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Survey of Human Factors Problems in Missile and Communications Systems

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6 SURVEY OF HUMAN FACTORS PROBLEMS IN MISSILE
AND COMMUNICATIONS SYSTEMS.

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FOREWORD

In 1959 and early 1960, members of the ELECTRONICS Task visited ten installations in CONUS and 29 installations in Europe obtaining validation data on the Electronics Selection Battery. The trip provided an opportunity to observe the Army's missile and communications systems in operation and to obtain the views of operating personnel at all levels on the human factors problems which they had personally encountered or observed.

Research Memorandum 60-17 presents in considerable detail such observations and impressions as were considered pertinent to a developing human factors research effort applied to missile and communications systems. The material is presented primarily as background which may be useful to personnel engaged in human factors research on electronics or related systems. At the same time, the observations reveal a number of specific problems in need of human factors research solutions and in some instances point to possible approaches.

SURVEY OF HUMAN FACTORS PROBLEMS IN MISSILE AND COMMUNICATIONS SYSTEMS

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SURVEY OF HUMAN FACTORS PROBLEMS IN MISSILE AND COMMUNICATIONS SYSTEMS

The development and application of electronic equipment has resulted in major changes in military strategy and tactics, and in the training and utilization of manpower. Many of the new tactical organizations depend directly on the effective functioning and successful utilization of complex electronic equipment incorporated in missile weaponry and communications systems. The components of such systems are so interdependent that failure of either man or machine, at any point, can mean total failure. In terms of national defense, the cost of failure leaves little room for human error or inefficiency.

It is essential, then, to know the characteristics and limits of human performance in relation to mission, materiel, and conditions under which a total system is to function. If the total system is to be depended upon to operate at its best at any time, such factors must be taken into account at every phase of systems development, from design of the physical equipment through the selection, training, and integration of the crew which is to man the system.

The activities of the ELECTRONICS Task, established in the Personnel Research Branch in FY 1958, have been largely directed toward improved selection of enlisted personnel for training in electronic maintenance, a major aspect of the human factors problems in electronic systems. An experimental selection test battery has been developed, and is currently being evaluated in terms of criteria of success in school and on the job. When the experimental tests were being administered to on-job incumbents in missile and communications systems in 1959 and early 1960, advantage was taken of the opportunity to examine equipment, to observe actual systems operations, and to interview knowledgeable personnel with respect to the human factors problems encountered in electronic systems operation. The present Research Memorandum, based on the survey, records observations considered pertinent to current and future research oriented toward improving electronics systems operations. The report is designed to serve three specific objectives:

1. To present a summary of human factors problems recently identified in operational missile and communications systems.

2. To focus attention on those human factors problem areas which are amenable to research and have promise of important payoff to the Army.

3. To indicate some steps toward providing research answers to these problems.

The types of human factors problem encountered fall into three broad classes: 1) problems of task organization and work methods to maximize system effectiveness; 2) equipment design in relation to human factors; and, 3) other conditions which affect performance. The problems cut across the various systems surveyed, and extend also to systems still under development. The research objectives and also the methodologies employed must therefore apply under varying conditions. For example, there are problems which may be peculiar to a given system scheduled to be replaced by improved designs. Short-term studies would be needed to facilitate operation of present equipment, but such studies would also look toward extraction of principles generalizable to the anticipated system. Such work could also lead to recommendations for equipment design features to be incorporated in the future system.

Ten installations in CONUS and 29 installations in Europe were visited. Particular attention was paid to the identification of problem areas that are militarily important. It is also important that the problems be considered in relation to specific types of organization, so that the problems may be studied in their functional setting, with interdependencies fully considered. A list of the organizations visited is presented in Appendix B. The following section of the Research Memorandum is devoted to a brief description of the systems included in the survey.

SYSTEMS VISITED

CORPORAL

The Corporal is a Field Artillery surface-to-surface guided missile system with atomic capability. A battalion of over 300 men fires one missile and at the same time readies a second missile for firing. The system is mobile, having over 100 vehicles. Seventy MOS are represented in the personnel required to operate the total system. The SOP for lauching the missile fills 60 pages. The high potential for error is obvious. Equally obvious is the disastrous effect of error.

HONEST JOHN

Honest John is a Field Artillery ballistic rocket system, mobile, self-propelled, with atomic capability. It is designed for "shoot and scoot" artillery tactics, its range being less than that of the Corporal. The battalion manning the Honest John consists of 230 officers and men in a Hq and S battery and a firing battery. Upon receipt of a fire mission, the Assembly and Transport platoon and Firing platoon move out from a hide area to surveyed firing sites, prepare the missile for firing, fire, and move to a hide area again.

THE MISSILE COMMAND

The Missile Command is a new type of organization which incorporates in a single command the functions of the Corporal, Honest John, and Armored Infantry, and the support services--Ordnance, Signal, Engineer, and Surveillance. This is the type of organization that, in the future, will have to be considered in studying utilization problems in surface-to-surface missile systems. The ultimate replacement of Corporal by Sergeant and possibly of Honest John by Little John may also affect some of the work of operators and maintenance personnel. One of the units within the Missile Command, the Aviation Company termed the Sky Cavalry, is concerned with target acquisition. It is relatively new in organization and type of equipment used. In this unit special problems of utilization exist, particularly in the employment of the surveillance drone for aerial photography and of long-range radar in the detection, location, and identification of moving targets.

THE LACROSSE

The Lacrosse is a later generation guided missile with atomic capability. It is small, light, and highly mobile, using solid propellant. The warhead is of the newer "go-no-go" type. A split-ring device makes assembly of warhead and rocket simple and rapid. The missile is easily and quickly checked--even in the original container in which it was delivered to the user--by automatic testing equipment which can detect malfunction in the missile or in the testing equipment itself. The assembled missile is transported and launched from a transporter-launcher vehicle. The vehicle is also equipped with automatic testing equipment. On a typical mission the Fire Direction Center would make all necessary computations for programming the missile flight; the Launcher Section would move to the launching site, check and lay the missile, and program its flight--following FDC computations--to a particular area in the sky where the Guidance Section has prepared to intercept it. Pre-programmed command guidance would then begin. The Guidance Section would have moved to a predesignated site, relatively close to the enemy, set up its equipment, and awaited the launching of the missile. The vehicles must operate over varying terrain, during any kind of weather, and either by day or by night. The men sometimes have to back-pack their equipment.

THE REDSTONE

Redstone is a large, heavy, liquid propellant, inertially guided missile with atomic capability. Movement, assembly, checkout, erection, and fueling all involve considerable equipment and numbers of personnel. Because of the multitude of controls that must be applied and the short period of time involved, many operations are performed simultaneously. The timing and sequence of checkout procedures must be controlled very carefully not only to assure adequate check on malfunctions but also to prevent erroneous indications of malfunctioning. The Firing Section Chief coordinates the activities and controls the sequence of checkout operations through communication with the appropriate personnel.

THE NIKE

The Nike guided missile surface-to-air system is designed for ground-based defense against aircraft. Two versions are currently in use, Ajax and Hercules. The latter is the more recent development and has superior capability in range and destructive power, including atomic capability. Nike Zeus, the anti-missile missile, is still under development. The Hawk (Homing All the Way Killer) system, just now being put into operation, is designed for defense against low-flying aircraft, and may be an adjuct to the Nike system of air defense. A Nike site consists of the Fire Control area and the Launcher area, separated by about a mile. Operation of a Nike installation in CONUS requires over 100 men and 6 vehicles. In Europe an additional 35 men and 35 vehicles are required. The Nike system usually operates as a fixed installation designed for defense of a fixed geographical area, although the system--at least the fire control equipment--can be moved. In CONUS, each primary defense area is surrounded by a ring of Nike sites, all fixed installations. In USAREUR, alternate launching areas are provided, each battery being required to maintain mobile capability. About 35 vehicles must be kept constantly in readiness for movement. However, movement is not actually practiced because of the cumbersomeness, potential for damage, and possible error in reassembling the equipment.

COMMUNICATIONS SYSTEMS

Some of the major types of communications organizations visited were:

- Fixed station telephone exchange
- Fixed teletype center
- VHF radio relay station
- Microwave relay station
- Operational (tactical) Signal Company
- Signal Company within Missile Command
- Signal Service Company
- Signal Field Maintenance Shop
- Army Command and Administrative Network--Receiving station, Transmitting station, and Command Center

The mission of the communications organization is determined by the types and echelons of organizations served by the Signal unit; similarly, the kinds and quantities of equipment used and the distances involved vary with the mission. The fixed station telephone exchange, which is part of a Signal battalion spread across 850 miles of territory, and which provides communication from Berlin to Paris and to all telephones in NACOM, is a different kind of operation from the individual microwave and VHF relay stations. The operational Signal company which provides tactical communications to combat units is different again. The Signal field maintenance shop visited in USAREUR supplies 3d and 4th echelon maintenance support to Army airfields, MP units, CIC, hospital broadcasting systems, Hammond organs, radio networks, fixed teletype, and telephones.

The communication system employed to meet the requirements of atomic warfare is the area (or grid) system. Responsibility for the communication system within the division area, down to the battle group, rests with the Signal battalion of the division. The battle group is responsible for communications within its own command post and to its subordinate elements. Communication sub-centers are established throughout the division area by teams from the division Signal battalion. These subcenters then establish communication with battle groups and other units in their area of responsibility. The number of communication centers to support an area depends, of course, on the tactical plan.

A major advantage inherent in this system is the flexibility afforded. The multi-channel systems provided by the subcenters permit switching and patching of circuits to provide communications from subordinate units in the area to their parent units, thus eliminating the requirement for many direct circuits. Another advantage of the area system is that destruction of one communication center or command post does not mean loss of communication with subordinate units. Lateral communication between communication subcenters is designed to permit immediate rerouting of circuits to re-establish communications. A disadvantage is the difficulty of providing the ground security necessary for the widely scattered communication subcenters. One method employed to provide security for the subcenters is to locate the subcenter in the proximity of the battle group command post. When the battle group command post displaces, the subcenter must either displace or provide its own security.

Communications involves the use of much electronic and electrical equipment, and in the case of tactical units, much mechanical (vehicular) equipment. In fact, the complexity and quanity of communications materiel is little less than is required in missile systems. The kinds of equipment used varies considerably, and includes radio, VHF, UHF, microwave, wire, teletype, telephone, and walkie-talkie. The number of vehicles needed by an operational Signal company to establish and maintain communications is over 70. In any communications organization some individuals must be cross-trained to know several types of equipment. All the equipment requires human operation and maintenance; the effect of failure at any point, whatever the cause, can be far-reaching indeed in terms of total military operations.

PROBLEMS OF OPTIMUM WORK METHODS AND TECHNIQUES

The new weapons systems and the missions for which they are designed make unprecedented demands on human beings in terms of speed, accuracy, and dependable performance under unusual and difficult circumstances. In missile weaponry and in communications there is constant monitoring of complex equipment in operation. Much of the behavior required of the operator-monitor is implicit rather than overt. The observable behavior may be as simple as manipulating a few switches, but the mentation involved in selecting the switches or the vigilance involved in monitoring many different dials and lights may be far from simple. There are problems of visual and auditory perception, concentration and distribution of attention, effects of distractive noise, monotony, and isolation, and, on occasion, the effects of drugs and alcohol. In some instances, the noise is so bothersome that the operator turns down the volume deliberately, and thereby fails to note an interruption in communication. Although there are standing operating procedures to be used in case of equipment or reception failure, such as switching to a standby set within a specified time, operators sometimes get confused or even panic and, hence, delay resumption of operation. The recognition of incipient failure of equipment is a central responsibility of the operator-monitor. Violation of safety procedures can, in many of the jobs, be as disabling (or fatal) to personnel as enemy action. Also, disregard for fragility of the equipment or the necessity for a certain sequencing of operations can lead to damage or disabling of gear or injury to personnel.

In any of the weapon systems, the need to operate under conditions of impairment of personnel or equipment due to enemy action (or other cause) is a real possibility. In general, however, present training does not provide special procedures for such special circumstances. Nor does it provide adequately for operation under gas attach or for dealing with electronic jamming. The Nike system, for example, receives target information from higher echelons before the target is within range of its own acquisition radar. Errors in this advance surveillance information can be crippling if not recognized and corrected in time. Need for research to develop optimal procedures for meeting emergencies such as these is indicated.

Even where tasks have been supremely simplified through deliberate equipment design, ultimate reliance is on human beings to do the right thing at the right time. By and large, work methods, task definitions, and assignments are made on the basis of the best judgments of personnel who are familiar with the equipment and the mission and who have had experience with the predecessor man-machine-mission combination. Try-outs are evaluated on the basis of common sense bolstered by experience.

Optimum solutions to human behavior problems are often subtle rather than obvious. They require the quantification of pertinent behavioral variables, systematic variation of methods under controlled conditions, and meaningful, quantitative means by which to measure and compare the effectiveness of different methods in relation to the system's mission. By systematic observation, by application of substantive information regarding human capabilities and limits, measurement-oriented personnel psychologists might suggest restructuring, resequencing, or reassigning tasks to maximize reliability of human behavior. They can then proceed to evaluate empirically the resultant gains. They would select for special attention those tasks which are critical to success or failure of the mission. Examples of critical tasks that were observed in the various missile systems are presented below.

THE CORPORAL MISSILE SYSTEM

In the Corporal system, the position of the Battery Control Station Chief is critical. The Control Station is the convergence point for information on the various aspects of the system. The Battery Control Station Chief has to keep track of all the incoming information, integrate it, coordinate various aspects of the whole system, and make decisions in view of the state of various subsystems--whether to go ahead with the preparatory process, for example, or whether or not to fire. Confusion and error at this point can cause misfires, unnecessary delays, inappropriate cessation of the process, or even failure to fire altogether. Much the same can be said of the Firing Panel Operator position. The combination of functions in such positions as the two mentioned may well characterize missile systems in the foreseeable future. The functions involved should be studied scientifically, with a view to determining optimum work methods and procedures in light of the limitations and characteristics of human beings available for assignment to such positions. In some instances, there are differences of opinion as to optimal operational procedures. The SOP for the field sometimes differs in detail from the SOP used in the annual firing at White Sands. A determination of the single best method for given conditions might avoid dangerous confusion in the minds of operational personnel when an emergency demand occurs. Moreover, established checklist procedures are sometimes bypassed by the personnel, to the detriment of system effectiveness. Optimal procedures for operating under extended emergency demands are not presently known.

HONEST JOHN

In the firing of Honest John, final launcher adjustment must be made about two minutes prior to firing. Windset equipment and/or balloons have to be set up and operated; precise data have to be obtained and translated into launcher adjustments. These operations are critical to the success of the firing. Optimal procedures have not yet been developed.

LACROSSE SYSTEM

The Guidance Section Chief, his section, and its operations are critical in this system. The Section has to work with a variety of equipment--generator, resolvers or computers, radio guidance transmitting and receiving equipment, antennae, optical distance-measuring devices, etc. Members of the section have to carry this equipment, emplace it properly, calibrate it, read meters, set dials--actions which must all be performed in proper sequence as coordinated by the Guidance Section Chief. Research here would deal with optimizing work methods, considering individuals, the group, and the coordinating functions of the section chief.

IN-FLIGHT SAFETY CONTROL

The In-flight Safety Officer has the problem of quickly integrating information received by phone from two observers and information from two radar sets to determine to what extent a missile in flight is deviating from the assigned course corridor. If at any moment the information indicates an off-course flight, the missile must be aborted and brought to earth. Personnel manning this operation must be maximally alerted at the moment of firing, and for the duration of the flight--at most a few minutes. During this time observations, communications, and decisions must be made with split-second timing lest serious injury and damage result from an off-course missile. The system described is currently being placed in operation, and the responsible military personnel would welcome any assistance that behavioral scientists can furnish to enhance the system's effectiveness. Techniques of measurement and observation to make possible quantitative comparisons of proposed methods need to be developed.

SKY CAVALRY DRONE CONTROL

In the Aviation Company (Sky Cavalry) of the Missile Command, one of the most important problems is drone retrieval when radar lock-on is lost after the pictures have been taken. Currently there appears to be no systematic procedure by which the drone controller and radar operator coordinate their efforts toward drone retrieval. Human factors research might well be fruitful here in developing techniques which would maximize probability of drone retrieval and radar lock-on. Such research would determine the critical information to be communicated between drone controller and radar operator, the information each must have, and the most effective means for transmitting the information, whether by code, signal, or other means. Further, the specific actions to be taken and how they should best be coordinated for speedy recovery of the drone need to be determined.

LONG-RANGE RADAR GROUND SURVEILLANCE

In the case of the long-range radar system, the operator sits in a small van at a console with controls, a radar scope, loudspeaker, and chart of the terrain to be studied. His function is to detect, locate, and identify moving objects on this terrain. He can search with the antenna either automatically or manually, and while searching he observes a radar scope and listens to the loudspeaker for target signals. A target is detected by the appearance of a pip on the radar scope. When this occurs (and is observed!), the operator manipulates controls which move the pip to a designated position on the scope, at which time the pip disappears and the auditory signals indicate to the operator--if he is sufficiently trained and experienced--the nature of the target. He is then able to relay the location and identity of the target to appropriate personnel. The constant sound presentation throughout this operation is reported to be extremely irritating. Optimal procedures for scanning terrain, for interpretation of visual and auditory stimuli, and for differentiating between real and apparent targets have not yet been worked out.

GRID COMMUNICATION, RELAY STATION

The installation and maintenance of the radio relay station in the Grid Communication system is a highly critical operation. Three men acting as a radio relay team must meet a wide variety of requirements, and there is a great deal of strain connected with their duties. The team is responsible for a large truck, a 12-channel radio terminal with carrier equipment and accessories, a trailer, and gasoline engine-driven generators. The men have to find their way over strange terrain to some remote hill or mountain top using maps and any other information available. They have to set up the radio equipment, install tall antennae, keep the generators running, maintain the equipment and protect themselves and their equipment as well as they can. Considering the diversity of the job in terms of skills required, varying conditions and demands, and the dependence of the team members on one another, it becomes critical to apportion work assignments effectively, and to assure that appropriate procedures are followed when communication is interrupted or when the team is impaired through enemy action or other emergency. A continuing problem concerns the maintenance of team alertness and proficiency during a long period of quiescence.

GRID COMMUNICATION, PATCH PANEL, AND TRAFFIC CONTROL

Small groups are engaged in switching, re-routing, and tying-in various communications channels, in a fluid situation with constantly changing configurations. In order for communication to be maintained at or near optimal level, the responsible individuals must keep a clear picture of the current configuration, anticipate requirements for rapid changes, make rapid decisions, and implement the total "patching" procedure rapidly and accurately. Similar operations--with similar human factors requirements--are performed at Net Control Centers. Human factors research would seem indicated in this area for the identification of the critical factors involved, causes of failure or inefficiency, and the development of techniques for assuring optimal operation as much of the time as possible. Some of the kinds of questions that need research answers are:

> What information does a man need in order to meet the requirements of "patching"? How must the essential information be displayed to keep him informed and in a position to operate quickly?
>
> How much input in the form of information, orders, and requirements can an operator receive, store, and act on without undue delay or error? How do individuals differ in this respect?
>
> What are the interaction or team problems that affect performance?

EQUIPMENT PROBLEMS

Over the past several years, a great deal of research has been done in the area that has come to be known as <u>human engineering</u> or <u>human factors engineering</u>. The prime objective of this work is to incorporate in the equipment those features and characteristics which facilitate effective operation and maintenance by human beings. Both in the civilian economy and in the military services, great strides have been made in this direction, and psychologists working with design engineers have been in the forefront of this effort. Some of the types of problems they have worked on, just to mention a few, are information display, involving dials, meters, lights, and scopes; panel and work-place layout; illumination and color; sizing of equipment for prospective operators; accessibility for maintenance; legibility; and controls. The impact of human factors engineering is very evident in the area of missile weaponry, particularly in second generation models--a salutary development which has contributed greatly to efficiency in both civilian and military operations, giving men better, more powerful, safer, and more efficient means for war-making. These developments have not eliminated the need for human beings; they have changed the demands made on human beings. They have also introduced new requirements in terms of aptitudes, skills, personal qualities, and information needed to utilize and maintain the war-making systems. The need for decision-making, teamwork, maintenance of alertness, and dependability under a variety of conditions are accentuated by the new complex systems.

It is at this point that the human factors psychologist becomes involved anew in problems pertaining to the optimum utilization of human capabilities. While the problem appropriately permeates all considerations of design, the work of the human factors engineer is generally finished, at least for the time being, when the equipment is delivered to the prospective user. Operational personnel now have the problem of selecting, training, allocating, and maintaining teams to operate and maintain the equipment as delivered. Research effort is needed to identify the human factors involved in various tasks, to determine the optimum combinations of tasks, the optimum combinations of skills and abilities within a given team, the effects of various conditions and emergency demands on performance, and the like.

Even though human factors engineers do their work exceedingly well in providing well-designed equipment to the user, further field experience by operational personnel frequently brings to light additional limitations of equipment and suggestions for modification or redesign which can contribute materially to increased tactical effectiveness of a system. While operating personnel in their day-to-day work generate many suggestions, human factors research scientists, proceeding systematically through controlled studies, should be able to arrive at procedures better designed to increase effectiveness of a total system. Certainly human factors research scientists can do a better job if the starting point in their thinking is the given military mission rather than the given organization and equipment. Where the latter are already established, at least for the time being, it is still worthwhile to study general concepts and alternate approaches to given missions for purposes of future development of equipment and organization of activities.

Especially in the area of missile weaponry, the rate of development of electronic equipment has been great indeed. By the time a system is fully operational, its successor is well on the way. The Corporal is scheduled to be replaced by Sergeant, Honest John by Little John, Redstone by Pershing, Nike Ajax is being converted to Nike Hercules, and Nike Zeus, the anti-missile missile, is nearing operational use. The second generation system is universally an improved one, both in performance characteristics and from the view of human factors engineering. Inevitably, however, the role of the human factor changes, however subtly, with each change in design.

Several inadequacies of present equipment were reported by operational personnel during this survey. In the long-range radar system, for example, it is highly questionable whether visual and auditory presentations are optimal for efficient ground surveillance by a human operator. When the target pip is moved into the listening position for identification purposes, the visual presentation of the target disappears and the target must be tracked by sound alone. The horizontal line presentation on the radar scope represents range (left end is closest to operator, and right end is farthest away) at the particular azimuth at which the antenna is pointed. Thus, some mental rotation is required of the operator in orienting the target with respect to his own position. It would seem that merely rotating the current scope 90° counter-clockwise from its present position would be much more realistic in relation to the individual's position. However, a major redesign of the system is probably desirable, in light of the fact that the displays and controls are not in harmony with the human operator's normal perceptual habits.

In the Battery Control Van of the Nike system, the Early Warning Plotting Board is positioned behind the man who uses it. While it is of fundamental importance that each Nike battery have an accurate time indicator, and that all elements be synchronized, no clock is provided as part of the system. From the observations made, it appears that the illumination and color scheme in the Nike vans is far from optimal for efficient operation, compared, for instance, with that of the Missile Master. The range dial in acquisition range is not illuminated, nor is the acquisition-scanning-elevation dial, nor the computer operator's dial. The battery commander needs a light in order to prepare certain reports, but snapping on a bright light destroys the dark-adaptation of the acquisition radar operator. On the new PPI scope (adapted for the Missile Monitor) there is a need for an outside control for centering the sweep line. There are high-voltage hazards when the assembly is opened for such centering, and it is cumbersome to replace this chassis after adjustment. Some accidents have occurred.

The communications system within the Nike battery also has some features that were the source of complaints. The head sets are annoying when used for any length of time. Intercom sets with loudspeakers were suggested as an improvement. It was also suggested that ash-trays and lighters with foot-controlled switches would be a help in keeping equipment clean and operators less distracted. Ventilation of the vans also becomes a problem at times. Particularly in the communications units visited in Europe, there is the problem of personnel trained on U. S. equipment having to work with foreign-made (German) equipment. This problem usually requires some additional training on the foreign equipment.

CONDITIONS WHICH AFFECT PERFORMANCE

In addition to equipment characteristics which have an impact on system effectiveness, a number of conditions were observed in this survey which affect system performance. These conditions are considered under the following general categories:

Fatigue-stress-monotony

Team integration

Environmental conditions

Relationships with support services

Administrative considerations

These conditions affect the individual's state of readiness to perform his job, his motivations and attitudes, his relationships with others, his personal position on the team, his satisfaction-dissatisfaction, his feelings of status and group approval and acceptance of group norms. The objectives of research in this area would be to determine the degree to which the several conditions do, in fact, affect individual and system performance, and to devise means for circumventing, eliminating, or delaying the undesired affects. Such research requires 1) the selection of critical variables for study; 2) quantification of these variables; 3) development of a quantitative criterion of individual and system effectiveness; 4) manipulation of the critical variables under controlled conditions; and 5) determination of the change in system effectiveness attributable to given change in the critical variable. The various groups of factors were considered in relation to conditions obtaining in the various weapons systems included in the survey.

FATIGUE-STRESS-MONOTONY

Corporal. Extended military operations required in transporting, setting up, checking, and firing the Corporal give rise to problems of fatigue and the influence of fatigue on operational effectiveness. Instances were reported of men falling asleep while standing up during a training exercise. Performance of a crew in an actual firing gives evidence that the nature of the stress is different from that under field practice conditions. As one Warrant Officer put it, "I've had 19 firings at White Sands (annual practice firings), but I still get butterflies in the stomach each time." The interaction of stress and fatigue and their resultant effects on complex behavior in a critical military situation are a major concern with respect to the Corporal system.

Nike System. The jobs of Nike operators, particularly those working in fire control, and maintenance technicians are complex. Again, there is concern with the effects of fatigue, loss of sleep, and residual intoxication on the performance of complex tasks which often require fine discrimination and extreme vigilance. The heavy requirement of housekeeping and vehicle maintenance makes fatigue a familiar problem. In addition to potential for downgrading the efficiency of operation of the system, there is potential for damage to the equipment, and for injury to the operators themselves. Since much high-voltage equipment is involved and work space is small, impaired equipment and personal injuries are not uncommon. The consequences of small errors may be severe indeed. In

USAREUR, the danger is often aggravated by the need to quarter the men at considerable distances from the site, with increased travel time. With frequent foggy weather in Europe, the travel time cuts appreciably into available manhours. Inadequate day-to-day maintenance that may result from perfunctory checks or errors made in last minute preparations can nullify the effectiveness of the system. For instance, faulty range calibrations can misalign the radar and cause the missile to miss the target. Personnel working in the Nike system reported that identification of a target on the Aquisition Radar Scope is not easy, nor is it easy to see the pip on the Target Track Radar Scope. A lapse of attention in operating the Acquisition Radar and consequent failure to switch to the correct range could result in failure to pick up the target altogether. The effect of continued scope reading on visual efficiency is not fully known; it is known that it is monotonous and fatiguing to most operators, and that men differ in scope reading proficiency. To offset these deleterious effects, an effort is made to rotate men to other positions after two or three hours of continued operation. Another source of monotony and fatigue to which everyone in the van is subjected is the 400-cycle hum. It was reported that there have been cases of visual and auditory failure after several years of exposure to such stimuli.

Communications Systems. While personnel at fixed communications installations are not for the most part subject to excessive stress or fatigue, personnel in tactical units may work for long periods and under difficult conditions. The establishment of communications facilities for combat operations involves transportation and manipulation of much equipment, and the installation, adjustment, and operation of the equipment under conditions of time pressure and emergency. In addition, there is exposure to all sorts of unfavorable environmental conditions, such as extremes of weather, terrain, geographic isolation, and prospects of the need for defensive combat. It is within this constellation of conditions that communications facilities must be established and the complex equipment monitored and maintained in operational order.

Sky Cavalry. Similarly, in Sky Cavalry, members of small crew which operates the surveillance drone must work within a few miles of enemy-held territory. They must check out complex mechanical, electrical, and electronic equipment, launch the drone, control and track its flight accurately, activate the camera over the exact area to be photographed (while the drone moves at approximately 200 miles per hour), return the drone to home base, and parachute it to earth. Unless this is done quickly and accurately, the mission of the entire missile command may be frustrated. The drone may be lost, photos may be incorrectly oriented with respect to the terrain, or information may be otherwise unusuable or misleading. Needless to say, there is much potential for stress throughout the operation, and little allowable tolerance of error.

Long-Range Radar. The operator of the long-range radar (ground surveillance for moving targets) is subject to a continuous, distracting, auditory stimulus as the antenna scans the terrain. This condition can be fatiguing and monotonous. The effect on the complex operations required is unknown. It is reported that operators often turn down the volume to avoid the noise, possibly missing important information. The operator is also subject to considerable social isolation, being limited during the operations to communication with unseen persons. It is known that complex performance is often degraded under conditions of isolation.

STATUS OF TEAM INTEGRATION

Field Artillery Missile Systems. A major problem in the operation of the Corporal system appeared to be the integration of a crew to operate as a team. Since realistic field training operations are expensive, cumbersome, and time-consuming--even though they do not include an actual firing--the number of practices for any given crew is limited. Practice firings are experienced only once annually, with equipment permanently located at a fixed site--White Sands, N. M. Since personnel turnover rate is high, there is a continual requirement for integrating new operators into the team. Optimal composition of such teams in terms of personal characteristics of the individuals is not known. The problem of team integration is also a concern in Honest John, Lacrosse, and Redstone operations.

Nike System. Within the Nike fire control vans there are seven operator positions in addition to the switchboard operator. Policy requires cross-training of operators within each van, but no anticipation of possible need to operate with a reduced crew under emergency conditions. Since turnover here is also high, there is also a continuing need to train the crew to work as a team. The Nike system is in wartime status, both in CONUS and overseas, constantly engaged in manning an air defense operation. In Nike, as with Corporal, the only firing of a missile during peacetime occurs at the annual practice firing at White Sands. There exists a very real problem of maintaining a state of psychological urgency over extended periods of time. The aperiodic Operational Readiness Checks are directed at this need, but these also are recognized as an exercise immediately after they begin, and so become regarded as routine. It is reported that an actual firing is a qualitatively different experience from these OR checks, even for personnel with considerable experience.

Communications Systems. The need for team integration in communications organizations seems to depend on the particular mission, and would be expected to be most pertinent in tactical communications, such as in setting up and operating relay stations.

Sky Cavalry. In the surveillance drone platoon of the Sky Cavalry, teamwork is a sine qua non in almost every step of the operation: launching, tracking, controlling, retrieving.

ENVIRONMENTAL CONDITIONS

Missile Systems. In Corporal operations, extremes of weather and temperature play a very important role both directly in their effect on personnel, and indirectly through their effect on equipment, vehicles, terrain, and difficulty of movement generally. While some of the work is carried on in vans, most activity is out in the open. Since there is so much equipment--electronic, vehicular, mechanical--maintenance demands resulting from weather are sizable. Much the same problems characterize the rest of the missile command, including Honest John, Sky Cavalry, the support services, and communications systems.

The particular geographic location of a Nike site has immediate implications for the availability of many kinds of necessary materiel and services, such as food, water, housing, medical services, recreation, Ordnance and Signal support, transportation, and QM supply. Weather is also, of course, a variant with geography, but is of somewhat less concern with Nike than with the Corporal or other field artillery systems. The kind of support available also has an effect on the maintenance and supply tasks of the Nike personnel.

Communications. Tactical communications units are, of course, subject to much the same kind of exposure to geographical and weather discomforts as the units they are servicing.

RELATIONSHIP OF MISSILE SYSTEMS TO SUPPORT SERVICES

Relationships with support systems (Ordnance, Engineer, Signal) and the influence of such relationships on mission effectiveness vary considerably with the several weapons and communications systems, as well as with theater of command, geographic location, and garrison vs field operations. In some cases, there is insufficient delineation of the specific function of the support agency, particularly where newly developing technology is being introduced. Also, the relative competence and experience of maintenance personnel in the specific units, rather than the prescribed allocation of responsibility, often has a determining influence on who assumes responsibility for a given operation.

Research is indicated here to determine optimal assignments of tasks to user and supporter with respect to 1) effectiveness of the missile system, 2) efficiency of the supporting service, and 3) costs of alternative arrangements. Such research would need to comprehend a large number of considerations: Who is to be trained to do what? What equipment should be provided, and to whom? What are the transportation, communication, and supply problems, and what impact does time pressure have on operations? How do varying arrangements affect the system's readiness in emergencies? Research methodology in this area would need to include collection of operational record-type data, operational analysis by means of mathematical models, simulation, perhaps by means of computers, and manipulation of critical variables where feasible.

ADMINISTRATIVE CONSIDERATIONS

All of the problems discussed above are, of course, immersed in a gigantic administrative complex which is concerned with recruitment, selection, training, promotion, replacement, distribution, support, supply, housing, transportation, pay, and other factors which all have their individual and resultant effects on every soldier's motivation.

SUMMARY AND CONCLUSIONS

Concurrently with the test validation activities of the ELECTRONICS Task, visits were made to 10 installations in CONUS and 29 installations in Europe to observe the Army's missile and communications systems in operation and to interview operating personnel at many levels of command. The purpose of the explorations was to identify problem areas that are important to the Army, and at the same time researchable, promising good payoff in terms of increased effectiveness.

In the area of missile weaponry, the commands visited were Corporal battalions and Honest John units, Nike Ajax and Nike Hercules batteries and battalions, and Missile Master and Missile Monitor installations. A variety of communications organizations were visited, including Army Command and Administrative Network installations, an operational Signal company, Signal field maintenance shops, VHF relay stations, and telephone and teletype exchanges.

Three general classes of problems emerged from these activities: 1) problems of task organization and work methods to maximize system effectiveness, 2) equipment design problems, and 3) conditions which affect performance.

Missile systems are generally characterized by newness of equipment design and advanced concepts of mission and organization. The systems are beset with problems of work methods and procedures. There is urgent need to balance the efforts--human and mechanical--which go into the operation of a system for maximum effectiveness of the total effort. Communications systems, particularly those which serve the new tactical missile systems, are also faced with the need for developing man-machine-method combinations which will most effectively serve the mission of the system. Scientific research in these areas seems essential. It is particularly within the newer types of tactical organization such as the missile command, which combines artillery, infantry, communications, and various support activities under the same command, that intensive study should be initiated. Here organization of tasks and allocation of responsibilities are still fluid, specifications of procedures are being evolved, optimum methods for given missions and conditions remain to be determined, the limits and characteristics of given man-machine-method combinations are not fully known, and management is most likely to be problem-oriented.

The most feasible approach to fruitful study of these problem areas at this time would seem to be as follows:

a) Identify the problems and tasks or sets of tasks, in the operation of a given system, which are most critical to total system effectiveness.

b) Study the effects of current methods and conditions on performance both of individuals and of the system or sub-system. Such study performed either in the field or by simulation in the laboratory, would involve the development of adequate criteria of performance of the individual, sub-system, and total system.

c) Devise practical means of improving procedures and minimizing or circumventing undersirable influences.

d) Test the proposed methods and procedures, first, perhaps, in the laboratory, against a proximate criterion, and ultimately in the field situation with a fully adequate operational criterion.

As a specific outgrowth of the visits and explorations reported in this survey, two new research task proposals have been submitted to Army R and D for consideration in future work programs of the Personnel Research Branch. The task statements for the two tasks, Utilization of Electronics Personnel in Army Tactical Missile Systems, and Increasing Personnel Effectiveness in Tactical Communication Systems, are given in Appendix A.

APPENDIX A

APPENDIX A

Task Title: Utilization of Electronics Personnel in Army Tactical Missile Systems--TACTICAL MISSILES

Scope:

Need for and objective of research: Army tactical missile systems are complex, man-machine systems characterized by a considerable amount of electronic equipment. Although many operations have been automated, the need for electronic equipment operators, monitors, and maintenance personnel has not been and is not likely to be eliminated. The performance of these personnel is more critical than ever in an era in which speed, mobility, and destructive power are bywords of military operations. Inasmuch as the overall effectiveness of tactical missile systems depends ultimately upon the human element, the need for human factors research is signal.

A number of human factors considerations applicable to both operator and maintenance personnel in man-machine systems must be dealt with before systems performance can be maximized. These factors should be considered continuously from the initial stages of development of any man-machine system through the operational implementation stage. In general, these factors are basic operations of the system, kinds of information communicated, operational and environmental conditions of the systems, composition of the personnel in the system, and personnel and systems performance measures. The task will have objectives such as the following:

1. To determine the basic operations that men must perform in the system, including the operations that can be eliminated or simplified, and the best sequence in which operations can be performed.

2. To determine the kinds of information handled and communicated by men in the system, the most effective form of this information, and the most accurate and rapid means of communicating the information.

3. To determine the operational and environmental conditions of the system under which men must perform, whether these conditions are excessive with respect to human abilities, and if so, the techniques needed to ward off or minimize performance degradation.

4. To determine the optimal composition and organization of personnel in the system, the nature, number, and levels of abilities required.

5. To determine standards of performance for man-machine systems as well as techniques for assessing the dependability of the system and the major sources of error in the system.

Method of attack: This task will supplement research task entitled, "Selection and Utilization of Electronics Personnel." The mission and organization of a current Army tactical missile system will be studied (Corporal-Sergeant, Honest John-Little John). Human factors problems will be isolated and defined through studies involving records of system performance under various conditions. Through systems performance analyses, the sources, causes, and magnitude of errors will be ascertained. Systems and human performance measures will be developed. Human factors will be manipulated in studies concerning scope watching, sensory deprivation, multiple warning stimuli, information and communication, and other critical operations in the system. The effects of manipulating the human factors will be assessed through the system and human performance measures.

Potential military research end-results: (1) Information as to optimal composition, number, and organization of personnel in the system, (2) System and human performance evaluative measures, (3) Improved operator and maintenance personnel performance, (4) Improved information handling and communication, and (5) Critical human factors information applicable to future systems.

Task Title: Increasing Personnel Effectiveness in Tactical Communication Systems--TACTICAL COMMUNICATION

Scope:

Need for and objective of research: Recent combat developments and plans for future field armies emphasize speed, mobility, dispersion of forces over large areas, and extreme destructive power. Consequently, there will be an increased emphasis and reliance, in future military operations, on communications systems at all echelons. Technological advances have enabled the Army to meet a large part of its new communications requirements with new equipment. However, these new plans and developments have created a host of human factors problems. Since the realization of these revolutionary plans and developments is possible only if the personnel in the new complex man-machine systems are effective, it is imperative that human factors research be undertaken.

Tactical communications systems derive their criticality from the fact that such systems must be continuously tied in at both the information collection and implementation and control ends of military operations. Tactical communication systems have input functions--information collection, processing, and dissemination; and output tactical and command functions--integration, coordination, and control of implementation of missions. Examples of human factors problems that reside in these functions are: (1) Information Collection--monitoring techniques (auditory, visual, motivation), detection and neutralization of enemy countermeasures; (2) Processing--coding, decoding, interpreting, accuracy; (3) Dissemination--accuracy, clarity; (4) Integration, Coordination, and Control--accuracy, clarity. Additional human factors problems arise from the effects of speed, mobility, extended operations, emergency conditions, and priorities requirements. Finally, there are the problems that have emerged as a result of increased and more widespread communications capability to units and individuals--increased disruption and 'noise' in the communications channels.

Method of attack: Systematic observations and interviews will be conducted at various experimental and operational tactical communications organizations. Preliminary identification of human factors problems and assessment of their criticality and impact will be accomplished. Criteria of human and system performance will be developed. Current techniques, operations, and conditions will be experimentally modified in accordance with human factors principles and the effects evaluated by way of the human and system performance criteria. This approach will result in the resolution of the above mentioned problems and provide valuable information for future systems.

Potential military research end-result: (1) Criteria of human and system performance, (2) Increased information collection capability, (3) Faster, more accurate processing and dissemination of information, (4) Techniques for warding off performance degradation under emergency or extended operations, (5) Reduction of disruption and 'noise' in communication channels, and (6) Information applicable to future communications systems.

APPENDIX B

APPENDIX B

ORGANIZATIONS VISITED

CONUS

Command Center, ACAN, Pentagon

ACAN Transmitter Station, Woodbridge, Va.

ACAN Receiver Station, LaPlata, Md.

Washington Air Defense Sector, Ft. Lee, Va.

Systems Development Corporation, Lodi, N. J.

Human Engineering Laboratory, Aberdeen Proving Ground, Md.

584th Ordnance Detachment, Ft. George G. Meade, Md.

35th Brigade (AD), Missile Master, Ft. George G. Meade, Md.

2d U. S. Medium Missile Command, Ft. Carson, Colo.

The U. S. Army Artillery and Missile Center, Ft. Sill, Okla.

USAREUR ORGANIZATIONS

1 AD BN 5th MSL

1 AD BN 5th MSL C BAT

1 AD BN 5th MSL D BAT

6 AD BN 4th MSL

6 AD BN 4th MSL B BAT

6 AD BN 4th MSL C BAT

6 AD BN 4th MSL D BAT

6 AD BN 5th MSL

6 AD BN 5th MSL C BAT

67 AD BN 1st MSL A BAT

110 AV CO SURVL SETAF

39 FA BN 1st MSL

40 FA BN 2nd MSL

80 FA BN 1st MSL

82 FA BN 1st MSL

48 IN BN 1st AR RIFLE

USAREUR ORGANIZATIONS (Cont)

505 IN GP 1st AB LSA-C
4 OD CO GM IFC HM
86 OD BN
566 OD DET GM DS
32 SC BN CORPS
59 SC CO SUPPORT
102 SC BN MICRO WVE RR CO A
102 SC BN MICRO WVE RR CO B
102 SC BN MICRO WVE RR CO C
124 SC CO
3808 USA SC SV CO
3976 USA AD W SPT CM
OPS BR SIG DIV

EUROPEAN CITIES VISITED

Baumholder
Bitburg
Darmstadt
Frankfurt
Gonsenheim
Idar-Oberstein
Kaiserslautern
Miesau
Munich
Pirmasens
Vicenza
Wiesbaden
Worms
Zweibrucken