 20 ms to send information between San Francisco and New York.

Transmission delay is the length of time it takes to put a packet on the media. The speed of the media and the size of the packet determine transmission.

Store-and-forward delay is the length of time it takes for an internetworking device such as a switch, bridge, or router to receive a packet before it can send it. Most internetworking devices receive a packet before sending it out on another interface. The amount of delay that is introduced depends on the size of the packet and the speed of the media.

Processing delay consists of steps such as looking up a route and changing a header. When a packet comes in, the networking device (bridge, router, or switch) needs to decide which interface it should be sent out on. In some cases, the packet also needs to be manipulated (by changing the data link layer encapsulation, changing the hop count, etc.).

(2) **Jitter.** When a network provides variable latency for different packets (some packets take 20 ms while others take 30 ms to be delivered), it introduces jitter (low frame loss), which will give an uneven quality to the image. A network with zero jitter takes exactly the same amount of time to transfer each packet. The most common technique to minimize jitter is to store incoming data to a router buffer and then the software or the hardware pulls the data out at fixed times. Computing the expected time for each router hop along the path can bound jitter. When a packet arrives at a router, the router checks to see how much the packet is behind or ahead of its schedule. This information is stored in the packet and updated at each hop. If the packet is ahead of schedule, it is held long enough to get back on schedule. If it is behind schedule the router tries to get it out the door quickly. In fact, the algorithm for determining which of several packets competing for an output line should go next can always choose the packet furthest behind in its schedule. In this way, packets that are ahead of

schedule get slowed down and packets that are behind schedule get speeded up, in both cases reducing the amount of jitter (Tanenbaum, 1996).

MPEG-2 coding removes jitter through the use of internal buffers in the coder/decoders (CODECS). Additionally, the clock signal embedded in MPEG-2 streams enables recovery of timing through the use of a phase-locked loop at the decoder, even in the presence of jitter in the ATM cell interarrival times. MPEG protection and recovery techniques include structure packing of encoded video into macroblocks, which enables rapid re-synchronization by discarding all data until the decoder recognizes the next macroblock. (McDysan, 1999)

2. Streaming Protocols

Streaming Protocols are used for video applications, which do not require reliable delivery and can accept message loss. In video applications, bandwidth reservation and low jitter are preferable, so streaming protocols are oriented towards this direction to satisfy video applications. Possible protocol solutions for the Brigade LAN that support the transmission of the real and non-real-time video are:

a. User Datagram Protocol (UDP)

UDP forsakes Transfer Control Protocol's (TCP) error correction and allows packets to drop out if they're late or damaged. When this happens, a dropout is heard or seen, but the stream will continue. Despite the prospect of dropouts, this approach is arguably better for continuous media delivery. If broadcasting live events, everyone will get the same information simultaneously. One disadvantage to the UDP approach is that many network firewalls block UDP information. (www.dstc.edu.au/RDU/staff /jane-hunter/video-streaming.html)

b. Real Time Streaming Protocol

In October 1996, Progressive Networks and Netscape Communications Corporation announced that 40 companies support the Real Time Streaming Protocol (RTSP), a proposed open standard for delivery of real-time media over the Internet. RTSP is a communications protocol for control and delivery of real-time media. It defines the connection between streaming media client and server software, and provides a standard way for clients and servers from multiple vendors to stream multimedia content. The first draft of the protocol specification, RTSP 1.0, was submitted to the Internet Engineering Task Force (IETF) on October 9, 1996. RTSP is built on top of Internet standard protocols, including: UDP, TCP/IP, RTP, RTCP, SCP and IP Multicast. Netscape's Media Server and Media Player products use RTSP to stream audio over the Internet. (www.dstc. edu.au/RDU/ staff/jane-hunter/video-streaming.htm)

c. Real-Time Transport Protocol (RTP) and Real-Time Transport Control Protocol (RTCP)

RTP is a protocol for multimedia applications with multiple recipients. It typically runs on top of UDP to use its multiplexing (combination of independent information sources (camera, microphone) into a form that can be transmitted over a single communication channel) and checksum (verifies that data is not corrupted during transmission) services. RTP supports data transfer to multiple destinations using multicasting provided by the underlying network. RTP works in conjunction with Real-Time Transport Control Protocol (RTCP). RTP provides real-time transmission of data packets, while RTCP monitors quality of service. (Foster, 1999)

RTCP is based on periodic transmission of control packets to all of the participants in a session. The traffic is monitored and statistics are gathered on the number of packets lost, highest sequence number received, and jitter. These statistics, transmitted in control packets, are used as feedback for diagnosing problems in the network, controlling congestion, handling packet errors, and improving timely delivery. (Foster, 1999)

d. Resource Reservation Protocol (RSVP)

RSVP can be deployed on LANs to support video applications that have strict quality of service requirements. It operates on top of Internet Protocol v.4 (IP v.4) or IP v.6. RSVP is not a routing protocol; it operates in tandem with multicast routing protocols. Whereas a routing protocol determines where packets get forwarded, RSVP is concerned with the quality of service those packets receive. RSVP is more suited for private Intranets and long-duration flows, such as those presented in video applications. Most router vendors and many multimedia application developers, including Microsoft, Intel, and Sun support RSVP. (Foster, 1999)

3. Multipoint Packet Delivery

In order to be effective, video imagery dissemination requires simultaneous communication between a group of computers known as multipoint communications. Figure 6.4 shows the three ways of multipoint communications:

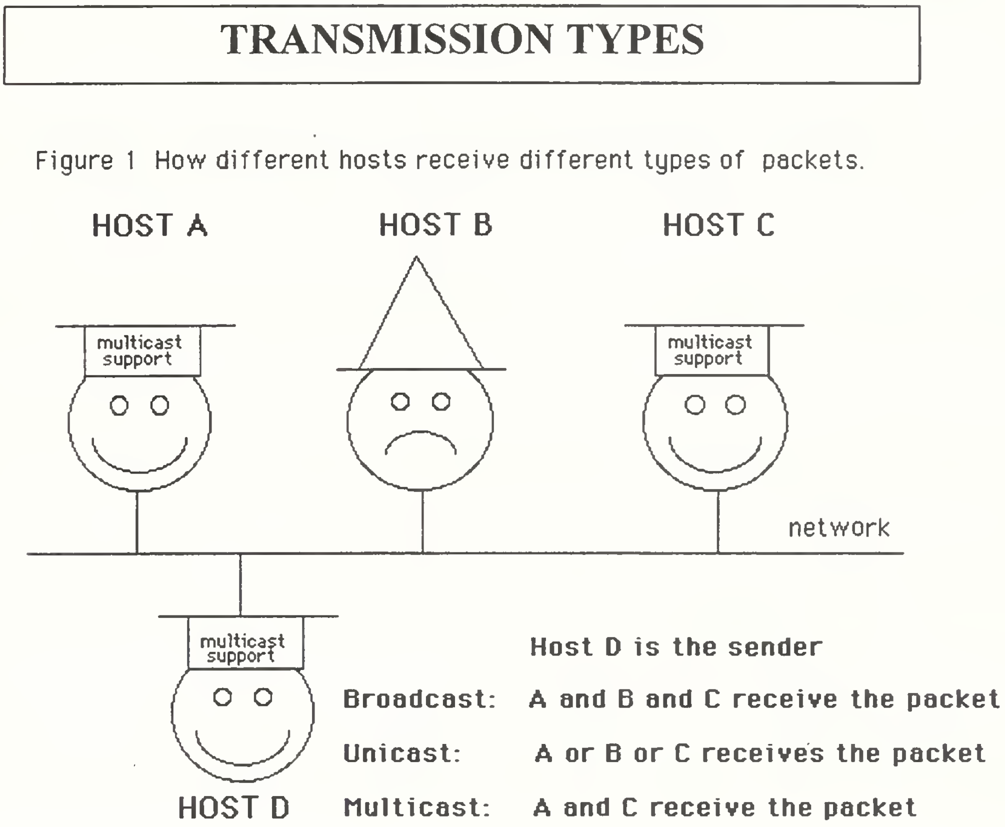

Figure 6.4. Different Hosts Receive Different Types of Packets. From (www.unige.ch)

a. Unicast

In unicast design a sender transmits a packet to a single destination (point-to-point). When a sender wants to send the same information to multiple recipients, it must send a copy of the same data to each one. In such a way identical data streams with the same information are carried multiple times, resulting to a large consumption of bandwidth. This technique uses large amount of processing power and memory.

b. Broadcast

Broadcast enables the delivery of a single data stream to every station of a subnetwork. In this way, one workstation of the network can simultaneously send video to all workstations contained in the same broadcast domain or subnet. The routers and switches of the network forward the broadcast but in doing so, they use bandwidth and have no way of knowing if any of the nodes on the other network wants the broadcast data.

c. Multicast

Multicast is a term that describes a process similar to television broadcasting. There is a limited amount of bandwidth that can support about 100 television channels. In TV, each channel is broadcasting over radio waves for viewer tuning. The computer network can be used in the same way with a server and a buffer or MPEG-2 encoder to deliver a broadcast of 1 or more MPEG-2 streams which end- users on the network can "tune in." The benefits of multicasting include the ability to support live video as well as greatly reduced use of the network's bandwidth. The network's bandwidth use is the same whether 1 or 1,000 users are viewing a multicast channel. Multicast video usually can offer only Play, Pause and Stop functionality, but not VCR-like controls such as Rewind, Fast Forward and Seek.

With a multicast design, applications can send one copy of each packet and address it to the group of computers that want to receive it. This technique addresses packets to a group of receivers rather than to a single receiver, and it depends on the network to forward the packets to only the networks that want to receive them. The sender computer must know the physical addresses (There is software for that purpose) of destination networks, or computers, in order to multicast packets. (Cisco Systems, 1998)

The playback of an MPEG stream requires 1.5 Mbps per client viewer. In a unicast environment, the video server sends 1.5 X n Mbps (where n = number of client viewers) of traffic to the network. With a 10-Mbps connection to the server, roughly six to seven streams could be supported before the network runs out of bandwidth. In a multicast environment, the video server sends only one video stream to a multicast address. Any number of clients can listen to the multicast address and receive the video stream. In this scenario, the server requires only 1.5 Mbps and leaves the rest of the bandwidth free for other uses. (Cisco Systems, 1998)

When a multipoint application such as video is traveling through different media types (ATM, Ethernet), multicast is best implemented at Open System Interconnection (OSI) Network Layer (Layer 3) of the streaming protocol. Network Layer (Layer 3) must define the following parameters in order to support multicast communications: (Cisco Systems, 1998).

(1) **Addressing.** There must be an OSI layer 3 address that is used to communicate with a group of receivers rather than a single receiver. In addition there must be a mechanism for mapping this address onto OSI Data Link Layer (Layer 2) multicast addresses where they exist.

(2) **Dynamic Registration.** There must be a mechanism for the computer to communicate to the network that it is a member of a particular group. Without this capability, the network cannot know which networks need to receive traffic for each group.

(3) **Multicast Routing.** The network must be able to build packet distribution trees that allow sources to send packets to all receivers. A primary goal of packet distribution trees is to ensure that only one copy of packet exists on any given network- that is, if there are multiple receivers on a given branch, there should be only one copy of each packet on that branch.

F. DISSEMINATION OF NON-REAL-TIME VIDEO IMAGERY (VIDEO ON DEMAND)

The evolution of video technology in conjunction with media communication, availability of networks, and client-server architecture raises the demand of individual exploitation of UAV video by the Brigade's stakeholders. The users need to concentrate on watching only the UAV video part that they are interested in, as well as to have full control over it (Review, Stop, Fast Forward, and Capture). This procedure will facilitate retrieval of specific information needed for operation plans and will reduce expected risk.

Some video server providers, such as InfoValue, supply integrated VOD/Multicast solutions which save multicast streams to the video server as they're played. For example, if the user is watching CNN on his computer network, and he sees a story that's really interesting, he can rewind the video and re-play the story. He can then click on a "Live" button to jump back to the live broadcast. The system automatically jumps between the live broadcast and the stored video on demand file. (www.sigmadesigns.com/ faq_streaming_mpeg_ video)

VOD files are not stored on a file server because standard file servers are designed to allow random access for opening and copying much smaller files. This is not ideal for video on demand, where the server needs to efficiently deliver many sustained streams of large MPEG video files. A video server is ideal for this purpose.

The Brigade should be able to provide independent video clips to multiple users simultaneously. This network application is a point-to-multipoint unidirectional, where the video comes from a storage device and is distributed by a video server using compressed video streams. Figure 6.5 shows a proposed overview of a Brigade video-on-demand system. The video server is the heart of the video-on-demand system. It is a post mission input-output device and is capable of storing and outputting a large number of video clips simultaneously. The server can dynamically modify the rate of transmission based on network congestion, greatly improving the quality of the delivered video.

The server has one or more high-performance Reduced Instruction Set Computer (RISC) Central Processing Units (CPUs), each with local memory, a massive Read Access Memory (RAM) cache for the video clips, a variety of storage devices for holding the movies, and some networking hardware, normally an optical interface to ATM network. (Tanenbaum, 1996)

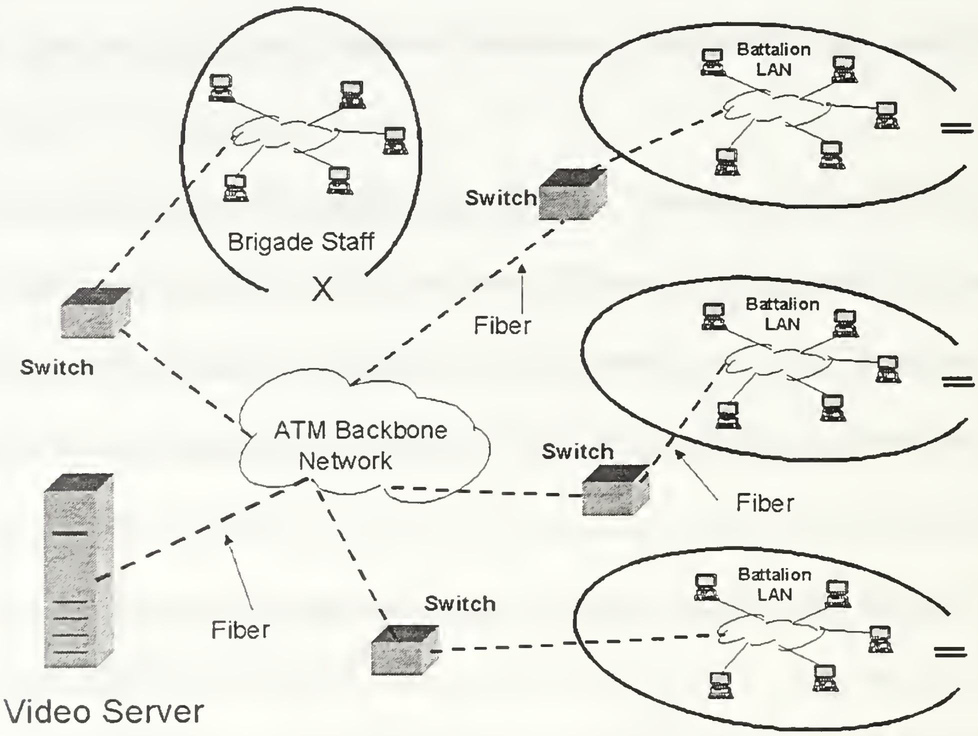

Figure 6.5. A Proposed Overview of the Brigade Non-Real-Time Video Dissemination

These subsystems are connected by an extremely high-speed bus of at least 1 GB/sec. The CPUs are used for accepting user requests, locating video clips, and moving data between devices. (Tanenbaum, 1996)

The server provides a gateway to other elements on the network, including cross platform interchange between PCs, and UNIX platforms. It streams video data continuously and without interruption, with high quality. From a hardware perspective, the performance of the video server becomes dependent upon hard disk access and interconnection speed. (Paulsen, 1998)

Video-on Demand (VOD) has been divided into four conceptual forms:

1. Near VOD,
2. Instantaneous VOD,
3. Live Interactive VOD. and
4. True Interactive VOD.

The Brigade should implement True Interactive VOD, where the clients have control over all media delivery. [forward, backward, restarted or paused in real time]. (Paulsen, 1998)

The interactive VOD service should provide for branching of programs, including the selection of in-depth video sidebars that can be viewed any time during the programming without missing a single portion of the mainstream content. The user will be able to interactively comment or take a side trip, then return without missing the main program content. (Paulsen, 1998)

The software, in this case the content creation, has the potential to extend a 10-minute short subject into 30 minutes or more- at the full control and complete discretion of the viewer. If the service is metered, it just keeps running, providing programmability and endless profitability. (Paulsen, 1998)

The point-to-multipoint unidirectional application, such as the video server, has ultimate results in the form of multicasting, because it requires only the bandwidth for a single stream that everyone tunes into. Since multicasts are often live addresses at a scheduled time, it is a relatively simple matter to prioritize them during the event and schedule other critical traffic around them. Taking an additional step, interested users can be required to sign up in advance so that the stream goes only to the subnets and client connections associated with users who have requested it. (Burger, Jeff, "Solutions for Video Resolutions," *NEWMEDIA,* April 1999)

Schemes for prioritizing network traffic have become critical in allowing real-time media traffic to coexist peacefully with more pedestrian corporate data. Prioritization goes beyond weighing video against other traffic. One way to implement prioritization is to embrace policy-based management (PBM). PBM imbues the system with business rules that automate the processes of security access, class and quality of service, and the configuration and monitoring of network equipment. (Burger, Jeff, "Solutions for Video Resolutions," *NEWMEDIA,* April 1999)

G. SUMMARY

The brigade should be able to watch real-time TUAV video of the area of operations to ensure rapid reaction to real time intelligence. In addition, they should be able to watch any desired video segment (non-real-time or video-on demand) that has been previously captured, exploited and stored in the Image Product Library (IPL). (Methods of capture are described in Chapter VII.)

In order to accomplish the above requirements the brigade should take advantage of video streaming technology that exists in the commercial environment. Real-time TUAV video should be transmitted, using RTP protocol, to the Tactical Control Station (TCS) and then multicast in an MPEG-2 compressed, streaming format throughout the Brigade LAN.

When one or more users request a specific video segment for non-real-time viewing, the video server should retrieve that video segment from the Image Product Library and multicast it to the user(s) also in an MPEG-2 compressed, streaming format. In both cases the delivered video segment must be decompressed at the user terminal for viewing.

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VII. ANALYSIS OF IMPLEMENTATION ALTERNATIVES FOR VIDEO CAPTURE AND STORAGE HARDWARE

A. INTRODUCTION

The Tactical UAV (TUAV), Tactical Control System (TCS), Global Broadcast System (GBS), and Tactical Internet (TI) will comprise the motion imagery intelligence collection and dissemination system for the Army brigade. This chapter addresses the video capture and storage hardware implementation alternatives within this system for both Real-time (RT) and Non-real-time (NRT) operations. These hardware implementations can be either centralized at the TCS or decentralized among the brigade Tactical Operations Center (TOC) and its subordinate battalion TOCs.

A TCS Operator Workstation subsystem is introduced in this chapter.

Each TCS houses two Operator Workstations and each Workstation contains two computers that are instrumental in controlling RT and NRT manipulation of TUAV video. RT and NRT computer requirements are addressed throughout the course of this chapter.

B. REAL-TIME OPERATIONS

Figure 7.1 depicts the data flows that allow the brigade to observe RT TUAV intelligence. This RT dissemination process occurs regardless of the operational implementation of video capture and storage hardware. Video capture and storage hardware implementations, however, do have an effect on the efficiency with which video segments traverse the brigade network.

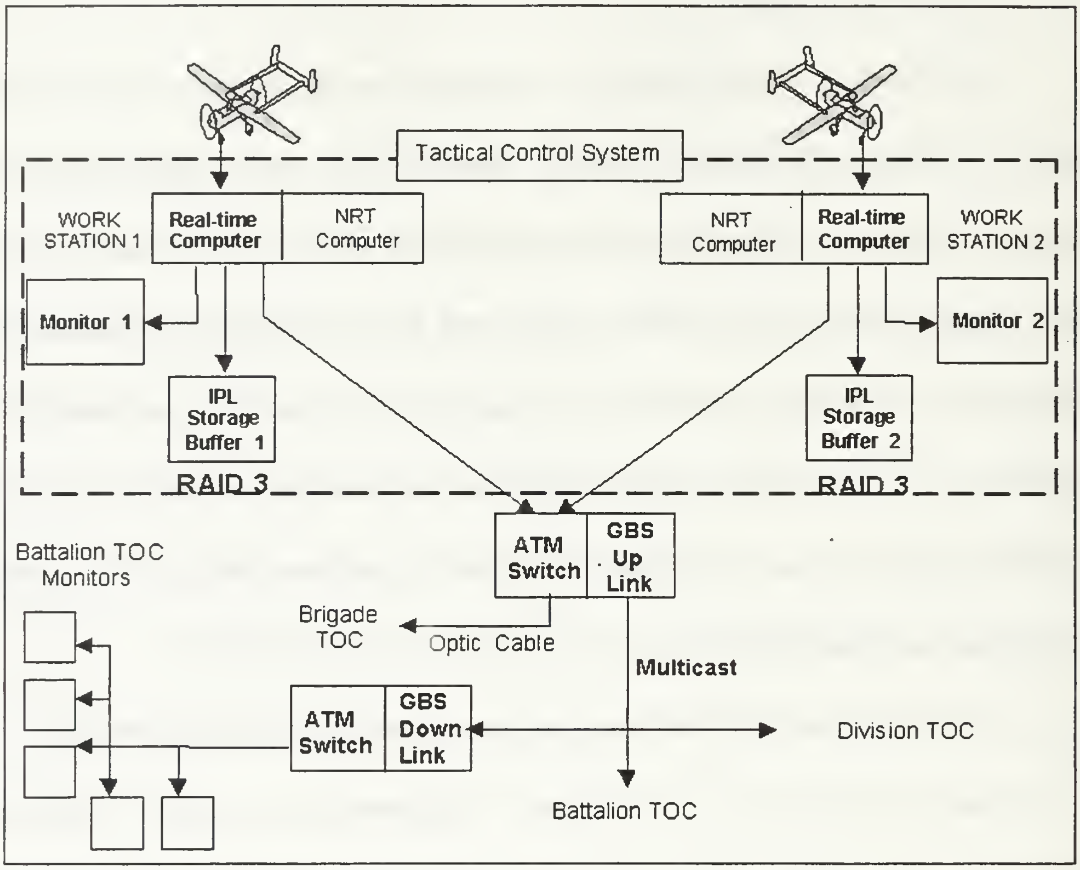

Figure 7.1. Real-Time Data Flow

Upon receipt of an MPEG-2 formatted data stream from the TUAV, a TCS RT computer channels the signal onto three parallel paths. One path directs the video data to the Image Product Library (IPL) Storage Buffer (Chapter IV) where it is written to disk in its MPEG-2 encoded and compressed format. This file becomes the master copy of the TUAV mission. The second path directs its signal to a video playback application where the formatted data is decoded, uncompressed, and forwarded to the operator's monitor for RT viewing.

The RT computer directs the third formatted signal to the Asynchronous Transfer Mode (ATM) switch for brigade multicast via the GBS data link. Each battalion TOC must decode and decompress the MPEG-2 video stream before viewing is possible. The brigade TOC will receive the data stream via a high-speed physical connection such as fiber-optic cable.

Logically, four RT video capture/storage implementation alternatives could be presented for analysis:

1. Centralized Capture, Centralized Storage;
2. Centralized Capture, Decentralized Storage;
3. Decentralized Capture, Centralized Storage;
4. Decentralized Capture, Decentralized Storage.

Since the TCS ORD does not establish a requirement for the RT computer to capture TUAV video segments during a mission flight, *Centralized Capture* is excluded from this analysis. The most likely explanation for omitting a video capture capability from the RT computer is that the Workstation operator must continuously monitor TUAV flight performance data and control the TUAV camera payload. Capturing video segments in addition to these two major responsibilities would probably overburden the operator.

1. Decentralized Video Capture, Centralized Storage

The FBCB2 Applique' computer (Chapter V) will not be equipped with video capture capability at initial fielding. It will, however, have at least one

The FBCB2 Applique' computer (Chapter V) will not be equipped with video capture capability at initial fielding. It will, however, have at least one

Peripheral Component Interconnect (PCI) expansion slot to permit video capture should the requirement materialize (Wright, 1999). Were the brigade and battalion battle staff computers so equipped, desired segments could be extracted and recorded from the RT multicast by the interested party.

Centralized storage, in regard to RT operations, refers only to the IPL Storage Buffer (Figure 7.2). No TCS exploitation occurs in RT. The IPL Video Server stores only exploited video segments and it will be addressed later in this chapter.

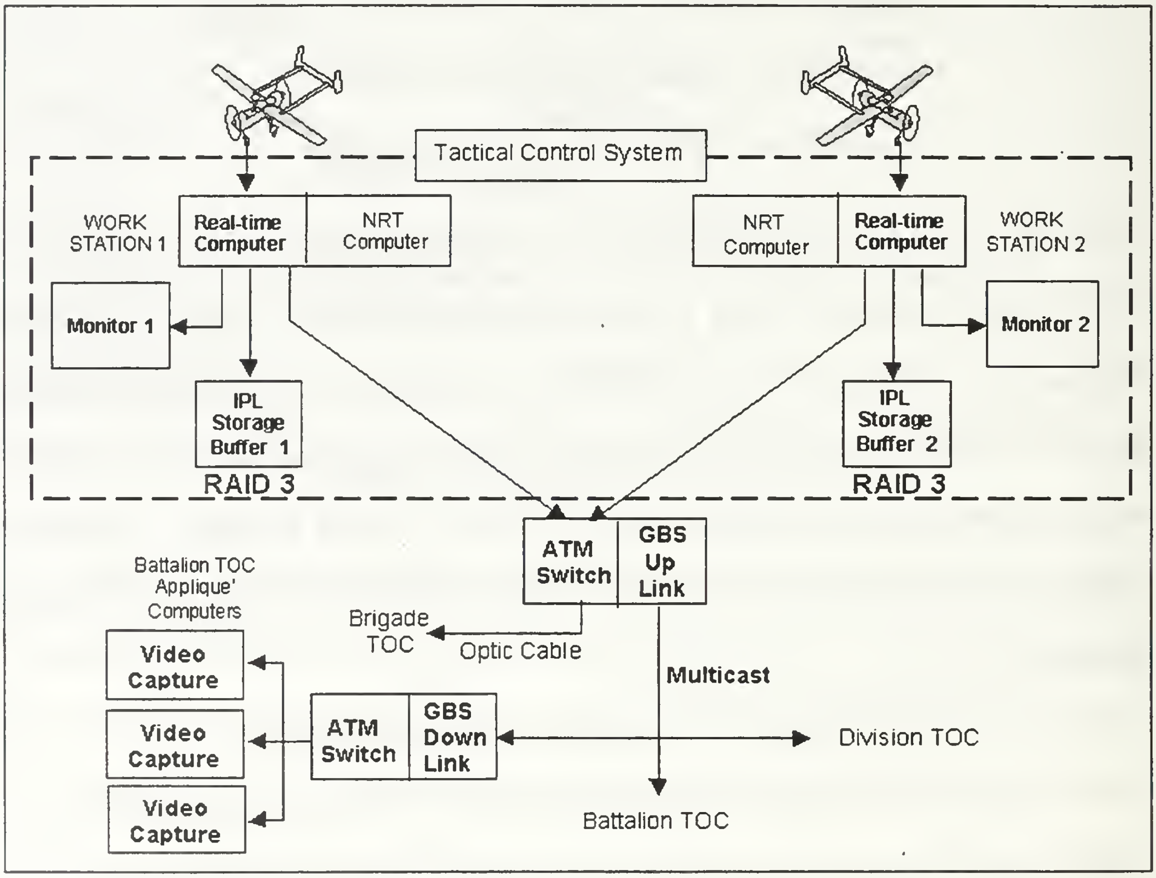

Figure 7.2. RT Decentralized Capture, Centralized Storage

a. Advantages

- Brigade stakeholders capture the exact segment desired.

- Decentralized capture eliminates referencing a specific segment by the displayed grid coordinates or mission clock (TUAV on-board processors add Global Positioning System data and a date/time group to the video stream).

- RT Decentralized capture eliminates NRT requirement for the TCS Workstation operator to sequentially access and capture referenced segments from the IPL Storage Buffer.

- Centralized storage reduces brigade hardware and software procurement costs.

- Division IPL archives RT mission video directly from GBS data link.

b. Disadvantages

- Decentralized video capture will rapidly saturate local Applique' computer hard drive capacity and restrict the number of segments that any one stakeholder can capture.

- Video capture training will be required for all brigade Applique' computer operators.

- Decentralized capture risks multiple copies of the same segment and/or segment overlap. Creates TCS segment management overhead to filter duplicate and overlapping captures.

2. Decentralized Video Capture, Decentralized Storage

Local storage for the FBCB2 Applique' computer is provided in the form of removable, 1.6 Giga-byte hard disk cartridges. Decentralized storage could be considered the hardware integrated into each brigade computer other than the IPL

Storage Buffer or a separate, large capacity device attached to each local network. Because the primary purpose of the FBCB2 network is command and control for both brigade and battalion, the Applique' computer hard disk cartridges will contain digital maps, digital maneuver overlays, digital obstacle overlays, and digital enemy situation templates. Exchanging local hard disk cartridges, for the sole purpose of saving large video files, is not desirable. From this point forward, decentralized storage is defined to be a RAID 6, multiple hard disk drive configuration attached to a local network outside the TCS (Figure 7.3).

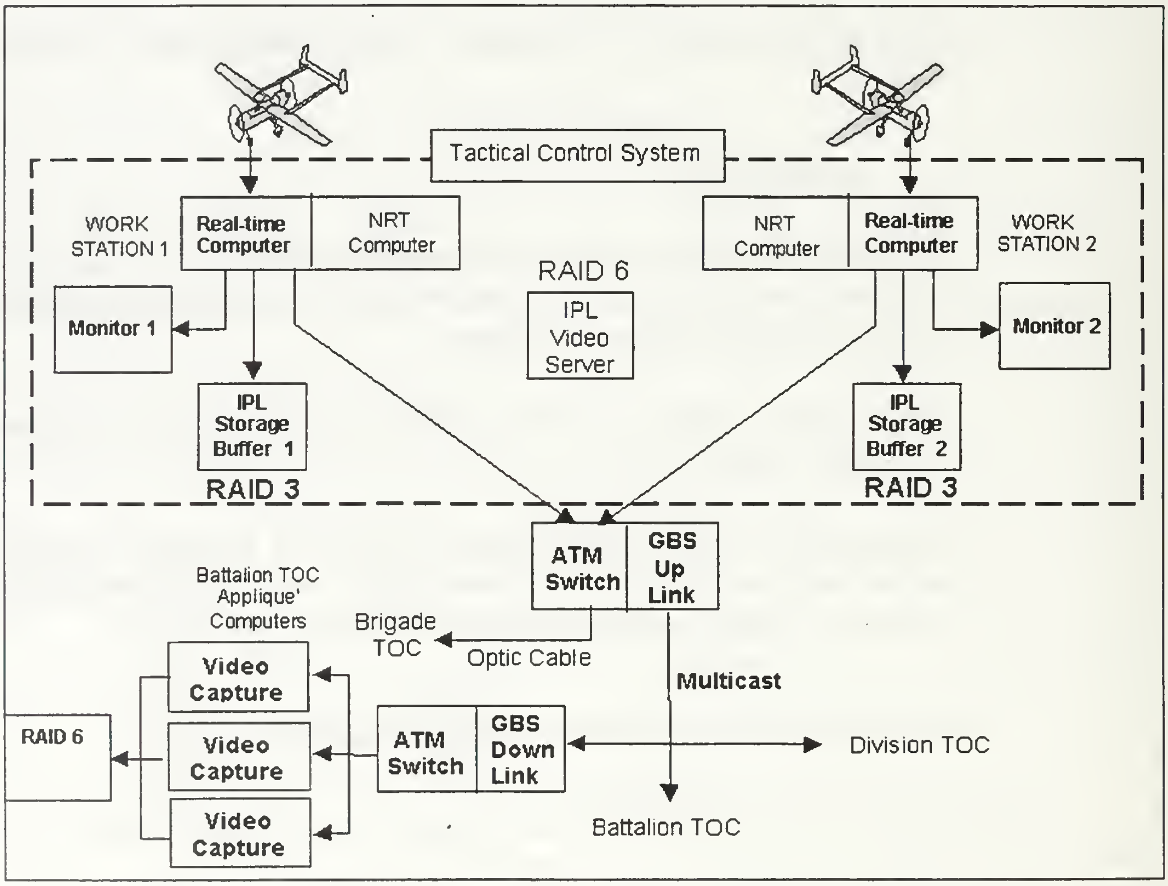

Figure 7.3. RT Decentralized Capture, Decentralized Storage

a. Advantages

- Decentralized storage eliminates the risk of saturating local hard disk drives with large video segment files.

- Decentralized storage increases RT storage redundancy within the brigade and maintains local network access to video segments should the TCS data link be severed.

- Brigade stakeholders capture the exact segment desired.

- Decentralized capture eliminates referencing a specific segment by the displayed grid coordinates or mission clock (TUAV on-board processors add Global Positioning System data and a date/time group to the video stream).

- RT Decentralized capture eliminates NRT requirement for the TCS Workstation operator to sequentially access and capture referenced segments from the IPL Storage Buffer.

b. Disadvantages

- Implements a complex and expensive infrastructure for RT capture and storage of motion imagery intelligence.

- Significant cost increase for additional storage hardware and storage management software.

- Decentralized video capture will rapidly saturate local Applique' computer hard drive capacity and restrict the number of segments that any one stakeholder can capture.

- Video capture training will be required for all brigade Applique' computer operators.

- Decentralized capture risks multiple files of the same segment and/or segment overlap. Creates TCS segment management overhead to filter duplicate and overlapping captures.

C. NON-REAL-TIME OPERATIONS

The TCS NRT computer is required to perform video capture operations. This capability permits the Work Station operator to extract a video segment, or segments, between 30 seconds to five minutes from a TUAV four-hour mission master file. Combined with an additional requirement to provide limited exploitation (editing) capability, the NRT computer will annotate intelligence-enhancing descriptive text or graphics directly onto the video segment. (TCS ORD, 1997) NRT manipulation of video permits a brigade stakeholder to review a specific segment of a TUAV mission sometime after the RT multicast and the requestor may ask to review a segment with or without exploitation annotations.

1. Centralized Video Capture, Centralized Storage

Centralized storage, in regard to NRT operations, refers only to the IPL Video Server. Segment exploitation occurs after completion of the TUAV mission. With video capture and editing capability centralized at the TCS, a brigade stakeholder may request and view a segment by the following procedure (Figure 7.4):

- **Step 1:** Submit request for segment to TCS via TI e-mail. (Segment length must be designated by referencing either the grid coordinates indicated by the TUAV camera or by the mission clock; both sources of information are transmitted by the TUAV for display)
- **Step 2:** Workstation operator extracts and exploits requested segment or segments.

- **Step 3:** Workstation operator loads segment(s) onto IPL Video Server with MPEG-2 formatting.

- **Step 4:** Workstation operator notifies requestor of segment availability via TI e-mail.

- **Step 5:** Requestor accesses IPL Video Server directory and designates specific segment for viewing.

- **Step 6:** Server streams video segment to requestor via ATM and GBS data link.

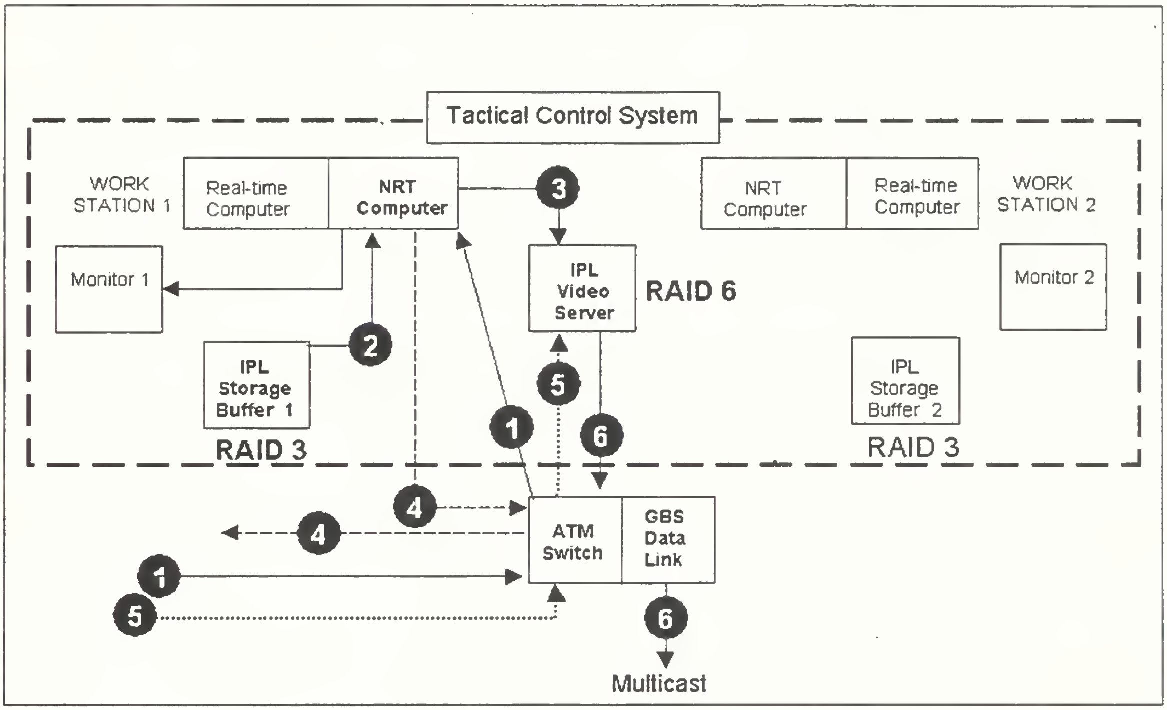

Figure 7.4. NRT Centralized Capture, Centralized Storage

a. Advantages

- E-mail requests consume minimal bandwidth.

- Requestor can access video server when most convenient.

- Exploited segment loaded onto video server is available to entire brigade.

- Centralized video capture and storage reduces brigade hardware and software procurement costs.

- Centralized video capture and storage reduces brigade hardware maintenance and training expense.

b. Disadvantages

- Sequential retrieval of multiple segment requests will be time consuming.

- Creates TCS segment management overhead to filter duplicate and overlapping requests.

- Loss of GBS data link terminates battalion access to IPL Video Server.

2. Centralized Video Capture, Decentralized Storage

Figure 7.5 depicts the addition of a large capacity digital storage device (RAID 6) to the battalion tactical operations center (TOC). The subsequent data flow differs from a centralized storage scheme only in that once a battalion requestor has accessed the IPL video server and received an exploited segment, that segment can be stored locally (Step 7).

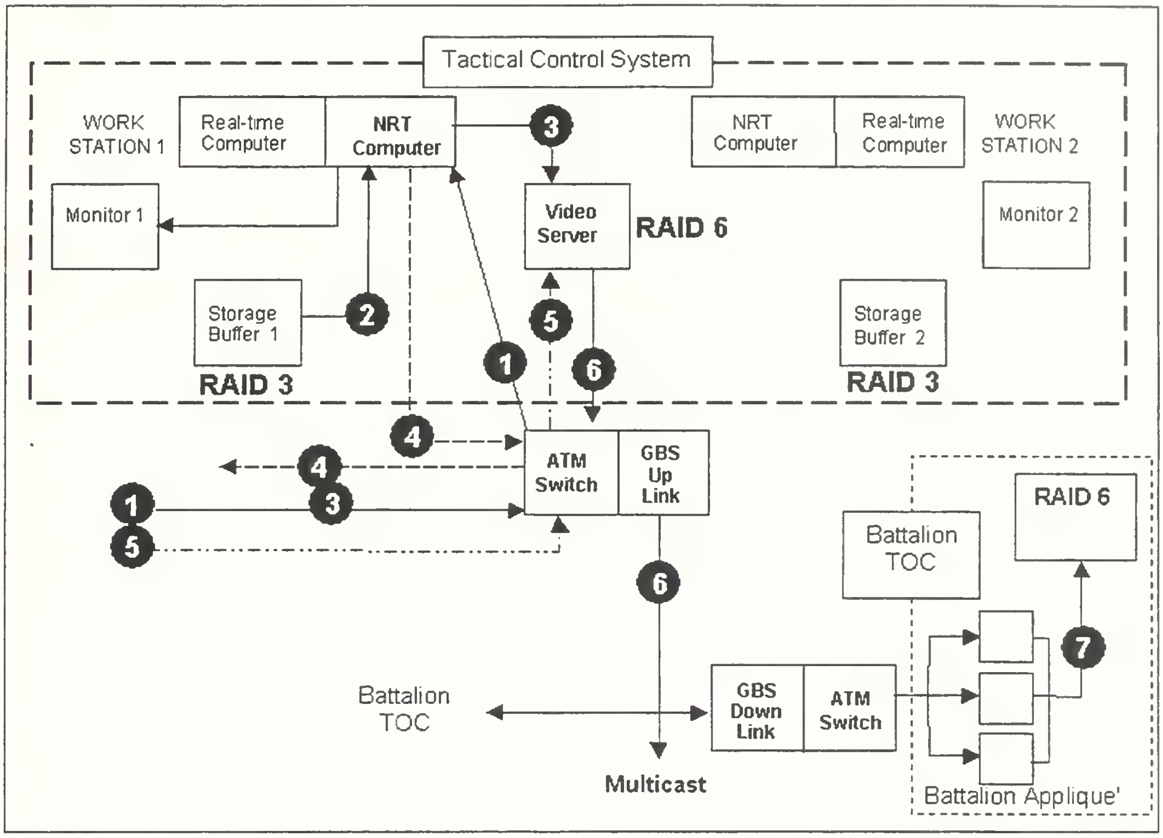

Figure 7.5. Centralized Capture, Decentralized Storage

a. Advantages

- Decentralized storage increases RT storage redundancy within the brigade and maintains local network access to video segments should the TCS data link be severed.
- E-mail requests consume minimal bandwidth.
- Requestor can access video server when most convenient.
- Exploited segment loaded onto video server is available to entire brigade.
- Centralized video capture reduces brigade hardware, software, maintenance, and training expense.

- Multiple edited video segments can be stored and reviewed repeatedly at battalion level without consuming brigade network bandwidth with continuous video streaming.

b. Disadvantages

- Sequential retrieval of multiple segment requests from the IPL Storage Buffer will be time consuming. Creates TCS segment management overhead to filter duplicate and overlapping requests.

- Large capacity storage hardware and storage management software for each battalion will increase procurement expense.

- Storage management overhead will increase for each brigade network administrator.

3. Decentralized Video Capture, Centralized Storage

After RT capture of a desired segment, this implementation would proceed as follows (Figure 7.3):

- **Step 1:** Requestor submits video segment to the TCS as a TI e-mail attachment.

- **Step 2:** TCS Workstation operator edits attachment without accessing IPL Storage Buffer and loads edited segment onto the video server.

- **Step 3:** TCS Workstation operator notifies requestor of edit completion via e-mail.

- **Step 4:** Requestor accesses video server.

- **Step 5:** Video server streams video file onto the GBS data link.

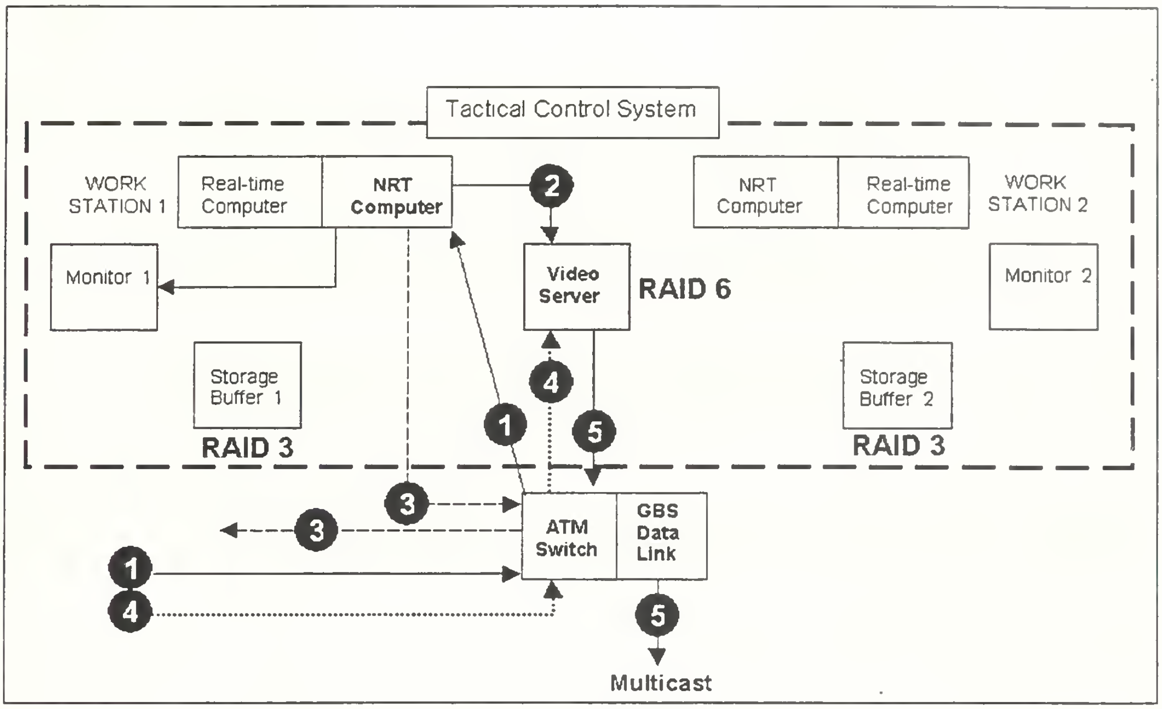

Figure 7.6. NRT Decentralized Capture, Centralized Storage

a. Advantages

- Brigade and battalion TOCs can capture and shorten edited segments for faster dissemination on the battalion networks.
- Centralized storage reduces brigade hardware and software procurement costs.
- Centralized storage reduces brigade hardware maintenance and training expense.

b. Disadvantages

- Large video files transmitted as attachments via e-mail will consume TI bandwidth.
- Additional training required for Applique' computer operators.

- Sequential retrieval of multiple segment requests will be time consuming.
- Creates TCS segment management overhead to filter duplicate and overlapping requests.
- Loss of GBS data link limits battalion video segment access to local storage capacity.

4. Decentralized Video Capture, Decentralized Storage

Figure 7.7 depicts the addition of a large capacity digital storage device (RAID 6) to the battalion tactical operations center (TOC) to complement the decentralized video capture capability.

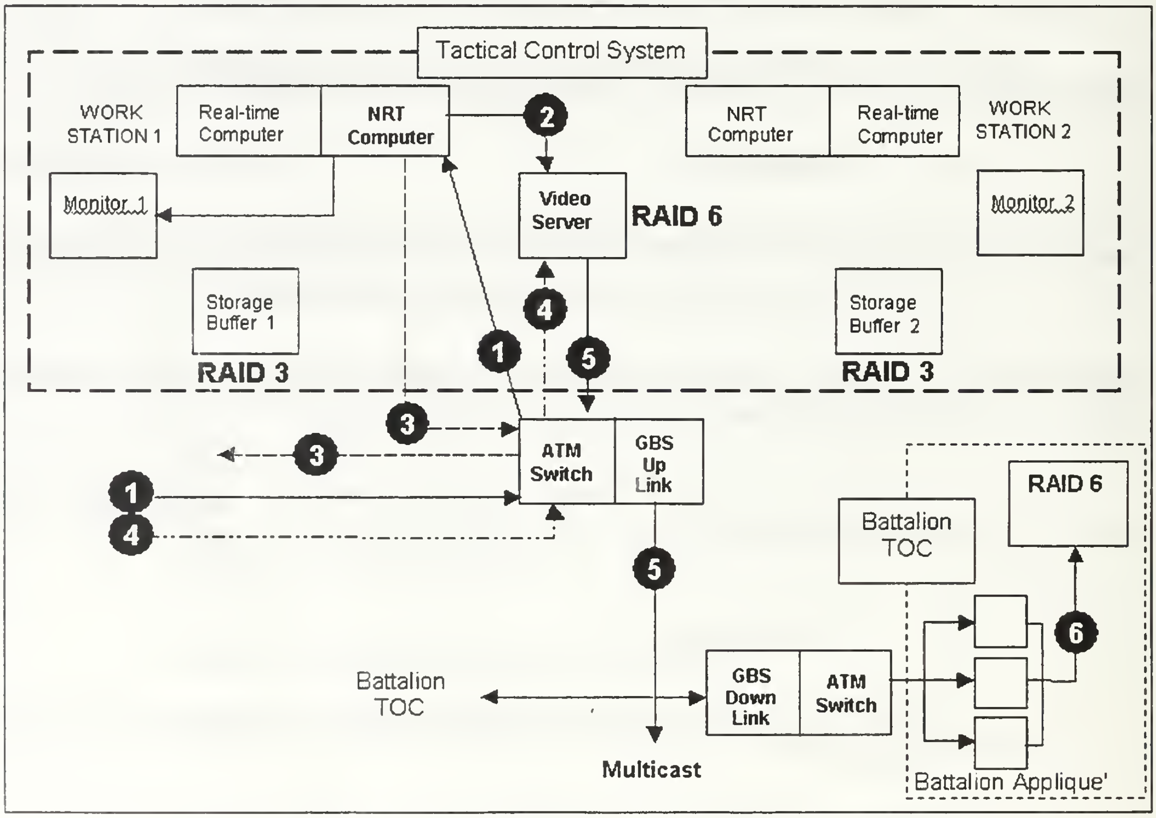

Figure 7.7. NRT Decentralized Capture, Decentralized Storage

a. Advantages

- Multiple edited video segments can be stored and reviewed repeatedly at battalion level without consuming brigade network bandwidth with continuous video streaming.

- The battalion battle staff will not be denied access to video segments should the transmission link to the IPL video server be severed.

- Storage hardware redundancy within the brigade will ensure the availability of replacement hardware in the event of an IPL video server failure.

- Brigade and battalion TOCs can capture and shorten edited segments for faster dissemination on the battalion networks.

b. Disadvantages

- Implements a complex infrastructure for RT capture and storage of motion imagery intelligence.

- Large capacity storage hardware and storage management software for each battalion will increase procurement expense.

- Storage management overhead will increase for each brigade network administrator.

D. CONCLUSION

The Army brigade should implement decentralized video capture and decentralized large capacity storage. The advantages of parallel segment capture and imagery intelligence protection through network compartmentalization outweigh the disadvantages of increased cost and management overhead. Storage hardware prices continue to fall due to competition among storage technology vendors and network management applications are available that compensate for the addition of new hardware.

E. SUMMARY

This chapter introduced the Real-time computer as the TCS subsystem primarily responsible for the RT channeling and storage of a TUAV video feed. The Non-real-time computer is also introduced as the TCS subsystem primarily responsible for extracting (capturing) video segments from the IPL Storage Buffer, exploiting the imagery, and loading the final product onto the IPL video server.

Several hardware implementation alternatives are presented for both video capture and large capacity storage hardware. The analysis attached to each implementation alternative identifies some of the advantages and disadvantages that video capture and storage technology bring to Real-time and Non-real-time video intelligence operations.

VIII. CONCLUSION AND RECOMMENDATIONS

A. CONCLUSION

The Department of Defense Joint Technical Architecture has mandated a migration from analog to digital technology in the Command, Control, Communication, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) community. Digital technology will significantly reduce the time required to distribute both real-time and non-real-time imagery intelligence at the tactical level. The Tactical Unmanned Aerial Vehicle (TUAV) and Tactical Control System (TCS) are two brigade imagery intelligence systems that the Army will field within the next three years to achieve information superiority on the modern digital battlefield. These two systems provide the brigade commander with an imagery collection and processing capability never before deployed under brigade control. Future deployment of the Warfighter Information Network (WIN) will ensure that a digital dissemination network is in place to handle the transmission bandwidth requirements of large digital video files.

The TUAV carries an electro-optical and/or infrared camera into the brigade area of operations using vantage point and travel speed to relay real-time "activity information" to the brigade battle planners. The TCS Operator Workstation will use a real-time computer to process the TUAV video data stream for real-time multicast. A workstation non-real-time computer will capture video segments from the TUAV mission file for exploitation and subsequent storage in the TCS Image Product Library.

B. ANSWERS TO PRIMARY RESEARCH QUESTIONS

1. What digital storage technology is available to the brigade motion imagery system?

Electro-magnetic media provides the greatest digital storage capacity per individual hard drive. A multiple hard drive configuration known as Redundant Array of Independent Disks (RAID) provides a fault tolerant, high capacity solution for storing large volumes of TUAV digital motion imagery.

2. What digital dissemination technology is available to the brigade motion imagery system?

Server-side streaming video technology compresses the large video file in order to transmit it over the network. Client-side streaming technology lets the receiving computer start displaying the video, with the aid of viewer software. Streaming video technology can use User Datagram Protocol, Real Time Streaming Protocol, Real Time Transport Control Protocol, and Resource Reservation Protocol.

MPEG-2 compression technology is a set of international computer and broadcast industry standard formats that take advantage of intraframe and interframe data redundancies to reduce digital video and audio transmission bandwidth requirements.

Multicast processing sends one copy of each data packet and addresses it to a group of computers that want to receive it.

The video server is a post mission input-output device and is capable of storing and outputting a large number of video clips simultaneously.

Video-on Demand (VOD) dissemination technology is divided into four conceptual forms: Near VOD, Instantaneous VOD, Live Interactive VOD, and True Interactive VOD.

C. ANSWERS TO SECONDARY RESEARCH QUESTIONS

1. Why does the tactical warfighter want motion imagery?

Motion imagery can capture activity information at thirty frames per second and remove the need for speculative analysis characteristic of viewing a sequence of still photographs separated by minutes or hours.

2. How does the brigade currently disseminate motion imagery intelligence?

The US Army does not currently field a brigade level video collection asset. The Hunter TUAV system is a development item that provides the Force XXI brigade an experimental source of motion imagery. The Hunter Ground Control Station records Hunter video on 8mm analog tape for review and exploitation. Dissemination is affected by tape-to-tape copy and courier distribution.

3. What imagery quality standards does the brigade require?

Tactical imagery quality standards have been established by the Video Imagery Standards Profile authored by the National Imagery and Mapping Agency.

SPATIAL RESOLUTION		IMAGE DEPTH	TEMPORAL RESOLUTION	COMPRESSION
Horizontal pixels	Vertical pixels	Bits	Frame Rate (fps)	Type (ratio)
720	576	10	30	MPEG-2 (5.5:1)

4. What are the digital storage capacity requirements for motion imagery transmitted by a Tactical Unmanned Aerial Vehicle?

Uncompressed Storage Requirement

$$= \frac{4\ \text{hrs}}{\text{UAV}} \times 2\ \text{UAVs} \times \frac{(\text{Horz. pixels} \times \text{Vrt. pixels})}{\text{frame}} \times \frac{10\ \text{bits}}{\text{pixel}} \times \frac{30\ \text{frames}}{\text{second}}$$

$$= \frac{4\ \text{hrs}}{\cancel{\text{UAV}}} \times 2\ \cancel{\text{UAVs}} \times \frac{(720 \times 576)\ \cancel{\text{pixels}}}{\cancel{\text{frame}}} \times \frac{10\ \text{bits}}{\cancel{\text{pixel}}} \times \frac{30\ \cancel{\text{frames}}}{\text{second}}$$

$$= 8\ \text{hrs} \times 414{,}720 \times 300\ \text{bits/ second}$$
$$= 8\ \cancel{\text{hrs}} \times 414{,}720 \times 1{,}080{,}000\ \text{bits/}\ \cancel{\text{hr}}$$
$$= 3.58 \times 10^{12}\ \text{bits} = 4.48 \times 10^{11}\ \text{bytes} = \mathbf{448\ GB}$$

The 448GB figure conservatively approximates the actual digital imagery information transmitted by two TUAVs over an eight-hour period. Intelligence surge operations may require the TUAVs to fly consecutive missions without allowing time for video segment exploitation between missions. In this case, the uncompressed storage basis increases to **896GB**.

Compressed Storage Requirement $= \frac{896\text{GB}}{5.5} =$ **162.9GB**

5. **What video dissemination architecture will be in place in three to five years?**

WIN will support Force XXI distributed operations and enhance situational awareness. According to the WIN Master Plan of November 1998, the Global Broadcast Satellite communication architecture is already in place for the Near-Term phase (FY97 thru FY99) to connect the strategic and tactical levels. The ATM packet switching architecture will be in place as part of WIN's terrestrial transport system. Together with fiber optic LAN connectivity, also from the Near-Term deployment, ATM fielding will continue to increase throughout its mid-term phase (FY00 thru FY02). The end user will view TUAV video imagery using the FBCB2 Applique' computer terminal.

6. **How might the brigade implement digital hardware for the capture and storage of motion imagery?**

TCS video capture and storage hardware may remain centralized at the brigade tactical operations (TOC) center or the hardware may be installed in the brigade TOC and all battalion TOCs as well. A centralized implementation will eliminate maintenance and management overhead for the brigade and battalion, but will require the TCS Workstation operator to sequentially extract all requested video segments. A decentralized implementation will allow brigade and battalion stakeholders to capture the exact segment desired and thereby free the Workstation operator to exploit all video segments. The decentralized implementation will increase both brigade hardware procurement costs and battle staff training requirements.

D. RECOMMENDATIONS

The TCS IPL should be divided into two hardware components: 1) a video storage buffer for recording four 4-hour TUAV missions, and 2) a video server for storing exploited video segments. The storage buffer should be capable of storing no less than 163GB of digital data. The TCS capability to simultaneously control and receive real-time video from two TUAVs requires that each TUAV have a dedicated storage buffer.

A RAID 3 architecture should be adopted for the high capacity IPL storage buffer solution. RAID 3 can handle the large-scale, contiguous data read and write operations required for recording four hours of video per session. The IPL video server should utilize a RAID 6 architecture, which best handles, the multiple I/O requests of many brigade clients.

Brigade real-time video imagery should be transmitted by streaming and multicasting video technology. A Real Time Transport Protocol (RTTP), in conjunction with Real-Time Transport Control Protocol (RTCP), should be adopted to provide real-time transmission of data packets and to monitor quality of service. The brigade non-real-time video imagery system should implement true interactive VOD, where the clients have control over all media delivery.

A decentralized video capture capability should be incorporated at the brigade and battalion TOCs to eliminate sequential segment extraction time delays at the TCS. High capacity storage hardware should be installed on the brigade TOC LAN and each battalion TOC LAN to afford the brigade data redundancy through storage decentralization.

E. RECOMMENDATIONS FOR FURTHER STUDY

1. RAID 7©

Investigate RAID 7© technology as a single storage hardware solution for both the IPL storage buffer and the video server. Installation of a RAID 7© architecture offers a local TCS hardware redundancy that permits swapping storage buffer and video server functions without having to reconfigure between RAID 3 and RAID 6.

2. Optical RAID

Investigate the technological development of RAID architectures that incorporate optical storage media. The tactical threat of Electro Magnetic Pulse puts data stored on magnetic media at risk. Optical media, however, are not susceptible to data loss from an Electro Magnetic Pulse source.

3. Signal Corps Data Warehouse

Research the efforts of the US Army Signal Corps to integrate data warehousing services into the Warfighter Information Network. A data warehouse would provide a redundant storage system for brigade video segments should the TCS IPL video server fail or should the TCS be detached from the brigade for another assignment.

4. Video Server Capacity Requirement

Investigate the capacity requirements for the IPL video server. Network traffic simulation for the brigade might provide a reasonable approximation of video server storage requirements.

5. Cost Benefit Analysis

Examine the cost benefits available to the Department of the Army by integrating commercial high capacity storage items into the brigade motion imagery processing system.

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