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THESIS

HERBICIDES IN SUPPORT OF
COUNTERINSURGENCY OPERATIONS:
A COST-EFFECTIVENESS STUDY

by

John Dalton Howard

Thesis Advisor: James R. Capra

March 1972

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Herbicides in Support of Counterinsurgency Operations:

A Cost-Effectiveness Study

by

John Dalton Howard
Major, United States Army
B.S., United States Military Academy, 1964

Submitted in partial fulfillment of the
requirements for a degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

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I. INTRODUCTION

A. PURPOSE

The purpose of this study is to conduct a cost-effectiveness evaluation of military herbicide systems in a counterinsurgency environment. The test case for the determination of relevant costs will be those dollar costs incurred during the systems' employment in vegetation removal and crop destruction missions in support of combat operations in the Republic of Vietnam (RVN) during 1965-1971. Since costs are the values of alternatives foregone, the study will address three other techniques used for foliage clearance and crop control in RVN during the same time-frame. The alternatives to herbicide operations which will be considered are:

1. Tactical land clearing operations.
2. "Slash and burn" clearing using indigenous labor forces.
3. Firebombing.

Each method will be discussed in detail in Chapter II. Specifically excluded from the scope of the study is consideration of the externalities that might result from possible damage to the ecological balance of the host country.

The cost measures will attempt to show the relative dollar expenditures among the systems involved. Several measures of effectiveness will be used to judge their output and ability to accomplish the missions of foliage removal and crop destruction under combat conditions. These, coupled with the cost measures, will yield cost-effectiveness figures which will be the basis for comparisons. These comparisons will present the decision maker with sets of data on the strengths and weaknesses of the individual alternatives and combinations of the systems.

B. BACKGROUND

The proper use of cover and concealment has always been a critical factor in planning military operations. History is full of examples of armies that effectively used natural cover and foliage. Often, judicious use of these elements made up for other deficiencies in the forces. The colonial settlers of early America learned the arts of cover and concealment from the Indians and later put them to good use in the War of Independence. As warfare evolved from the straight-line formations of the 19th century and the trenches of World War I, it became apparent that strict adherence to the principles of concealment was not reserved solely for the guerrilla or irregular soldier. Hence, tactics and methods were developed in an attempt to deny any potential enemy, insurgent or conventionally organized, the protection and sustenance that might be offered by the vegetation.

The term "herbicide" was coined in the 1930's to encompass that family of chemicals which are antiplant agents. Some members of this family were found to be systemic hormones which entered broad-leaf plants touching off wild growth and eventually killing them. Others were determined to be dessicants which injured the foliage by direct chemical action on contact. Throughout World War II, military research in chemical warfare played an important role in the development of the potent herbicides now in world-wide use. Although initial efforts were directed at the discovery of suitable dessicants (for use as anticrop agents), scientists from the University of Chicago determined that some of these growth regulators might be applied to grasses and tropical plants. This generated a great deal of interest in the defoliation or foliage removal properties of the chemicals since many tons of explosives had been expended on Pacific islands to deny the Japanese concealment afforded by the tropical rain forests. In early 1945, successful tests were conducted in the Florida Everglades concerning the possibility of using several inorganic defoliants in aerosol form. The results from this work prompted the Army to recommend the use of ammonium thiocyanate in the Pacific theater. This recommendation was not adopted for fear of the repercussions that might arise from the agent's association with chemicals of the cyanide family. The war ended prior to the testing of a more suitable agent.

In the late forties, the research generated during World War II was readily employed by civilian industry. The previous discovery of the organic chemicals 2,4-D and 2,4,5-T fostered revolutionary steps in chemical plant control and stimulated the development of a host of new agents. These herbicides were more effective, more selective, and less hazardous than the former compounds. Chemicals such as picloram, bromacil, cacodylic acid, and paraquat were tailored to perform specific kinds of vegetation control. Consequently, their use at home and abroad became widespread. In 1950 the estimated market for herbicides came to $1.5 million while by 1965, it had grown to over $211 million. (This was prior to extensive military purchase of certain agents for use in RVN.) In 1959 alone, American farmers treated 53 million acres of acres of agricultural land not to mention the thousands of miles sprayed by local government agencies and private corporations to control growth along highways, powerline right-of-ways, fire breaks, and ditches. [House and others, 1967.]

The Department of Defense (DOD) did not become involved in herbicide operations until 1958. The success of British defoliation operations with helicopters in Malaya prompted several feasibility studies on acceptable defoliants and delivery techniques. In 1961, on request of President Diem and the government of RVN, a test program was established to assist in countering that nation's growing Communist-inspired insurgency. The Vietnamese army (ARVN) found that the most difficult and frustrating task was locating the enemy. The dense forests and jungles offered the Viet Cong (VC) excellent concealment which permitted them to move with relative impunity to within striking distance of key military installations, lines of communications (LOC), and government centers. By removing parts of the foliage, the Allied forces hoped to increase aerial and ground surveillance capabilities and deny the use of certain areas as sanctuaries.

The actual herbicide operations began under the codename RANCH HAND in January 1962 with three specially configured U.S. Air Force (USAF) UC-123B aircraft. The operations proceeded for the next two years at a moderate scale but with increased enemy resistance. Ground fire became so intense that in March of 1965 fighter escorts were provided on a permanent basis. The demand for defoliation and controlled crop destruction missions increased as U.S. participation in the war grew. This resulted in the RANCH HAND program being expanded in 1966 into a squadron-size unit, 12th Air Commando Squadron (later the 12th Special Operations Squadron), with an equipment level of 18 aircraft and headquarters at Bien Hoa Air Base. In the peak years of defoliation operations (1967-1968), the squadron was increased to 24 aircraft. [McConnell, 1970.] To supplement the 12th Special Operations Squadron, some U.S. division commanders were given the authority to conduct local defoliation and crop destruction missions in their area of operations (AO) with U.S. Army helicopters. These operations were usually complementary to the RANCH HAND sorties and employed local aviation assets that were diverted from other lift tasks.

From the inception of the test program, great effort was made to insure proper targets were picked and spraying of friendly areas was prevented. Each mission was approved by the local Vietnamese province chief, the Military Assistance Command Vietnam (MACV), and the U.S. Embassy. Crop destruction targets were subject to special scrutiny so that the most harm would be done to the VC and the least to the local inhabitants. A commission was established to compensate and reimburse those people who had suffered financial loss as a result of herbicides. Although friendly areas were never specifically targeted, some spray did occasionally drift causing damage to rice crops or rubber trees. U.S. authorities attempted to take prompt action on any claims whenever this situation occurred. [Gonzales 1968]

Concurrent with increased herbicide operations in Vietnam, there was an expanding controversy over the program in the United States. Critics asserted that if chemical herbicides were commonly used, it might not be long before more noxious chemical agents are considered usable. Others have claimed that such an indiscriminate weapon results in as much suffing for the local populace as the VC. [Hersh 1968] and [Lewallen 1971]. The scientific community raised the question of the ecological consequences of repeated herbicide applications. The American Association for the Advancement of Sciences (AAAS) has been and still is the center of the controversy. Probably the most vocal and widely quoted critic within AAAS is Dr. Matthew Meselson, a Harvard University biologist. Dr. Meselson chaired the AAAS Herbicide Assessment Commission and visited Vietnam on a five-week tour. In the committee statement to an AAAS convention, the following assertions were made:

1. The Army's crop destruction program was a failure.
2. One-fifth to one-half of Vietnam's mangrove forests had been "utterly destroyed."
3. One-half the trees in the mature hardwood forests north and west of Saigon were dead.[1]

Several other scientists who had previously visited RVN in 1968-1969 strongly recommended and lobbied for the cancellation of the herbicide operations until scientists had time to study the long-term effects of the program. [Orians and Pfeiffer 1970]

These recommendations coupled with severe criticism from certain members of Congress and other citizens helped bring about the suspension of herbicide operations in the summer of 1970. On 7 October 1970, Public Law 91-441 directed the Secretary of Defense to prepare a study to identify the role

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[1]Boffey, Phillip M., "Herbicides in Vietnam: AAAS Study Finds Widespread Devastation," Science, 15 January 1971, p. 43.

of herbicides in support of combat operations and evaluate their utility in RVN. It also required him to contract with the National Academy of Sciences (NAS) for a comprehensive study to determine the ecological and physiological effects of the herbicide program in RVN. By 1 March 1972, the Secretary of Defense was required to transmit the DOD findings together with the NAS study to the President and the Congress.

It is against this background of U.S. use of herbicides and Congressional concern about the role of herbicides that the examination of the alternatives discussed in the next section has been undertaken.

II. ALTERNATIVES

A. AERIAL DELIVERY OF HERBICIDES

Aerial delivery is the prime method of dissemination of chemical herbicides for large-scale defoliation or crop destruction missions. Other methods, such as use of the three-gallon hand-pump sprayer, the M-106 riot control dispenser, and boat-mounted spray systems, have been employed in Vietnam but will not be considered in the context of this study. However, all herbicide missions are designed to accomplish some or all of the following objectives:

1. Deny the enemy cover and concealment and channel his movement.
2. Deny the enemy the capability to forage off the land.
3. Deny the enemy ambush sites adjacent to LOC.
4. Provide improved aerial and electronic surveillance.

1. Delivery By Fixed Wing Aircraft (UC-123)

The major portion of the U.S. herbicide effort is carried by a modified version of the Air Force's two-engine medium cargo carrier, the C-123B "Provider." The aircraft is given a spray capability ("UC" designation) by the installation of the Hayes AA-45 system which consists of a 1,000 gallon internal tank, an operator console, and three high pressure spray booms. Since most missions are carried out at low altitudes and low speeds, the performance of the aircraft is significantly upgraded by the addition of turbo-jet engines. The intensity of enemy ground fire in Vietnam has forced the Air Force to further protect the UC-123K with additional armor plating for the crew and engines. The UC-123K's travel in fighter escorted flights ranging anywhere from two to seven aircraft, depending on the target configuration. Each aircraft dispenses its 1,000 gallon load in four minutes at less than 150 miles per hour and 150 feet off the ground. The Hayes system can be adjusted for variable dissemination rates; however, these rates are usually between one and one-half gallons to three gallons per acre. [Major Pyatt]

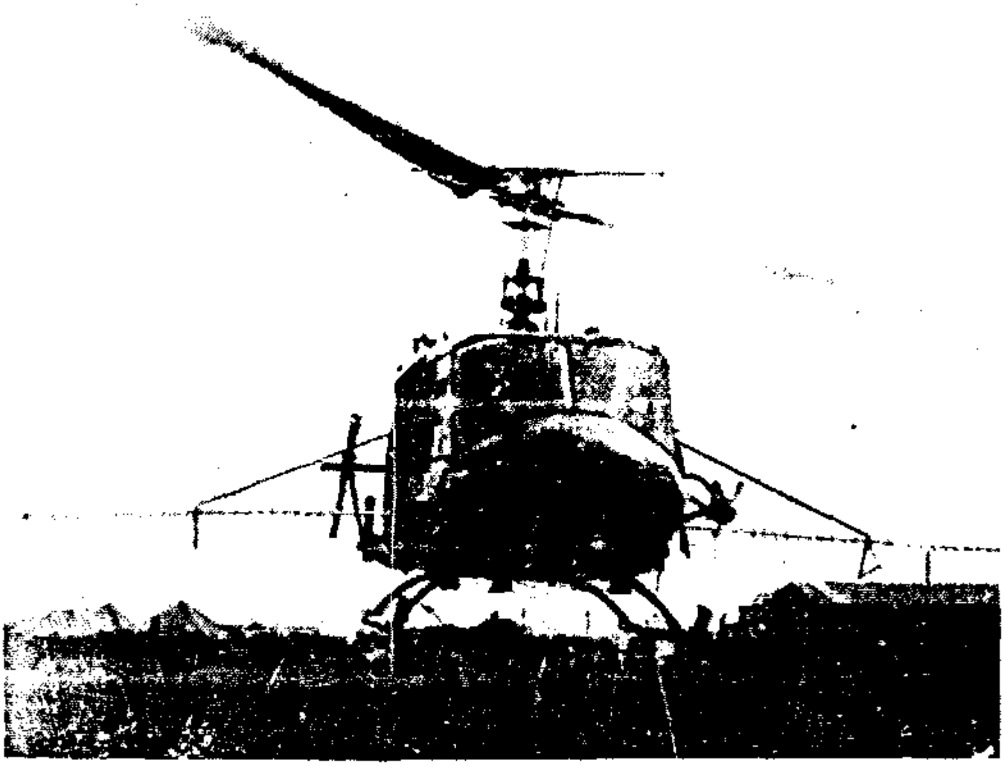
Photo # 1: Four UC-123 aircraft of the 12th Air Commando Squadron defoliating a jungle area east of Saigon. June 1968
U.S. Army Photograph

2. Delivery By Rotary Wing Aircraft (UH-1)

In certain areas, ground commanders are authorized to conduct local herbicide operations. When UC-123 aircraft are not available to do the job or the target is too small to merit fixed wing sorties, the UH-1 helicopter (commonly known as the "Huey") can be equipped with an internal tank and spray booms. In initial operations in RVN, some U.S. Army units used a field expedient which employed a 55-gallon drum fitted with rubber hoses and sprayers mounted on the helicopter skids. The second generation system used in the UH-1 is the AGAVENCO sprayer, developed by a Las Vegas firm for use in agricultural work. This system can be mounted in the aircraft in less than one-half hour and consists of a 200 gallon tank, pump, and pressurized nozzles. [Department of the Army (DA) Training Circular (TC) 3-16 1969]. The UH-1 fitted with the AGAVENCO provides the same dissemination rates as the UC-123 but its capacity is considerably less. Although the system is designed for a 200 gallon capacity, the combat requirements of two pilots, two door gunners, and a system operator cut the UH-1's lift capability to such an extent that the tank can only be loaded with 100 gallons. [LTC Rudrow]

The use of the helicopter in RVN for delivery of herbicides has been far less standard than the operations of the 12th Special Operations Squadron. Since division commanders were the controlling authorities for these missions in each AO, the methods used varied considerably throughout the theater. Ideally, several "Hueys" should be employed for efficiency's sake. However, since no helicopters were set aside specifically for herbicide missions, they were normally diverted on a one-by-one basis from other combat sorties. The security escorts, the AH-1G ("Huey Cobra"), faced the same problem, and while a defoliation helicopter should be supported by two Cobras, on many occasions, none were available. However, this lack of security did not curtail the missions. [LTC Rudrow and LTC Sanches]

Photo # 2: UH-1 helicopter taking-off on a defoliation mission. U.S. Army Photograph



3. Chemical Agents

ORANGE, WHITE, and BLUE will be the agents considered in this study. These chemicals do not constitute the complete spectrum of herbicides, but they were the most widely used in support of U.S. combat operations in RVN.

Table II-1: Composition and Use of Selected Agents[2]

AGENT	COMPOSITION	USES
ORANGE	50% 2,4-D(n-butyl,2-4 dichlorophenoxyacetate) 50% 2,4,5-T(n-butyl,2,4,5-trichorophenoxyacetate)	General defoliation: mangrove, jungle, and low-land scrub trees.
WHITE	20% Picloram (4-amino-3,5,6-trichloropicoline acid) 80% 2,4-D(trisopropanolamine)	General defoliation: Slower acting but more persistent than ORANGE
BLUE	3 pounds per gallon of water of: 65% cacoclylic acid 35% inert ingredients: sodium chloride, sodium sulfate, calcium sulfate and water.	Crop destruction: Most effective against grassy plants, rice, manioc, corn, and banana trees.

During defoliation operations in RVN, agents ORANGE and WHITE were used interchangeably. It was found that these agents did not permanently destroy all vegetation, although the mangrove swamps still show heavy effects of the spraying. Recent pictures taken of heavily defoliated areas show considerable regrowth of foliage in hardwood forests and along waterways. The NAS study will address this question

[2]DA TC 3-16, Employment of Riot Control Agents, Flame, Smoke, Antiplant Agents, and Personnel Detectors in Counter-Guerrilla Operations, p. 80-81, April 1969.

in detail along with other ecological effects of chemical herbicides. [Tschirley 1969] and [Office of Deputy Assistant Secretary of Defense (ODASD) 1971]..

4. Coverage and Limitations

The present sprayer systems used in both fixed and rotary wing aircraft allow variable dissemination of herbicides. These rates are as follows:

Table II-2: Herbicide Dissemination Rates

Mission Type	Rate
Defoliation	Three gallons/acre
Crop Destruction	One and one-half to three gallons/acre

[DA TC 3-16 1969]

The use of herbicides in support of combat operations is limited in several respects. The best time to apply them is during the particular plant's most active growing period. While spraying during the dry season (which corresponds to the non-active period of most plants) does produce defoliation, the vegetation dies at a slower rate. In addition, the proper atmospheric conditions must exist to insure maximum coverage of the aerosol, assuming the aircraft is flying at the proper speed and altitude. An inversion temperature gradient and a wind of less than eight knots insure not only proper coverage of the target but also minimize the probability of drift onto friendly areas. This is particularly important in an insurgency environment where unintentional destruction of the indigenous population's property and crops would be detrimental to the position of the counterinsurgent forces.

B. TACTICAL LAND CLEARING

A tactical land clearing operation is designed to support the ground tactical forces by denying the enemy any use or benefit that might be gained from heavily vegetated terrain. Unlike herbicide missions, a well-planned clearing operation seeks to not only remove foliage but also the source of it as well. This produces an advantage above those received by defoliation since surveillance is improved in the horizontal dimension as well as the vertical. This improvement is realized by:

1. An increased ground-based anti-personnel radar capability.
2. Increased visual observation.
3. Improved fields of fire.
4. Physical elimination of potential ambush sites and base areas.

A secondary benefit derived from land clearing is the possible economic enhancement of the area. Marketable timber felled during the operation can be extracted for the local lumbering industry, and if the tactical situation permits, there is the potential for conversion of this unused land for productive agricultural cultivation. [DA Pamphlet (Pam) 525-6 1970].

1. Equipment and Organization

Tactical land clearing revolves around the proper use of a standard crawler tractor equipped with the Rome K/G blade and kit assembly. This item of equipment, commonly referred to as the "Rome Plow," was developed by Ernest Kissner of Lottie, Louisiana for land reclamation of heavily wooded tracts. The success of the blade prompted Mr. Kissner to sell the rights to his equipment to the Rome Plow Company of Cedartown, Georgia. Since 1957, it has been produced to fit all standard sizes and makes of tractors (Caterpillar, Allis-Chalmers, International Harvester). The tractor and Rome blade became the method accepted for military land clearing in 1966 after a test period at Fort Belvoir, Virginia and Vietnam of practically all known commercial clearing equipment. [Rome Plow Company, Training Program November 1971].

The Rome K/G treedozer, unlike the bulldozer blade which clears by uprooting, works on the shearing principle in that the total horsepower of the tractor is applied to the sharp cutting edge extending the length of the blade. In addition to the cutting edge, a wedge-like projection, the "stinger," extends forward from the left of the leading edge of the blade. This allows larger trees to be split in one or more passes before they are actually felled by the cutting edge. In order to permit faster operation with less operator fatigue, a flat sole is mounted on the heel of the blade to float on the surface of the ground and conform to topographic irregularities. Through the technique of shearing the vegetation at ground level or below, its disposal by burning or extraction is much faster because it is soil free. There is less soil disturbance since the tilted blade cuts the vegetation rather than uprooting it. [DA Pam 525-6 1970].

The "Rome Plow" has become the nucleus of the recently organized Engineer Land Clearing Company whose primary mission is, "... to destroy or clear extensive dense vegetation in critical areas for the purpose of denying its use by the enemy as bases of operation, supply bases, marshalling areas, ambush sites, and cover and concealment."[3] This unit, part of the U.S. Army Corps of Engineer organization, has thirty medium crawler tractors each equipped with the Rome kit. It was spawned by the success of the "Rome Plow" used initially in twos and threes by practically all engineer elements in RVN. The land clearing role became so large that in 1969 the Army organized the 62nd Engineer Battalion to handle the clearing requirements in Military Region III. Usually one of its three plow companies was placed in support of a divisional clearing mission. The company was found to be the primary unit for employment since fragmenting it into smaller elements for prolonged periods of time resulted in the loss of maintenance posture. [62nd Engineer Battalion Letter February 1971]

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[3]United States Army Combat Developments Command, Table of Organization and Equipment Number 5-87T - Engineer Land Clearing Company, p. 1, 7 February 1969.

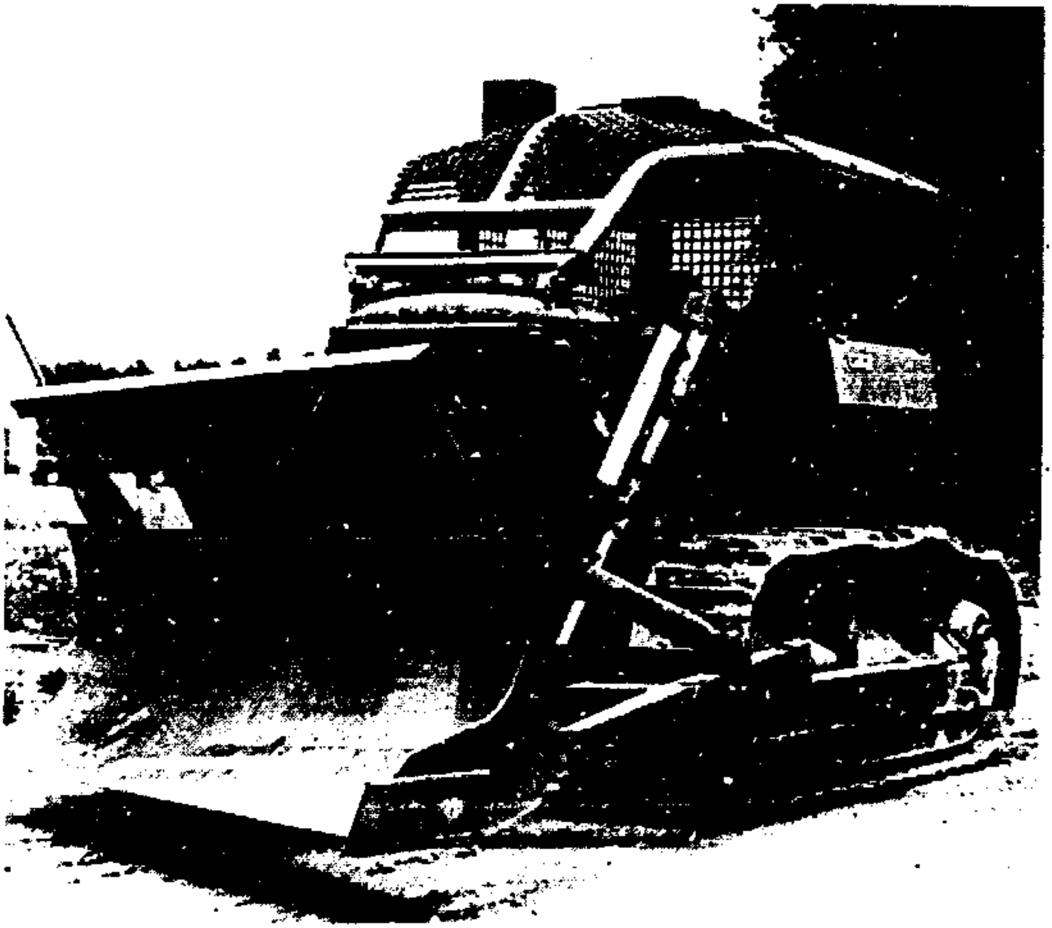

Photo # 3: Rome K/G blade and protection group on a Caterpillar D7F tractor. Rome Plow Company Photograph

2. Clearing Estimates and Limitations

It is virtually impossible to establish exact rates at which any piece of equipment can clear land. Such factors as vegetation type, terrain, climate, enemy situation, and quality of assets available will directly influence this. Accurate estimates require a detailed clearing reconnaissance to include several "tree counts" for tree size, diameter of large trees, and secondary growth estimates. The information from this reconnaissance can be placed into one of several formulas developed by the Rome Plow Company to determine time required per acre cleared. [Rome Industries Salesgram, 1 September 1971.] In the event that this procedure cannot be followed, the Department of the Army has established planning estimates for clearing operations using one land clearing tractor for various types of cuts:

Table II-3: Land Clearing Estimates (Equipment-hours/unit)[4]

VEGETATION	UNIT	AREA CLEARING	STRIP CLEARING
LIGHT: Less than 12 inches in diameter	Acre	.4	.6
MEDIUM: 12 to 18 inches in diameter	Acre	.8	1.3
HEAVY: Greater than 18 inches in diameter	Acre	1.3	2.1

Several factors which constrain tactical clearing operations are soil trafficability, support requirements,

[4] Department of the Army Pamphlet 525-6, Land Clearing Lessons Learned, p. 60, 16 June 1970.

and determination of the enemy to resist the land clearing mission. Since the medium tractor with the Rome kit has a gross weight of more than 20 tons, the ground must be relatively solid to permit movement. This would restrict its use in areas subject to heavy seasonal rainfalls and locations that are inundated on a regular basis, such as mangrove swamps. Even if the terrain permits movement of the tractors, there is always the possibility that it is interlaced with streams, canals, or steep-sided gullies. Supporting troops are necessary to install bridging across these obstacles and assist in tractor recovery operations. Aviation support is required for proper command and control of large scale cutting operations. In many cases, the engineer commander must be airborne to guide the lead tractors since, in heavy vegetation, the operators' visibility is negligible. Aerial reconnaissance of the cut is also essential for sound planning and accurate assessment of the clearing to be accomplished. During RVN clearing operations, the land clearing companies of the 62d Engineer Battalion were furnished observation helicopters on the average of five hours per working day. [62d Engineer Battalion Letter, February 1971.]

For immediate protection of the land clearing company, the desired security force is one armored cavalry troop or one mechanized infantry company. Foot infantry would have difficulty in keeping up with the tractors and would have no protection from falling trees. If the area

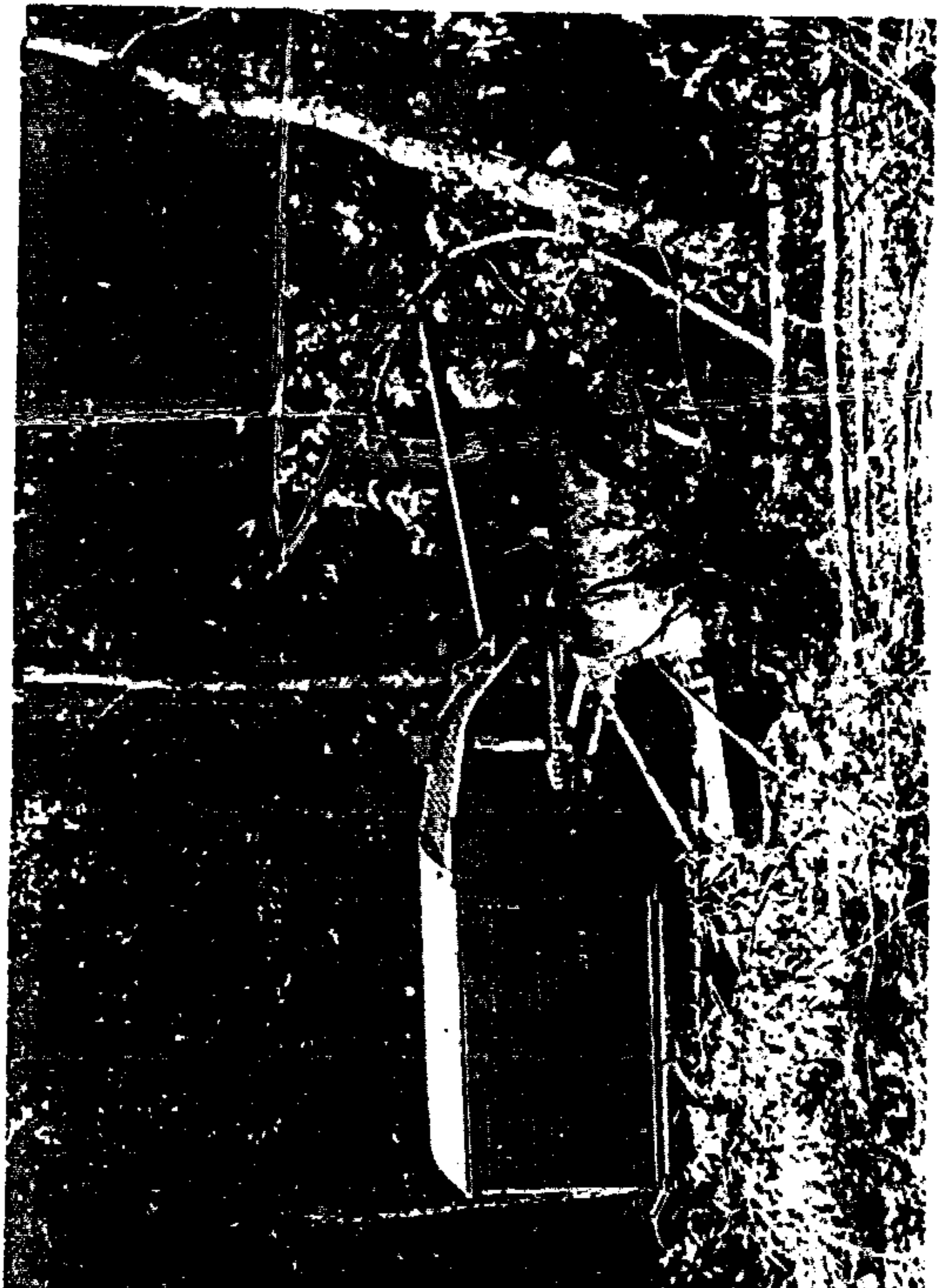

Photo # 5: Land clearing with the Rome K/G blade on a D7 Caterpillar tractor. Rome Plow Company Photograph

C. "SLASH AND BURN" CLEARING

Indigenous personnel can be hired to assist in many land clearing operations or to conduct small-scale clearing efforts on their own ("slash and burn" operations). They can be employed in clearing vegetation adjacent to lines of communications (LOC), around support bases, and removing/burning debris from other operations. The objectives of this technique are similar to the tactical land clearing operations with the additional function of releasing U.S. troops for more pressing combat roles.

1. Organization

Usually, the personnel for the operations are recruited and hired by the U.S. force's Civil Affairs staff working in conjunction with the host country's local and national labor office. These officials determine the salaries and working conditions. They attempt to get job applicants with previous experience in clearing or lumbering. The equipment, support, and supervision for the clearers is furnished by the U.S. unit working in the AO.

This system was used by the Army during the Korean War. It was designed to help the Republic of Korea's massive unemployment problems and assist the allies in accomplishing tasks requiring unskilled labor. The Koreans served as ammunition bearers, porters, kitchen police, and woodcutters. Its success was such that at the end of the war the Korean Service Corps (KSC) was formed on a paramilitary basis.

To the present day, the KSC has provided labor augmentation for the residual United Nations troops that have remained in Korea.

2. Clearing Estimates and Limitations

Like tactical land clearing, production rates are dependent upon many variables: morale, health, state of experience, terrain, crew size, and supervision. Planners must also consider the time required to transport the personnel to and from the clearing sites since security requirements would eliminate the possibility of remaining in the area overnight. The planning rates that have been established by DA are:

Table II-4: Clearing By Hand[5]

VEGETATION	UNIT	MAN-HOURS PER UNIT
LIGHT: Less than 12 inches in diameter.	Acre	125
MEDIUM: 12 to 18 inches in diameter.	Acre	350
HEAVY: Greater than 18 inches in diameter.	Acre	600
LIGHT: Same as above but strip 10 meters wide.*	100 Linear Meters	25**
MEDIUM: Same as above but strip 10 meters wide.*	100 Linear Meters	70**

*Strip clearing.
**Approximately 100 man-hours/linear acre and 280 man-hours/linear acre.

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[5] Ibid., p. 55.

The use of "slash and burn" techniques for vegetation removal is usually limited to secure areas or where major combat operations are already in progress. Time serves as an additional constraint on the method since a great many cutters are required to clear an area in a short period. However, it is particularly useful in areas where the soil trafficability will not support the heavy equipment required for tactical land clearing.

D. FIREBOMBING

Firebombing is a method of reducing vegetation by burning the foliage with incendiary munitions. The primary means to accomplish this is by dropping drums of thickened fuel (napalm) from helicopters or fixed wing aircraft. The technique is especially applicable to area clearance in locations where there is a definite dry season during the year. The objectives of firebombing coincide with those of herbicide operations but the results differ in that the trees are permanently destroyed and not subject to regrowth. The tactic was first used in RVN in 1967 during Operation PINK ROSE in which Air Force aircraft were employed to drop the cannisters of napalm on the target areas. Its purpose was to burn-off enemy infiltration routes in the northern provinces and base areas in War Zone C and D, all of which had been previously treated with herbicides. [McConnell 1970]

1. <u>Organization and Equipment</u>

Authority to burn portions of an AO is usually delegated to the division commanders. The Army uses the twin-engine CH-47 helicopter ("Chinook") to conduct firebombing missions. Thickened fuel, consisting of gasoline mixed with M-4 fuel thickener, is placed in salvaged 55-gallon drums and sling-loaded beneath the CH-47. Fifteen to twenty drums are carried in one lift, depending on the aircraft's fuel load and weather conditions. When the aircraft is over the target, the drums are released and fall in a cluster into the impact area. The drops are supervised by a command and control officer in a light observation helicopter (LOH), and if air assets are available, security is provided by several helicopter gunships (AH-1G). [LTC Rudrow]

2. <u>Coverage and Limitations</u>

Evaluation of the coverage of a firebombing mission is very difficult since proper burning is subject to many conditions. Some of the factors that effect and limit the coverage are:

(1) Dryness of the vegetation

(2) Wind and temperature

(3) Probability of a drum cluster detonation upon contact with the ground

(4) Number of drums per lift.

These variables dictate the use of a probabilistic model to estimate the coverage of any particular firebombing mission.

In addition to the factors mentioned above, firebombing missions are limited by the utilization of the CH-47 in other roles. The "Chinook" has become the workhorse for the Army's medium lift tasks. In RVN, it has been extensively used for transportation of artillery pieces and resupply of forward bases. Hence, there is a high demand for the aircraft, and the commander must decide on which missions he places the higher priority.

III. METHODOLOGY

The alternatives for this study will be analyzed with respect to the two primary missions of herbicide operations:

1. Removal of foliage (defoliation) in order to deny the enemy cover and concealment.

2. The destruction of crops in the enemy's territory in order to curtail his ability to forage off the land. To accomplish this, costs for each method must be isolated in some uniform manner and in units to facilitate a cost-effectiveness evaluation for several measures of effectiveness (MOE). The vectors resulting from this evaluation can then be compared on an intra-system, inter-system and force-mix basis.

The analysis of the alternatives will take the form of the major subheadings below. Each of these sections attempts to amplify the "how and why" of the methodology used in Chapter IV through VII.

A. GENERAL ASSUMPTIONS

Implicit in the assumptions for each alternative is the adherence to the system descriptions of Chapter II. Several general assumptions are also applicable.

In order to simplify the analysis and the data collection, all alternatives are assumed to have commenced their operations at the same point in time. It is also assured that all systems are in "steady state" and not subject to the initial erratic fluctuations in costs that new systems often demonstrate prior to the occurrence of the "learning curve" phenomena. At the end of the systems' life, all are given a zero residual value.

Finally, no adjustments are made to the costs for inflation. While inflationary pressures have abated slightly, it is doubtful that the price stability of the early 1960's will return in the near future. This could introduce some bias when looking at yearly costs, total system cost (TSC), and investment replacement of primary mission equipment (PME) over the planning horizon. [Augusta and Snyder 1970]

B. PARAMETERS

The planning horizon for the analyses will be ten years. Like the explicitly stated parameters for each alternative, this is a reasonable estimate but in no way reflects any official policy. The reviewer should be cautioned that the planning horizon and other inputs are optimistic estimates and adverse conditions can change them significantly. Where a great deal of uncertainty exists as to the parameter values, upper (U) and lower (L) cost bounds will be specified for each alternative. Most of these bounds reflect the judgement of men who were involved with these systems during counterinsurgency operations in RVN.

C. COST ANALYSIS

All costs will be determined in reference to one unit equipment (UE). A UE could be one specially equipped aircraft, one crawler tractor with the Rome kit, or a crew of indigenous cutters for "slash and burn" clearing. With this in mind, life cycle costs will be identified through a generalized input structure. Since no research and development (RD) costs are encountered, only the following major cost categories will be investigated:

Investment Cost (IC)	Operating Cost (OC)
Procurement Costs	Maintenance
Stock Costs	Modernization
Replacement of Equipment due to Attrition or Operational Loss	Replacement
Initial Travel	Pay and Allowance
Transportation	Fuel, oil and lubricants (FOL)
	Replacement Training
	Munitions
	Security
	Special Control
	[Fisher 1971]

These inputs are used to obtain a system cost (SC) by evaluating each cost category with respect to the major subsystems of each alternative. The basic equation used in the analysis is:

$$SC = a \sum_{i} \sum_{j} IC_{ij} + a \sum_{i} \sum_{j} OC_{ij}$$

where $\underline{a}$ is a constant to obtain costs in the desired units (i.e., \$/year, \$/mission, or \$/day) and IC_{ij} is the jth investment cost of the ith subsystem. Generally, costs will be determined in units associated with basic operating times.

Ground-based systems will be evaluated in terms of dollars per day and aviation systems in dollars per mission.

Included in the operating cost input program will be several opportunity costs. Although they will never be reflected in tables of costs held by service comptrollers, they are very real costs due to the scarcity of personnel and equipment assets in combat. There is difficulty judging what cost should be attached to a supervisory or security force that could be gainfully employed in other combat operations. In order to tackle this problem in the study, the cost assessed will be that operating cost incurred by the force over the period that it was used.

D. EFFECTIVENESS CRITERIA AND COST-EFFECTIVENESS MEASURES

1. Effectiveness Criteria

The measures of effectiveness (MOE) should be closely related to the mission objectives. However, it is very hard to quantify the results of any denial operation because one soon gets into the realm of trying to determine "why something did not happen." These types of objectives force the writer away from "objective-oriented" MOE's and toward the "performance-oriented" effectiveness criteria.

Two MOE's will be utilized in order that a balanced presentation of each alternative may be achieved.

a. MOE # 1 - "Area"

The first MOE will be that of "area treated, cleared or burned per normal operating period." These three terms show the different effects that each alternative has on the terrain. However, they present an evaluation of each system's effectiveness and give a specific indication of their performance capability during a normal operating period.

b. MOE # 2 - Constrained Cost Minimization

This MOE is designed to determine which alternatives can complete a given mission subject to the exigencies of combat. It attempts to take a reasonable mission of denying the enemy cover and concealment in a given area and requiring that this be completed prior to certain time limits and within theater asset constraints. In program format:

Minimize the cost of denying cover and concealment in a 6,000 acre base area

Subject to: (1) Mission accomplishment in 30 days or less.

(2) Mission asset requirements within the supply capability of the responsible commander.

A vegetation removal mission was chosen since these were the most common of the herbicide missions in RVN. The figure of 6,000 acres was designated because this is approximately 25 grid squares on a 1:25,000 or 1:50,000 topographical map and could easily be a suspected insurgent base area. Although this is a large scale mission, it is not unreasonable since there have been defoliation/clearing operations in War Zone C and other parts of Military Region

III in RVN that encompassed larger areas (during Operation JUNCTION CITY). The effects of reducing the mission size are also examined in Chapter VIII, Section B.

Constraint # 2 of the program requires the determination of what will be the "supply capability of the responsible commander." To resolve this, the author will use his judgement and past experience in RVN to determine what are "reasonable" and "unreasonable" asset requirements to accomplish a particular mission.

2. Cost-Effectiveness Measures

Using the cost measures of the analysis section and the effectiveness criteria, cost-effectiveness measures can be developed for each system in dollars per acre. These measures can then be segregated into mission categories for foliage removal and crop destruction with maximum and minimum cost limits. These coupled with the cost minimization vectors will help illuminate the differences in the systems, their costs, and their effectiveness in support of counter-insurgency operations.

E. PARAMETER SENSITIVITY

Sensitivity analysis will be used to test the parametric uncertainties in each system. The testing will examine the system costs as the parameters vary over a reasonable range of values. Although the only relevant costs are dollar costs, the sensitivity tables will show dollars and cents. Certainly, the calculation of costs to the actual pennies is not relevant or meant to be a serious cost estimate. However, this is done since they demonstrate the orders of magnitude of change over the range of the parameter values.

IV. ANALYSIS OF AERIAL DELIVERY OF HERBICIDES

A. ASSUMPTIONS

1. UC-123

a. Each aircraft has an expected life of ten years after modification for herbicide operations. [Major Pyatt]

b. Each sortie has an expected duration of two hours. [Major Hidalgo]

c. Flights over a given target consist of between two and seven herbicide aircraft.

d. Security for each flight consists of four USAF A-1E "Skyraider" aircraft. Control for each flight consists of one forward air controller (FAC) in a USAF OV-10 "Bronco." [Downs and Scrivner 1970]

e. Each UC-123K has a 90 per cent coverage efficiency for its 1,000 gallon load. (See sensitivity analysis, Sec. E)

2. UH-1

a. A variety of "Hueys" have been employed in RVN. For this study, use of the UH-1H is assumed.

b. Each sortie has a duration of one-half hour. [LTC Rudrew]

c. A flight over a given target consists of one helicopter.

d. The AGAVENCO sprayer will be the only helicopter-mounted system considered. Although the capacity of the tank is 200 gallons, weight limitations under combat conditions curtail the load. A 100 gallon per mission load will be analyzed. [LTC Sanches] and [DA TC 3-16 1969]

e. When available, armed helicopter security consists of two AH-1G "Cobras." [LTC Rudrow]

f. The UH-1H has a 90 per cent coverage efficiency for its 100 gallon load. It is employed under the same operational and climatic conditions as the UC-123 missions. (Also see sensitivity analysis, Sec. E)

B. PARAMETERS

1. Flying Hours

Since the UC-123K has a two-hour mission duration, 25 missions per month per aircraft (or 600 hours per year) will be the study parameter. Data indicates that the sortie rate varies considerably over a year's operation and that the use of 25 sorties per month would not be unreasonable [Major Hidalgo]. A similar number of flying hours per year for the UH-1H would dictate a sortie rate of 100 missions per month. However, this is probably less than the normal rate since the UH-1H has a programmed flying-hour limit of up to 960 hours per year in an active combat environment. [DA Field Manual (FM) 101-20 1970]. This implies that the effects of the sortie generation rate for both aircraft should be examined in a sensitivity analysis (Section E).

2. Cost Bounds

Bounds on certain portions of the herbicide costs are set by the variation in security, control, and transportation costs that can occur in normal operations. These parameters set the "optimistic and pessimistic" bounds for system cost. Since the UC-123 flights range from two to seven aircraft, the security and control cost (for four A-1E's and one OV-10) must be pro rated in accordance with the number of herbicide aircraft per flight to obtain a cost for one unit equipment (UE). Costing the helicopter system does not present this problem since the operations are usually conducted with one UH-1 (assumption c). Hence, the security costs for a UH-1 mission can range from zero to the cost of using two "Cobras" for one-half hour. The UH-1 has an additional bound on the investment cost formed by the mode of transporting (surface or air) the AGAVENCO system to the combat theater.

C. COST ANALYSIS

1. Isolation of Relevant Costs

A detailed breakdown of these costs can be found in Appendix A.

a. UC-123K

Research and Development: None.

Investment Costs for the aircraft subsystem:

(1) Initial procurement of the aircraft is a sunk cost since the C-123B's were drawn from air assets that

existed in the Air Force inventory. Hence, it will not be considered.

(2) Jet engine modification: Conversion of the C-123B to a turbo-jet model (C-123K): $302,732/aircraft. [Miss Lucky]

Operating Costs for the aircraft subsystem:

(1) Operating and maintenance (O&M): $700,000/ aircraft. [Captain Wallace]

(2) Modernization cost: A two per cent per year cost is incurred by each aircraft for modernization expenditures. .02 x $870,000/aircraft = $17,400/aircraft/year. [Captain Wallace]

(3) Security costs: The operating cost for one A-1E is $200/hour. Major Sims The munition expenditures for one A-1E are $1250/mission. [LTC Cooper] For a two-hour mission with four A-1E's, the cost amounts to $6600/ mission.

(4) Control costs: The operating cost for the OV-10 is $54/hour and $1000/aircraft for a full load of munitions. [LTC Monoham] This amounts to a control cost of $1108/mission.

(5) Combat attrition rates are negligible since only two aircraft have been lost to enemy fire since 1962. [Downs and Scrivner 1970]

Investment Cost for the aerosol subsystem:

(1) The dispenser mechanism consists of the installation of the Hayes AA-45 system at a cost of $37,254/aircraft. [Miss Lucky]

(2) Additional armor plating: $19,354/aircraft. [Miss Lucky]

Operating Costs for the aerosol subsystem:

(1) Maintenance of the dispenser system, training the operators, and stocking spare parts are included in the cost of operating the aircraft.

(2) Cost of herbicides: The USAF is responsible for procurement of herbicides for all users. The cost of the agent includes shipment and storage costs. [Mr. Carter]

AGENT	COST/GALLON	COST/MISSION
WHITE	$7.78	$7,780
ORANGE	$7.24	$7,240
BLUE	$2.31	$2,310

b. UH-1H

Research and Development: None.

Investment Cost for UH-1H: This is a sunk cost since the helicopter used for herbicide operations is diverted from Army aviation assets on a "need" basis.

Operating Cost for UH-1H:

(1) O&M costs are rated at 15 per cent of the aircraft procurement cost. [Mr. Donaldson] Since the UH-1H

costs $266,578 [DA FM 101-20 1970], the O&M cost is approximately $40,000/year.

(2) Crew salaries are not included in Army O&M estimates. Normal combat crew on a UH-1 is two pilots and two door gunners. These yearly opportunity costs amount to:

2 x $14,000/officer/year = $28,000/year

2 x $10,000/enlisted man/year = $20,000/year [DA Fact Sheet 1971] and [Major Howe]

(3) Security costs range from zero (no security) to $200/mission for two AH-1G "Cobras." (Appendix A)

<u>Investment Costs for the aerosol subsystem:</u>

(1) Procurement of AGAVENCO system: $7,850 [Mr. Drake]

(2) Transportation cost for the AGAVENCO: $545 by ship and $1,937 by aircraft. [Major Howe]

(3) The expected life of the UH-1H equipped for herbicide missions is ten years. [Mr. Donaldson]

<u>Operating Cost for the aerosol subsystem:</u>

(1) The maintenance cost of the AGAVENCO system is nine per cent of the procurement cost: $707/year. [Mr. Drake]

(2) The system requires one operator: $10,000/year.

(3) Herbicide costs:

AGENT	COST/GALLON	COST/MISSION
WHITE	\$7.78	\$778
ORANGE	\$7.24	\$724
BLUE	\$2.31	\$231

[Mr. Carlton]

2. Yearly Costs

Using the relevant costs and the herbicide parameter, a yearly system cost can be developed from the formula:

$$SC = a \sum_i \sum_j IC_{ij} + b \sum_i \sum_j OC_{ij}$$

where a is the reciprocal of the expected life (and equal to the planning horizon) and b is a dimensional constant to obtain costs in dollars per year.

a. Identification of Costs for UC-123K

Investment Cost = 1/10 (Engine modification + spray system + armor) = \$35,934/year.

Operating Cost = O&M cost + Security cost + Control cost + Agent cost.

The security and control (S&C) costs for a UE on any particular mission can be found in the following manner:

Security cost (U): $\frac{\$6600/\text{flight}}{2\ \text{aircraft/flight}} = \$3300/\text{aircraft}$

Security cost (L): $\frac{\$6600/\text{flight}}{7\ \text{aircraft/flight}} = \$943/\text{aircraft}$

(A similar procedure determines the control cost.) Using the parameter that a UC-123K flies 25 missions per month, the yearly mission rate would be 300 missions (msn) per year. A typical calculation, this one for the upper bound using Agent WHITE, is as follows:

Operating Cost = \$700,000/yr + \$17,400/yr + 300 msn/yr x \$3300/msn + 300 msn/yr x \$554/msn + 300 msn/yr x \$7780/msn = \$4,207,600/year.

Table IV-1: Yearly Costs for UC-123K
(Costs in Millions of Dollars per Year)

AGENT	LOWER BOUND	UPPER BOUND
WHITE	\$3.417	\$4.244
ORANGE	\$3.257	\$4.081
BLUE	\$1.777	\$2.603

b. Identification of Costs for UH-1H

Investment Cost = 1/10 (AGAVENCO Cost + Transportation Cost) = \$979/year (U) or \$840/year (L).

Operating Cost = O&M Cost + Security Cost + Agent Cost.

The UH-1 will fly 100 missions per month. (Section B) An upper bound cost using Agent WHITE: Operating Cost = \$98,707/yr + 1200 msn/yr x \$200/msn + 1200 msn/yr x \$778/msn = \$1,272,307/year.

Table IV-2: Yearly Costs for UH-1H
(Costs in Millions of Dollars per Year)

AGENT	LOWER BOUND	UPPER BOUND
WHITE	\$1.033	\$1.273
ORANGE	\$ .968	\$1.208
BLUE	\$ .377	\$ .617

Table IV-2: Yearly Costs for UH-1H

(Costs in Millions of Dollars per Year)

AGENT	LOWER BOUND	UPPER BOUND
WHITE	\$1.033	\$1.273
ORANGE	\$ .968	\$1.208
BLUE	\$ .377	\$ .617

c. Remarks

At this point a total system cost could be readily identified. However, like the yearly cost, it is extremely sensitive to the particular input parameters. The parameter of "missions per year" accounts for a major portion of the system cost solely by virtue of its multiplicative role in the cost formula. The reviewer must consider this when evaluating the systems with respect to the outlay of funds on a yearly basis for a UE. More important than the magnitude of the costs involved is the relative difference between the two systems.

3. Mission Costs

The cost of a herbicide mission gives the reviewer a better insight into the dollars involved for a UE. This cost is more suitable to relate to an effectiveness criterion that is oriented toward performance.

Mission Investment Cost:

$$\frac{\text{Summation of the Investment Costs}}{\text{(Expected Life)} \times \text{(Number of Msn/Year)}}$$

Mission Operating Cost:

$$\frac{\text{Summation of O\&M Costs/Year}}{\text{Number of Msn/Year}} + \text{Summation of Security, Control, and Agent Costs/Mission}$$

Table IV-3: UC-123K Mission Costs
(Dollars per Mission)

AGENT	LOWER BOUND			UPPER BOUND		
	IC	OC	SC	IC	OC	SC
WHITE	$120	$11,272	$11,392	$120	$14,025	$14,145
ORANGE	$120	$10,732	$10,852	$120	$13,485	$13,605
BLUE	$120	$ 5,802	$ 5,922	$120	$ 8,555	$ 8,675

The costs are not categorized for the helicopter since the UH-1H investment cost is negligible.

Table IV-4: UH-1H Mission Costs
(Dollars per Mission)

AGENT	LOWER BOUND	UPPER BOUND
WHITE	$861	$1061
ORANGE	$807	$1007
BLUE	$314	$ 514

It is evident after this analysis that the agent cost comprises a large portion of the system cost for both alternatives. It accounts for approximately 50 per cent of the UC-123K costs and about 80 of the UH-1 mission cost. The extent of this can be examined by looking at the two systems participating in defoliation operations. If the cost of the agent is varied from one dollar to ten dollars per gallon, the effect on "dollars per mission" can be better illustrated. This can also allow the reviewer the opportunity to examine the cost expectation of a sudden technicological breakthrough in the chemical industry causing a decrease in prices or if current trends in upward prices continue.

Table IV-5: Cost Variation Due to Agent Costs
(Dollars per Mission)

COST OF AGENT ($/Gal)	SYSTEM COST UH-1 ($/Msn)		UC-123	
	Min	Max	Min	Max
1	183	383	4612	7365
2	283	483	5612	8365
3	383	583	6612	9365
4	483	683	7612	10365
5	583	783	8612	11365
6	683	883	9612	12365
7	783	983	10612	13365
8	883	1083	11612	14365
9	983	1183	12612	15365
10	1083	1283	13612	16365

D. EFFECTIVENESS CRITERIA AND COST-EFFECTIVENESS MEASURES

1. Effectiveness Criteria

a. MOE #1 - "Area"

This measure of effectiveness, "acres treated per mission," presents the systems' overall or net effectiveness during a normal operating period.

$$\text{Effectiveness Criterion (EC)} = e \times \frac{\text{Gallons/Mission}}{\text{Gallons/Acre}}$$

where e is the coverage factor. For UC-123 operations,

$$EC = .9 \times \frac{1000 \text{ gal/msn}}{3 \text{ gal/acre}} = 300 \text{ acres/mission}$$

EFFECTIVENESS CRITERIA (Acres/Mission)

AGENT	LOWER BOUND		UPPER BOUND	
	UH-1H	UC-123	UH-1H	UC-123
WHITE	30	300	30	300
ORANGE	30	300	30	300
BLUE	60	600	30	300

b. MOE # 2 - Constrained Cost Minimizatior

This MOE takes the following mathematical programming format:

Minimize the cost of defoliating 6000 acres

Subject to:

Mission completion $\leq$ 30 days

Assets required $\leq$ Command's supply capability

In addition to the assumptions of this chapter, several more are necessary to restrict the analysis.

(1) Flights by UC-123K's will be examined in relation to a minimum of two and a maximum of seven aircraft per flight.

(2) Agent ORANGE will be the defoliant.

(3) Spraying must be completed within five days.

The last restriction is necessary since herbicides require approximately three to four weeks to act on tropical vegetation. For herbicides to be effective, they must remove a sufficient amount of foliage to deny the enemy use of the terrain for base areas and daylight movement and to permit improved aerial observation. The requirement is amplified by the following chart:

Defoliant	Rate	1 Wk	2 Wk	1 Mo	3 Mo	6 Mo	1 Yr
ORANGE	3 gal/acre	19/8	73/32	89/73	79	66	54

(The figure to the left of the slash represents percentage of leaves desicated; that to the right represents the percentage of leaves defoliated. The single figure is defoliation.)[6]

Therefore, it is imperative that the agent be applied quickly to insure maximum defoliation at the end of 30 days.

2. Cost-Effectiveness Measures

a. MOE #1

Cost-Effectiveness Measure =

$$\frac{\text{Mission Cost}}{\text{Effectiveness Criterion}}$$

Table IV-6A: Aerial Delivery of Herbicides
(Dollars per Acre)

AGENT	LOWER BOUND		UPPER BOUND	
	UH-1H	UC-123	UH-1H	UC-123
WHITE	$29	$38	$35	$47
ORANGE	$27	$36	$34	$45
BLUE	$ 5	$10	$17	$29

Breaking these costs into the two primary mission categories (defoliation and crop destruction), maximum and

6 House, W. B. and others, Assessment of the Ecological Effects of Extensive or Repeated Use of Herbicides, p. 141, Midwest Research Institute, 1967.

minimum limits are formed. The mission categories facilitate comparison with the other alternatives. This is readily done since ORANGE and WHITE are general purpose defoliants and BLUE is exclusively used for crop destruction. In the next table, the maximum and minimum limits on defoliation missions are formed by using Agent WHITE's upper bound and ORANGE's lower bound. The maximum and minimum cost vectors for crop destruction can be taken directly from Table IV-6A.

Table IV-6B: Cost-Effectiveness Measures for Aerial Delivery of Herbicides

(Dollars per Acre)

MISSION	UH-1H		UC-123	
	MIN	MAX	MIN	MAX
Defoliation	$27	$35	$36	$47
Crop Destruction	$ 5	$17	$10	$29

b. MOE #2

Defoliation of a 6,000 acre area would require ten flights of two UC-123K's or three flights of seven UC-123K aircraft (each aircraft covering 300 acres per mission). The five-day dissemination period could easily be accomplished even with the smallest flight. If a squadron organization existed, the requirement would have little or no effect.

Upper Bound:

$13,605/aircraft/msn x 2 aircraft x 10 missions = $272,100.

Lower Bound:

\$10,852/aircraft/msn x 7 aircraft x 3 missions = \$227,892.

Using the UH-1H's effectiveness criterion of 30 acres per mission, 200 sorties would be required. This implies that 100 helicopter flying hours would be needed in a five-day period. This would be a tremendous drain on the aviation assets of a division commander and would mean that he would have to divert five to ten helicopters a day for the better part of a week to perform the defoliation task. Hence, a violation of the second constraint might be realized.

Table IV-7: Minimum Cost Program For Defoliation
(Costs in Dollars)

SYSTEM	LOWER BOUND	UPPER BOUND
UC-123K	\$227,892	\$272,100
UH-1H**	\$161,400	\$201,400

**The program constraints make the UH-1 virtually infeasible for a mission of this scale.

E. PARAMETER SENSITIVITY

The sensitivity analysis is presented to determine the effect of variation of three of the parameterized inputs for the herbicide alternative. The tests are performed on the maximum and minimum limits for the cost-effectiveness categories in Table IV-6B.

1. Sensitivity of Sortie Generation Rate

a. UC-123 (Table IV-8A & 8B)

A sensitivity analysis indicates that this parameter is not as crucial to the system cost explanation as one might expect. Examination of the costs indicates that even at the lower number of sorties per month the system cost does not experience any appreciable rise. As flying hours increase past the 600 hour per year mark, the cost begins to experience an almost linear decrease.

TABLE IV-8A

SENSITIVITY ANALYSIS - HERBICIDE DELIVERY BY UC-123K

SENSITIVITY OF SORTIE GENERATION RATE ($/ACRE)

DEFOLIATION

SORTIES PER MO.	HOURS PER YR.	INVESTMENT COST	O & M COST MIN	O & M COST MAX	SYSTEM COST MIN	SYSTEM COST MAX
15.	360.	0.67	41.09	52.07	41.75	52.73
16.	384.	0.62	40.26	51.23	40.88	51.86
17.	408.	0.59	39.53	50.50	40.11	51.09
18.	432.	0.55	38.87	49.85	39.43	50.41
19.	456.	0.53	38.29	49.27	38.82	49.79
20.	480.	0.50	37.77	48.74	38.27	49.24
21.	504.	0.48	37.29	48.27	37.77	48.74
22.	528.	0.45	36.86	47.84	37.32	48.29
23.	552.	0.43	36.47	47.44	36.90	47.88
24.	576.	0.42	36.11	47.08	36.52	47.50
25.	600.	0.40	35.77	46.75	36.17	47.15
26.	624.	0.38	35.47	46.44	35.85	46.83

TABLE IV-8A (Continued)

SORTIES PER MO.	HOURS PER YR.	INVESTMENT COST	OPERATING COST MIN	OPERATING COST MAX	SYSTEM COST MIN	SYSTEM COST MAX
27.	648.	0.37	35.18	46.16	35.55	46.53
28.	672.	0.36	34.92	45.90	35.28	46.25
29.	696.	0.34	34.67	45.65	35.02	46.00
30.	720.	0.33	34.45	45.42	34.78	45.76
31.	744.	0.32	34.23	45.21	34.55	45.53
32.	768.	0.31	34.03	45.01	34.34	45.32
33.	792.	0.30	33.84	44.82	34.14	45.12
34.	816.	0.29	33.66	44.64	33.96	44.93
35.	840.	0.29	33.50	44.47	33.78	44.76
36.	864.	0.28	33.34	44.32	33.62	44.59
37.	888.	0.27	33.19	44.17	33.46	44.44
38.	912.	0.26	33.05	44.02	33.31	44.29
39.	936.	0.26	32.91	43.89	33.17	44.15
40.	960.	0.25	32.79	43.76	33.03	44.01

TABLE IV-8B

SENSITIVITY ANALYSIS - HERBICIDE DELIVERY BY UC-123K

SENSITIVITY OF SORTIE GENERATION RATE ($/ACRE)

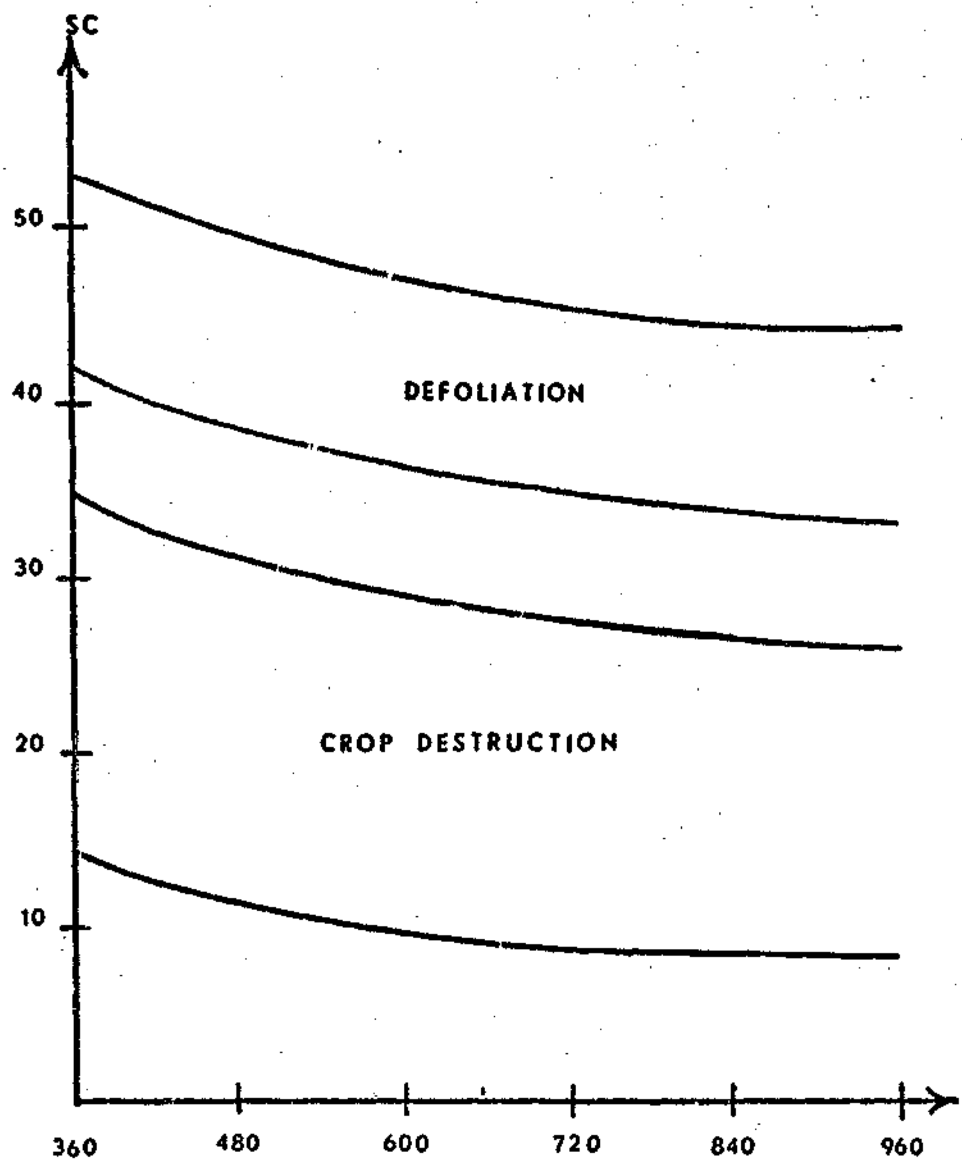
CROP DESTRUCTION

SORTIES PER MO.	HOURS PER YR.	INVESTMENT COST	OPERATING COST		SYSTEM COST	
			MIN	MAX	MIN	MAX
15.	360.	0.67	12.66	33.83	12.33	34.50
16.	384.	0.62	12.22	33.00	11.91	33.63
17.	408.	0.59	11.84	32.27	11.55	32.86
18.	432.	0.55	11.50	31.62	11.22	32.17
19.	456.	0.53	11.19	31.03	10.93	31.56
20.	480.	0.50	10.92	30.51	10.67	31.01
21.	504.	0.48	10.67	30.04	10.43	30.51
22.	528.	0.45	10.44	29.60	10.21	30.06
23.	552.	0.43	10.23	29.21	10.02	29.64
24.	576.	0.42	10.04	28.85	9.84	29.27
25.	600.	0.40	9.87	28.52	9.67	28.92

TABLE IV-8B (Continued)

SORTIES PER MO.	HOURS PER YR.	INVESTMENT COST	OPERATING COST		SYSTEM COST	
			MIN.	MAX.	MIN.	MAX.
26.	624.	0.38	9.71	28.21	9.52	28.60
27.	648.	0.37	9.56	27.93	9.38	28.30
28.	672.	0.36	9.42	27.66	9.24	28.02
29.	696.	0.34	9.29	27.42	9.12	27.76
30.	720.	0.33	9.17	27.19	9.01	27.52
31.	744.	0.32	9.06	26.97	8.90	27.30
32.	768.	0.31	8.95	26.77	8.80	27.09
33.	792.	0.30	8.86	26.59	8.70	26.89
34.	816.	0.29	8.76	26.41	8.62	26.70
35.	840.	0.29	8.67	26.24	8.53	26.53
36.	864.	0.28	8.59	26.08	8.45	26.36
37.	888.	0.27	8.51	25.93	8.38	26.20
38.	912.	0.26	8.44	25.79	8.31	26.05
39.	936.	0.26	8.37	25.66	8.24	25.91
40.	960.	0.25	8.30	25.53	8.18	25.78

CHART IV-1: SENSITIVITY OF SORTIE GENERATION RATE (UC-123)
(System Cost (SC) in Dollars/Acre)



Flying Hours per Year

b. UH-1H (Table IV-9A & 9B)

Table 9A and 9B show that the costs per acre for defoliation and crop destruction are virtually insensitive to the sortie generation rate of the aircraft. The cause for this is the dominance of the agent cost. For a mission flown with Agent ORANGE (lower bound), the cost less the defoliant is $83 per mission. This condition persists throughout this analysis.

2. Sensitivity of Security and Control Costs

a. UC-123K (Table IV-10)

In the analysis, S & C costs range from $1100 per mission to approximately $3850 per mission. The lower spectrum of the scale shows the costs that might be incurred in a low-intensity environment that would require little or no security. The costs above $4000 per mission indicate the incremental changes when high-performance aircraft are allocated to security roles in lieu of propeller-driven "Skyraiders."

b. UH-1H (Table IV-11A & 11B)

c. Both sets of tables (10 and 11) show the effect that security has on determining bounds on cost estimates. They also point out that the difference in Agent WHITE and Agent ORANGE for a similar security posture is almost negligible.

TABLE IV-9A

SENSITIVITY ANALYSIS - HERBICIDE DELIVERY BY UH-1

SENSITIVITY OF SORTIE GENERATION RATE ($/ACRE)

DEFOLIATION

SORTIES PER MO.	HOURS PER YR.	INVESTMENT COST	O & M COST MIN.	O & M COST MAX.	SYSTEM COST MIN.	SYSTEM COST MAX.
60.	360.	0.05	28.70	37.17	28.74	37.22
64.	384.	0.04	28.42	36.88	28.45	36.93
68.	408.	0.04	28.17	36.63	28.20	36.67
72.	432.	0.04	27.94	36.41	27.97	36.45
76.	456.	0.04	27.74	36.21	27.77	36.24
80.	480.	0.03	27.56	36.03	27.59	36.06
84.	504.	0.03	27.40	35.86	27.43	35.90
88.	528	0.03	27.25	35.72	27.28	35.75
92.	552.	0.03	27.11	35.58	27.14	35.61
96.	576.	0.03	26.99	35.46	27.01	35.48
100.	600.	0.03	26.88	35.34	26.90	35.37
104.	624.	0.03	26.77	35.24	26.79	35.26

TABLE IV-9A (Continued)

SORTIES PER MO.	HOURS PER YR.	INVESTMENT COST	O & M COST MIN.	O & M COST MAX.	SYSTEM COST MIN.	SYSTEM COST MAX.
108.	648.	0.03	26.67	35.14	26.69	35.16
112.	672.	0.02	26.58	35.05	26.60	35.07
116.	696.	0.02	26.50	34.96	26.52	34.99
120.	720.	0.02	26.42	34.88	26.44	34.91
124.	744.	0.02	26.34	34.81	26.36	34.83
128.	768.	0.02	26.28	34.74	26.29	34.76
132.	792.	0.02	26.21	34.68	26.23	34.70
136.	816.	0.02	26.15	34.62	26.17	34.64
140.	840.	0.02	26.09	34.56	26.11	34.58
144.	864.	0.02	26.04	34.50	26.05	34.52
148.	883.	0.02	25.99	34.45	26.00	34.47
152.	912.	0.02	25.94	34.40	25.95	34.42
156.	936.	0.02	25.89	34.36	25.91	34.38
160.	960.	0.02	25.85	34.31	25.86	34.33

TABLE IV-9B

SENSITIVITY ANALYSIS - HERBICIDE DELIVERY BY UH-1

SENSITIVITY OF SORTIE GENERATION RATE ($/ACRE)

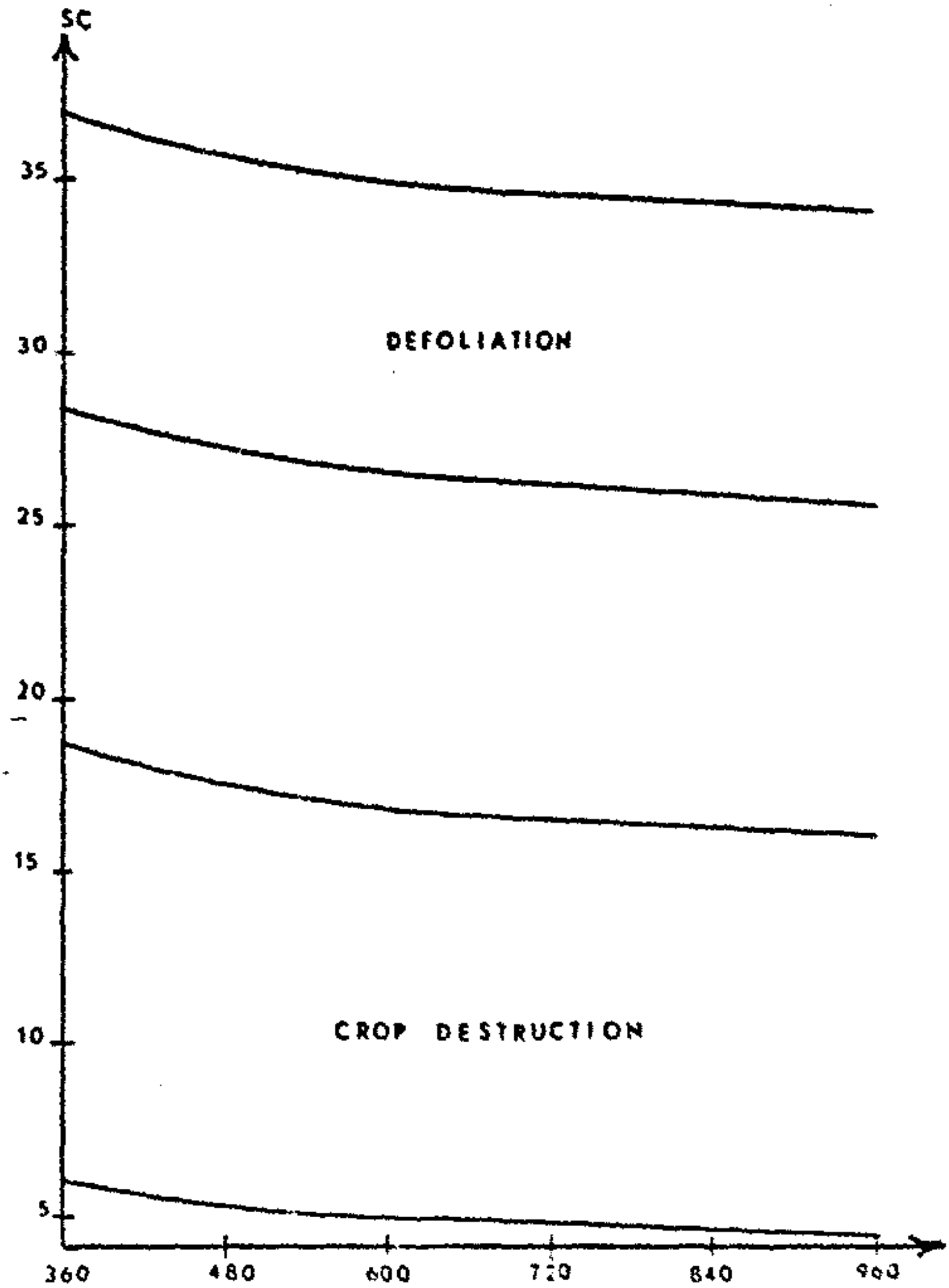
CROP DESTRUCTION

SORTIES PER MO.	HOURS PER YR.	INVESTMENT COST	O & M COST		SYSTEM COST	
			MIN.	MAX.	MIN.	MAX.
60.	360.	0.05	6.13	18.94	6.15	18.98
64.	384.	0.04	5.99	18.65	6.01	18.69
68.	408.	0.04	5.87	18.40	5.88	18.44
72.	432.	0.04	5.75	18.17	5.77	18.21
76.	456.	0.04	5.65	17.97	5.67	18.01
80.	480.	0.03	5.56	17.79	5.58	17.83
84.	504.	0.03	5.48	17.63	5.50	17.66
88.	528.	0.03	5.41	17.48	5.42	17.51
92.	552.	0.03	5.34	17.35	5.42	17.51
96.	576.	0.03	5.28	17.22	5.29	17.25
100.	600.	0.03	5.22	17.11	5.23	17.14

TABLE IV-9B (Continued)

SORTIES PER MO.	HOURS PER YR.	INVESTMENT COST	O & M COST		SYSTEM COST	
			MIN.	MAX.	MIN.	MAX.
104.	624.	0.03	5.17	17.00	5.18	17.03
108.	648.	0.03	5.12	16.91	5.13	16.93
112.	672.	0.02	5.07	16.81	5.08	16.84
116.	696.	0.02	5.03	16.73	5.04	16.75
120.	720.	0.02	4.99	16.65	5.00	16.67
124.	744.	0.02	4.96	16.58	4.96	16.60
128.	768.	0.02	4.92	16.51	4.93	16.53
132.	792.	0.02	4.89	16.44	4.90	16.46
136.	816.	0.02	4.86	16.38	4.67	16.40
140.	840.	0.02	4.83	16.33	4.84	16.34
144.	864.	0.02	4.80	16.27	4.81	16.29
148.	888.	0.02	4.78	16.22	4.78	16.24
152.	912.	0.02	4.75	16.17	4.76	16.19
156.	936.	0.02	4.73	16.12	4.74	16.14
160.	960.	0.02	4.71	16.08	4.71	16.10

CHART IV-2: SENSITIVITY OF SORTIE GENERATION RATE (UH-1)
(System Cost (SC) in Dollars/Acre)



Flying Hours per Year

TABLE IV-10

SENSITIVITY ANALYSIS - HERBICIDE DELIVERY BY UC-123K

SENSITIVITY OF SECURITY & CONTROL COST ($/MSN)

DEFOLIATION

SECURITY +	CONTROL =	TOTAL S & C COST ($/MSN)	SYSTEM COST ($/ACRE) MIN.	MAX.
0.	0.	0.	32.50	34.30
600.	100.	700.	34.84	36.64
1200.	200.	1400.	37.17	38.97
1800.	300.	2100.	39.50	41.30
2400.	400.	2800.	41.84	43.64
3000.	500.	3500.	44.17	45.97
3600.	600.	4200.	46.50	48.30
4200.	700.	4900.	48.84	50.64
4800.	800.	5600.	51.17	52.97
5400.	900.	6300.	53.50	55.30
6000.	1000.	7000.	55.84	57.64
6600.	1100.	7700.	58.17	59.97

CROP DESTRUCTION

0.	0.	0.	8.04	16.07
600.	100.	700.	9.20	18.40
1200.	200.	1400.	10.37	20.74
1800.	300.	2100.	11.54	23.07
2400.	400.	2800.	12.70	25.40
3000.	500.	3500.	13.87	27.74
3600.	600.	4200.	15.04	30.07
4200.	700.	4900.	16.20	32.40
4800.	800.	5600.	17.37	34.74
5400.	900.	6300.	18.54	37.07
6000.	1000.	7000.	19.70	39.40
6600.	1100.	7700.	20.87	41.74

TABLE IV-11A

SENSITIVITY ANALYSIS...HERBICIDE DELIVERY BY UH-1

SENSITIVITY OF SECURITY COSTS

DEFOLIATION

SECURITY COST ($/MSN)	SYSTEM COST ($/ACRE)	
	MIN.	MAX.
0.	26.90	28.70
10.	27.24	29.03
20.	27.57	29.37
30.	27.90	29.70
40.	28.24	30.03
50.	28.57	30.37
60.	28.90	30.70
70.	29.24	31.03
80.	29.57	31.37
90.	29.90	31.70
100.	30.24	32.03
110.	30.57	32.37
120.	30.90	32.70
130.	31.24	33.03
140.	31.57	33.37
150.	31.90	33.70
160.	32.24	34.03
170.	32.57	34.37
180.	32.90	34.70
190.	33.24	35.03
200.	33.57	35.37
210.	33.90	35.70
220.	34.24	36.03
230.	34.57	36.37
240.	34.90	36.70
250.	35.24	37.03
260.	35.57	37.37
270.	35.90	37.70
280.	36.24	38.03
290.	36.57	38.37
300.	36.90	38.70

TABLE IV-11B

SENSITIVITY ANALYSIS - HERBICIDE DELIVERY BY UH-1

SENSITIVITY OF SECURITY COSTS

CROP DESTRUCTION

SECURITY COST ($/MSN)	SYSTEM COST ($/ACRE)	
	MIN.	MAX.
0.	5.23	10.47
10.	5.40	10.80
20.	5.57	11.13
30.	5.73	11.47
40.	5.90	11.80
50.	6.07	12.13
60.	6.23	12.47
70.	6.40	12.80
80.	6.57	13.13
90.	6.73	13.47
100.	6.90	13.80
110.	7.07	14.13
120.	7.23	14.47
130.	7.40	14.80
140.	7.57	15.13
150.	7.73	15.47
160.	7.90	15.80
170.	8.07	16.13
180.	8.23	16.47
190.	8.40	16.80
200.	8.57	17.13
210.	8.73	17.47
220.	8.90	17.80
230.	9.07	18.13
240.	9.23	18.47
250.	9.40	18.80
260.	9.57	19.13
270.	9.73	19.47
280.	9.90	19.80
290.	10.07	20.13
300.	10.23	20.46

3. <u>Sensitivity of Effectiveness Criterion</u> (Table IV-12 and Table IV-13)

These tables demonstrate the effect on system cost when commanders insist on conducting herbicide operations when conditions such as temperature, wind, and weather are less than favorable.

4. <u>Remarks</u>

Prior to completing the analysis, the effect of variation of the agent cost in terms of dollars per acre can be investigated. (Reference Table IV-5) These show the dominance of the agent costs.

<u>Cost Variation Due to Agent Costs</u>

(Cost in Dollars per Acre)

COST OF AGENT	UH-1 ($/ACRE)		UC-123 ($/ACRE)	
	MIN.	MAX.	MIN.	MAX.
$ 1	$ 6	$13	$15	$25
$ 2	$ 9	$16	$19	$28
$ 3	$13	$19	$22	$31
$ 4	$16	$23	$25	$35
$ 5	$19	$26	$29	$38
$ 6	$23	$29	$32	$41
$ 7	$26	$33	$35	$45
$ 8	$29	$36	$39	$48
$ 9	$33	$39	$42	$51
$10	$36	$43	$45	$55

TABLE IV-12

SENSITIVITY ANALYSIS - HERBICIDE DELIVERY BY UC-123

SENSITIVITY OF EFFECTIVENESS OF COVERAGE

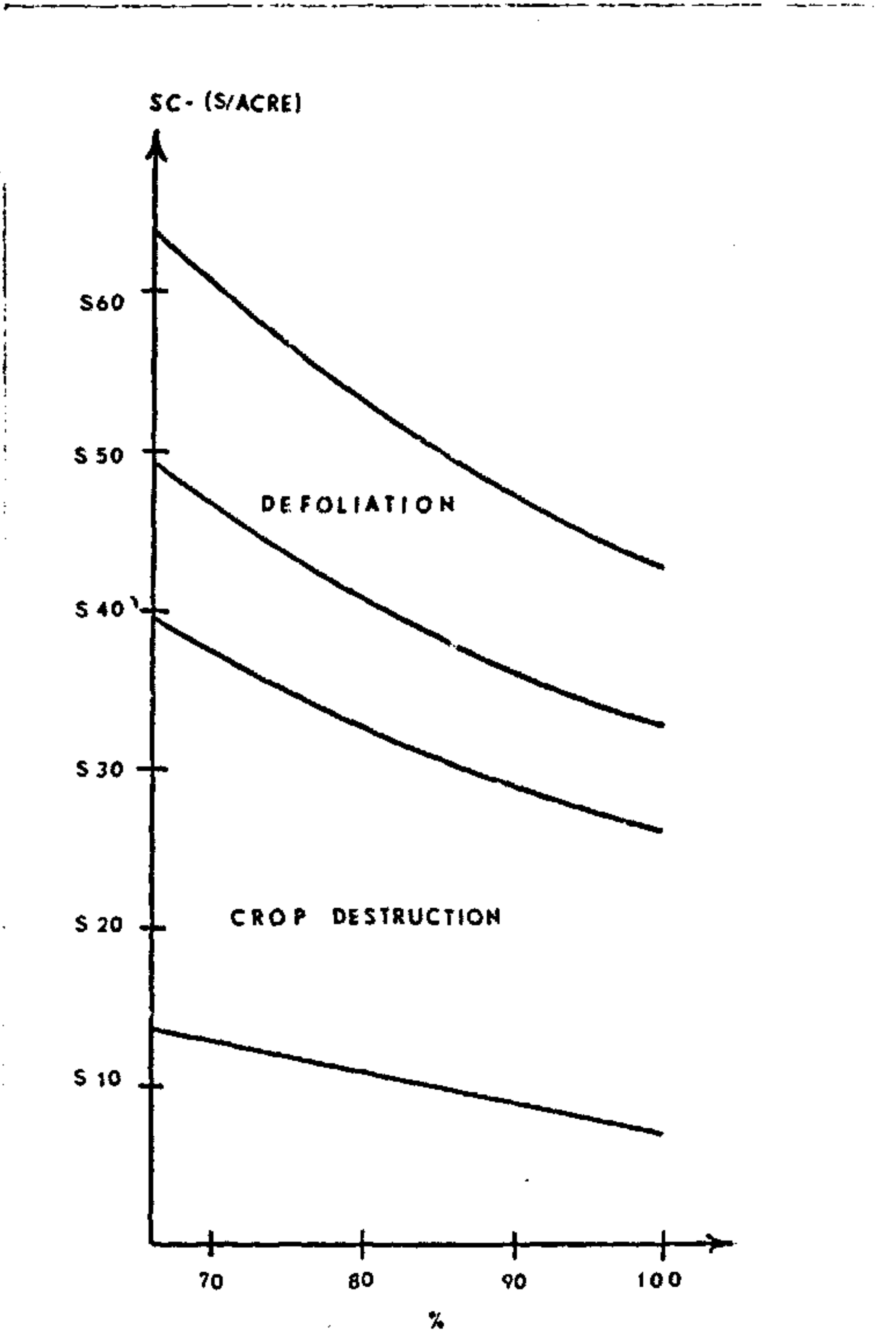
DEFOLIATION

COVERAGE (ACRES/MSN)	% EFFECTIVE	SYSTEM COST ($/ACRE)	
		MIN.	MAX.
220.	66.0	49.33	64.30
230.	69.0	47.18	61.50
240.	72.0	45.22	58.94
250.	75.0	43.41	56.58
260.	78.0	41.74	54.40
270.	81.0	40.19	52.39
280.	84.0	38.76	50.52
290.	87.0	37.42	48.78
300.	90.0	36.17	47.15
310.	93.0	35.01	45.63
320.	96.0	33.91	44.20
330.	99.0	32.89	42.86

CROP DESTRUCTION

COVERAGE (ACRES/MSN)		% EFFECTIVE	SYSTEM COST ($/ACRE)	
MIN.	MAX.		MIN.	MAX.
440.	220.	66.0	13.46	39.43
460.	230.	69.0	12.87	37.72
480.	240.	72.0	12.34	36.15
500.	250.	75.0	11.84	34.70
520.	260.	78.0	11.39	33.37
540.	270.	81.0	10.97	32.13
560.	280.	84.0	10.58	30.98
580.	290.	87.0	10.21	29.91
600.	300.	90.0	9.87	28.92
620.	310.	93.0	9.55	27.98
640.	320.	96.0	9.25	27.11
660.	330.	99.0	8.97	26.29

CHART IV-3: SENSITIVITY OF EFFECTIVENESS OF COVERAGE (UC-123)



Percentage of Effectiveness

TABLE IV-13

SENSITIVITY ANALYSIS - HERBICIDE DELIVERY BY UH-1

SENSITIVITY OF EFFECTIVENESS OF COVERAGE

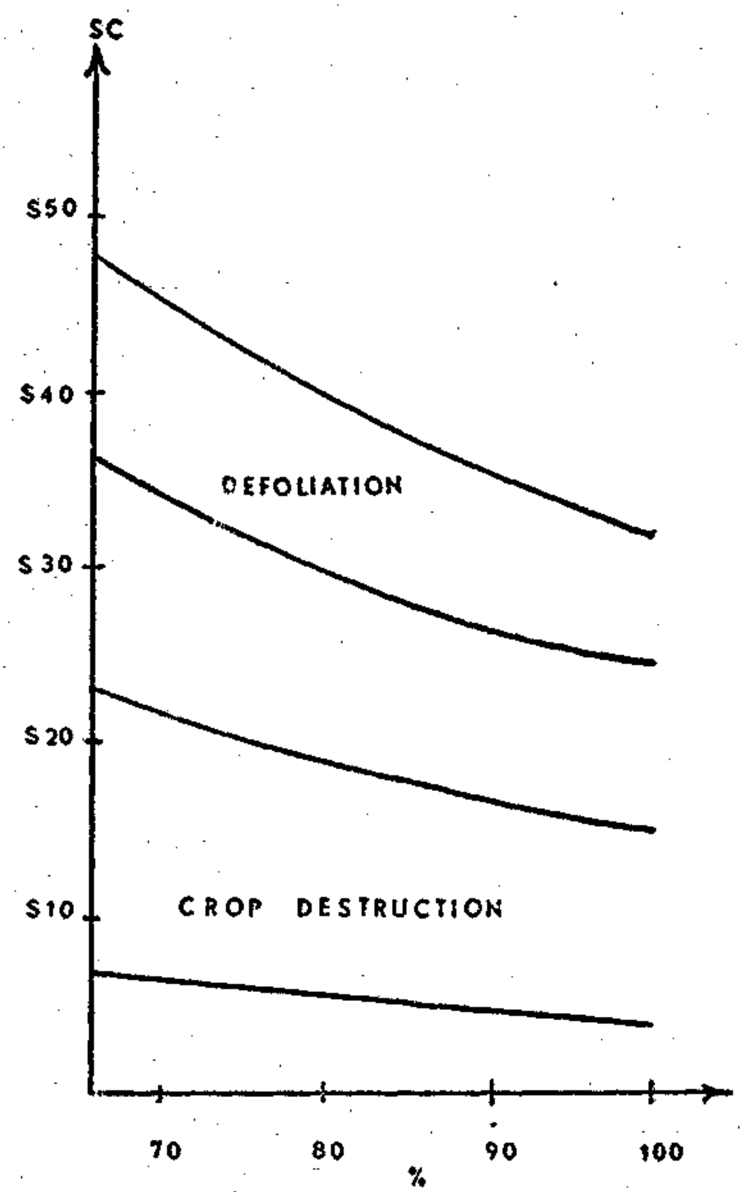
DEFOLIATION

COVERAGE (ACRES/MSN)	% EFFECTIVE	SYSTEM COST ($/ACRE)	
		MIN.	MAX.
22.	66.0	36.68	48.23
23.	69.0	35.09	46.13
24.	72.0	33.62	44.21
25.	75.0	32.28	42.44
26.	78.0	31.04	40.81
27.	81.0	29.89	39.30
28.	84.0	28.82	37.90
29.	87.0	27.83	36.59
30.	90.0	26.90	35.37
31.	93.0	26.03	34.23
32.	96.0	25.22	33.16
33.	99.0	24.45	32.15

CROP DESTRUCTION

COVERAGE (ACRES/MSN)		% EFFECTIVE	SYSTEM COST ($/ACRE)	
MIN.	MAX.		MIN.	MAX.
44.	22.	66.0	7.14	23.37
46.	23.	69.0	6.83	22.35
48.	24.	72.0	6.54	21.42
50.	25.	75.0	6.28	20.56
52.	26.	78.0	6.04	19.77
54.	27.	81.0	5.81	19.04
56.	28.	84.0	5.61	18.36
58.	29.	87.0	5.41	17.73
60.	30.	90.0	5.23	17.14
62.	31.	93.0	5.06	16.58
64.	32.	96.0	4.91	16.06
66.	33.	99.0	4.76	15.58

CHART IV-4: SENSITIVITY OF EFFECTIVENESS OF COVERAGE (UH-1)
(System Cost (SC) in Dollars/Acre)



Percentage of Effectiveness

V. TACTICAL LAND CLEARING

A. ASSUMPTIONS

1. The vehicle examined will be the D7E/D7F medium crawler tractor (made by the Caterpillar Tractor Company) equipped with the Rome K/G clearing blade and protection kit.

2. The expected life of the tractor under combat conditions is two years. [Major Bennett] The expected life of the blade and protection kit is one year. [62d Engineer Battalion]

3. A land clearing company has 25 of its 30 medium tractors operational at any one time. [Planning factor from DA Pam 526-6 1970]

4. Security forces consist of one armored cavalry troop or a comparable-size mechanized infantry unit. [Major Bennett] The operation is controlled by the commander who is airborne in a light observation helicopter (LOH).

5. Crops are considered under the category of light vegetation.

6. The discount rate is ten per cent.

B. PARAMETERS

1. Utilization

The operating time for ·e Rome-equipped tractor will be eight hours per day. ..ormally, these vehicles work in the field for 45 days prior to returning to their base areas for a 15-day "stand down" and maintenance period. [62d Engineer Battalion Letter, February 1971] This implies a 75 per cent work factor and 270 work days per year.

2. Cost Bounds

a. Investment Cost

The investment cost for a tractor is bounded by the consideration of inherited assets. When the Rome clearing blade was introduced in RVN, the tractors "in country" were equipped with bulldozer blades. These blades were simply converted by unit maintenance personnel. In other situations, the kits and tractors were sent to RVN to form land clearing units. Thus, the upper bound considers procurement of the initial tractor while the lower bound considers the initial tractor to be a sunk cost.

b. Operating Cost

The operating costs are bounded by the security, control, and readiness postures of the clearing unit. The desired security for a land clearing company is an armored cavalry troop while a mechanized infantry company (-) is a less desired but acceptable replacement. [DA Pam 525-6 1970] The security costs will be considered to range from \$130 per day to \$80 per day for a UE. (Appendix B) The control costs are directly proportional to the use of the LOH that is attached to the land clearing company during clearing operations. The attachment can be from several hours to all day. [62d Engineer Battalion 11 April 1971]

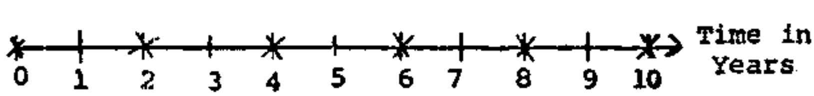
The unit readiness rating determines the equipment and personnel manning levels. High ratings dictate the assignment of two operators per tractor. However, during periods of budgetary austerity or when the manpower pool cannot support this requirement, this is lowered to the assignment of one operator per tractor. [USACDC TOE 5-58T 1969]

C. COST ANALYSIS

1. Isolation of Relevant Costs (Appendix B)

a. Investment Cost

(1) Investment cost for D7 Tractor. This investment cost is bounded by the requirement to procure the initial tractor. Additionally, the expected life of the D7 dictates replacement across the ten year planning horizon. Since replacement is necessary, the planner must consider the present value of the dollars spent in order for an equitable comparison to be made with the other alternatives. The replacement schedule will be:



The present value coefficients will be:

$$PV1 = \sum_{i=0}^{8} \frac{1}{(1+r)^{i}} = 3.5404 \text{ and } PV2 = \sum_{i=2}^{8} \frac{1}{(1+r)^{i}} = 2.5404$$

for i an even integer and $r = .10$. [Hirshleifer 1970]

D7 procurement cost:	\$32,916	[DA Supply Bulletin (SB) 700-200 1971]
	\$ 2,400	[DA DCS, Logistics (LOG) 1971] (Appendix B)
Total =	\$35,316	

Upper bound on the investment cost: 3.54 x \$35,316=\$125,019

Lower bound on the investment cost: 2.54 x \$35,316=\$ 89,703

(2) Investment cost for the Rome K/G blade and kit. The blade and kit have an expected life of one year in combat which means purchase from time zero to the end of year nine.

$$PV3 = \sum_{i=0}^{9} \frac{1}{(1+r)^{i}} = 6.759 \text{ where } r = .10 \text{ and}$$

$i = 0,1,2,\ldots,8,9.$

Procurement cost:	\$ 7,623	[DA SB 700-200 1971]
Transportation to RVN:	\$ 900	[DA DCSLOG 1971]
Total =	\$ 8,523	(Appendix B)

Investment cost: 6.759 x \$8,523 = \$57,607.

(3) Investment cost due to combat attrition. The Rome-equipped tractors of the 62d Engineer Battalion (Land Clearing) have experienced a 25 per cent attrition rate when engaged in tactical clearing. [Major Bennett] This would mean the replacement of the tractors and kits on a yearly basis. The present value will be:

$$PV4 = \sum_{i=1}^{9} \frac{1}{(1+r)^{i}} = 5.759 \text{ where } r = .10 \text{ and}$$

$i = 1,2,\ldots,8,9.$ The investment cost for a UE is:

5.759 x .25 x (\$35,316 + \$8,523) = \$63,117.

(4) The total investment amortorized over the planning horizon is $24,574 per year (U) and $21,043 per year (L).

b. Operating Cost

(1) Hourly costs. Unless otherwise noted, the costs listed here come from the Caterpillar Performance Handbook.

Fuel: (Light Vegetation) 5.5 gal/hr x $.15/gal = $.83/hr

(Medium Vegetation) 7.0 gal/hr x $.15/gal = $1.05/hr

(Heavy Vegetation) 9.0 gal/hr x $.15/gal = $1.35/hr

Lubricants and filters: $.33/hr.

Tractor repairs: Using the Caterpillar repair factor, the repair cost would be $4.60 per hour. However, a review of the data furnished by Major Bennett indicates that $7.00 per hour is a more realistic figure.

Rome blade and kit repairs: $1.80/hr. [Major Bennett]

Total hourly costs:

Heavy vegetation	Medium Vegetation	Light Vegetation
$10.48	$10.18	$9.96

(2) Daily costs.

Operators' salaries:		Security cost:		Control cost:	
$55 (U)	$27 (L)	$130 (U)	$80 (L)	$6 (U)	$4 (L)
				(Appendix B)	

2. Daily Costs

IC = Yearly cost/365 days and OC = 8 hours/day x Hourly cost + Summation of Daily Costs.

Table V-1: Daily Costs
(Dollars per Day)

VEGETATION	LOWER BOUND			UPPER BOUND		
	IC	OC	SC	IC	OC	SC
Light	$58	$191	$249	$67	$271	$338
Medium	$58	$193	$251	$67	$273	$340
Heavy	$58	$195	$253	$67	$275	$342

3. Yearly Costs

Investment cost: 365 days/year x Investment cost/day. Operating cost: 270 days/year* x Operating cost/day.

*Tractors work 270 days per year (Section B).

Table V-2: Yearly Costs
(Dollars per Year)

VEGETATION	LOWER BOUND			UPPER BOUND		
	IC	OC	SC	IC	OC	SC
Light	21,043	51,570	72,613	24,574	73,170	97,744
Medium	21,043	52,110	73,153	24,574	73,710	98,284
Heavy	21,043	52,650	73,693	24,574	74,250	98,824

D. EFFECTIVENESS CRITERIA AND COST-EFFECTIVENESS MEASURES

1. Effectiveness Criteria

a. MOE # 1 - "Area"

This MOE considers the system's net effectiveness during a normal day's operation. The criteria takes into consideration the three classifications of vegetation and the two principal types of cuts.

$$\text{Effectiveness Criterion} = \frac{\text{Hours available}}{\text{Clearing rate}}$$

Using the clearing rates from Table II-3, the effectiveness criteria for a UE can be obtained.

Table V-3: Effectiveness Criteria for One Tractor (Acres per Day)

VEGETATION	AREA CLEARING	STRIP CLEARING
Light	20	13.33
Medium	10	6.15
Heavy	6.15	3.8

b. MOE # 2 - Constrained Cost Minimization

Minimize the cost of clearing 6000 acres

Subject to:

Mission completion $\leq$ 30 days

Assets required $\leq$ Ability of commander to supply

In order to examine the performance of the land clearing operation under constrained cost minimization, several additional assumptions are necessary:

(1) Vegetation is either categorized as heavy or medium.

(2) Area clearing is required.

(3) Cost per day is based on 30 tractors in the unit although only 25 are operational.

(4) Land clearing company has a high readiness rating and security is provided by a cavalry troop (i.e., upper bound cost figures for heavy and medium area clearing will hold). Area clearing rates for a land clearing company

with 25 of its 30 medium tractors conducting sustained operations are:

Heavy vegetation	Medium vegetation
100 acres/day	250 acres/day

[DA Pam 525-6 1970]

2. Cost-Effectiveness Measures

a. MOE #1

Table V-4: Tactical Land Clearing

(Dollars per Acre)

VEGETATION	AREA CLEARING		STRIP CLEARING	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
Light	$12	$17	$19	$25
Medium	$25	$34	$41	$55
Heavy	$41	$56	$66	$90

The mission categories must take into consideration the terrain sensitivity of this alternative. The minimum cost for both land clearing and crop destruction are those costs incurred during light area clearing while the maximum costs for land clearing are those that occur during heavy strip clearing (maximum costs for crop destruction come during light strip clearing).

Table V-5: Cost-Effectiveness Measures for Tactical Land Clearing

(Dollars per Acre)

MISSION	MINIMUM	MAXIMUM
Land Clearing	$12	$90
Crop Destruction*	$12	$25

*The Rome-equipped tractor is limited to areas where crops grow on trafficable terrain. This eliminates many paddy-grown crops from this type mission.

b. MOE # 2

As pointed out previously, a medium land clearing company can clear 100 acres per day in heavy vegetation and 250 acres per day in medium vegetation. The time constraint on a 6,000 acre mission would require two companies working for 30 days in heavy vegetation and one company working for 24 days in medium vegetation. The cost per day for a company are:

Heavy vegetation - $10,260 Medium vegetation - $10,200.

The cost in dollars for this MOE is:

UPPER BOUND: $615,600

LOWER BOUND: $244,800

E. PARAMETER SENSITIVITY

1. Utilization (Table V-6 A,B, & C)

The tables show the variability in costs (dollars per acre) that occur in accordance with the operational hours per day of each vehicle. The tables indicate the importance of a high utilization factor, consistent with the operators' and support elements' ability to perform the required daily maintenance on the tractors.

2. Security (Table V-7A, B, & C)

The fluctuation in security cost demonstrates the effect on system cost when the commander varies his security posture from no protection to that equivalent of a reinforced armored cavalry troop.

TABLE V-6A: MAX COST - LAND CLEARING

SENSITIVITY ANALYSIS - TACTICAL LAND CLEARING

SENSITIVITY OF EQUIPMENT UTILIZATION - STRIP CLEARING

Heavy Clearing

UTILIZATION (HOURS/DAY)	R & D COST	INVESTMENT COST	O & M COST	SYSTEM COST
5.0	0.00	28.28	102.14	130.42
5.5	0.00	25.71	94.86	120.57
6.0	0.00	23.57	88.79	112.35
6.5	0.00	21.75	83.65	105.40
7.0	0.00	20.20	79.25	99.45
7.5	0.00	18.85	75.43	94.28
8.0	0.00	17.67	72.09	89.77
8.5	0.00	16.63	69.15	85.78
9.0	0.00	15.71	66.53	82.24
9.5	0.00	14.88	64.18	79.07
10.0	0.00	14.14	62.08	76.22
10.5	0.00	13.47	60.17	73.63
11.0	0.00	12.85	58.43	71.29
11.5	0.00	12.30	56.85	69.14
12.0	0.00	11.78	55.40	67.18

TABLE V-6B: MAX. COST - CROP DESTRUCTION

SENSITIVITY ANALYSIS - TACTICAL LAND CLEARING
SENSITIVITY OF EQUIPMENT UTILIZATION - STRIP CLEARING

Light Clearing

UTILIZATION (HOURS/DAY)	R & D COST	INVESTMENT COST	O & M COST	SYSTEM COST
5.0	0.00	8.08	28.87	36.95
5.5	0.00	7.35	26.79	34.14
6.0	0.00	6.73	25.06	31.79
6.5	0.00	6.22	23.59	29.80
7.0	0.00	5.77	22.33	28.10
7.5	0.00	5.39	21.24	26.63
8.0	0.00	5.05	20.29	25.34
8.5	0.00	4.75	19.44	24.20
9.0	0.00	4.49	18.70	23.18
9.5	0.00	4.25	18.03	22.28
10.0	0.00	4.04	17.42	21.46
10.5	0.00	3.85	16.88	20.73
11.0	0.00	3.67	16.38	20.06
11.5	0.00	3.51	15.93	19.44
12.0	0.00	3.37	15.52	18.88

TABLE V-6B: MIN. COST - CROP DESTRUCTION AND LAND CLEARING

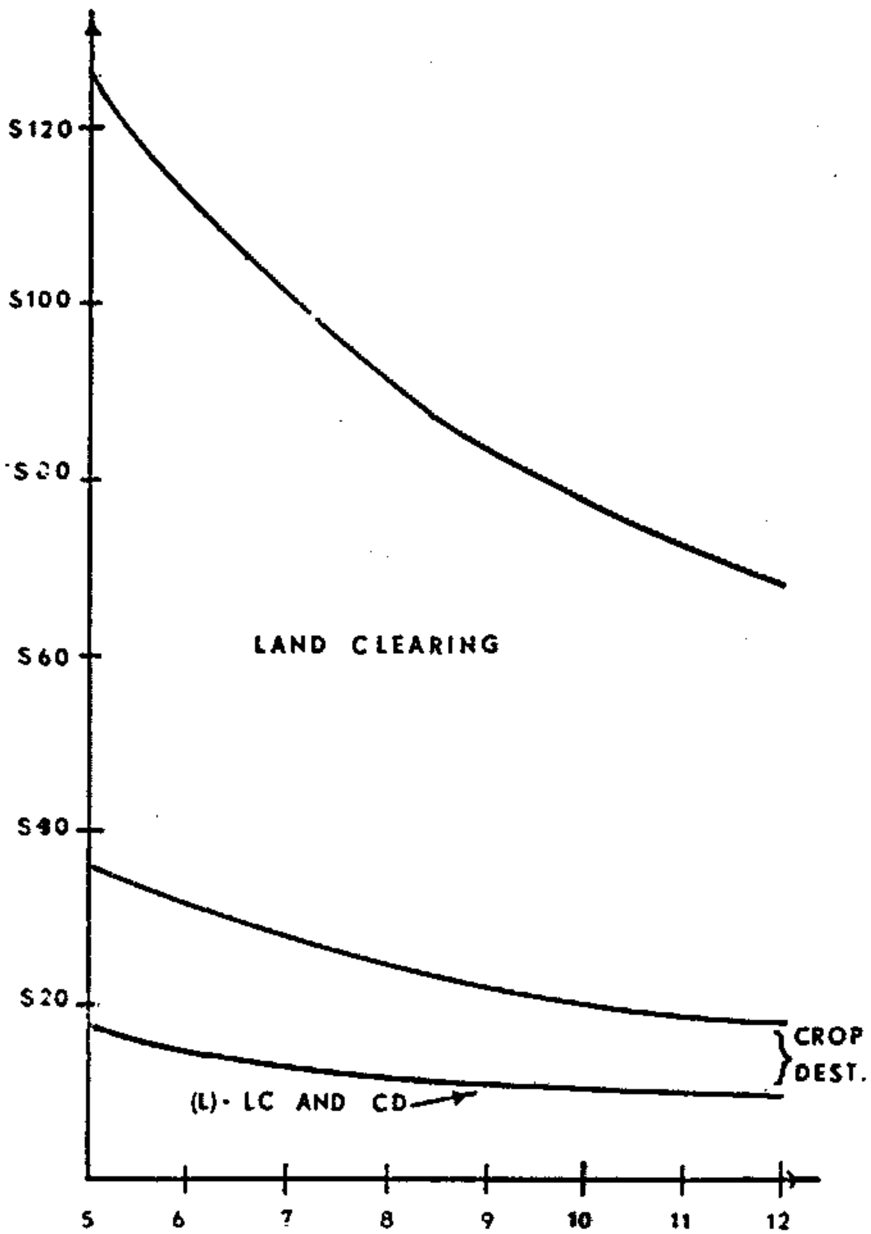
SENSITIVITY ANALYSIS - TACTICAL LAND CLEARING

SENSITIVITY OF EQUIPMENT UTILIZATION - AREA CLEARING

Light Clearing

UTILIZATION HOURS/DAY	R & D COST	INVESTMENT COST	O & M COST	SYSTEM COST
5.0	0.00	4.61	12.90	17.51
5.5	0.00	4.19	12.09	16.28
6.0	0.00	3.84	11.41	15.25
6.5	0.00	3.55	10.84	14.39
7.0	0.00	3.29	10.35	13.64
7.5	0.00	3.07	9.93	13.00
8.0	0.00	2.88	9.55	12.44
8.5	0.00	2.71	9.23	11.94
9.0	0.00	2.56	8.94	11.50
9.5	0.00	2.43	8.67	11.10
10.0	0.00	2.31	8.44	10.75
10.5	0.00	2.20	8.23	10.42
11.0	0.00	2.10	8.03	10.13
11.5	0.00	2.01	7.86	9.86
12.0	0.00	1.92	7.70	9.62

CHART V-1: SENSITIVITY OF TRACTOR UTILIZATION
(System Cost (SC) in Dollars/Acre)



Utilization - (Hours/Day)

TABLE V-7A: MAX. COST - LAND CLEARING

SENSITIVITY ANALYSIS - TACTICAL LAND CLEARING

SENSITIVITY OF SECURITY COST.....STRIP CLEARING

Heavy Clearing

SECURITY COSTS ($/DAY)	SYSTEM COST ($/ACRE)
0.	55.64
10.	58.27
20.	60.89
30.	63.52
40	66.14
50.	68.77
60.	71.39
70.	74.02
80.	76.64
90.	79.27
100.	81.89
110.	84.52
120.	87.14
130.	89.77
140.	92.39
150.	95.02
160.	97.64
170.	100.27
180.	102.89
190.	105.52
200.	108.14

TABLE V-7B: MAX. COST - CROP DESTRUCTION

SENSITIVITY ANALYSIS - TACTICAL LAND CLEARING

SENSITIVITY OF SECURITY COST.......STRIP CLEARING

Light Clearing

SECURITY COSTS ($/DAY)	SYSTEM COST ($/ACRE)
0.	15.59
10.	16.34
20.	17.89
30.	17.84
40.	18.59
50.	19.34
60.	20.09
70.	20.84
80.	21.59
90.	22.34
100.	23.09
110.	23.84
120.	24.59
130.	25.34
140.	26.09
150.	26.84
160.	27.89
170.	28.34
180.	29.09
190.	29.84
200.	30.59

TABLE V-7C: MIN. COST - LAND CLEARING AND CROP DESTRUCTION

SENSITIVITY ANALYSIS - TACTICAL LAND CLEARING

SENSITIVITY OF SECURITY COST......AREA CLEARING

Light Clearing

SECURITY COSTS ($/DAY)	SYSTEM COST ($/ACRE)
0.	8.44
10.	8.94
20.	9.44
30.	9.94
40.	10.44
50.	10.94
60.	11.44
70.	11.94
80.	12.44
90.	12.94
100.	13.44
110.	13.94
120.	14.44
130.	14.94
140.	15.44
150.	15.94
160.	16.44
170.	16.94
180.	17.44
190.	17.94
200.	18.44

VI. ANALYSIS OF "SLASH AND BURN" CLEARING

A. ASSUMPTIONS

1. A crew consists of 45 men with one U.S. enlisted man as supervisor. All crew members are considered workers since no allowance is made for any internal chain of command among the personnel. [Mr. Underwood]

2. Payment of the indigenous cutters is consistent with those rates paid in Military Region IV in the fall of 1970.

3. This type of clearing takes place in secure areas or where security is provided by units already engaged in major land clearing operations.

4. The U. S. units provide transportation for the workers to and from the clearing site. Tools for the cutters are drawn from current inventories. [Mr. Underwood]

5. Crops fall into the category of light vegetation.

While the first four statements can be categorized as "assumptions," they all have basis in fact. Mr. Elton Undersood of the Army's Engineer Strategic Studies Group verified these on a trip to RVN in May and June of 1971. The data he returned with contained detailed information on a U.S.-sponsored operation in An Kuyen Province on the Cau Mau Peninsula during the period September to December 1970. However, their inclusion as assumptions is meant to preclude their being taken as policy for MACV as a whole.

B. PARAMETERS

1. The utilization parameter will be in units of "hours per day." For this portion of the study, a utilization factor of eight hours per day and 270 work days per year will be used. This corresponds to the utilization rates of Chapter V. However, both of these inputs are part of the working conditions that are agreed upon by the U.S. Civil Affairs office prior to hiring the civilian crews.

2. Cost Bounds

The bounds on each method of cutting and each type of vegetation are set by the maintenance and transportation costs. These costs can range from zero to some preset value. The cost for maintenance of the workers' tools and equipment will be set at five dollars per crew per day. The transportation cost will be ten dollars per crew per day (based on the utilization of two trucks for approximately one hour per day).

C. COST ANALYSIS

1. Isolation of Relevant Costs

The only costs incurred by this method of clearing are operating costs. The only investment cost would be the procurement of tools, but by assumption # 4, these are sunk costs.

a. Salaries

Each man is paid 200 piasters per day and furnished one meal at a cost of 37 piasters per day.

[Mr. Underwood] This amounts to approximately $.86 per man or $38.80 per crew per day based on the 1970 exchange rate of 275 piasters to one U. S. dollar.

b. Supervision

The opportunity cost for using one U. S. enlisted man as a supervisor is $10,000 per year or $27 per day. [Major Howe]

c. Transportation

In some cases, the crews could walk from their assembly points to the clearing sites. If this were not feasible, two trucks would be needed for approximately an hour each day to transport the crews. Cost: $10/crew/day (U) or zero (L). (Section B)

d. Maintenance

Cost: $5/crew/day (U) or zero (L). (Section B)

2. Daily Costs

Daily cost = Crew salaries + Supervision + Transportation + Maintenance

Upper Bound: $81 per crew per day

Lower Bound: $66 per crew per day

3. Yearly Costs

Yearly cost = 270 days/year x Cost per day

Upper Bound: $21,870 per year

Lower Bound: $17,820 per year

D. EFFECTIVENESS CRITERIA AND COST-EFFECTIVENESS MEASURES

1. Effectiveness Criteria

a. MOE # 1 - "Area"

This MOE presents the system's net effectiveness during a normal day's operation. Since this alternative is sensitive to the three classifications of vegetation and two types of clearing (strip and area), six criteria will be determined.

$$\text{Effectiveness Criterion (EC)} = \frac{\text{Hours available x Crew size}}{\text{Clearing Rate}}$$

The clearing rates are obtained from Table II-4. For light area clearing:

$$EC = \frac{8 \text{ hr/day x } 45 \text{ men}}{125 \text{ man-hours/acre}} = 2.88 \text{ acres/day}$$

Table VI-1: Crew Effectiveness Criteria
(Acres per Day)

VEGETATION	AREA CLEARING	STRIP CLEARING
Light	2.88	3.6
Medium	1.0	1.3
Heavy	.5	.5

b. MOE # 2 - Constrained Cost Minimization

Minimize the cost of clearing 6,000 acres

Subject to:

Mission completion $\leq$ 30 days

Personnel and equipment required $\leq$ Ability of Local Area to Supply

Several assumptions are necessary to complete the examination of this MOE:

(1) The vegetation is either medium or heavy.

(2) Method of clearing will be "area" type.

2. Cost-Effectiveness Measures

a. MOE # 1

$$\text{Cost-Effectiveness Measure} = \frac{\text{Cost/crew/day}}{\text{EC}}$$

For area clearing in light vegetation (U):

$$\frac{\$81/\text{crew/day}}{2.88\ \text{acres/day}} = \$28 \text{ per acre.}$$

Similar calculations yield the following table:

Table VI-2: "Slash and Burn" Clearing

(Dollars per Acre)

VEGETATION	AREA CLEARING		STRIP CLEARING	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
Light	\$23	\$28	\$18	\$23
Medium	\$64	\$79	\$51	\$63
Heavy	\$147	\$180	\$147	\$180

If these costs are to be depicted by mission categories, the vegetation classifications and the method of clearing must be encompassed by the maximum and minimum limits. Although this gives a large interval for the costs to be within, the review must remember that vegetation removal by ground personnel and equipment is extremely sensitive to the type of terrain which the work is being conducted in.

Table VI-3: Cost-Effectiveness Measures for "Slash and Burn" Clearing

(Dollars per Acre)

MISSION	MINIMUM	MAXIMUM
Land Clearing	$18	$180
Crop Destruction	$18	$ 28

b. MOE # 2

In order to analyze this program, one must first look at the constraints. In medium vegetation, a crew of 45 can only clear one acre per day. The size of the operation dictates that at least 200 acres must be cleared per day in order to meet the 30 day time constraint. This would mean 200 crews or 9,000 men would have to be hired. It is doubtful that the host government could supply or the U. S. units could secure that many workers. Hence, this method of clearing is considered infeasible for a large scale land clearing operation.

E. PARAMETER SENSITIVITY

Since indigenous cutters are paid by the day, it would be important to examine the cost fluctuation over a range of possible utilization factors. As might be expected by noting the units of the clearing rates (man-hours per acre), changing the utilization factor from the established eight hours per day results in a large cost variation. This shows the importance of negotiating a work agreement that insures enough "time on the job." It also amplifies the costs incurred if the cutters' pick-up point were far from the clearing site, causing an excessive amount of transportation time to decrease the crew utilization, or if the supervisor were unable to motivate his crew.

TABLE VI-4: VEGETATION REMOVAL

SENSITIVITY ANALYSIS....SLASH AND BURN CLEARING

SENSITIVITY OF CREW UTILIZATION...AREA BURNING

(Heavy Clearing)

UTILIZATION (HOURS/DAY)	MAXIMUM SYSTEM COST ($/ACRE)
5.0	$288.61
5.5	262.37
6.0	240.51
6.5	222.01
7.0	206.15
7.5	192.41
8.0	180.38
8.5	169.77
9.0	151.90
10.0	144.31
10.5	137.43
11.0	131.19

SENSITIVITY OF CREW UTILIZATION.....STRIP CLEARING

(Light Clearing)

UTILIZATION	MAXIMUM SYSTEM COST
5.0	29.41
5.5	26.74
6.0	24.61
6.5	22.63
7.0	21.01
7.5	19.61
8.0	18.38
8.5	17.30
9.0	16.34
9.5	15.48
10.0	14.71
10.5	14.01
11.0	13.37

TABLE VI-5: CROP DESTRUCTION

SENSITIVITY ANALYSIS....SLASH AND BURN CLEARING

SENSITIVITY OF CREW UTILIZATION...AREA CLEARING

(Light Clearing)

UTILIZATION (HOURS/DAY)	MAXIMUM SYSTEM COST ($/ACRE)
5.0	45.10
5.5	41.00
6.0	37.58
6.5	34.69
7.0	32.21
7.5	30.06
8.0	28.18
8.5	26.53
9.0	25.05
9.5	23.73
10.0	22.55
10.5	21.47
11.0	20.50

SENSITIVITY OF CREW UTILIZATION..STRIP CLEARING

(Light Clearing)

UTILIZATION	MAXIMUM SYSTEM COST
5.0	29.41
5.5	26.74
6.0	24.51
6.5	22.63
7.0	21.01
7.5	19.61
8.0	18.38
8.5	17.30
9.0	16.34
9.5	15.48
10.0	14.71
10.5	14.01
11.0	13.37

VII. ANALYSIS OF FIREBOMBING

A. ASSUMPTIONS

1. Firebombing is conducted with the C-model medium helicopter (CH-47C - "Chinook").

2. Each sortie has an expected duration of one-half hour. [LTC Rudrow]

3. A flight over a given target consists of one CH-47C. [LTC Rudrow]

4. Salvaged slings and salvaged 55-gallon drums are used in the drops. M-4 fuel thickener is mixed with gasoline to form a six per cent solution of thickened fuel. [DA TC 3-336 1965] Twenty drums will be carried on one mission (or more common terminology, one "drop"). [LTC Rudrow]

5. The number of missions over a target area is dependent on the requirement to have a .90 probability of success from one or more drops.

6. When available, security forces consist of two AH-1G armed helicopters. However, unlike herbicide missions with the UH-1, firebombing missions will not be flown unless one AH-1G is present. One OH-6A or OH-58A light observation helicopter will provide the necessary control. [LTC Rudrow]

B. PARAMETERS

1. Flying Hours

Initially, the flying hours for the CH-47 that will be used as basis for the analysis will be the same as the other aerial systems. A mission duration of one-half hour implies that the helicopter will fly 100 sorties per month in order to reach the specified 600 flying hours per year. However, like the UH-1 helicopter, this is below the CH-47's programmed limit of flying (720 hours per year) in an active combat environment. [DA FM 101-20 1970] The effects of this difference will be examined in a sensitivity analysis of the sortie generation rate in Section E.

2. Cost Bounds

The bounds on the mission costs are obtained by the variation of the security and control posture that often results during normal employment. Control of a drop is accomplished by a representative of the ground commander in an LOH. However, if the Chinook pilots are familiar with the mission and the AO, the presence of the LOH is unnecessary. Under normal operating conditions, security is provided by two AH-1G helicopters. The lower cost bound is reached when only one armed helicopter is used. The use of one "Cobra," even under the most austere conditions, is due to the vulnerability and lack of maneuverability of the CH-47.

C. COST ANALYSIS

1. Isolation of Relevant Costs

The only costs incurred by this method of vegetation removal are those that are categorized as operating costs. The procurement of the CH-47 is treated as a sunk cost since the helicopter is diverted from normal lift missions to conduct firebombing operations.

a. O & M cost is rated at 15 per cent of the procurement cost of the helicopter. [Mr. Donaldson] The procurement cost for the CH-47C is $1,536,424. [DA SB 700-200 1971] O & M cost: $230,000 per year.

b. Crew salaries: Crew consists of two officers and one enlisted man. [DA FM 101-20 1970] Total cost: $38,000 per year. [Major Howe]

c.	Security forces:	$200 per mission (U)-2 AH-1G's.
		$100 per mission (L)-1 AH-1G. (Appendix A)
d.	Control:	$ 25 per mission (U)
		0 (L) (Appendix C)
e.	Thickened fuel:	$163 per mission. (Appendix C)

2. Mission Cost

$$SC = \frac{(\text{O \& M cost} + \text{Salaries})}{\text{Number of Missions/Year}} + \text{Security cost} +$$

Control cost + Agent cost

Cost per Mission

LOWER BOUND	UPPER BOUND
$ 486	$ 611

3. Yearly Costs

The yearly cost is extremely sensitive to the input parameters. This, coupled with the fact that the CH-47 would never be solely employed for firebombing missions, diminishes its importance.

Cost per Year

LOWER BOUND	UPPER BOUND
\$583,200	\$733,200

D. EFFECTIVENESS CRITERIA AND COST-EFFECTIVENESS MEASURES

1. Effectiveness Criteria

a. MOE # 1 - "Area"

The effectiveness of any one mission is contingent upon many variables. The condition of the vegetation, weather, scattering effect of the incendiary fuel, and the probability of detonation of the drum cluster require that the evaluation of effectiveness be accomplished with a probabalistic model. An appropriate model would be a two or three dimensional fragmenting projectile model. However, this would require the determination of a lethality function and directional variances of the bursting radii of the cluster just to obtain a conditional single drop probability of burn (p_B). Since this data was not available, a simpler model was used. The probability statement is:

$$\text{Prob}\begin{bmatrix}\text{Fire burns 50 acres in one}\\ \text{or more drops (missions)}\\ \text{when } n \text{ drops are made}\end{bmatrix} = \text{Prob}(p_B, n) = .90.$$

This uses the data from assumption # 5 and has the implicit assumption that 50 acres will be burned per n drops (missions).

$$\text{Prob}(p_B, n) = 1 - (1 - p_B)^n$$

where p_B is the probability that 50 acres are burned on any particular drop.

Inherent in this model are the assumptions that:

(1) p_B is the same for all drops.

(2) There is statistical independence between drops (or no information is gained from one mission to the other).

An evaluation of n for $\text{Prob}(p_B, n) \geq .90$ yields:

p_B	n	$\text{Prob}(p_B, n)$
.2	10	.9 (app)
.3	7	.918
.4	5	.922
.5	4	.938
.6	3	.936
.7	2	.91
.8	2	.96
.9	1	.9

For this portion of the analysis, $p_B = .4$, which will necessitate five drops or missions to insure a .9 probability of burning 50 acres on at least one of the five drops.

b. MOE # 2 - Constrained Cost Minimization

Minimize the cost of burning 6,000 acres

Subject to:

Mission completion $\leq$ 30 days

Assets required $\leq$ Local command supply capability

Two CH-47 helicopters would be required to fly ten sorties per day for 30 days in order to be 90 per cent sure that this method would burn off 6,000 acres. Like aerial delivery of herbicides in the UH-1 constrained case, this represents a significant drain on the area's aviation assets. Few commanders could afford such a program due to the important role the "Chinook" plays in combat support and combat service support operations in an insurgency conflict. For this reason, it is felt that the second constraint is violated, and thus, the alternative is infeasible. The area would have to be reduced significantly for firebombing to be a viable alternative.

2. Cost-Effectiveness Measures

$$\text{System Cost} = \frac{\text{N x Mission Cost}}{\text{50 acres/mission}} \quad \text{where N = the}$$

number of missions (drops).

No differentiation is made between crop destruction and foliage removal for this alternative. The reviewer should not overlook the problems encountered in RVN when attempts were made to burn large caches of dry rice. Therefore, live rice and other paddy-type crops would be virtually impervious to destruction by firebombing.

Table VII-1: Cost-Effecti ness Measures for Firebombing
(Doll rs per Acre)

MINIMUM	MAXIMUM
$49	$61

E. PARAMETER SENSITIVITY

1. Sensitivity of Sortie Generation Rate (Table VII-2)

Table VII-2 indicates that the number of missions flown per month has relatively little effect on the cost of burning an acre. This is due to the fact that only $223 per mission are subject to fluctuations caused by a variable sortie rate. (Mission cost vector: ($611, $486).) The remainder of the costs are caused by security, control, and fuel costs and these are based on a flat rate per mission.

2. Sensitivity of Probability of Burn on any Single Drop (p_B) (Table VII-3)

This testing shows the effect of varying the single drop probability of burn over a reasonable range of values. In actual operations, p_B would have a tendency to be at the lower end of this spectrum rather than the higher.

3. Sensitivity of Security Costs (Table VII-4)

These parameter values range from zero to the cost that would be incurred if three escort helicopters accompanied the mission.

TABLE VII-2

SENSITIVITY ANALYSIS - FIREBOMBING WITH CH-47

SENSITIVITY OF SORTIE GENERATION RATE ($/ACRE)

SORTIES PER MO.	HOURS PER YEAR	SYSTEM COST MIN.	SYSTEM COST MAX.
78.	470.	54.81	67.31
80.	480.	54.22	66.72
82.	490.	53.65	66.15
83.	500.	53.10	65.60
85.	510.	52.57	65.07
87.	520.	52.07	64.57
88.	530.	51.58	64.08
90.	540.	51.11	63.61
92.	550.	50.66	63.16
93.	560.	50.23	62.73
95.	570.	49.81	62.31
97.	580.	49.40	61.90
98.	590.	49.01	61.51
100.	600.	48.63	61.13
102.	610.	48.27	60.77
103.	620.	47.91	60.41
105.	630.	47.57	60.07
107.	640.	47.24	59.74
108.	650.	46.92	59.42
110.	660.	46.60	59.10
112.	670.	46.30	58.80
113.	680.	46.01	58.51
115.	690.	45.72	58.22
117.	700.	45.44	57.94
118.	710.	45.17	57.67
120.	720.	44.91	57.41

TABLE VII-3

SENSITIVITY ANALYSIS - FIREBOMBING WITH CH-47

SENSITIVITY OF PROBABILITY OF BURN ON ONE DROP

($/Acre)

# OF DROPS	P_8	SYSTEM COST MIN.	SYSTEM COST MAX.
10.	0.20	97.27	122.27
8.	0.25	77.81	97.81
7.	0.30	68.09	85.59
6.	0.35	58.36	73.36
5.	0.40	48.63	61.13
4.	0.45	38.91	48.91
4.	0.50	38.91	48.91
3.	0.55	29.18	36.68
3.	0.60	29.18	36.68
3.	0.65	29.18	36.68
2.	0.70	19.45	24.45
2.	0.75	19.45	24.45
2.	0.80	19.45	24.45
2.	0.85	19.45	24.45
1.	0.90	9.73	12.23

TABLE VII-4

SENSITIVITY ANALYSIS - FIREBOMBING WITH CH-47

SENSITIVITY OF THE SECURITY COSTS

($/Acre)

SECURITY COSTS ($/MSN)	SYSTEM COST MIN.	SYSTEM COST MAX.
0.	38.63	41.13
25.	41.13	43.63
50.	43.63	46.13
75.	46.13	48.63
100.	48.63	51.13
125.	51.13	53.63
150.	53.63	56.13
175.	56.13	58.63
200.	58.63	61.13
225.	61.13	63.63
250.	63.63	66.13
275.	66.13	68.63
300.	68.63	71.13

VIII. INSIGHTS AND CONCLUSIONS

The need for defoliation and crop destruction is a direct result of the tropical growth, climate, and peculiarities of insurgency warfare. It would be difficult to imagine the necessity of these measures in a conventional war in a barren country like the Republic of Korea or in many areas of Western Europe. Conventional war raises the additional security problem of antiair protection and the costs incurred to insure local air superiority. These and other problems of the "linear war" have not been considered here. Hence, the conclusions drawn from this study are applicable only to those parts of the world affected by certain climates, vegetation, and the pressing needs of combating an enemy insurgent.

A. RESULTS OF THE ANALYSIS

1. MOE # 1

The first measure of effectiveness attempted to focus on each system's performance capability. A complete display of the results allows a better comparison of the alternatives.

Table VIII-1: Cost-Effectiveness Vectors for MOE # 1
(Dollars per Acre)

FOLIAGE REMOVAL

	HERBICIDES UC-123	HERBICIDES UH-1H	TACTICAL LAND CLEARING	"SLASH AND BURN"	FIREBOMBING
MAX.	$47	$35	$90	$180	$61
MIN.	$36	$27	$12	$ 18	$49

CROP DESTRUCTION

	HERBICIDES UC-123	HERBICIDES UH-1H	TACTICAL LAND CLEARING	"SLASH AND BURN"	FIREBOMBING
MAX.	\$29	\$17	\$25*	\$28	\$61*
MIN.	\$10	\$ 5	\$12*	\$18	\$49*

*Not appropriate where rice is the staple of the diet. (See Table V-5)

Tactical land clearing and "slash and burn" clearing show considerable variability in their maximum and minimum cost limits. This is due to the terrain sensitive nature of both systems. This, coupled with the different clearing results (one improves vertical surveillance while the other improves both vertical and horizontal surveillance), makes comparison with aerial-supported methods difficult. If comparisons are made within aerial categories and within ground categories for each mission type, dominance can be used to eliminate some vectors, since the maximum and minimum limits for these two groups of systems are caused by the same factors.

FOLIAGE REMOVAL

	Aerial Systems UH-1	Ground Systems "Rome Plow"
MAX.	\$35	\$90
MIN.	\$27	\$12

When tactical land clearing and firebombing are eliminated as alternatives for crop destruction, herbicide delivery by UH-1 dominates all other vectors.

2. MOE # 2

This measure of effectiveness attempted to amplify which system(s) could meet a rigorous set of hypothetical combat conditions. The program format was:

Minimize the cost of defoliating/clearing 6,000 acres

Subject to:

(1) Mission accomplishment in 30 days

(2) A reasonable amount of assets to complete the task.

The major additional assumptions stated:

(1) Spraying (using Agent ORANGE) must be accomplished within five days.

(2) The vegetation is either medium or heavy and area clearing is required.

(3) Ground systems are considered to be in a high state of readiness.

Table VIII-2: Cost Minimization Vectors for Foliage Removal (6000 acres) with Time and Resource Constraints**

(Costs in Dollars)

Herbicides	UC-123K	Tactical Land Clearing
(U)	$272,100	$615,600
(L)	$227,900	$244,800

**Infeasible alternatives are not shown.

The preceding table shows that only two alternatives can meet a stringent set of combat conditions.

More important than the actual dollar costs is the relative cost difference between the two systems. By looking at this change in the cost minimization vectors, it is possible to examine the incremental costs incurred to gain another dimension in surveillance capability. A defoliation mission usually improves only vertical surveillance. Although most of the leaves are off the vegetation, the trees and undergrowth remain to restrict visual and electronic surveillance from the ground. A tactical land clearing operation removes all vegetation and thus produces a horizontal capability as well as the vertical. It can also be assumed that an area which has been subjected to land clearing restricts enemy movement and channelizes his movement far more than the same defoliated terrain.

B. INSIGHTS

In order to check the information of Table VIII-2 is not biased by the scale of the operation, the mission size can be restricted. By reducing the area by 50 per cent, another set of cost minimization vectors can be obtained. The assumptions of MOE # 2 are maintained with the exception of having the UC-123 flights range from two to five aircraft.

Table VIII-3: Cost Minimization Vectors for Vegetation Removal of 3,000 Acres
(Costs in Dollars)

	HERBICIDES UH-1	HERBICIDES UC-123	TACTICAL LAND CLEARING
(U)	$100,700	$136,050	$307,800
(L)	$ 80,700	$112,930	$112,400

(Firebombing would be feasible only if the area were less than 1,000 acres.)

The relaxation of mission requirements indicates that the UH-1 defoliation system is minimum cost system and for this program dominates the other alternatives. However, the figures do not show the faster mission accomplishment rate of the UC-123 or the complete clearance capability of the D7 tractor equipped with the Rome K/G clearing blade.

In order to gain more insight into the problem of distinguishing between the systems, a "common mission" vector can be obtained for each alternative. This vector attempts to show the cost per acre for foliage removal under conditions that are most likely to occur in a counter-insurgency situation. It differs from the results of Table VIII-1, which were oriented toward optimistic and pessimistic estimates, in that it can be considered to be the "best estimate." The conditions making up the "common mission" are:

1. Defoliation/foliage removal operation (far more common than crop destruction).

2. The vegetation is classified as medium or heavy since thicker terrain is more valuable to the enemy for use as sanctuaries, staging areas, hospitals, and base camps.

3. Clearing is limited to area type since strip clearance is restricted to vegetation removal (anti-ambush measures) along lines of communication.

4. Defoliation systems use Agent ORANGE since it is faster acting than WHITE but not as persistent.

5. Land clearing units have two operators per tractor and the optimum security and control available.

Reference: Table IV-6A, Table V-4, Table VI-2, and Table VII-1.

Table VIII-4: Common Mission Vectors (Dollars/Acre)

	HERBICIDES		TACTICAL LAND CLEARING	"SLASH AND BURN"	FIREBOMBING
	UH-1	UC-123			
(U)	$34	$45	$56	$180	$61
(L)	$27	$36	$34	$ 79	$49

Again, herbicide delivery by UH-1 helicopter dominates all other alternatives. These results serve to confirm the findings shown in Tables VIII-1 through VIII-3.

C. CONCLUSIONS

The cost-effectiveness measures obtained in this study through the evaluation of the two measures of effectiveness indicate that a force mix of herbicide aircraft and land clearing tractors would most likely provide a cost-effective solution to the foliage removal/crop destruction missions faced during counterinsurgency operations in an RVN-type environment, especially when one takes into account that horizontal and vertical vision is desirable. However, this is not meant to exclude the employment of firebombing or "slash and burn" clearing when the other systems are not available to do the job.

The ratio of the force-mix must be determined through further examination of the problem. The decision to use the UH-1, UC-123, or both as herbicide delivery systems would depend on the intensity of the conflict, the commitment of U.S. assets, and the desired flexibility of the over-all force structure. Certainly the helicopter provides more flexibility since it can be used for many other combat support tasks. The UC-123 accomplishes its mission at a much faster rate but is entirely committed to herbicide operations since its configuration does not lend itself to easy modification. Likewise, the amount of tractors and their desired organization (sections, companies, battalions) would be a function of the increased costs that the decision maker might be willing to accept to gain the benefit of a two dimensional surveillance capability.

If the results of this study are to be useful in the allocation of funds to foliage removal/crop destruction missions, the decision maker must develop a detailed situation estimate and employment model. This would include a threat analysis of enemy forces and capabilities, an estimate of friendly forces and objectives, and a contingency analysis of possible commitment areas. If this were accomplished and if an RVN-type environment were encountered in the scenario, then the results of this study may be applicable in determining a proper mix of systems to effectively accomplish these two combat support missions.

APPENDIX A

DETAILED HERBICIDE COSTS

A. UC-123K

1. Yearly operating cost for a squadron in Pacific Air Force (PACAF): [Captain Wallace]

Direct element

Modification/spares	$ .5 million
Maintenance - Operating	$1.7 million
Support Equipment	$ .1 million
Personnel	$2.9 million
	$5.2 million

Major support commands

Base operating	$ .7 million
Depot Maintenance	$1.2 million
Other	$1.3 million
	$3.2 million

TOTAL = $8.4 million

This figure is for 12 aircraft. Thus the operating cost for one aircraft is $700,000 per year.

2. Modification costs [Miss Lucky]

a. Installation of the Hayes AA-45 system. Total of 51 aircraft modified.

$1.4 million	Hardware
$ .3 million	Installation
$ .2 million	Initial Spares
$1.9 million	

b. Engine modification. Total of 13 aircraft.

$36.1 million	Hardware
$11.2 million	Initial spares
$ 8.1 million	Installation
$55.4 million	

c. Armor plating. Total of 31 aircraft.

$400,000	Hardware
$100,000	Initial spares
$100,000	Installation
$600,000	

B. UH-1H

Security costs for UH-1 herbicide missions. Direct flying hour costs for AH-1G: $64 per hour [DA FM 101-20 1970] or $32 per mission. If approximately $70 were allowed for munitions and salaries of pilots, the cost of one AH-1G on a security escort mission would be $100.

APPENDIX B

DETAILED COSTS FOR TACTICAL LAND CLEARING

A. Cost of lubricants and filters. The <u>Caterpillar Performance Handbook</u> (Sec. 21, p. 5) gives a quick estimate of $.26 per based on oil at $1 per U.S. gallon, grease at $.20 per pound, EP oil at $1.10 per U.S. gallon, and filters at U.S. Consumer's List Prices. Under heavy operating conditions, these costs increase by 25 per cent.

B. Typical repair costs over a two-year period for medium tractor and Rome kit in RVN: [Major Bennett]

Number	Equipment	Unit Cost	Total Cost
5	Engine	$6,129	$30,645
2	Transmissions	$4,498	$ 8,996
1	Winch	$4,750	$ 4,750
5.5	Cabs	$1,600	$ 8,800
18	Cutting Blades	$ 278	$ 5,004
2.5	Blades	$1,887	$ 4,718
1.2	Radiators	$1,200	$ 1,440
2	Track assembly	$1,249	$ 2,498
			$66,850

C. Security costs are based on the approximate field strengths of an armored cavalry troop and a mechanized infantry rifle company (-). Usually, the troop will field approximately 130 to 140 men while the infantry company would have between 100 and 120 men. The cavalry troop would have 20 or more tracked vehicles and the infantry unit would have 10 to 15.

D. Costs for a light observation helicopter are based on direct flying hour costs of $30 per hour. [DA FM 101-20 1970]

E. Transportation Cost to RVN:

Shipping, Surface	General Cargo ($/Ton)
Line Haul within U.S.	$40
Port Handling, West Coast	$21
Ocean Shipping	$72
Port Handling, RVN	$14
Other	$ 3
	$150 per Ton [DCSLOG 1971]

D7 Tractor: 16 tons x $150/ton = $2400

Rome kit and blade: 6 tons x $150/ton = $ 900

Equipment weights: [Mr. Soules].

APPENDIX C

DETAILED COSTS FOR FIREBOMBING

A. Control costs are based on direct hour flying costs of the LOH which are $30 per hour. [DA FM 101-20 1970] This coupled with the pilot's salary and the ground commander's representative yields a control cost of $25 per mission.

B. Thickened Fuel:

Pounds of M4 Thickener Needed for Various Blends of Thickened Fuel

Gallons of Gasoline	4%	6%	8%
40	5	7½	10
50	6½	10	13½

[DA TC 3-366 1965]

Ten pounds of M4 thickener are used with each drum (55 gallon) of gasoline. M4 thickener costs $1.30 per 20 pound can. [DA SB 700-200 1971] Using a cost of $.15 per gallon of gasoline, a drum of thickened fuel costs $8.15.

$8.15/drum x 20 drums/mission = $163 per mission

APPENDIX D: DATA SOURCES

The personnel listed in this appendix contributed in the assembly of data for the study. The contributions and the office/address (as of June 1971) are listed as documentation.

1. Aerial delivery of herbicides.

Mr. Carlton W. Carter: USAF Deputy Chief of Staff (DCS), Systems and Logistics (S & L), Washington, D. C. Costs of herbicides to include transportation and storage.

a. UC-123K

(1) Miss Joyce E. Lucky: USAF ODCS, S & L, Washington, D. C. UC-123 modification costs for engine modifications, spray system, and armor plating.

(2) Captain James A. Wallace, USAF: Office of the Comptroller of the Air Force, Washington, D. C. Procurement and operating costs for the UC-123K.

(3) Major Robert Pyatt, USAF: ODCS, Plans and Operations (Special Operations Division), Washington, D. C. General information about herbicide operations.

(4) Major Peter D. Hidalgo, USA: Office of the Assistant Chief of Staff for Force Development (OACSFCR), Washington, D. C. Verification of sortie duration and sortie generation rates.

(5) LTC Kenneth M. Cooper, USAF: ODCS, S & L, Washington, D. C. Operating cost for A-1E.

(6) LTC Arthur L. Monaham, USAF: ODCS, S & L, Washington, D. C. Munition costs for FAC's.

(7) Major John D. Sims, USAF: ODCS, Programs and Resources, Washington, D. C. Hourly operating costs for the OV-10 and A-1E.

b. UH-1:

(1) LTC Manuel L. Sanches and LTC Robert G. Rudrow, USA: OACSFOR, Washington, D. C. Aerosol system and capacity, attrition rates, security configurations, mission duration, and system coverage.

(2) Mr. F. X. Donaldson: OACSFOR, Washington, D. C. Maintenance factors and expected life of UH-1.

(3) Mr. Drake: Operations Manager, Agricultural Aviation Engineering Company, 1333 Patrick Lane, Las Vegas, Nevada, 89109. AGAVENCO System: Cost, size, maintenance factor, and capacity.

(4) Major Robert Howe, USA: Engineer Strategic Studies Group, Washington, D. C. Personnel salaries costs and transportation costs for the AGAVENCO.

2. <u>Tactical Land Clearing</u>.

a. Major Richard Bennett, USA: Engineer Strategic Studies Group (ESSG), Washington, D. C. D7 tractor and Rome kit repair costs and rates.

b. Mr. Jim Guthrie: Supervisor of Defense Services Section, Caterpillar Tractor Company, Peoria, Illinois. General information about the Caterpillar tractor.

c. Mr. J. T. Soules: Vice President of International Department, Rome Plow Company, Cedartown, Georgia. General information about the Rome clearing blade and kit.

3. "Slash and burn" Clearing.

Mr. Elton Underwood: ESSG, Washington, D. C. Payment rates for indigenous clearing crews and verification of clearing rates.

4. Firebombing.

LTC Robert G. Rudrow, USA: OACSFOR, Washington, D. C. Security, control, equipment, and duration of the missions.

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