QUASI-ALGORITHM METHODS AND TECHNIQUES FOR SPECIFYING OBJECTIVE JOB/TASK PERFORMANCE REQUIREMENTS

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ARI





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for quasi-algorithmic TS of a number of Field Artillery Fire Direction Center activities. These TS are listed. Improved procedures for routine development are outlined. Diverse uses of quasi-algorithmic TS, as such, are discussed. In Part II a mathematical model for structuring TS is presented. Abstract representation of TS in terms of attribute vectors is explained. A binary vector model is developed with reference to a TS from Part I. The concepts of dominance and cardinality are introduced, and it is shown how they structure any TS or set of TS. Applications to training, task taxonomy, duty assignments, career fields, etc. are outlined. The improved sensitivity of a model employing fuzzy subset theory is explained briefly.

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QUASI-ALGORITHM METHODS AND TECHNIQUES FOR SPECIFYING OBJECTIVE JOB/TASK PERFORMANCE REQUIREMENTS

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FOREWORD

This report describes research conducted to explore the potential of quasi-algorithm methods and techniques for specifying objective job and task performance requirements. The report also presents a model for developing data structures compatible with the quasi-algorithm task specifications (TS). This research was performed by the Institute for Psycho-Logic (IP-L) under Contract DAHC19-78-C-0004 with the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI). This technological base research, done under Army project 2Q161102B74F, is of primary interest to job and task analysts and trainers.

Numerous Army functions such as training, personnel management, and manpower planning depend on detailed and accurate occupational information. Much of this information is produced by methodologies and techniques for describing and analyzing jobs and tasks. However, operational job/task description and analysis techniques suffer from various deficiencies -- arbitrary category systems, vague terms, restriction to individual level tasks, failure to relate jobs or tasks to unit missions, failure to order or integrate tasks, or failure to specify concrete task behaviors or performance standards. The exploration of the quasialgorithm methodology included a look at its potential to overcome these deficiencies as well as to provide standard occupational information with reasonable cost and efficiency.

Quasi-algorithm task specifications (TS), as described in the report, are basically tables of sequential overt (observable) and covert (mental) behaviors necessary and sufficient to accomplish the tasks. A basic feature and advantage of TS is that they are objective behavioral specifications that both describe and prescribe the tasks. TS are expressed in a format and language readily understood by trainers and the soldiers who perform the tasks. TS are neither so abstract as to be divorced from everyday reality nor so fine grained as to be useful only to very specially trained analysts. In short, TS are not based on an arbitrary category system and do not use vague terms but do order task behavior and do specify concrete task behaviors.

Perhaps the strongest contribution TS methodology can make is to produce occupational information directly adaptable to training. Since TS describe and specify the actual behavioral sequences required for and resulting in successful task performance, training and curriculum development in terms of TS can promote uniform and efficient task performance.

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When task performance is not successful, it means the TS was not followed. Because the TS is a series of sequential steps, the behavior of the unsuccessful task performer can be traced directly to the point in the sequence where the performer is having difficulty. In other words, TS are superb devices for the diagnosis or troubleshooting of learning problems. Because the precise step where the task performer is having difficulty can be located, TS usually indicate the appropriate remedy. For example, a soldier may be unable to perform a sequential step because he does not have the requisite knowledge, the necessary skill, or the appropriate physical or mental capability. The lack of knowledge or skill can be remedied by additional training through more fine grained TS. The lack of capability can only be remedied by the proper prior selection of soldiers for training (or perhaps by a change in equipment design or task procedure).

Besides being directly adaptable to curriculum development and the diagnosis if learning problems, TS methodology is compatible with the development of correspondence courses, soldier's manuals, skill performance aids, and skill qualification tests (SQTs). TS based SQTs can provide not only appropriate testing machinery but also the built-in capability for diagnosing performance problems. With the TS describing what needs to be done for successful task performance, the development of task and job standards becomes an easy next step whether the standard is measured by time to task completion, degree of error, or some other means. Again the diagnosis capability - to discover where performance falls below the standard - implies the appropriate type of remedy.

The creative use of TS might lead to their adaptation for the development of objective enlisted efficiency reports, to solidly founded job and MOS structures, and to better job assignment. TS are also advantageous in that they can be used for analysis at the individual or the group level of performance, although there appears some question as to whether TS can be used efficiently for a joint analysis of both the individual and group levels. As an additional plus, the method brings out the background knowledges and skills (elementarity) needed to perform a task or job. In this vein, the TS may be useful in "soft skill" description and analysis, especially since the method handles both overt and covert operations by treating a task as a process. A further benefit derives from the fact that the TS can be referenced to unit missions. Finally, TS are updatable, and their development per se requires no statistics.

Part II of the report presents a model for building data structures on FS. With TS forming a firm foundation for the data structures, much important information can be developed. For example, attributes associated with a particular task can be analyzed (as indicated in the report) and compared with attributes of other tasks in the same or a different MOS. These comparisons can shed considerable light on which tasks should be structured together, where cross-training in tasks would be most efficient, and what members of a group would be the best substitute task performers.

The attribute data structure could be adapted to provide a myriad of important information for personnel management, training, and other major Army functions. For example, in terms of job structure, the tasks composing a job may require a coherent set of related attributes or may require a conglomeration of unrelated attributes. A job whose task attribute structure is of the latter type is more easily restructured than is a job whose task attributes are interrelated and similar. As another example, the concept of dominance (presented in the report) of tasks based on their attribute structure can be used to assess training priority or task criticality. Since TS and their attributes can be codified, their pertinent codes can be used to sort tasks, for example, by skill requirements, mission, ARTEPs, scenario, preferred type of training, or "softness." The codes can also be used to describe common tasks across duty positions, MOS, or pay grade in terms of measured attributes rather than ambiguous common terms or words.

As fruitful as the TS methodology may be, it is not without shortcomings. The time and trained manpower to create TS may not be available. The cost of continually updating TS may limit their usefulness to a few key jobs or tasks. The crucial TS concept of elementarity may prove to be quite loose and to beg the real questions, i.e., what, where, when, and how must one teach soldiers so that they will possess the elementarity needed to carry out the TS. The making of more fine grained TS at a lower level of elementarity may increase costs prohibitively so that TS may cost a reasonable amount to create at a level of elementarity possessed by school graduates but entirely too much at the level of detail needed by beginning students. In brief, the cost aspects of the TS methodology have not yet been assessed.

Individual and group streams of behavior, which are important to describe and analyze for certain purposes, do not appear to be encompassed by the TS methodology. Soldiers, individually and in groups, may be doing unrelated tasks simultaneously or in sequence. For example, a soldier may attend a race relations seminar in the morning, prepare an artillery surveyed firing chart in the early afternoon, and "paint rocks" later in the day. Where that soldier's job begins or ends is not clear. An occupational survey methodology, such as the Instructional Systems Development (ISD) model uses, can include questions about the time spent in non-MOS tasks. The TS methodology is not directly designed to collect this type of information.

For the TS methodology to provide extensive occupational information, attribute data structures must be built on the basic TS. These attribute structures, as envisioned in this report, are subject to many of the same criticisms as present techniques. Attribute categories may be quite useful but also arbitrary. The usual problems concerning measurement and assignment of attribute values are bound to occur, fuzzy subsets (as presented in the report) notwithstanding. It may be difficult to handle the attribute structures across tasks and jobs of varying levels of elementarity, i.e., attribute values may change depending on the degree of elementarity at which a TS is written. The attribute measurement and applied coding scheme must be done by someone. As with factor ratings of training priority in the ISD model, questions will arise as to how, when, and by whom measurement and coding should be done. Further, what these possible attributes can or should be is neither determined, delimited, nor obvious. Finally, while TS may not require statistics in their development, attribute data structures built on the TS are likely to require a degree of statistical sophistication for their use. Thus, as with the manipulation and interpretation of task inventory data in the ISD model, the analysis of attribute data structures is likely to be confined to those who have the recessary amount of training, time, and machinery to use them.

One key problem in developing an Army occupational information system is the lack of explicit criteria by which a given methodology or mix of methodologies can be evaluated. Another key problem is the extent to which methodologies are underused. It is possible that a mix of the TS and the ISD task inventory methodologies would be quite valuable, but without specific evaluation criteria, the value of the mix cannot be determined. Further, measurement of their value, either individually or in a mix, is likely to be substantially hindered if the methodologies are as underused as the ISD methodology is currently.

Job description/analysis at the macro level and task description/ analysis at the micro level must be seen as an interrelated whole. TS methodology may prove useful for task analysis and for specifying tasks to be used in building an ISD task inventory. The task inventory methodology, if fully utilized, in turn may provide most of the macroscopic information necessary for an overview of an MOS or for other purposes requiring aggregate information. It may be that a developed TS attribute structure can create the ties that bind the integrated system together. In any case, TS methodology appears to have great potential for use, individually or in combination with other methodologies, in providing important occupational information for training and other crucial Army functions.

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PART I. QUASI-ALGORITHMIC TASK SPECIFICATIONS

OBJECTIVE SPECIFICATION OF ACTIVITY

To go from any point A to some other point B on this earth, especially if one has never visited point B, one must have a map so as to plot the route. To aim an artillery piece at a target with even a slight chance of hitting it the location of gun and target must both be represented on a chart. To build a modern house -- its frame, plumbing, wiring, etc. -- without an accurate set of blueprints is virtually impossible. To diagnose the extent of -- say -- a brain tumor and to apply some discriminative, effective radiation treatment without x-ray photos of the affected area is unthinkable. In a slightly different vein: to alter the processing of, perhaps, a payroll by a computer without a copy of the relevant programs is quite impossible. In each case an accurate and reliable representation of reality is needed in order to cope with it. Lacking such an <u>accurate</u> representation we are forced to make do with incomplete or inaccurate approximations and to grope as the blind person does in the visual world.

Each kind of representation provides information not only as to a set of component elements (locations, objects, parts, anatomical features, processing operations), but also about their relationships to each other. The whole is greater than the sum of its parts, because the relation(s) on the set of parts constitutes additional information not contained in the sum itself. Any whole that is not conceived as an atomic entity has a <u>structure</u>. When we think in terms of terrain, buildings or even the hunan body the structure is one of physical objects. In the case of a computer program, however, the structure is not physical. Coded instructions usually go through a series of transformations into sequences of electrical impulses, and it is the information carried by these pulses which determines the course of action that the computer takes. The structure is the <u>logical</u> structure of <u>logical</u> objects (computer instructions). Instruction <u>A</u> precedes instruction <u>B</u>, and instruction <u>B</u> precedes instruction <u>C</u> or <u>D</u>. and so on. In the case of physical objects (e.g., a piece of machinery) lever <u>A</u> moves gear <u>B</u> so as to engage either gear <u>C</u> or gear <u>D</u>. Clearly, the abstraction of the actual object (machinery) in a drawing also represents a <u>logical</u> structure (synonym: organization), albeit diagrammatically.

The uses of an accurate representation of (logical) structure are, of course, legion. A succinct illustration of its importance can be given with reference to one of the major scientific discoveries of this century. As James Watson (1968) tells it, he and Francis Crick deliberately set out to discover the structure of the gene at a time when conventional wisdom held that the puzzle of genetics could be solved only through biochemistry. Once the <u>structure</u> of the gene had been established it became transparently clear how genetic replication is guaranteed. The structure proved to be the key to an understanding of the genetic <u>process</u> and to its effective control. In a sense the information stored by the gene (a relation of chemical components!) is the program for "re-computing" or re-constructing the individual.

In this introduction we have -- with some deliberation -- mixed apples and oranges. When we referred to maps, blueprints and x-rays we were referring to representations of static entities whereas programs for a computer, for example, are representations of dynamic processes. A process, in turn, achieves some specific outcome (e.g., the living individual) from a set of anteceding conditions (e.g., forms of energy) in one or more transformations (e.g., according to the prescriptive instructions in the gene). Where there is minimal interference (e.g., from hard radiation) which changes the "program" itself that program will unfailingly compute and re-compute identical individuals (e.g., twins, or clones).

The technical term for the "program" that describes and prescribes any process is "algorithm." Properly speaking algorithms are abstractions that are valid only in the formal world of logic and mathematics and are no more to be confused with the actual process they describe/prescribe than a map is to be confused with the real terrain it represents. An algorithm <u>describes</u> what happens in the process of arriving at some given outcome, and, at the same time, the algorithm <u>prescribes</u> what must be done in order to attain this outcome. To accomplish the latter the prescriptive directions of the algorithm must be such as to <u>completely determine</u> the actions of the "doer" or executor so that he does neither more nor less than is required and only in the permissible order(s).

As we can see algorithms are very <u>specific</u>, i.e., they must not leave room for chance or choice on the part of the executor, nor may they be ambiguous or equivoval (allow two or more interpretations). If an algorithm has been properly prepared, it may be executed by anyone possessing the requisite capabilities. It is also <u>general</u>, because it can be applied to attaining the sought after outcome in each and every one of a defined set of situations. Lastly, algorithms <u>guarantee results</u>. When properly applied and executed, the sought after outcome is invariably obtained.

The importance of these three properties of <u>specificity</u>, <u>generality</u> and <u>resultivity</u> is undoubtedly self-evident and needs no lengthy discussion. As we have seen, an algorithm can be likened to a map, a blueprint, an x-ray and (loosely) to a plan of operation(s). We now see that a properly constructed

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algorithm will carry an inherent guarantee of being an accurate representation of a real process due to its possession of these properties (specificity, generality and resultivity). These properties are at once the promise and the test of a proper algorithm L^{\prime} .

The Description of Human Activity

The accurate and reliable description of human occupational and learning activity has been a problem of long standing. Job analysis was explained as follows in one early textbook.

"Job analysis involves dissecting a job both from the standpoint of the work and from the standpoint of the worker. It leads to a detailed job specification or occupational description which may be used for improving working conditions, promoting health and safety, perfecting methods of training, and supplementing employment procedure." (Burtt, 1942, p. 532)

In later years the desirability of more precise and detailed descriptions of job activity led to <u>task</u> analysis, i.e., of the major activities repeatedly performed by a given job or duty incumbent. The applications expanded beyond those envisioned by Burtt such as, matching the worker to (selecting for) the job, to include performance assessment, equipment design for optimal man-machine interaction, prediction of training requirements, occupational engineering, and so forth. In short, analysis and specification of relevant activity is seen to be the key to dealing effectively and efficiently with any matter involving human performance of any sort and in any way. As pointed out in the preceding section, some form of representation is necessary in order to deal effectively with any situation.

Whether at the relatively gross level of job analysis or at the fine-grained level of task analysis the source of information and the nature of the activity description have been problematical. For example, Burtt (1942) suggests that interviews of incumbents or observing their job performance are the ways to obtain the data for the descriptions. Refinements of this approach include questionnaires and recordings of observed activity, but do not alter the hearsay and intuitive and judgmental character of the methodology (see, e.g., Fine, 1955a, b, 1962, 1963, 1965; McCormick, Cunningham and Gordon, 1967; McCormick, 1970; Prien and Ronan, 1971). It will be recognized that incumbents may not be performing their job properly, that they are often unable to describe <u>how</u> they perform some task or other (e.g., tying some complex knot) and that many decision processes are cognitive, covert and, therefore, not amenable to outside observation. These latter capabilities are often called "soft skills." Therefore, emerging job or task descriptions must of necessity resemble the mediaeval maps drawn from accounts of travelers augmented by liberal imagination. The accuracy of these representations is hardly ever tested and verified, and normally accepted on faith.

So long as the foundations are not firm, any schemes erected on these foundations (e.g., performance tests, training plans and outlines) will have an arbitrary and vulnerable status. The issue was most clearly put in the opinion of an English judge in India, rendered many years ago in a case involving intricate statistical data, which held that while the (British) government is very fond of amassing statistics, of combining data and reaching intricate conclusions, one must remember that the original information comes from the lowly village official "who puts down what he damn well pleases." One example of elaborate and sophisticated structures erected on the problematical foundations of traditional task descriptions is a taxonomy of human performance². The validity of such a system of classification will be only as dependable as the validity of the data underlying it.

An Alternate Approach to Activity Description 3/

At the outset we began to explain the concept of the algorithm, its powerful properties and how these properties provide the key to an accurate and verifiable representation of dynamic processes. It may be seen that most, though not all $\frac{1}{2}$ task performance by human beings is of that type. The algorithm of a task provides its description, prescription and specification. The overwhelming majority of of industrial and military tasks can be specified in algorithmic terms. Before showing how this may be done, however, some further explanation must be made.

 $\frac{3}{1}$ A fuller treatment of material in this section can be found in Landa (1974).

^{4/} For a discussion of semi-algorithmic, semi-heuristic and heuristic tasks see Landa (1976, Ch. 5).

 $[\]frac{1}{2}$ A more comprehensive explanation of algorithms can be found in Trakhtenbrot (1963) and a rigorous mathematical development in Markov (1954).

^{2/} See, for instance, Wheaton (1968), Farina (1969), Theologus (1969), Chambers (1969), Theologus, Romashko and Fleishman (1970), Miller (1971a, b), Farina and Wheaton (1971), Teichner and Whitehead (1971), Levine and Teichner (1971), Theologus and Fleishman (1971), Levine, Romashko and Fleishman (1971).

We pointed out that an algorithm is properly valid only with respect to logical and mathematical problems. This is due to the requirement that there must be no room left for chance and choice. In the real world, unlike the formal world, all uncertainty about future events and/or conditions to be encountered by the task executor (performing individual) cannot be excluded so that some degree of chance and, hence, choice must of necessity enter. This violates the important requirements for absolute specificity and univocality in the prescriptive directions. In other words, because he cannot entirely foresee what will happen or what conditions will be encountered, the author -- the creator of the algorithm -- cannot provide <u>all</u> of the information required to completely determine what is to be done.

The difficulty can be overcome for <u>practical</u> purposes. Human beings have the unique capability of supplying missing information so that they can potentially follow directions that do not provide <u>all</u>, but only <u>most</u> of the information required to determine what is to be done. Their ability to follow such incomplete prescriptions increases the more the range of choice left to them (the requirement for independent judgment -- action not determined by given directions) decreases. When the range of choice has been reduced to triviality, the activity of the task executor is virtually completely determined and there is virtual certainty that the correct, missing information will be furnished. For example, rather than saying "go to a fire exit" it can be specified "go through the red steel door at the end of this hallway..." So long as the behavior (actions) of the task executor does, in fact, correspond entirely with the intent of the prescriptive directions uncertainty has been neutralized, and the above mentioned difficulty has been eliminated. Properly speaking the set of prescriptive directions in such a case does not constitute an algorithm but rather a <u>quasi-algorithm</u>. It differs from an algorithm in not absolutely and unconditionally possessing the properties of specificity, generality and resultivity, but only with an exceedingly high probability (e.g., .999...). For <u>practical</u> purposes the distinction vanishes.

Quasi-algorithms are extremely close approximations to (formal) algorithms, but they are not entirely identical. In the above example about the fire exit, it will be self-evident that the behavior of non-English speaking persons will <u>not</u> be determined by the given directions. The author and the recipient of the directions must share the same language and the same alphabet. Thus quasi-algorithms (not formulated in the universal language and symbols of mathematics) are valid only <u>relative</u> to a defined population, the English speaking population in our example. There is, also, a further way in which the validity of a formulated quasi-algorithm is relative to a defined population.

Assume a prescriptive direction within an algorithm which reads "integrate sin <u>t</u> with respect to <u>t</u> from 0 to $\pi/2$." If the direction for this operation is addressed to a population with mathematical sophistication (mathematicians, engineers), it can be presumed that the direction will be <u>elementary</u>. That is to say that virtually any individual from this sophisticated population will know exactly what to do in following the direction and will be able to execute the given instruction. On the other hand, if the addressed person were a soldier with no more than 12 years of education and little mathematical training, it is unlikely that he could comprehend and execute the given direction. For this latter person the instruction would have to be broken down into finer detail (into a more fine-grained algorithmic segment) in which each given direction is <u>elementary</u> for the addressed individual. Elementarity of prescriptive directions (for operations to be executed), then, is relative to a given addressed person, or as a practical compromise to a defined population.

The example of a mathematical calculation leads to another notable point. The execution of such a calculation takes place "in the head" and is not directly observable. In <u>cognitive</u> activity (e.g., evaluating a situation, reflecting about possible courses of action, reaching a decision -- the so called "soft skills") generally the process is covert. However, the results of that process, including intermediate results, will be or can be made overt. In principle the process of correct reasoning (about some though not all problems) can be algorithmically or quasi-algorithmically delineated, and the consequences of improper execution of component steps for overtly displayed results can be inferred. In turn, the place and character of the mistake in reasoning can then be deduced from the fault in the displayed result. This precise diagnostic capability confers on the quasi-algorithm its x-ray like character. As with no other extant technique the <u>internal structure of "soft skill" reasoning processes can be revealed</u> so that they may be precisely delineated, checked and guided. Also, it should be noted that the quasi-algorithmic specification of cognitive and, therefore, covert tasks is far more precise and defensible than the vague, intuitive statements in traditional job/task analytic approaches. Simon (1976) even demonstrates the uses of computer simulations (i.e., formai algorithms rather than quasi-algorithms) in identifying basic abilities underlying intelligent performance of complex tasks.

A final point to which attention must be drawn is the possibility of multiple, equivalent quasialgorithms, since there is often "more than one way to skin a cat." In principle, the number of such alternate ways of accomplishing identical ends could be quite large. As we shall see later in this report, this is not truly the case in many industrial and especially in military contexts in which specific ways of doing things are usually prescribed. That significant alternate versions can be reduced to a very few for practical purposes also follows from these considerations. First, absurd variants can be ignored for practical purposes (e.g., one does not change a tire on a car while standing on one's head). Second, trivial differences can be ignored (e.g., data may be entered into the FADAC keyboard either righthanded or lefthanded). Third, many alternative versions will involve nothing more than a rearrangement of some sequences of activity (e.g., in changing a tire; fastening lug-nuts immediately versus first starting each nut and then tightening the nuts in sequence).

Specifying Tasks in Quasi-Algorithmic Form

Up to this point it has been suggested that traditional approaches to describing much of "practical" human task behavior are found wanting, because of their imprecision and unreliability. At the same time it was hinted that a solid foundation to the description, prescription or specification of task-executing behavior could be provided by an algorithmic, or rather a quasi-algorithmic approach. The latter approach will merit consideration over traditional approaches <u>if and only if</u> the accuracy and sufficiency of the quasi-algorithm in describing/prescribing the path to successful task accomplishment can be objectively demonstrated, because traditional approaches have been found wanting in this respect.

It was said that a (quasi-)algorithm at once describes what happens in arriving at some set of outcomes (task objectives, results) and prescribes what must be done (by anyone) in order to arrive at these outcomes. Not only can anyone (from the applicable population) follow the established prescriptions, but (when properly applied) these persons may do so for any task in the defined set. For example, the algorithm for dividing one real number by another real number is applicable not only to dividing 243 by 3, or to dividing 3.1416 by 2.17, but to the division of <u>any</u> real number by another real number. These are the properties of <u>specificity</u> and <u>generality</u>. The third property, <u>resultivity</u>, guarantees (in the case of quasi-algorithms practically guarantees) that the sought after outcome will be (more or less) inevitably obtained.

The test or the verification of a quasi-algorithm -- the proof of its validity and reliability -follows directly from its properties. If every individual in a sample of people drawn from the applicable population performs a given type of task according to its prescriptive directions (perhaps with different, but applicable data sets) and everyone uniformly achieves the specified outcome, both, reliability and validity are demonstrated. In principle, the experimental proof is exceedingly simple and straight forward, and practice, as will be seen later, does not fall far short of the ideal. While the reliability of the developed quasi-algorithmic task specification (the consistency with which successful task execution will occur) can be estimated via distribution free statistical tests (such as, run tests), they will not really be necessary if such task specifications have been meticulously prepared.

A practical procedure incorporating this verification methodology takes the following form. A draft of a task specification is prepared. Then an expert in the subject-matter area within which the task falls is recruited to participate in the test procedure. The prescriptive directions in the draft task specification are read off to the expert step-by-step (operation-by-operation). The expert must agree to follow the given directions exactly. He may ask for clarification of any component direction from the "author" or person administering the draft task specification. Any such request is honored, noted, and a suitable revision in the prescriptive direction is made. So long as the <u>intent</u> of the given prescriptive direction <u>is clear</u> to the participating expert he must at once follow it to the letter and seek to escape from it. In short, he must try to demonstrate that the prescriptive direction(s), a note is again taken and a revision must be made. If he cannot escape and is forced to complete the task successfully, this constitutes convincing evidence that the established set of prescriptive directions -- the quasialgorithmic task specification -- has, in fact, totally determined (controlled) the expert's task execution.

The practical procedure is one that must be repeated (iterated) with several successive experts. Normally the initial iteration(s) will reveal flaws, and these must be progressively corrected. Since the flaws are being progressively eliminated, a stage is reached in which the participant expert's task execution is completely controlled by the prescriptive directions, and this will tend to be equally true (though not <u>absolutely</u> guaranteed) for succeeding experts. While "dottings of i's and crossings of t's" may still occur, these trivia no longer significantly affect the course of task execution. In practice the author (possibly in consultation with the experts) reaches a conviction that additional administrations will not reveal any more invalidating flaws and terminates the verification procedure; this conviction can be statistically evaluated and confirmed, as explained above.

An additional stage of development and verification will be required where the intended use of the task specification is instructional. This is due to inevitable differences in the elementarity of prescriptive directions for expert instructors and trainees. While the previously outlined procedure with expert participants guarantees the basic validity of the task specification, it does not guarantee that each of the component directions will be elementary for different (e.g., student) populations. An apprepriate level of elementarity must be developed by breaking down some prescriptive directions (e.g., "read the value on the scale") into a more fine-grained algorithmic segment (e.g., how to read that scale). Then the adequacy of the break-down -- of the elementarity -- must be tested with a sample of students in a manner analogous to that outlined for the experts.

TRIAL DEVELOPMENT AND TEST

In order to assess the practical feasibilities of the possibilities outlined in the preceding segment of this report an exploratory trial development and verification of some quasi-algorithmic task specifications was undertaken. The context chosen for this purpose was the Fire Direction Center (FDC) of some hypothetical Field Artillery (FA) Battalion equipped with 155 mm self propelled (SP) howitzers. Since it would be impossible within the scope of this exploratory project to deal with all activities of all members of the FDC, a plausible sample of certain standard FDC mission activities was selected. The activities included the individual tasks associated with the preparation of a surveyed firing chart, and those associated with a type of routine fire mission described in FM \pounds -40 (Ch. 18). In the latter the FDC receives a call for fire (CFF) from a Forward Observer (FO), a single piece fires several adjust rounds of high explosive (HE) ammunition with Fuze Quick (impact detonation), and this is followed by a fire for effect (FFE) phase in which an entire designated Battery (or Batteries) fires a specified number of HE rounds possibly detonated by time (Ti) or proximity (VT) fuzes.

Again it was not possible to deal with all tasks of all members of a standard FDC team. Therefore, only those tasks performed by normally active (rather than passive, supervising) FDC team members were selected and only those having some significant content. For example, the activities of the Radio Telephone Operator (RTO) were excluded, because he is confined to parroting the message traffic. Conversely, the decision processes of the Fire Direction Officer (FDO) were considered too complex for consideration at this exploratory stage. Thus, approximately, the tasks considered are those of the enlisted personnel (MOS 13E 10/20/30) that are regarded to be of sufficient significance to merit instruction in the U. S. Army Field Artillery School (USAFAS). It must be remembered that the intent of the project was an <u>exploratory trial</u> rather than an exhaustive development.

Development of Draft Task Specifications

As a first step pertinent documents were sought and obtained. They include AR 611-201, ARTEP 6-365 (Dec 1976), FM 6-40, FM 6-40-5, and a set of self-study guides prepared at the USAFAS, Ft. Sill, OK. It was chiefly these documents which were studied so as to obtain a preliminary grasp of the relevant situations and tasks. The realis... of these situations was checked against an actual Army Training Test for a FA Battalion (ATT 6-155, 3rd Armored Division Artillery, 1975). A sketch plot of events and their order in the routine fire mission were drawn up and conscure points noted. This plot and the questions were then reviewed with some knowledgable persons². Appropriate corrections were made. Gradually the set of individual tasks comprising the routine fire mission and their interrelationships began to emerge. Also, very general and provisional notions as to how these tasks should be performed began to be developed. They were again reviewed with the expert consultants.

At this stage some very brief and preliminary attempts were made to perform the identified individual tasks. These attempts were principally for the purpose of identifying relevant questions. These questions were then taken to USAFAS at Ft. Sill and reviewed exhaustively with an expert^{Ω'} by one of the present authors (EHK). Upon his return he taught back the procedures he had learned to the other author (FFK). Since this instruction had already taken on an algorithmic cast, it proved to be highly effective and efficient. In other words, both authors felt moderately confident that they now "knew how" and could perform the tasks in question with the support of the reference documentation.

As a next step each of the authors <u>independently</u> developed a rough draft specification for each identified task. It must be stressed that these rough-drafts were more in the nature of procedural notes than meeting the requirements of clarity, univocality, specificity, etc. of a proper quasi-algorithm. However, these rough drafts were sufficiently clear for mutual administration; A read off his prescriptive directions to B, took notes of ambiguities, failures, etc. and then B reveresed his role with respect to A. On the basis of this experience and of the notes made it was possible to draw up a set of draft task specifications in proper form, i.e., with extreme restrictions on choice, coverage of all possible conditions, elimination of ambiguities and equivocalities, and so forth. The level of elementarity at which the prescriptions were drawn up was presumed to be appropriate for an eventual <u>expert</u> test population.

At this stage, it may be clear, the draft task specifications had gone through possibly two cycles of revision (in the mutual administration). Next an expert was recruited— and talked through the prescriptive directions comprising each and every draft task specification. Surprisingly only a few minor

5/ Invaluable help in terms of advice and the loan of equipment was provided by LTC Robert E. Klein, CPT Stephen M. Lutz and SGM Charles H. Fagg of the U. S. Army ROTC Unit of La Salle College in Philadelphia, PA.

 $\frac{6}{2}$ SFC Russell Evans, Fire Direction Division, Gunnery Department, USAFAS.

 $\frac{27}{2}$ CPT S. M. Lutz of the La Salle College Army ROTC Unit.

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remaining mistakes were identified and corrected. Hence, the draft task specifications were thought to be ready for final test and verification cycles.

Economics of Development

An attempt had been made throughout to keep an accounting of the time spent in developing each drait task specification. A starting and stopping time was recorded on every draft document to make this possible. Hence elapsed time could be recovered. This account of time spent in the <u>actual drafting and revising of task specifications</u> is shown in Table 1.

 Table 1

 Development Times for Draft Task Specifications

	(10 141	ules)	
Task and Version	First Draft	Revision	lst Draft Plus <u>Revision</u>
010	60	60	120
020	240	70	310
030	180	60	240
040	210	180	390
051	90	-	90
052	30	30	60
053	60	-	60
060	30	-	30
070	20	-	20
080	10	-	10
090	60	45	105
101	45	-	45
102	30	-	30
111	30	-	30
120	5	-	5
130	15	-	15
140	5	-	5
150	30	-	30
160	30	-	30
170	10	-	10
180	10	-	10
190	5		5
Total Minutes	1205	445	1650
Total Hours	20 hrs 05 m	n 7 hrs 25	5 m 27 hrs 30 m

It should be noted, first of all, that actual drafting of the quasi-algorithmic task specifications could not begin until a given task had been identified (within the overall FDC mission) and mastered resonably well. The time for this background preparation was too scattered, uncertain, could not be summarized and is not included in Table 1. Also, the account is only for a single author's time. The time for the previously mentioned duplicate development was not included, because (a) these versions were extremely rough and preliminary, and (b) the accounting should reflect the economics of a normal, single (not duplicate) development. Finally, the times shown are those for formulating and handwriting a draft; the time needed to convert to typed copy is not included.

It will be seen in Table 1 that a grand total of some 27½ hours was devoted to arriving at revised "semi-final" task specifications. Of these 20 hours and 5 minutes were devoted to preparing the original drafts and 7 hours and 25 minutes to making revisions. Only six out of 22 distinct task specifications required any revision. The greatest amount of time for preparation and for revision was required in the relatively lengthy, complex and perhaps more cognitively demanding tasks related to preparing a surveyed firing chart. All of these draft specifications had to be revised. Of the remaining 18 only 2 needed revision.

Revisions, as that word is used here, refer only to basic changes in substantive content and organization (structure) of the task specifications. Hence they do not reflect <u>corrections</u> needed, for example, because of a mistake in the numbering of some prescriptive direction (see explanation of Index Numbers, p. 12). Such mistakes entail complex consequences, because subsequent Index Numbers inevitably also become incorrect, subsequent references to specific Index Numbers become misleading, and so forth. Correction of such mistakes tends to be time consuming, but such efforts are also not reflected in Table 1.

Verification Procedures and Results

The revised draft task specifications were taken to the USAFAS at Ft. Sill, OK and subjected to the test/verification cycles described in principle earlier (see, Specifying Tasks in Quasi Algorithmic Form). Through prior arrangements with the Fire Direction Division of the Gunnery Department, five members of its senior instructional staff² were made available as expert subjects for these purposes. Each of these senior instructors was intimately familiar with each task in the set, had himself performed it innumerable times, and had also taught it to others. Administrator of task specifications and expert subject (one per session) met in a quiet room with all requisite implements on hand. The following explanation was read to, and simultaneously by each participant expert.

PROCEDURE FOR CHECKING OUT TASK SPECIFICATIONS

The purpose of this exercise is to test the accuracy and completeness of certain Task Specifications. IT IS IN NO WAY A TEST OF YOUR CAPABILITIES! The tasks that are specified or described are tasks which you know how to do very well. Because you are an expert, we are asking for your help in this research effort which is being conducted for the Army.

Together we will test each of these Task Specifications in the following way:

l. I will read a set of precise directions as to what you or anyone else must do to accomplish each task. I will read the directions one at a time. You may want to read along with me in your copy. However, DO NOT READ AHEAD OR ANTICIPATE ACTIONS.

2. After a direction is read you may ask for clarification. For example, you may want to have the meaning of some word or phrase explained. The object is to have you UNDERSTAND PRECISELY WHAT THE DIRECTIONS TELL YOU TO DO. Don't do anything until you have it clear in your mind what you are to do.

3. Next, you must do EXACTLY what you have been told to do, BUT if there is a way of defeating the given direction while following it to the letter -- A WAY OF "DOING IT WRONG" THAT IS PERMITTED BY THE WAY THE DIRECTION IS SET UP -- you must try to find it. For example, if the direction tells you "find the next grid line" (but does not say next after which other one, nor in what direction) try to pick a wrong one. Or again, if the direction tells you to "align graduation with pinhole" (but not which particular pinhole), try to make trouble. At the same time, let's not quibble over things that are perfectly clear in context.

Please note that each direction that is listed is identified by a unique number. If there is no number in the "Branch to Index No." column, you go to the next higher number. In other words, you go to the direction listed immediately below the current one. Otherwise you go to the direction with the specified Index No.

Let me explain a few words that you will find and the standard meaning we have given them. First, there is the word STORE. It means that information is to be held for later use. At this time this means that the information may be held in memory, jotted down on a scratch pad, entered on DA Form 4504, or what have you. STORE does not care how it is done so long as the complete and correct information can be readily retrieved. Of course, RETRIEVE means simply that previously stored information is brought back, ready for use.

On occasion we may use a phrase "reference tick mark". It means the tick mark that represents a particular point (perhaps a battery) with reference to which some measurement or calculation is being made.

Whenever something "goes wrong" I will have to stop and take notes. Please be patient and wait. Also, after each task is completed I will ask some questions.

 $\frac{8}{}$ SSG S. L. Davis, SFC R. Evans, SFC P. Ives, SFC J. L. McFadden, and GYSGT L. E. Nowak (USMC).

The administrator then proceeded to reaj off successively the prescriptive directions in the various tasks. Normally the expert could easily envision the effect of each given direction. When there was any doubt, the step(s) was overtly performed using the available equipment. In each administration <u>all</u> conditions and branches were entered. That is, as soon as a branch entered under the assumption that condition A applied was completed, administrator and expert recycled to the beginning of the branch and assumed condition B, and so forth. Not only could the experts test each branch, but they could also judge whether every (practically) possible condition had been covered. Upon conclusion of each task and of all tasks the participant expert was asked for general judgments about the adequacy of the task specifications and for elaborative comments. The time required to complete this procedure for the set of 22 task specifications ranged from two to two and one half hours.

In effect, none of the participant experts was able to escape from the prescriptive directions that had been prepared. While some changes were suggested, these changes did not arise from a lack of validity of the task specifications.

Some changes were necessitated by idiosyncratic disagreements among the experts. For example, should identification of a chart grid-square be maintained by inserting a pin in it, making a pencil mark within it, or by pointing to it. Some changes were due to recent FA doctrinal changes. For example, the FDC team member known as the Computer announces the number of rounds to be fired and the fuze type to his Battery not when the fire mission is first announced (Task 13), but only on first giving Quadrant Elevation (Task 19). Some changes only endow the task specification with a greater range of applicability. For example, in establishing a Vertical Interval (VI) via a vertical shift an observer's location as well as a designated known point may be used as the reference location for the shift. Finally, a good many changes were of a refining, "polishing" type having scarcely any practical significance. For example, how to number grid lines on a chart with minimal or no margins.

Changes of the above types that suggested themselves during the verification procedure have been incorporated into the final versions of the task specifications which follow in the next segment.

TASKS AND THEIR SPECIFICATIONS

Tasks for which quasi-algorithmic specifications were developed are listed by title in Table 2 below. A fuller explanation of the Index Numbers follows (p. 12), but for the moment it must be understood that the first two digits of the Index Number constitute the Task Number.

<u>Table 2</u>

Index No.	Index No.	Individual Task Specification
010000	010300	Numbering Blank Firing Chart
020000	020470	Plotting Critical and Non-Critical Points
030000	030550	Constructing Azimuth Indexes
040000	040600	Constructing Deflection Indexes
051000	051110	Plot Target - Grid Coordinates Method
052000	052100	Polar Plot of Target
053000	053140	Plot Target by Shift from Known Point
060000	060090	Determine Range with RDP
070000	070050	Determine Deflection with RDP
080000	080060	Giving Rg and Df to Battery Computer(s)
090000	090130	Determine Angle T
101000	101130	Determine Vertical Interval from Map
102000	102120	Determine VI via Vertical Shift
111000	111170	Compute Site
120000	120050	Announcing Site
130000	130060	Record Fire Order and Announce Fire Mission
140000	140070	Re-Announcing Number of Rounds and Fuze to Battery
150000	150080	Compute and Announce Deflection to Battery
161000	161150	Compute Quadrant Elevation
170000	170070	Derive Time or Fuze Setting (FS)
180000	180050	Announce FFE Data to Battery
190000	190060	Announce Quadrant Elevation

Tasks 01, 02, 03, and 04 represent the preparation of a surveyed firing chart by a chart operator (HCO or VCO) to whom the requisite data are given (for example, a student at the USAFAS). The approximate context for this set of tasks derives from ARTEP 6-365 (Dec 76) on page 3-46, "Task (1)." A summary explanation of the purposes of firing charts and a general description of their preparation may be found in FM 6-40 (C1) pp. 16-11 to 16-14.

In preparing a Surveyed Firing Chart the first task to be accomplished is the numbering of the blank chart grid. This will be followed by the plotting of various critical and non-critical points, such as, battery locations, observer locations, registration points, etc. Next, the required azimuth (Az) indexes would normally be constructed, and then the appropriate deflection (Df) indexes. The simple sequence of these tasks

01 02 03 04

is mainly dictated by the progressive generation of more or less essential information on the Chart. Thus points cannot be plotted until grid lines have been numbered, and Az and Df indexes cannot be constructed until their points of reference (tick-marks) have been plotted. In principle, there is no true obstacle (lack of pre-requisite information) to constructing Df indexes before Az indexes so that the order of their possible performance is as follows.

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It should be noted that Tasks 01 through 04 represent the activities of a single individual rather than a team effort. While the individual (the Chart Operator) must have certain items of information (e.g., Az of lay), it can be easily presumed that this information was developed "long ago" -- was written down -- and is readily available to him. His ability to proceed is not contingent on the information concurrently developed by another FDC team member. Thus the specification of the permissible order(s) of task execution is a relatively simple matter.

In general the task specifications for Tasks 01 - 04 assume that a full 6400 p chart is being prepared. In the case of Task 01 a minor restriction in applicability exists. That is, where there is a grid zone convergence a sudden discontinuity in the grid line numerical sequence will occur rather than these numbers constituting a simple ones-incremental (or decremental) series. Under these conditions the Task Specification will not produce the sought after outcome. However, grid zone convergence is an extremely rare (and, therefore, practically negligible) condition.

In the case of Task 03 it is possible to construct successive supplemental Az indexes around the clock by constructing each successive index from the immediately prior one. Because this method will accumulate excessive degrees of error, it is frowned upon. While this argument does apply, as well, to Task 04, the Df indexes are constructed in the around-the-clock fashion. This seeming contradiction is due to the fact that Df indexes tend to be constructed only for a fairly restricted arc (principal direction or zone of fire), and -- Tasks 03 and 04 being quite similar -- the development of task specifications for both methods could be essayed.

For each of Tasks 01 - 04 the necessary implements are assumed to be on hand. That means: a blank firing chart has been taped down on a suitable surface, a 6H pencil has been sharpened to a wedge point, and a 4H pencil, red/blue pencil, green and orange pencils have each been sharpened to conical points, and that pins and erasers are also available. Also on hand are all of the standard "tools of the trade" including the Range Deflection Protractor (RDP), Coordinate Scale, etc.

Unlike Tasks 01 - 04, Tasks 05 - 19 represent the activities of a Fire Direction Center (FDC) team, i.e., the interaction of several individuals. The approximate context for this set of tasks is the simple fire mission illustrated in FM 6-40 (Cl) pp. 18-13 through 18-16. Constraints of time precluded the inclusion of all activities of all participants in this type of fire mission. Also, a comprehensive task specification development falls clearly outside the scope of an exploratory effort such as this one. While it was not possible to consider, in detail, the activities of a Forward Observer (FO), Fire Direction Officer (FDO), Chief or Assistant Chief Fire Direction Computer and of the Radio Telephone Operator (RTO), the tasks of the principal actors are all specified. By the latter are meant the Horizontal Control Operator (HCO), the Vertical Control Operator (VCO) and each of the Battery Computers whose activities normally parallel each other.

In this mission context the FO enters only in providing an information input: (1) the call for fire (CFF), (2) corrections of range (Rg), deflection (Df), etc., and (3) specifying when Fire for Effect (FFE), as opposed to adjusting rounds, is to commence. The FDO decides whether to accept, modify or reject the CFF and issues the Fire Order (comprising 10 elements of information shown below). If the Fire

FIRE ORDER STANDARDS				
ELEMENT	CURRENT STANDARD			
UNIT TO FIRE				
ADJUSTING ELEMENT/METHOD				
OF FIRE OF ADJUSTING				
ELEMENT				
BASIS FOR CORRECTIONS				
DISTRIBUTION				
PROJECTILE				
AMMUNITION LOT AND CHARGE				
FUZE				
NUMBER OF ROUNDS				
RANGE SPREAD, LATERAL				
SPREAD, ZONE FIRE, OR				
SWEEP FIRE				
TIME OF OPENING FIRE				

Order has been standardized, he need scarcely enter at all and can allow the mission to proceed on the basis of pre-established information. Thus for present purposes the FDO's role is "minor," but also too highly complex to be dealt with. By contrast the RTO is frequently involved in the mission (i.e., the coordinated activities of the FDC team), but, since he merely parrots the message traffic, his activities are trivial.

Triviality of the activity also led to the making of an underlying general assumption for the entire set of individual tasks, i.e., that FADAC was not available. Further, it was assumed that Graphical Firing Tables (GFT) rather than printed Tabular Firing Tables (TFT) would be used. The corrected set-tings for the GFT (elevation and time) are assumed to have been previously established. Also, it is assumed that a surveyed firing chart has been prepared (Tasks OI - O4).

The overall mission, then, is quite representative of an uncomplicated reality. It is a "textbook" mission of the type to which new trainees tend to be introduced. Most of the essential component tasks were analyzed and are specified, but not all. For example, no specification was developed for the announcement of Angle T, which is not an inevitable event. Neither were specifications developed for those activities that tend to occur after the FFE phase including the proper completion of DA Form 4504 (Record of Fire).

Subject to these qualifications the normal course of events in this kind of fire mission is as follows. The FO transmits a Call for Fire (CFF) containing these six elements of information: (1) Self-



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Identification, (2) Warning Order (i.e., type of mission), (3) Target Location, (4) Target Description, (5) Method of Engagement, and (6) Authentication. The very first element of the CFF triggers the Battery Computers to record the incoming information (plus such changes to Fire Order standards as the FDO may issue) and to announce the Fire Mission (Task 13). The third element of the CFF triggers both Chart Operators (HCO and VCO) to engage in the plotting of the target on their charts (Task 05 in any of 3 versions). Next the HCO determines the range (Task 06) and then deflection (Task 07), and then he announces both to the Battery Computer(s) (Task 08). Thereafter the HCO will proceed with the determination of Angle T (the angle formed at the target by the Observer-Target line and the Gun-Target line); this is Task 09. The VCO meanwhile will be determining the Vertical Interval (Task 10 in either of 2 versions), then compute Site (Task 11) and then announce Site to Battery Computers (Task 12). Df (from HCO) enables the Battery Computer to compute and announce the corrected Df (Task 15). Rg (from HCO) and Site (from VCO) allow him to compute Quadrant Elevation or QE (Task 16). The preparation for the first round in the Adjust Fire Phase terminates with the Computer's announcement of QE which causes the firing unit to fire the first shot.

In turn, observation of this shot leads the FO to transmit the necessary corrections (e.g., to Rg, to Df) which are noted. For the next and all subsequent adjust rounds the NCO, the VCO and the Computer(s) repeat these respective activities. The HCO will re-plot the target (Task 05 version 3), redetermine Rg (Task 06) and Df (Task 07), and then announce them (Task 08). The VCO will be duplicating the HCO's activities except for the overt announcement. The Computer(s) will compute and announce the corrected Df (Task 15), then compute QE (Task 16) and again announce QE (Task 19). The announcement of QE again causes a round to be fired by the firing unit(s).

When the FO transmits the FFE call the HCO and VCO repeat the same activities as during the Adjust Fire phase. However, the Computer(s) then reminds the Battery of the number of rounds to be fired and the fuze type per the Fire Order (Task 14) and then performs Tasks 15 and 16 as before. Then it is necessary to derive Time or Fuze Setting (Task 17), and then all the regisite FFE information is announced (Task 18).

A plot suggestive of the order of task execution in the representative, routine fire mission (per FM 6-40) is shown in Figure 1. To simplify the representation redundant activity (e.g., of VCO and HCO or of multiple Battery Computers) has been omitted. Tasks are plotted in their approximate phase relationship with time proceeding from left to right. Clearly, a discontinuity occurs each time a round is fired. Where the execution of an individual team member's task is contingent on an information input from an outside source (i.e., information that he does not receive in parallel or himself generates) this has been indicated by dashed lines.

Reading Task Specifications

1. <u>Headings</u>. The headings which precede each task specification are not a formal part of it. These headings merely provide some orientation for the reader as does the title of a book or a chapter heading. Undoubtedly, disagreements with the headings are possible, idiosyncratic changes might be made, but this would not affect the validity of the body of the task specification; as mentioned before, the label on the box is only suggestive of the contents and not a part of it

The headings suggest, first of all, the general mission context. This corresponds roughly to the use of "TASK" in an ARTEP and represents some outcome to be achieved (usually) by coordinated activity of a team or unit. Next it is suggested which team member (i.e., duty position) is likely normally to execute the task. Last, a task title is given to provide a convenient verbal label for the individual task.

2. <u>Index Numbers</u>. Merely to demonstrate the possibility of such a code, which would be absolutely essential for storing and retrieving this sort of information in a computer a provisional and arbitrary scheme was devised. The scheme works readily in the present circumstances, but for any operational purposes it is likely to need expansion. If a new and more capacitous code were to be devised, the present could be mapped into or onto the new one. In other words, the job of renumbering is easily accomplished.

The present Index Numbers are established in accordance with this code. The <u>first two</u> digits designate the individual task. For example, "Numbering a Blank Firing Chart" has the code Ol in the first two positions, i.e., it is Task Ol. The assignment of a number is completely arbitrary, but it must be a unique assignment.

The digit in the <u>third</u> position represents the version of the task (i.e., equivalent quasialgorithms leading to the same outcomes). If there are thought to be no known or permitted varients (alternate ways of doing the same ti'ng), the code is 0. Clearly, it is questionable whether particularly any of the set of Tasks 05 - 19 could be legitimately so coded, since most of them could be accomplished through FADAC. The pro's and con's need not be argued, since the obj `t, at present, is to explore and demonstrate feasibilities and not to develop some definitive design documentation.

Digits four and five designate the particular operation tection or decision within a given task and version. Assignment of these numbers scarred as their associated operations were written, but they do not necessarily designate the order so in which these operations must be executed. Again, the assignment of these numbers is arbitrary, but unique.

The sixth digit represents the version of an operation. If there are no known or permitted variants the code is 0. Otherwise codes 1 - 9 are assigned to distinguish the variants.

An Index Number according to the above code uniquely designates any elementary prescriptive direction, e.g., a version of an operation within a version of a task within a set of tasks. Hence, all items of prescriptive information may be stored, retrieved, addressed and ordered simply in terms of their Index Numbers.

Because a six-digit code is somewhat difficult to read (for human beings) a simplifying convention has been followed in the printed Task Specifications. The full, six-digit Index Number appears at the beginning of any task or task version. Thereafter, on the remainder of that page, those codes that do not change have not been printed (but must be envisioned to exist) so as to simplify reading and reader orientation. Only the fourth and/or fifth digits (which designate the corresponding operation) are printed. This is also true for Index Numbers designated in the "Branch to" column. Unless a branch outside the given task and version is intended only digits four and/or five are shown (and the rest are understood. The full six-digit code is not printed again until there is a page change (thereby uniquely identifying the page) and/or when the end of the particular Task Specification (TS) has been reached.

3. Operations. The middle column provides the prescriptive directions as to the actions to be taken or the decision to be reached. Actions to be taken may be either overt (e.g., "select a pin") or covert (e.g., "divide by five"). The obligation of the reader is to "get it completely clear in his mind" and in every detail what he is being directed to do. Decisions are represented in binary form. When there are multiple branches from a single point, this is handled through a succession of binary decisions.

4. Reading in Ordered Sequence. Begin reading any Task Specification at its beginning, that is with the operation whose Index Number is coded 00 in the fourth and fifth digits. Then proceed to the very next operation (No. 1). If no Index No. appears in the "Branch to" column next to that operation, proceed to the very next operation below; otherwise, proceed to the Index No. shown in the "Branch to" column, read it and go on from there. So long as there are no Index Numbers in the "Branch to" column always proceed to read the next operation below.

If any next operation involves a decision, the "Branch to" column will always contain two Index Numbers. The decision to be made is between the conditions represented by "YES" and by "NO." If "YES" applies, branch to the Index Number associated with it, else branch to the Index Number associated with "NO." In some cases, it will be seen, the reader is directed into an endless cycle by being referred back to the beginning or to the very same operation (decision). This amounts to saying "you must wait until the condition changes and, for example, some requisite information has been furnished."

If the operations specified are actually performed, the corresponding task will be completed when the operation labeled "END" is reached as the next one. Provided the hypothetical execution of the preceding prescriptive directions has been totally faithful to their intended meaning (has been absolutely determined by them), the task will have been accomplished successfully.

Specifications for Tasks 01 - 19

Index No.	OPERATION: Action to be taken or Decision to be made	Branch to Index No.
2	Orient chart so that long axis corresponds to indicated cardi- nal direction.	
3	Have initial reference coordi- nates been given?	
	YES	4 5
4	Do they designate LLHC?	2
	YES NO	6 5
5	Determine intersection of grid lines at center of chart; point to assure continuing identi-	۲
	Index No. 2 3 4 5	Index OPERATION: Action to be taken No. or Decision to be made 2 Orient chart so that long axis corresponds to indicated cardi- nal direction. 3 Have initial reference coordi- nates been given? YES NO 4 Do they designate LLHC? YES NO 5 Determine intersection of grid lines at center of chart; point to assure continuing identi- fication

vergence Condition.

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fication.

Index No.	OPERATION: Action to be taken or Decision to be made	Branch to Index No.	Index No.	OPERATION: Action to be taken or Decision to be made	Branch to Index No.
010060	Determine grid lincs forming lower left hand corner of chart.		20	Is the next grid line $(N \pm 1)$ the last one (farthest North)	
7	Using 4H pencil write (½" high) the first two digits associated with (e.g., below) the identi- fied easting grid line; write		21	on the chart: YES NO Is it above the one that was	19 21
	the next two digits associated with (e.g., left of) the iden- tified northing grid line.			labeled last on this axis? YES	22
8	Is there an easting grid line remaining to be labeled?	Q	22	NU Add l to the digit pair immediately below the line	26
	NO	19		to be labeled now.	
9	Is the next grid line $(N \pm 1)$ the last one (farthest East) on the chart?		23	Is the sum equal to 100? YES NO	24 25
	YES NO	8 10	24	Drop the "1" and retain only the "00".	
10	Is it to the right (East) of the one that was labeled last on thi axis?	5	25	Using 4H pencil write (½" high) the two digit sum next to the left end of the grid line	
	YES NO	11 15		immediately above (North) of the one labeled last on this axis.	19
11	Add l to the digit pair immediately to the left (West) of the line to be labeled now.		26	Was the northing grid line lab labeled last assigned "00"?	
12	Is the sum equal to 100?			YES NO	27 28
	YES NO	13 14	27	For calculational purposes only let 00 = 100.	
13	Drop the "1" and retain only the "00".		28	Subtract 1 from the digit pair immediately above (North) the	
14	the two digit sum in associa- tion with the next grid line to the right (East) of the last labeled one on this axis.		29	line to be labeled now. Using 4H pencil write (½" high) the two digit remainder next to the left end of the grid line immediately below (South) the	
15	Was the easting line labeled			last labled one on this axis.	19
	YES NO	16 17	010300	END	
16	For calculational purposes only		Mission	LASK SPECIFICATION	ring Chart
17	let $00 = 100$.		FDC Tea	m Member(s): HCO and/or VCO	ing chart
17	Subtract 1 from the digit pair immediately to the right (East) of the one to be labeled now.		Individ	ual Task: <u>Plotting Critical and N</u> <u>Points</u>	on-Ciltical
18	Using 4H pencil write (½" high) the two digit remainder in		Index No.	OPERATION: Action Lo be taken or Decision to be made	Branch to Index No.
	association with the next grid line to the left (West) of the last labeled one on this axis.	8	020000 1	BEGIN Has at least one item of rele-	
19	Is there a northing grid line remaining to be labeled?			vant information been given, received and stored?	~
	YES	20 30		YES NO	2 0
	нU	50	2	Do any points remain to be plotted (data in storage)?	
				YES NO	3 47

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Index No.	OPERATION: Action to be taken or Decision to be made	Branch to Index No.	Index No.	OPERATION: Action to be taken or Decision to be made	Branch to Index No.
020030	Select next item of data in storage.		16	Select pin and place into chart at a point opposite vertical	
4	Determine easting grid line whose numbers correspond to the first two digits of the easting (first) digit group.			<pre>(northing) scale that corresponds to the last two digits (to near- est 10 M) of the northing (sec- ond) digit group.</pre>	5
5	Determine northing grid line whose numbers correspond to		17	Leaving clear, precise pinhole remove and store pin.	
,	the first two digits of the northing (second) digit group.		18	Select straight edge and place horizontally so that pinhole made last is precisely bisected.	
0	On the chart determine the intersection of the two pre- viously identified grid lines.		19	Is pinhole just made located within 80 M or less of a grid	
7	Assure continuing identifica- tion of grid square (e.g., mark with pencil or pin. or			line or marked point? YES NO	20 21
	point) that lies NE of the identified intersection.		20	Rotate straight edge 45 ⁰ around pinhole center.	21
8	Is chart scale 1:25,000?		21	Is point in question a	
	YES NO	9 10		maneuver check point?	
9	Select 1:25,000 scale on co-			YES NO	23 22
10	ordinate square.	11	22	Is point in question a target	
10	ordinate square.			located by firing?	24
11	Looking straight down, place			NO	25
	(meter/yards held legible side		23	Select blue pencil.	26
	up) precisely over the identi-		24	Select red pencil.	26
	lied intersection, and align horizontal scale edge with		25	Select 4H pencil.	
12	northing grid line. Still looking straight down and maintaining established alignment move square East (right) until scale reading		26	Draw a line from a point 190 M left of pinhole to one 40 M left of pinhole, then skip to 40 M right of pinhole and draw line to point 190 M right of	
	(to the nearest 10 M) corres- ponding to the last two digits in easting (first) digit group		27	pinhole. Has tick mark (4 lines) been completed?	
	lies over the identified easting grid line.			YES	29
13	Is point to be plotted a non-		• 0	NO	28
	critical point?	16	28	Rotate straight edge 90° around pinhole center,	26
	NO	14	29	Does completed tick mark repre- sent a battery location?	
14	On scale estimate visually the precise location of the third			YES	30
	digit within the bracketing scale graduation; precisely		30	NU Is it A-Battery?	22
	adjust scale so that this location lies over the easting		30	YES	31
15	grid line.		32	Using red pencil mark "A" (*)	22
15	Select pin and place into chart at a point opposite the vertical (northing) scale that		52	high) in upper right quadrant of tick mark.	46
	corresponds to the last three digits of the northing (sec- ond) digit group; estimate pre-		33	Using 4H pencil mark "B" (לד" high) in upper ríght quadrant of tick mark.	46
	cise location of the last digit within bracketing gradu- ations as before.	17			

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Index	OPERATION: Action to be taken	Branch to		TASK SPECIFICATION		
<u>No.</u>	or Decision to be made	Index No.	Mission	ission Context: Preparing a Surveyed Firing Char		
020340	Using blue pencil mark "C" (%" high) in upper right quadrant		FDC Tea	m Member(s); <u>HCU and/or VCO</u>		
	of tick mark.	46	Individ	lual Task: Constructing Azimuth Index	es	
35	Is it a radar location?	26	Index No.	OPERATION: Action to be taken B or Decision to be made I	ranch to ndex No.	
	YES NO	36	030000	BEGIN		
36	Using green pencil mark 🕢 (ኒ" high) in upper right quadrant of tick mark.	46	1	Is there a tick mark remaining for which an azimuth (Az) index is to be constructed?		
37	Is it a registration point lo- cation?			YES NO	2 55	
	YES	38	2	Select pin and place vertically		
	NO	39		and securely into center of		
38	Using 4H pencil write "REG PT" (½" high) plus number assigned to it in the upper right quad- rant of the tick mark.	46	3	tick mark in question. Is the cardinal direction from which the next Az index is to be established North (0 or $6400 + 0^2$		
39	Is it an OP location?			0-00 \$0.	6	
	YES	40		NO	4	
40	Using 4H pencil write observer's identification ($\frac{1}{2}$ " high) in the upper right quadrant of the	4 1	4	Is the cardinal direction from which the next Az index is to be established East (1600 ¢)?		
	tick mark.	46		YES	18	
41	Is it a target location?		-		2	
	YES NO	42 43	2	which the next Az index is to be established South (3200 p/)?		
42	Using 4H pencil write the three- digit identification number (½" high) in the upper right quad- rant of the tick mark; place optional information in upper left and/or lower right quadrant.	46	6	YES NO Plot easting of tick mark center in question as far North on chart grid as possible (with- in reach of RDP range arm);	25 32	
43	Is it a maneuver check point?			place pin precisely to mark		
	YES NO	44 45	7	Place RDP vertex against pin		
44	Using 4H pencil write the one- digit identification number $(\frac{1}{2})$ high) in the upper right quad- rant of the tick mark and		8	Rotate RDP until left edge of range arm is tight against last placed pin.		
45	draw a tight circle around it. Using 4H pencil write appropri-	46	9	Select pin and place in chart at O graduation on Az Scale on RDP arc.		
	ate identification (numbers and/or symbols ½" high) in upper right quadrant of tick mark.		10	Without disturbing any pins, lift RDP, rotate clockwise beyond last placed pin, reposi-		
46	Obtain altitude for the identi- fied point and, using 4H pencil, write three-digit altitude (½" high) in the lower left quad-			tion RDP vertex on pin in ref- erence tick mark, and push left edge of range arm against last placed pin.		
020470	rant of the tick mark. END	2	11	Remove last placed pin, and using wedge sharpened 6H pencil draw a 2" line bisecting the pinhole.		
			12	Above the last drawn line and slightly to right of pinhole write (%'' high) the reference tick mark's identification plus "AZO."		

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Index No.	OPERATION: Action to be taken or Decision to be made	Branch to Index No.	Index No.	OPERATION: Action to be taken or Decision to be made
030130	Return left edge of RDP range arm to position it against the pin placed in 030060.		28	Select pin and place in to chart at 200 f graduation on Az scale on RDP arc.
14	Select pin and place in chart at 400 n graduation on Az scale on RDP arc.	•	29	Without disturbing any pins, lift RDP, rotate clockwise beyond the last placed pin,
15	Without disturbing any pins, lift RDP, rotate clockwise beyond last placed pin, re- position RDP vertex on pin in		20	re-position RDP vertex on pin in reference tick mark and push left edge of range arm against last placed pin.
	reference tick mark and push left edge of range arm against last placed pin.		30	and using wedge sharpened 6H pencil draw a 2" line bisecting the last made pinhole.
16	Remove the two last placed pins, and using wedge sharpened 6H pencil draw a 2" line bisecting the last made pinhole.		31	Above last drawn line and slightly to right of pinhole write (2" high) the reference tick mark's identification
17	Above the last drawn line and slightly to the right of the pinhole write (½" high) the reference tick mark identifi- cation plus "AZ 6000."	39	32	plus "AZ 3000." Plot northing of reference tick mark center as far West on chart grid as possible (within reach of range arm): place pin pre-
18	Plot northing of reference tick mark center as far East on chart grid as possible; place pin precisely to mark location.		33	cisely to mark location. Place RDP vertex against pin in reference tick mark.
19	Place RDP vertex against pin in reference tick mark.		34	Rotate RDP until left edge of range arm is tightly against
20	Rotate RDP until left edge of range arm is tightly agains? last placed pin.		35	Select pin and place in chart at 800 fg graduation on Az scale
21	Select pin and place into chart at 600 ₥ graduation on Az scale on RDP arc.		36	Without disturbing any pins, lift RDP, rotate clockwise
22	Without disturbing any pins, lift RDP, rotate clockwise beyond last placed pin, re- position RDP vertex on pin in reference tick mark and			beyond last placed pln, re- position RDP vertex on pin in reference tick mark and push left edge of range arm against the last placed pin.
23	<pre>push left edge of range arm against last placed pin. Remove the two last placed pins.</pre>		37	Remove the two last placed pins, and using wedge sharpened 6H pencil draw a 2" line bisecting
	and using 6H wedge sharpened pencil draw a 2" line bisecting the last made pinhole.		38	the last made pinhole. Above last drawn line and slight- ly to right of pinhole write (%"
24	Above the last drawn line and slightly to the right of the pinhole write (%"high) the		39	high) the reference tick mark's identification plus "AZ 4000." Have relevant Az indexes at 0 m,
25	reference tick mark's identi- fication plus "AZ 1000."	39		1000 f, and 6000 f been construc- ted?
25	mark center as far South on chart as possible (within reach of RDP range arm); place pin precisely to mark location.		40	IS NO Is another supplementary Az index required?
26	Place RDP vertex against the pin in the reference tick mark.			YES NO
27	Rotate RDP until left edge of range arm is tight against last placed pin.			

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Branch to Index No.

39

40 4

41 1

Index No.	OPERATION: Action to be taken or Decision to be made	Branch to Index No.	Index No.	OPERATION: Action to be taken or Decision to be made	Branch to Index No.
30410	Determine previously established Az index whose value is $\pm 1000 \text{ fm}$ from supplementary index to be marked now.		54	Above the last drawn line and slightly to right of pinhole write $(\frac{1}{2})''$ high) the reference tick mark's identification plus	
42	Is ϕ value of the selected pre- vious Az index less than the ϕ value of the index to be marked now?		030550	ted previous Az index minus 1000. END	40
	YES	43		TASK SPECIFICATION	
	NO	49	Mission	Context: Preparing a Surveyed Fir	ing Chart
43	Place the RDP vertex against		FDC Teau	m Member(s): <u>HCO and/or VCO</u>	
	mark.		Individ	ual Task: <u>Constructing Deflection</u> (Referred Df = 3200 ft)	Indexes
44	Align 1000 n graduation of Az scale on RDP arc with the selected previous Az index.		Index No.	OPERATION: Action to be taken or Decision to be made	Branch to Index No.
45	Select pin and place into chart		040000	BEGIN	
	at 0 f graduation of Az scale on RDP arc.		1	Is there a tick mark remaining for which a deflection (Df) index is to be constructed?	
46	Without disturbing any pins, lift RDP, rotate clockwise beyond last placed pin, re-			YES NO	2 60
	position RDP vertex on pin in reference tick mark an push left edge of range arm against last placed pin.		2	Place pin vertically and secure- ly into center of tick mark in question.	
47	Remove last placed pin, and		3	Has Az of lay been given?	
	using wedge sharpened 6H pencil draw 2" line bisecting the last made pinhole.			YES NO	4 3
48	Above the last drawn line and		4	Is Az of lay close to principal direction of fire N (0 Or 6400 th)	?
	write (χ " high) the reference			YES NO	7 5
	"AZ" and the sum of 1000 and the m value of the selected	10	5	Is Az of lay close to principal direction of fire E (1600 ϕ)?	
49	previous A2 index. Place RDP vertex against pin in	40		YES NO	12 6
	reference tick mark.		6	Is Az of lay close to principal	
50	Align 0 m graduation of Az scale on RDP arc with the selected previous Az index.			direction of fire S (3200 f)? YES	20
51	Select pin and place into chart at 1000 f graduation of Az scale on RDP arc.		7	Plot easting of reference tick mark center as far North on chart grid as possible (within	۷,۵
52	Without disturbing any pins, lift RDP, rotate clockwise beyond last placed pin, re-			reach of range arm); select pin and place precisely to mark location.	
	position RDP vertex on pin in reference tick mark and push left edge of range arm against		8	Place RDP vertex against pin in reference tick mark.	
53	last placed pin. Remove last placed pin, and		9	Rotate RDP until left edge of range arm is tightly against last placed pin.	
	using wedge sharpened 6H pencil draw a 2" line bisecting the last made pinhole		10	Select pin and place into chart either at 0 graduation on the Az scale on the RDP arc (tempo- rary Az 0) or at the 400 ph graduation (temproary Az 6000).	

Index No.	OPERATION: Action to be taken Br or Decision to be made Ir	ranch to Idex No.	Index No.	OPERATION: Action to be taken or Decision to be made	Branch to Index No.
040110	Rotate RDP clockwise until the sum of the chosen pin location (0 or 6000) and the Az scale graduation opposite the pin equals the stated Az of lay.	33	25	Plot northing of reference tick mark center as far West on chart grid as possible (within reach of range arm); select pin and place precisely to mark location.	
12	Plot northing of reference tick mark center as far East on chart		26	Place RDP vertex against pin in reference tick mark.	
	as possible (within reach of range arm); select pin and place precisely to mark location.		27	Rotate RDP until left edge of range arm is tightly against last placed pin.	
13	Place RDP vertex against pin in reference tick mark.		28	Select pin and place into chart opposite the 800 ø graduation	
14	Rotate RDP until left edge of range arm is tightly against the last placed pin.		20	on the Az scale on the RDP arc (temporary Az 4000).	
15	Select pin and place into chart opposite the 600 $\#$ graduation on the Az scale on the RDP arc (tomocary Az 1000)		29	5000 - 6000 d? YES	30 32
16	Is announced Az of lay between 2000 - 3000 p? YES	17	30	Rotate RDP clockwise until the 1000 ∮ graduation on the Az scale is precisely aligned with the last placed pin.	
	NO	19	31	Without moving RDP, remove last	
17	Rotate RDP clockwise until 1000 f graduation on the Az scale is pre- cisely aligned with the last placed pin.			placed pin and place it into chart opposite the 0 f gradua- tion on the Az scale (temporary Az 5000).	
18	Without moving RDP, remove last placed pin and place it into chart opposite the 0 \$\mu\$ gradua- tion on the Az scale (temporary Az 2000).		32	Rotate RDP clockwise until the sum of the pin location (4000 or 5000) and the Az scale gradu- ation opposite the pin equals the stated Az of lay.	
19	Rotate RDP clockwise until the sum of the pin location (1000 or 2000) and the Az scale gradua- tion opposite the pin equals the stated Az of lay.	33	33	Without moving RDP, move last placed pin to a point opposite the 200 f graduation on the de- flection (Df) scale on the RDP arc; push down straight and securely.	
20	Piot easting of reference tick mark center as far South on chart grid as possible (within reach of range arm); select pin and place precisely to mark location.		34	Without disturbing any pins, lift RDP, rotate clockwise beyond last placed pin, re- position RDP vertex on pin in reference tick mark and push left edge of range arm anainst	
21	Place RDP vertex against pin in reference tick mark.			last placed pin.	
22	Rotate RDP until left edge of range arm is tightly against last placed pin.		35	Remove the two last placed pins, and using wedge sharpened 6H pencil draw a 2" line bisecting the last made pinhole.	
23	Select pin and place into chart opposite the 200 \$\phi\$ graduation on the Az scale on RDP arc		36	Did reference tick mark represent A-Battery?	29
24	(Lemporary AZ 3000). Rotate RDP clockwise until the			YES NO	30 37
	sum of the pin location (3000) and the Az scale graduation		37	Did reference tick mark represent B-Battery?	
	opposite the pin equals the stated Az of lay.	33		YES NO	39 40
			38	Select red pencil.	41

Index No.	OPERATION: Action to be taken	Branch to Index No.	Index No.	OPERATION: Action to be taken or Decision to be made	Branch to Index No.
040390	Select 4H pencil.	41	56	Remove RDP and draw arrow head	
40	Select blue pencil.			pointing toward reference tick	
41	Remove RDP and draw arrow head pointing toward reference tick mark so that arrow tip will be		5 7	1/8" outward from pinhole in last drawn line.	
	l/8" outward from pinhole in last drawn line.		57	Was last Dr Index labeled "O"? YES	58
42	Is selected pencil red?		- 0	NO	29
43	YES NO	44 43	58	Horizontally across outer end of last drawn line write cap- ital letter as for primary in- dex and "6."	47
	YES NO	45 46	59	Horizontally across outer end	
44	Horizontally across outer end of last drawn line write "A 3" (½" high).	47		ital letter as for last Df index while subtracting 1 from accompanying number of that last Df index.	
45	Horizontally across outer end of last drawn line write "B 3" (%" biob)	47	040600	END	
46	Horizontally across oute: and of	47		TASK SPECIFICATION	
40	last drawn line write "C 3"		Mission	Context: <u>Call for Fire</u> - Adjust	Fire Phase
	(½" high).		FDC Tea	m Member(s): <u>HCO and/or VCO</u>	
47	Is there another supplementary Df index to be constructed?		Individ	ual Task: <u>Plot Target - Grid Coor</u> <u>Method</u>	dinates
	YES NO	48 1	Index No.	OPERATION: Action to be taken or Decision to be made	Branch to Index No.
48	Place RDP vertex against pin in reference tick mark.		051000 through	Equivalent to:	
49	Rotate RDP until 0 \$\overline{pt}\$ graduation on Df scale on RDP arc is pre- cisely aligned with the last constructed Df index		051110	TASK SPECIFICATION	
50	Was the last Df index labeled		Mission FDC Tea	Context: <u>Call for Fire - Adjust</u>	Fire Phase
	UES	52	Individ	ual Task: Polar Plot of Target	
	NO	51	Index	OPERATION: Action to be taken	Branch to
51	Select pin an place into chart opposite the 1000 \$ graduation on the Df scale on RDP arc:		<u>No.</u> 052000	or Decision to be made BEGIN	Index No.
52	push down straight and securely.		1	Has FO given direction and dis- tance to target?	
52	opposite the 400 \$\phi\$ graduation on the Df scale on RDP arc;			YES NO	2 0
53	Without disturbing any pins, lift RDP, rotate clockwise		2	Has FO shifted from pre-plotted position and given a new (six digit) position?	
	position RDP vertex on pin in reference tick mark and push left edge of range arm against		3	YES NO Plot FO's (critical point)	3 5 .
C /	Last placed pin.			position: perform 020040 through 020150.	
54	Remove last placed pin, and using wedge sharpened 6H pencil draw a 2" line bisecting the last made pinhole.		4	Establish FO's Az index(es): as needed perform 03000 through 03055.	
55	Select same pencil used for labeling primary Df index.		5	Place vertex of RDP precisely against pin in FO's position.	

 b) 20200 Align a graduation on Ar scale of RP are oth appropriate distribution of the second direction (A-digit group) equals the first digit of the given direction (A-digit group). 7 Notate RP until the sum of the Ar scale graduation above its main its graduation above its main its graduation above its main its age of the arrow until the distance of free photocols its main its graduation above its main its graduation above its main its graduation above its main its may provide its photocols its main its graduation above its main its may provide its photocols its photocols its main its may provide its photocols its photocols	Index No.	OPERATION: Action to be taken or Decision to be made	Branch to Index No.	Index No.	OPERATION: Action to be taken or Decision to be made	Branch to Index No.
7 Rotate RPP until the sum of the Az scale graduation above it equals the graduation above it equals the spreadilised later is finite iter is stimet visually as precisely as possible. Iter iter iter iter iter iter iter iter i	052060	Align a graduation on Az scale of RDP arc with appropriate observer's Az index whose first digit (in 4-digit group) equals the first digit of the given direction (4-digit group).		11	Move pin laterally from center of target grid in the specified direction (L or R) along the cen- ter line that is perpendicular to the arrow until the distance of pin from center of target grid	-
 8 Select pin and place into chart tightly against last placed distance. 9 Push pin into chart vertically and securely. 9 Push pin into chart vertically and securely. 13 Push pin into chart vertically and securely. 14 Nave served to a state the period of the secure of the secure	7	Rotate RDP until the sum of the Az index and of the Az scale graduation above it equals the given direction; estimate visu- ally as precisely as possible.		12	<pre>(each line = 100) equals the specified lateral shift. Move pin precisely vertically from point identified in the last step in the direction</pre>	
 9 Push pin into chart vertically and securely. 052100 END TASK SPECIFICATION TASK SPECIFICATION Mission Context: Call for Fire - Adjust Fire Phase FDC Team Member(s): HCO and/or VCO Individual Task: Plot Target by Shift from Known Point To Decision to be taken Branch to or Decision to be made Index No. O Decision to be taken Branch to or Decision to be made Index No. To Team Member(s): HCO and/or VCO Individual Task: Plot Target by Shift from Known Point The Team Member(s): HCO and/or VCO Individual Task: Plot Target by Shift from Known Point No O Store information. 3 On chart identify the known point that has been specified. Store information. 3 On chart identify the known point that has been specified. Store information. 3 On chart identify the known point that has been specified. Store information. 3 On chart identify the known point the target grid and insert pin through center. 5 Place pin (in target grid) precisely altered of the mark representing the battery in question. 7 Select pin and place into chart precisely altigned with any ocharget grid line is precisely altigned with any chart grid grid ticrumference (above arrow tip). 8 Rotate target grid until a mil ecale grid until a mil ecale grid until and ecale grid until and ecale grid until and is cale grid until and is ecale grid to chart on side away from expected activity (below). 10 Select pin. 8 Rotate target grid until and is ecale grid to chart on side away from expected activity (below). 10 Select pin. 8 Rotate target grid until a mil ecale grid to chart on side away from expected activity (below). 10 Select pin. 8 Rotate target pin. 8 Rotate target pin. 8 Select pin. 8 Rotate	8	Select pin and place into chart tightly against left edge of RDP range arm at a point cor- responding to stated distance.			<pre>specified (add or +: toward arrow head; drop or -: toward arrow tail) until the vertical distance covered (each line = 100) equals the specified range</pre>	
TASK SPECIFICATIONMission Context: Call for Fire - Adjust Fire PhaseFDC Team Member(s): NCO and/or VCOIndividual Task: Plot Target by Shift from Known PointIndex OPERATION: Action to be taken No.Index OPERATION: Action to be taken provided?1 Have target location data been provided?1 Have target location data been provided?2 Store information.3 On chart identify the known point that has been specified.4 Select target grid and insert pin through center.5 Place pin (in target grid) no chart grid line.7 Select pin and place into chart procisely at the 0 # graduation of the scale around target grid inte scale graduation equivalent to specified direction is precise in signed with last placed pin.8 Rotate target grid unti a scale graduation equivalent to specified direction is precise in signed with last placed pin.9 Select pin and place into chart procisely at the 0 # graduation edified with any one target grid inte scale grid unti a stiper ecise in signed with last placed pin.9 Select pin (s) and tack target grid to chart on side away from expected activity (below).10 Select pin.10 Select pin.110 Select pin.12 Select pin.13 Select pin.14 Context target grid with ast placed pin.15 Select pin.16 Select pin.17 Select pin (s) and tack target grid to chart on side away from expected activity (below).10 Select pin.11 Select pin.12 Select pin.13 Select pin.14 Select pin.15 Select pin	9 052100	Push pin into chart vertically and securely. END		13	value. Push pin vertically and precise- ly into point reached so as to	
 Mission Context: <u>Call for Fire - Adjust Fire Phase</u> FDC Team Member(s): <u>HCO and/or VCO</u> Individual Task: <u>Plot Target by Shift from Known</u> <u>Dotation</u> Index OPERATION: Action to be taken Branch to <u>No.</u> <u>or Decision to be made</u> <u>Index No.</u> <u>OPERATION: Action to be taken Branch to</u> <u>No.</u> <u>or Decision to be made</u> <u>Index No.</u> <u>Index varget location data been provided?</u> <u>I Have target location data been provided?</u> <u>YES 2</u> <u>NO 0</u> 2 Store information. <u>On chart identify the known point that has been specified.</u> <u>Select pin through center.</u> <u>Place pin (in target grid and insert pin through center.</u> <u>Place pin (in target grid jope-cisely at ligned with any or chargt grid line is precisely aligned with any charle grid line.</u> <u>Select pin and place into chart precisely aligned with any or chargt grid line.</u> <u>Select pin and place into chart precisely aligned with any or chargt grid until a mil scale graduation equivalent to specified direction is precise-ily aligned with last placed pin.</u> <u>Select pin (above arrow tip)</u>. 	092100	TASK SPECIFICATION		0521/0	keep it securely in place.	
FDC Team Member(s): <u>HCO and/or VCO</u> TASK SPECIFICATION Individual Task: <u>Plot Target by Shift from Known</u> <u>Foint</u> Mission Context: <u>Call for Fire - Adjust Fire Phase</u> FDC Team Member(s): <u>HCO</u> Index OPERATION: Action to be taken <u>norvided?</u> Branch to <u>Index OPERATION: Action to be taken</u> provided? Branch to <u>No.</u> 1 Have target location data been provided? Index NO. 2 Store information. 1 3 On chart identify the known point that has been specified. 1 4 Select target grid and insert pin through center. YES 5 Place pin (in target grid) pre- cisely into center of known point tick mark. 3 6 Rotate target grid so that arrow tip points North and so that any one <u>target grid</u> line is precisely aligned with any <u>chart grid line.</u> 3 Place torin data graduation of the scale around target grid its cale graduation equivalent to specified direction is preciser- ily aligned with last placed pin. 4 Rotate target grid until a mil scale graduation equivalent to specified direction is preciser- ily aligned with last placed pin. 5 Is chart scale at the point of the target pin location; estimate visually to the nearest lo M. 8 7 On RDP range am read range in meters on the scale at the point of the target pin location; estimate visually to the nearest lo M. 8 8 Store range value. 8 <td>Mission</td> <td>Context: Call for Fire - Adjust</td> <td>Fire Phase</td> <td>053140</td> <td>END</td> <td></td>	Mission	Context: Call for Fire - Adjust	Fire Phase	053140	END	
Individual Task:Plot Target by Shift from Known PointMission Context:Call for Fire - Adjust Fire Phase FDC Team Member(s):IndexOPERATION: Action to be taken or Decision to be madeBranch to Individual Task:Decemp cancel OPERATION: Action to be taken or Decision to be madeIndexOPERATION: Action to be taken provided?Branch to Index No.1Have target location data been provided?OPERATION: Action to be taken or Decision to be madeBranch to No. or Decision to be made1Have target location data been provided?VES 2 NOOPERATION: Action to be taken or Decision to be madeBranch to No. or Decision to be made1Have target location data been provided?YES 2 NOO2Store information.1Hast target location been estab- lished?3On chart identify the known point that has been specified.1Hast target location the target grid and insert pin through center.5Piace pin (In target grid) that any one target grid line is precisely allgned with any chart grid line.3Place vertex of RDP precisely against last placed pin.6Rotate target grid outil a mil scale graduation of the scale around target grid circumference labove arrow tip).1Place vertex of RDP precisely against last placed pin.7Select pin and place into chart precisely allgned with any chart grid line target grid duction equivalent to specified direction is precise- ny aligned with last placed pin.69Select pin.87On RDP range ar	FDC Tea	m Member(s): HCO and/or VCO			TASK SPECIFICATION	
Index NotFointIndex NotOPERATION: Action to be taken or Decision to be madeBranch toNo.or Decision to be madeIndex Not1Rave target location data been provided?Index Not1Nave target location data been provided?YES 2 NO 02Store information.0600003On chart identify the known point that has been specified.14Select target grid and insert pin through center.95Place pin (in target grid) pre- cisely into center of known point tick mark.36Rotate target grid ot that arrow tip points North and so that any one target grid line is precisely a ligned with any chart grid line.37Select pin and place into chart precisely at the 0 \$ graduation of the scale around target grid circumference (above arrow tip).58Rotate target grid until a mil scale graduation equivalent to specified direction is precise- iy aligned with last placed pin.99Select pin.810Select pin.810Select pin.811Select pin.812Select pin.13Select pin.814Select pin.815Select pin.16Select pin.17Select pin.18Select pin.19Select pin.10Select pin.10Select pin.11Select pin.12Select pin.13 <t< td=""><td>Individ</td><td>hual Task: Plot Target by Shift fr</td><td>om Known</td><td>Mission</td><td>Context: Call for Fire - Adjust H</td><td>ire Phase</td></t<>	Individ	hual Task: Plot Target by Shift fr	om Known	Mission	Context: Call for Fire - Adjust H	ire Phase
Index No.OPERATION: Action to be taken or Decision to be made Index No.Branch to Index No.053000BEGINOPERATION: Action to be taken or Decision to be madeBranch to Index No.1Nave target location data been provided?OPERATION: Action to be taken or Decision to be madeBranch to Index No.1Nave target location data been provided?YES 2 NO 0BEGINBranch to Index No.2Store information.1Has target location been estab- lished?NoO3On chart identify the known point that has been specified.2Select pin and push vertically into precise center of tick mark representing the battery in question.15Place pin (in target grid) pre- cisely into center of known point itck mark.3Place target grid so that arrow tip points North and so that any one target grid line is precisely aligned with any chart grid line.1Place vertex of RDP precisely against last placed pin.6Rotate target grid until a mil scale graduation equivalent to specified direction is precise- ly aligned with last placed pin.YES 6 NO 77Select pin.6On RDP range arm read range in meters on the scale at the point of the target pin location; estimate visually to the nearest 10 M.8Store range value.89Select pin.89Select pin.89Select pin.89Select pin.89Select pin.89Select pin.<	11101040	Point		FDC Tea	m Member(s): HCO	
No. or Decision to be made Index No. OPERATION: Action to be taken or Decision to be made Branch to Index No. 053000 BEGIN No. or Decision to be made Index No. 1 Have target location data been provided? No. Or Decision to be made Index No. 2 Store information. YES 2 No 0 3 On chart identify the known point that has been specified. YES 2 Select pin and push vertically into precise center of tick mark representing the battery in question. YES 2 5 Place pin (in target grid) precisely attrophint for mark. Place vertex of RDP precisely against last placed pin. Place vertex of RDP precisely against last placed pin. 6 Rotate target grid so that arrow tip points North and so that arrow tip points North and so that arrow tip painte and place into chart precisely at the 0 for graduation of the scale around target grid ince is specified direction is precise- ity aligned with last placed pin. YES 6 7 Select pin. Select pin. YES 6 8 Rotate target grid until a mil secified direction is precise- ity aligned with last placed pin. 7 On RDP range arm read range in meters on the scale at the point of the target pin location;	Index	OPERATION: Action to be taken	Branch to	Individ	ual Task: Determine Range with RDI	2
1 Have target location data been provided? 1 Have target location data been provided? 1 YES 2 NO 0 2 Store information. 1 3 On chart identify the known point that has been specified. 1 4 Select target grid and insert pin through center. NO 0 5 Place pin (in target grid) precisely into center of known point tick mark. 3 Place vertex of RDP precisely against last placed pin. 6 Rotate target grid ot that arrow tip points North and so that any one target grid line. 3 Place vertex of RDP precisely against last placed pin. 7 Select pin and place into chart precisely alt Bod & graduation of the scale around target grid circumference (above arrow tip). 5 Is chart scale 1:25,000? 8 Rotate target grid until a mil scale graduation equivalent to specified direction is precisely in scale grid uth and place dpin. 5 Is chart scale the point of the target pin location; estimate visually to the nearest 10 M. 9 Select pin. 8 7 On RDP range arm read range in meters on the scale at the point of the target pin location; estimate visually to the nearest 10 M. 9 Select pin. 8 8 Store range value. 10	<u>No.</u> 053000	or Decision to be made BEGIN	Index No.	Index No.	OPERATION: Action to be taken or Decision to be made	Branch to Index No.
1 Has target location been established? YES 2 2 Store information. 3 On chart identify the known point that has been specified. 4 Select target grid and insert pin through center. 5 Place pin (in target grid) precisely into center of known point tick mark. 6 Rotate target grid so that arrow tip points North and so that any one target grid line. 7 Select pin and place into chart precisely atlegned with any circumference (above arrow tip). 8 Rotate target grid until a mil scale graduation of the scale around target grid circumference (above arrow tip). 8 Select pin(s) and tack target grid mutil ast placed pin. 9 Select pin(s) and tack target grid mutil ast placed pin. 9 Select pin(s) and tack target grid octart on side away from expected activity (below). 10 Select pin. 10 Select pin.	1	Have target location data been		060000	BEGIN	<u> </u>
NO0YES22Store information.YES203On chart identify the known point that has been specified.2Select pin and push vertically into precise center of tick mark representing the battery in question.25Place pin (in target grid) pre- cisely into center of known point tick mark.3Place vertex of RDP precisely against last placed pin.6Rotate target grid so that arrow tip points North and so that any one target grid line is precisely aligned with any chart grid line.4Rotate RDP counterclockwise until left edge of range arm 	-	provided? YES	2	1	Has target location been estab- lished?	
2 Store information. NO 0 3 On chart identify the known point that has been specified. 2 Select pin and push vertically into precise center of tick mark representing the battery in question. 4 Select target grid and insert pin through center. 3 Place pin (in target grid) precisely into center of known point tick mark. 3 Place vertex of RDP precisely against last placed pin. 5 Place pin (in target grid) precisely into center of known point tick mark. 4 Rotate target grid so that arrow tip points North and so that any one target grid line is precisely aligned with any citrumference (above arrow tip). 3 Is chart scale 1:25,0007 7 Select pin and place into chart precisely ard the 0 if graduation of the scale around target grid until a mil scale graduation equivalent to specified direction is preciseiseriate visually to the nearest 10 M. 8 8 Rotate target grid until a mil scale graduation equivalent to specified direction is preciseiseriate grid to chart on side away from expected activity (below). 7 0 0 9 Select pin. 8 8 7 9 Select pin. 8 8 10 Select pin. 8 8 10 Select pin. 8 10 meters on the scale at the point of the target pin location and divide reading by 2; estimat		NO	0		YES	2
 3 On chart identify the known point that has been specified. 4 Select target grid and insert pin through center. 5 Place pin (in target grid) precisely into center of known point tick mark. 6 Rotate target grid so that arrow tip points North and so that any one target grid line is precisely aligned with any chart grid line. 7 Select pin and place into chart precisely arthous of the scale around target grid circumference (above arrow tip). 8 Rotate target grid until a mil scale graduation of the scale around target grid circumference (above arrow tip). 8 Rotate target grid until a mil scale graduation equivalent to specified direction is precise-ly aligned with last placed pin. 9 Select pin(s) and tack target grid to chart on side away from expected activity (below). 10 Select pin. 2 Select pin and push vertically into precise ly aligned with (below). 2 Select pin. 2 Select pin and push vertically into precise center of tick mark representing the battery in question. 3 Place vertex of RDP precisely against last placed pin. 3 Place vertex of RDP recisely against previously placed target pin. 4 Rotate RDP counterclockwise until left edge of range arm is tight against previously placed target pin. 5 Is chart scale 1:25,000? 6 On RDP range arm read range in meters on the scale at the point of the target pin location; estimate visually to the nearest 10 M. 8 Store range value. 9 Select pin. 8 Store range value. 9 Select pin. 	2	Store information.			NO	0
 Select target grid and insert pin through center. Place pin (in target grid) precisely into center of known point tick mark. Rotate target grid so that arrow tip points North and so that any one target grid line is precisely aligned with any chart grid line. Select pin and place into chart precisely at the 0 \$\phi\$ graduation of the scale around target grid circumference (above arrow tip). Rotate target grid until as target grid until as target grid until as target pin. Select pin(s) and tack target grid precise-ly aligned with last placed pin. Select pin. Sele	3	On chart identify the known poin that has been specified.	t	2	Select pin and push vertically into precise center of tick	
 5 Place pin (in target grid) precisely into center of known point tick mark. 6 Rotate target grid so that arrow tip points North and so that any one target grid line is precisely aligned with any chart grid line. 7 Select pin and place into chart precisely at the 0 \$\phi\$ graduation of the scale around target grid circumference (above arrow tip). 8 Rotate target grid until a mil scale graduation equivalent to specified direction is precise-ly aligned with last placed pin. 8 Rotate target grid until a mil scale graduation equivalent to specified direction is precise-ly aligned with last placed pin. 9 Select pin(s) and tack target grid to chart on side away from expected activity (below). 10 Select pin. 7 Place vertex of RDP precisely against last placed pin. 8 Rotate target grid line is cale activity (below). 10 Select pin. 9 Select pin. 10 Select	4	Select target grid and insert pin through center.		2	question.	
 point tick mark. 6 Rotate target grid so that arrow tip points North and so that any one target grid line is precisely aligned with any chart grid line. 7 Select pin and place into chart precisely at the 0 \$\pi\$ graduation of the scale around target grid circumference (above arrow tip). 8 Rotate target grid until a mil scale graduation equivalent to specified direction is precise- ly aligned with last placed pin. 9 Select pin(s) and tack target grid to chart on side away from expected activity (below). 10 Select pin. 4 Rotate RDP counterclockwise until left edge of range arm is tight against previously placed target pin. 5 Is chart scale 1:25,000? 6 On RDP range arm read range in meters on the scale at the point of the target pin location; estimate visually to the nearest 10 M. 7 On RDP range arm read range in meters on the scale at the point of the target pin location and divide reading by 2;estimate visually to nearest 10 M. 8 Store range value. 	5	Place pin (in target grid) pre- cisely into center of known		د ر	against last placed pin.	
 is precisely aligned with any chart grid line. 7 Select pin and place into chart precisely at the 0 \$\pi\$ graduation of the scale around target grid circumference (above arrow tip). 8 Rotate target grid until a mil scale graduation equivalent to specified direction is precise-ly aligned with last placed pin. 9 Select pin(s) and tack target grid to chart on side away from expected activity (below). 10 Select pin. 5 Is chart scale 1:25,000? 7 Is chart scale 1:25,000? 8 Rotate target grid until a mil scale arm read range in meters on the scale at the point of the target pin location; estimate visually to the nearest 10 M. 8 Rotate target grid until a mil scale at the point of the target pin location and divide reading by 2; estimate visually to nearest 10 M. 10 Select pin. 8 Rotate target pin. 9 Select pin. 10 Select	6	point tick mark. Rotate target grid so that arrow tip points North and so that any one target grid line		4	Notate RDP counterclockwise until left edge of range arm is tight against previously placed target pin.	
chart grid line.YES67Select pin and place into chart precisely at the 0 \$\phi\$ graduation of the scale around target grid circumference (above arrow tip).6On RDP range arm read range in meters on the scale at the point of the target pin location; estimate visually to the nearest 10 M.68Rotate target grid until a mil scale graduation equivalent to specified direction is precise- ly aligned with last placed pin.6On RDP range arm read range in meters on the scale at the point of the target pin location; estimate visually to the nearest 10 M.89Select pin(s) and tack target grid to chart on side away from expected activity (below).7On RDP range arm read range in meters on the scale at the point of the target pin location and divide reading by 2; estimate visually to nearest 10 M.10Select pin.8Store range value.10Select pin.8Store range value.		is precisely aligned with any		5	Is chart scale 1:25,000?	
 precisely at the 0 m graduation of the scale around target grid circumference (above arrow tip). 8 Rotate target grid until a mil scale graduation equivalent to specified direction is precise-ly aligned with last placed pin. 9 Select pin(s) and tack target grid to chart on side away from expected activity (below). 10 Select pin. 6 On RDP range arm read range in meters on the scale at the point of the target pin location; estimate visually to the nearest 10 M. 8 Rotate target grid until a mil scale graduation equivalent to specified direction is precise-ly aligned with last placed pin. 9 Select pin(s) and tack target grid to chart on side away from expected activity (below). 10 Select pin. 8 Store range value. 060090 END 	7	<u>chart</u> grid line. Select pin and place into chart			YES NO	6 7
or kotate target grid until a mill for the finite visually to the hearest scale graduation equivalent to 10 M. specified direction is precise- 7 ly aligned with last placed pin. 7 9 Select pin(s) and tack target grid to chart on side away from divide reading by 2;estimate expected activity (below). 8 10 Select pin. 8 Store range value. 060090 END	9	precisely at the 0 \$\$ graduation of the scale around target grid circumference (above arrow tip).		6	On RDP range arm read range in meters on the scale at the point of the target pin location;	
 9 Select pin(s) and tack target of the target pin location and grid to chart on side away from expected activity (below). 10 Select pin. 10 Select pin.	o	scale graduation equivalent to specified direction is precise- ly aligned with last placed pin.		7	On RDP range arm read range in meters on the scale at the point	8
10 Select pin. 8 Store range value. 060090 END	9	Select pin(s) and tack target grid to chart on side away from expected activity (below).			of the target pin location and divide reading by 2;estimate visually to nearest 10 M.	
060090 END	10	Select pin.		8	Store range value.	
				060090	END	

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TASK SPECIFICATION

determined?

Index

No.

070000 BEGIN 1

2

Mission Context: Call for Fire - Adjust Fire Phase FDC Team Member(s): HCO

or Decision to be made

Individual Task: Determine Deflection with RDP OPERATION: Action to be taken

Has target been pinned and range

On RDP arc determine value on

deflection (Df) scale for gradu-

TASK SPECIFICATION

FDC Team Member(s): HCO

Branch to

Index No.

2 060000

YES

NO

Mistion Context: Call for Fire - Adjust Fire Phase

Individual Task: Determine Angle T

Index No.	OPERATION: Action to be taken or Decision to be made	Branch to Index No.
090000	BEGIN	
1	Was target established by shift from known point?	

YES

NO

2

3

5

- 2 Shift previously used target grid so that its center (with pin through it) is precisely over plotted target; push in straight and securely.
 - 3 Select target grid and pin.
 - Push pin through center of 4 target grid and place pin precisely into target pinhole; push down to secure.
 - 5 Orient target grid so that arrow head points up (N on chart); precisely align any target grid line with any chart grid line underneath.
 - 6 Select pin and place into chart opposite 0 n graduation on peripheral target grid scale.
 - Rotate target grid until direc-7 tion value given by FO (i.e., Az) is aligned with last placed pin; secure target grid with pin(s) to maintain orientation.
 - With RDP vertex on pin represenring Battery in question, rotate RDP until left edge of range arm is tight against pin in target grid center.
 - q Is arrow tip on target grid visible?

10 11

12

1

VES NO

- 10 Select the smaller angle formed by the arrow tip on the target grid and the left edge of RDP range arm; count the number of mils between arrow tip and left edge in 100 # units (to nearest 100 m).
- 11 Select the smaller angle formed by the arrow tail on the target grid and left edge of RDP range arm; count the number of mils between arrow tail and left edge in 100 # units (to nearest 100 m).
- 12 Store obtained Angle T.
- 090130 END

	ation that coincides with a index for the Battery in question; estimate visually nearest mil.	to	
3	Multiply value of Df index used by 1000 and add Df sca reading from last step; sum is Df.	le 1	
4	Store deflection value.		
070050	END		
	TASK SPECIFICATION		
Mission	Context: Call for Fire - Ad	ljust	Fire Phase
FDC Tean	n Member(s): <u>HCO</u>		
Individu	al Task: <u>Giving Range and I</u> Battery Computer(e	Deflec)	tion to
Index No.	OPERATION: Action to be tak or Decision to be m	ten lade	Branch to Index No.
080000	BEGIN		
1	Is communication channel currently in use?	1r -	
		YES NO	0 2
2	Announce (1) phonetic alpha code for Battery in questic (2) "range" and (3) retriev value of range from 060080.	bet on, ved	
3	Does Battery Computer read back correctly?		
		YES NO	4 2
4	Announce (1) "deflection" a (2) retrieved value of defl tion from 070040.	and .ec-	
5	Does Battery Computer read back correctly?		
		YES	6
		NO	4
080060	END		

	TASK SPECIFICATION		Index No.	OPERATION: Action to be taken or Decision to be made	Branch to Index No.
Mission	Context: <u>Call for Fire - A</u> djust I	Fire Phase	11	Subtract target altitude from	
FDC Tea	m Member(s): <u>VCO</u>			Battery altitude an label the	
Individ	ual Task: <u>Determining Vertical Int</u> from Map	terval		(-) sign.	
Index No.	OPERATION: Action to be taken or Decision to be made	Branch to Index No.	12 101130	Store vertical interval (VI). END	
101000	BEGIN			TASK SDECIFICATION	
1	On map locate square having the		Mission	Context: Call for Fire - Adjust	Fire Phace
	same coordinates as correspon- ding square on chart grid that		FDC Tea	m Member(s): <u>VCO</u>	
2	contains target location.		Individ	ual Task: <u>Determine Vertical Int</u> Vertical Shift	erval Via
2	coordinate square.		Index	OPERATION: Action to be taken	Branch to
3	Looking straight down, place 0/0 point of coordinate square		<u>No.</u>	or Decision to be made	Index No.
	(meters/yards held legible		102000	DEGIN	
	left corner of identified square and align lower horizontal scale on coordinate square with north-	,	1	known point or observer's loca- tion from which shift is occurring.	
	ing grid line of identified intersection.		2	Did information furnished by observer include a vertical	
4	Still looking straight down and maintaining established			component ("up" or "down" and value?	
	alignment, move coordinate square East (right) until			YES	3
	scale reading (to nearest 10 M) corresponding to last two digits in easting (first) tar-		3	Was given value preceded by "up"?	Ø
	get digit group lies over the easting line of identified			YES	4 5
5	Select pin and place into map		4	Add given value to altitude of known point.	8
	cal (northing) scale on the coordinate square that cor-		5	Subtract given value from altitude of known point.	8
	responds to the last two digits of the northing (second) target digit group.		6	Was omi ss ion (probably) intentional?	
6	Visually identify upper and			YES	7
	lower contour lines on map which form band that contains		7	Altitude of known point	0
7	on map determine altitude		8	Is target altitude greater than	·
	values for upper and lower			altitude of Battery in question	?
8	Add $\frac{1}{2}$ of difference (upper			YES NO	9 10
	minus lower contour line altitude) to lower contour line altitude to obtain target altitude; remove pin from map.		9	Subtract Battery altitude from target altitude and label resul tant value with a positive (+) sign.	- 11
9	Is target altitude greater than altitude of Battery in question?		10	Subtract target altitude from altitude of Battery in question and label the resultant value with a negative (-) sign.	
	YES	10 11	11	Store vertical interval (VI) da	ta.
10	Subtract Battery altitude from target altitude and label the resultant value with a positive (+) sign.		102120	END	

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4

TASK SPECIFICATION

Mission Context: Call for Fire - Adjust Fire Phase Mission Context: Call for Fire - Adjust Fire Phase FDC Team Member(s): VCO FDC Team Member(s): VCO Individual Task: Compute Site OPERATION: Action to be taken Index Branch to Index No. No. or Decision to be made Index No. 120000 BEGIN 111000 BEGIN 1 Select proper Graphical Site 1 Table (GST). 2 Is charge number given in fire order shown on slide (center) 2 of GST? 3 YES 4 3 NO 3 Remove slide of GST and resite. insert with other side showing. 4 Move manufacturer's hair line correctly? 4 (MHL) to a value on the D scale that corresponds to the absolute value of the VI. 120050 END 5 Visually select scales on slide labeled with charge in question. Has VI a positive sign? YES 7 NO 8 7 Without changing MHL setting, move slide until value of established target range on the Index No. TAG (black) scale is under MHL. g 130000 BEGIN Without changing MHL setting, move slide until value of 1 established target range an the TBG (red) scale is under MHL. 9 Read value on D scale opposite M-gage point. Was TAG (black) scale used? 10 YES 11 2 NO 12 Label value read at gage point 11 13 posítive (+). order, and Label value read at gage point 12 elements. negative (-). 3 Was Rg change-over point on scale used (TAG or TBG) 13 reached or exceeded? YES 14 4 NO 15 14 Round off Rg to next lower value shown numerically on scale. Approximately divide VI (in 15 meters) by Rg/1000 to estimate decimal point. 5 16 Store site data. 111170 END

TASK SPECIFICATION

Individual Task: Announcing Site OPERATION: Action to be taken Branch to or Decision to be made Index No. Is communication channel in use? YES 0 NO 2 Retrieve site from 111160. Announce (1) "site", (2) phonetic alphabet code for Battery in question, and (3) value of Does Battery Computer read back YES 5 3 NO TASK SPECIFICATION Mission Context: Call for Fire - Adjust Fire Phase FDC Team Member(s): Computer(s) Individual Task: Record Fire Order and Announce Fire Mission OPERATION: Action to be taken Branch to or Decision to be made Index No. Store in order received: (1) observer identification (2) warning order (3) target location (4) target description (5) method of engagement (6) authentication. Store in order received: (1) changes, if any, in standard elements of fire (2) added, non-standard Is communication channel clear? YES 4 NO 3 Announce to Battery in order: (1) "fire mission," (2) "battery adjust,"(3) "charge" plus value given in fire order (if necessary, address standard fire commands). Does RTO read back correctly? YES

6

1.

NO

130060 END

	TASK SPECIFICATION		Index No.	OPERATION: Action to be taken or Decision to be made	Branch to Index No.
Mission	Context: Call for Fire - FFE Pha	ise	7	Does Battery RTO read back	
FDC Tea	<pre>m Member(s): Computer(s)</pre>			correctly?	
Individ	ual Task: <u>Re-Announcing Number of</u> and Fuze to Battery	Rounds		YES NO	8 6
Index No.	OPERATION: Action to be taken or Decision to be made	Branch to Index No.	150080	END	
140000	BEGIN			TASK SPECIFICATION	
1	Have changes been made in pre- viously established fire order?		Missio	n Contxt: <u>Call for Fire - Adjust</u> <u>Phases</u>	and FFE
	YES	2	FDC Te	am Member(s): <u>Computer(s)</u>	
	NO	3	Indivi	dual Task: Compute Quadrant Eleva	tion
2	Note changes, if any, affecting number of rounds to be fired and/or fure type to be used.	4	Index No.	OPERATION: Action to be taken or Decision to be made	Branch to Index No.
з	Retrieve from established fire	-*	161000	BEGIN	
5	<pre>(1) number of rounds to be</pre>		1	Select proper Graphical Firing Table (GFT) for charge in fire order.	
4	(2) fize type to be used. Is communication channel clear?		Z	Has a currently valid Kg value been received?	
	YES	5		YES	4
	NO	4	3	Request data from HCO	2
5	Announce: "battery," value from 1:020 or 140030 plus "rounds," "fuze" plus type from 140020 or 140030, (add, if required, shell type).		4	Set MHL on Rg scale to current Rg value; determine value on elevation scale which lies under previously marked line	L
6	Does Battery RTO read back			for corrected elevation setting.	
	correctly?		5	Store elevation.	
	YES NO	7 4	6	Determine 100/R value on 100/R scale that lies under MHL.	
140070	END		71	Multiply 100/R by .2 to obtain 20/R.	
	TASK SPECIFICATION		72	Divide 100/R by 5 to	
Mission	Context: <u>Call for Fire - Adjust</u>	Fire Phase	_	obtain 20/R.	
FDC Tea	m Member(s): <u>Computer(s)</u>		8	Store 20/R.	
Individ	ual Task: <u>Compute and Announce De</u> <u>to Battery</u>	flection	9	Has site been received? YES	11
Index No.	OPERATION: Action to be taken or Decision to be made	Branch to Index No.	10	NO Request site from VCO	10
150000	BEGIN		11	Le Ti or VT in offect?	,
1	Has currently valid deflection (Df) been received?		11	YES	12
	YES	3	10		د1
2	NO Request Df from HCO.	2 1	12	algebraically sum elevation, site and 20/R.	14
3	Store Df data.		13	Retrieve elevation; algebra-	
4	Algebraically add previously			ically sum elevation and site.	
	established Df correction to last received/stored Df.		14 161150	Store QE. END	
5	Is communication channel clear?		101170		
	YES	6 5			
6	Announce: "deflection" and algebraic sum obtained in 150040				

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TASK SPECIFICATION TASK SPECIFICATION Mission Context: Call for Fire - Adjust Fire Phase Mission Context: Call for Fire - FFE Phase FDC Team Member(s): Computer(s) FDC Team Member(s): Computer(s) Individual Task: Deriving Time or Fuze Setting Individual Task: Announcing Quadrant Elevation (QE) OPERATION: Action to be taken OPERATION: Action to be taken Index Branch to Index Branch to No. or Decision to be made Index No. No. or Decision to be made Index No. 170000 BEGIN 190000 BEGIN Is communication channel clear? 1 On previously selected GFT is 1 MHL still on current Rg? YES YES 3 NO NO 2 Is this the initial adjust 2 2 Set MHL to current Rg value on round of this mission? Rg scale. YES Is VT in effect? 3 NO YES Announce to Battery in order: 4 3 NO 5 (1) number of rounds given in fire order plus "rounds", On FS M564 scale read value to 4 (2) fuze type to be used during nearest whole second that lies FFE plus "in effect," under the previously marked line (3) "quadrant" plus value for corrected time (fuze) retrieved from 161140. setting. Announce to Battery: "quadrant" 4 5 On FS M564 scale read value to plus value retrieved from nearest .1 second that lies 161140. under the previously marked line for corrected time (fuze) 5 Does RTO read back correctly? setting. YES Store obtained value. NO 6 170070 END 190060 END TASK SPECIFICATION Mission Context: Call for Fire - FFE Phase FDC Team Member(s): Computer(s) Individual Task: Announcing FFE Data to Battery OPERATION: Action to be taken Index Branch to No. or Decision to be made Index No. 180000 BEGIN 1 Retrieve: (1) Df from 150040, (2) time or FS from 170060, (3) QE from 161140. 2 Is communication channel clear? YES 3 2 NO 3 Announce in order: (1) "time" plus value retrieved in 180010, (2) "deflection" plus value retrieved in 180010, (3) "quadrant" plus value retrieved in 180010. Does Battery RTO read back 4 correctly? YES 5 NO 3 180050 END

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3

4

5

6

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APPROACHES TO ROUTINE DEVELOPMENT

The uses of precise, detailed, valid and reliable task specifications (TS) are manifold, and this has been pointed out from the beginning. More will be said about various uses in the next segment. If such uses are to be made and made routinely on an operational scale, efficient and economical approaches to the rapid development of quasi-algorithmic TS need to be established. The procedures followed in this present, exploratory effort were clearly not of that type. This effort was primarily a test, on a moderate scale, of the practical feasibility of something for which a priori only a strongly plausible rationale could be exhibited. Hence, procedures used (as described in the second segment of this report) were claify of quasi-algorithmic TS necessitates the outline delineation of the feasibility and practicality of quasi-algorithmic TS necessitates the outline delineation of a more systematic approach to development.

Some Background Considerations

As explained earlier, quasi-algorithms are an approximation to formal algorithms. While formal algorithms have many important uses in formal logic and in pure and applied mathematics, their most widely known application is the digital computer program. Quasi-algorithms are not exactly like formal algorithms, and quasi-algorithmic TS are not to be thought exactly like computer programs of either the digital or the analog type; neither are human beings exactly like either analog or digital computers. However, quasi-algorithmic TS and (particularly digital) computer programs, if not of the same genus and species are members of the same family or, perhaps, only order or class. For practical purposes they do share certain characteristics and introduce, at least, some similar problems.

Once it has been developed and validated (tested, verified) a quasi-algorithmic TS retains its <u>specific</u> validity and usefulness indefinitely. So long as there is no significant change in the type of task(s) to which it is applicable, the population on which it was validated, or the kind of use to which it is put its "shelf life" is indefinite. In a similar sense this is also true of computer programs. So long as there is, for example, no change in the way a pay-roll is computed, so long as there is no change in the computer (make, model, configuration) for which the program was written, and so long as there is no new or additional output requirement (e.g., summarize not only pay, taxes, deductions, etc., but also accumulated vacation and sick leave credits) the program may be used over and over again. However, changes of various types do occur over time, and programs must be "maintained", updated, augmented, and so on. There is a strong presumption that analogous changes will take place with respect to TS.

We had a specific example of a change even within the present exploratory effort. As explained earlier, the Battery Computer (in the FDC) no longer announces the number of rounds to be fired and the fuze type when first alerting his Battery to a fire mission (Task 13), but only on first giving Quadrant Elevation (Task 19). A change such as this one is conceptually not difficult -- perhaps trivial, but does entail tedious rearrangements. Not only will the text of one or more operations change (in source as well receiving TS), but some operations may be eliminated and/or others added. Index Numbers in both TS may change. References to the "old" Index Numbers must be found and changed. Possibly a change in some sort of nomenclature may occur, or perhaps in a phrase used repeatedly throughout several TS. All of the instances of prior use must be found and the corrections made.

So long as TS information is stored in printed form any changes are likely to present a staggering clerical problem. The tracing of concatenated change effects through reams of printed paper is likely to entail labor costs that may well turn out to be greater in the long run than the original costs of developing the TS. The solution to this problem is suggested by the standard mode of dealing with computer programs. Storing the basic information in magnetic form via a computer simplifies the change procedures immensely and reduces attendant labor costs to a much more reasonable level. As is the case with computer programs, the stored information can be printed out or displayed on a cathode ray tube(CRT) at will. In addition, computer furnished clerical supports of <u>assigning</u> unique Index Numbers, of text editing, of searching, of locating incomplete or "open" branches (to name but an obvious few) can simplify and expedite original task specification development and validation (verification, testing) and provide similar simplification in useful applications of TS.

Storage and handling of TS information can be accomplished on almost any kind of general purpose digital computer. It can be done in a batch-processing mode or, with far greater convenience, on an individual terminal in a time-sharing mode. However, it can be argued that the "personal" type of micro-computer that is being currently introduced commercially offers important advantages. The chief advantages would seem to be (1) simplicity, (2) portability and (3) cost. These micro-computers have been designed for a market of minimal sophistication so that the operation of these devices does not demand or pre-suppose any substantial degrees of skills or knowledges on the part of prospective users. They require no special environments (air conditioning, electric power, etc.), weigh perhaps 20 - 30 lbs, occupy no more than one half of a desk top, and use ordinary tape-cassettes for mass information storage. They

are, therefore, clearly and easily portable and useable, for example, in any office or field environment with 115 V service. Lastly, costs of currently advertised commercial products tend to be about the same as for good quality electric typewriters (less than \$1000).

If micro-computers can be assumed as a tool or helpmate for developers, maintainers and some users of TS, both, efficiency and economy will probably be achieved. Tape-cassette storage of substantive information guarantees its rapid and inexpensive reproducability. In principle, this information can be readily transferred to other information storage and handling environments. These considerations must be kept in mind as a practical backdrop for the development framework which follows.

Jobs/Tasks/Operations Inventories

The significance (by any sort of criterion) of all jobs or duty positions is not equal. Some can be said to be of major significance, while others are of little or no significance. This is equally true of individual tasks. For example, the computation of Site by the VCO can probably be considered as being highly significant, while the parroting of message traffic by the RTO is of little significance (though possibly of great importance to mission success). Similarly, some operations within individual tasks are significant (e.g., reading correct value of Site on GST) and others trivial (e.g., deciding whether the communication channel is in current use). However one might define "significant," it will be appreciated that there is no need to subject any and all job/task activities to analysis and detailed, quasialgorithmic specification. Rather such analysis probably should be only selectively undertaken. The issue of the criteria for selection goes beyond the scope of this report.

Hayes, Meltzer and Wolf (1970) pointed out that substantive conclusions to be drawn from a data analysis, or the model (image or representation of reality) that emerges is very much dependent on the fine-grainedness of the data that are considered. Two models may be equally correct, though seemingly very different. For example, the structures apparent under a microscope at the highest and lowest levels of magnification will be very different, though both will be of the same object. As in the case of the microscope, it will not invariably be desirable to examine any and all human activity to the level of the (extremely) elementary operation. For many purposes it may suffice to stay at the leve! of the individual task (minimal "magnification" and maximal "area of view"). However, as in any structure, representation at all "levels of magnification" must have a cross-level coherence or internal, mutually consistent morphology.

If one considers, for example, Tasks 05 through 19 as specified in this report, it will be evident that a different sort of task identification, grouping of operations or structure would likely have been produced in an inventory derived from questioning MOS 13E personnel about "what they do." The problem of inventorying tasks so as to maintain a coherent morphology can be identified as requiring a solution, but the solution again goes beyond the scope of the present project.

A related problem that was addressed without a wholly satisfactory solution is the algorithmic or quasi-algorithmic representation of a group or team of interacting individuals. Unlike the serial activities of individuals such activities occur in parallel and with different degrees of interdependence and synchrony. In Figure 1 an approximate task plot was provided for a routine fire mission, but this graphic representation does not have the degree of rigor, for example, that would be represent for computer implementation or simulation. An examination of pertinent literature (Miller, 1973; Varsonyi, 1977, 1978) suggests that Petri nets may provide the formal basis for a solution, and an attempt was made to develop an augmented Petri net in accordance with Peterson (1977) and Zisman (1978). A graphic depiction of Tasks (5 - 19) as an augmented Petri net rapidly becomes too complex and cumbersome, since input, processing and output nodes must be distinguished. A conversion of the net to an isomorphic table alleviates the problem only a little. A lengthier and more exhaustive examination of this problem will be necessary to assure feasibility of computer implementation of (including analytic/synthetic operations on) task structures of teams (groups rather than individuals).

Within the foregoing qualifications and identification of issues requiring further, more elaborate examination it is suggested that tasks as such be surveyed and inventoried first before proceeding to an uncritical, detailed analysis of any and all tasks (i.e., analysis to the level of operations). The criteria for proceeding to a detailed analysis will, no doubt, be somewhat contingent on the intended purposes. If, for instance, the purpose is one of assessment or prediction of team performance, the criticality to overall mission success might be considered a factor. If the purpose is training, statistics on a task's being a steady source of inadequate performance, or of being difficult to learn -- being a known instructional problem -- may be the more weighty factor. Whatever the criteria, however, only tasks for which there exists an adequate justification should be specified in detail in quasi-algorithmic form.

Analyst - Expert Collaboration

This segment of the report deals with suggestions that can be made at this stage of experience concerning approaches to effective, efficient and economical routine development of quasi-algorithmic TS. So far the advantages of developing TS with the aid of micro-computers have been outlined. The host of implications carried by this recommendation is too large for a minutely detailed consideration, and it must be hoped that this missing information can be supplied by readers. Also, a <u>selective</u> subjection of tasks to detailed analysis was recommended. Within these two major framework considerations a practical procedure such as the following one seems indicated.

The time consuming technique used in this present exploratory effort of locating relevant documentation, analysing its content, synthesizing from it the gross algorithm, etc. is clearly very inefficient. A better technique will make an expert in a given subject-matter area available to the task analyst. The analyst will go to the expert's location so that requisite equipment and other resources will be available. The analyst will carry with him a portable micro-computer with key-board, CRT and tape-cassette reader/recorder.

For tasks in a list selected according to applicable criteria from a pre-established inventory, analyst and expert will now collaborate. The expert will define, explain and demonstrate as necessary exactly how a given task is accomplished. The expert will elicit all information needed to eliminate ambiguity, choice, equivocality and so forth through questions to the expert. Provisionally, operation-byoperation, segment-by-segment or branch-by-branch the analyst will begin to formulate the prescriptive directions and store them via the key-board in the computer. On completion of any major segment or of an entire task the (structured) stored information will be retrieved in its various permissible orders, reviewed, reformulated or revised. When expert and analyst agree that the stored formulations seem to meet the criteria for a proper quasi-algorithmic TS, they will go on to repeat the procedure for the next task

Ultimately the list of tasks will have been exhausted. A corresponding set of TS will have come into existence and be stored within the micro-computer. Next, these draft-specifications might be reviewed and revised for textual niceties and serious typographical errors. Then they will be ready for verification with several additional experts who will not include the original collaborator.

Rather than having to listen and read from the printed page as in procedures followed by the present authors, the expert will have the successive prescriptive directions presented to him on the CRT. He will not be distracted by irrelevant information such as, preceding and succeeding operations and lists of Index Numbers. This information will be invisible to him, but perform its role in linking individual operations (prescriptive directions) appropriately. As mistakes and deficiencies are uncovered or supplementary comments are made, they can be entered on the key-board and later retrieved in association with the operation(s) to which they apply.

When task specifications have been adequately verified, a final round of revisions will be made. Again they will be made directly via the key-board with computer-furnished clerical supports and with respect to information displayed on the CRT. Final versions of TS can be duplicated on tape-cassettes or printed out, or the information can be transferred to larger computers.

USES OF TASK SPECIFICATIONS

All of the uses of task specifications (TS) remain to be discovered as with any innovation. What can be discussed here are only some of them and with respect to development procedures.

Instruction

There is virtually universal agreement in the pertinent literature that the development of effective and efficient instruction must be based on carefully pre-established instructional objectives (see, e.g., Ammerman and Melching, 1966; Banathy, 1968; Briggs, 1970; Mager, 1961; Smith, 1964 a, b). Such predefined and properly stated objectives are necessary to orient the designer of the instruction and to assure complete coverage. These and related efforts are sometimes referred to as the "front-end analysis" in the planning and development of training. The implicit object of these efforts is to provide a "map" or a "blueprint" that can guide detailed instructional development.

With reference to explanations given in the first segment of this report it will be recognized that instructional objectives by themselves do not provide a complete and detailed "blueprint" of a learning task. The question of how these objectives can be attained is left begging, and instructional designers must fall back upon their intuition. Instructional objectives, at best, provide a sort of "architectural sketch;" it is only properly developed quasi-algorithmic (learning) task specifications that provide the full blueprint.

It must be stressed that quasi-algorithmic specifications of the learning task do <u>not</u> solve all of the instructional design and development problems. They <u>do specify</u> what must be done to accomplish the given task, but <u>do not specify</u> how the task executor (e.g., the trainee) can be controlled (guided, constrained, so as to perform any and all component operations properly. The <u>learning</u> task is not identical with the <u>teaching</u> task, although it contains essential information for the formulation of the latter (see Pask, 1975, Ch. 7).

When TS are being prepared for use in instructional development, the previously outlined procedures should be extended in two ways. First, as has been explained before, though a given TS may have been validated for a population of experts, the component prescriptive directions are unlikely to be of sufficient elementarity for a population of novices/students/trainees. This elementarity will need to be adjusted in collaboration with students from the population in question. Such an adjustment must not in the least change the structure of the prescriptive directions. Only those directions which are not comprehensible to students (they cannot tell what they are to do and/or how they are to do it) must be broken down into (replaced by) a more finely grained, structured set of operations. In effect, an operation that is elementary for the expert may constitute a mini-task for the student. In principle, the process of developing a quasi-algorithmic specification for the mini-task parallels that used for any task. The mini-task specification must be "patched" into the place formerly occupied by the original, non-elementary prescriptive direction.

The second additional development requirement arises when it is desired to take advantage of the diagnostic possibilities by quasi-algorithmic (learning) TS in adaptive forms of instruction (individualized instruction, computer administered instruction or CAI). Each operation in a TS resulting in a potentially observable outcome must be examined to determine the consequences of all types of possible mistakes. Ideally the implications of combinations of mistakes should also be determined. The object of these efforts is to develop a set of observable "symptoms" that point to specific causes in the students' learning task performance and inherently suggest the precise, required, remedial instructional action.

Assessment/Testing

All of the ways in which TS can be used in assessment undoubtedly have not yet been discovered. For example, there is an intuitive presumption that quasi-algorithms have a pertinence for adaptive, individualized or tailored testing as they do for instruction, but we have not established such a connection. Certain it is that there are applications in, both, normative and criterion-referenced testing.

So long as the elementarity of a given prescriptive direction (operation) or, in the aggregate, of an entire TS is relative to a defined population, the level of elementarity is capable of being scaled. Hence, a score based on that scale can express the standing of that person on that scale. Establishment of the scale as such will parallel the procedures used in conventional psychometrics.

With respect to criterion-referenced testing tasks (in the sense used herein) could constitute items or subtests in an achievement battery such as, skill qualifications tests (SQT's). In principle, a test administrator or observer could use the task specification (a) to pre-identify <u>all</u> observable intermediate outcomes and their values, and (b) to record, at least, success or failure at each observation point. Not only could degree of mastery be ascertained, but an accurate diagnostic analysis coupled with specific recommendations for supplementary study could be provided. The degree of diagnostic detail desired will determine the amount of additional development necessary as in the case of instruction.

Duty/Task Structuring and Taxonomy

Quasi-algorithmic TS unlike the products of traditional approaches provide a reliable, verified foundation for data structures erected on them. They provide the foundation, for example, for meaning-ful task taxonomies. Given the application of a metric or semi-metric to a <u>sound</u> data structure the relative degrees of relationship among operations, among tasks and among jobs (duty positions) can be calculated. It is to be expected that the degree of such a relationship would express a degree of "transfer of mastery" of how much in a new task or duty position remains to be mastered by any incumbent who has already mastered another task or job.

Kingsley and Kopstein (1977), in an initial exploration, developed the concept of a dominance relation among occupational groupings. This relation imposes a partial order on a set of occupational entities (job families, jobs or duty positions, tasks, etc.) which can be viewed as an ordering according to "similarity." Also, a hierarchical structure among the occupational entities is established. The dominance relation and any other more elaborate taxonomic development require that each entity (job or task or operation) have associated with it a set of attributes ("characteristics") defining it. Clearly, the assignment of values to each attribute even in a pre-established set constitutes an additional development. However, attribute sets provide the basis for erecting more elaborate data structures and for the extraction of information from these structures. These issues are discussed in Part II of this report.

 $[\]frac{9}{2}$ This is not to be equated with the concept of transfer of training which expresses the savings in mean number of trials to learn a second task after learning a first one.

PART II. A MODEL FOR STRUCTURING TASK SPECIFICATIONS

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ABSTRACT REPRESENTATIONS OF TASK SPECIFICATIONS

Part I of this report has dealt with the ways and means for obtaining accurate and reliable specifications of human activities within certain military occupational duties. It was shown how quasi-algorithmic task specifications constitute an advance over traditional approaches, because they possess the very useful and important properties of <u>specificity</u>, <u>generality</u> and <u>resultivity</u>. Thus the quasi-algorithmic form of task-activity specification provides the basic, objective, detailed and valid information about the operations and their organization that comprise task accomplishment. The practical feasibility of developing and verifying quasi-algorithmic task descriptions/specifications was demonstrated.

In this Part II of the report we proceed to our exploration of the ways and means by which the full range of information in quasi-algorithmic task specifications may be elaborated, extracted and used. To be sure, some of the ways in which the obvious and "raw" information may be put to use have already been suggested in the preceding discussion of some uses of the task specifications (TS). However, these immediate and direct forms of information use represent only a small part of a far greater potential. That potential resides in data structures (models) being erected on the solid foundations of objectively verified TS. The precise kinds of structures to be erected on existing foundations -- as in the case of a building -- is primarily dependent on the uses intended for them. However, there are many possible uses; the different kinds of data structures and the information that can be extracted from them can serve in many personnel oriented management decision processes, or can themselves constitute certain management models.

The possibilities are certainly manifold and within each type of application there are numerous variants on the potential data exploitation. Unfortunately at this initial stage of exploration <u>all</u> of the possibilities can be neither identified nor fully characterized. At a comparable stage the present uses for digital computers, lasers, operations research methods, or any other innovation could also not be clearly and minutely foreseen. Nor could all of the development problems toward actual, smooth implementation be specified in advance. Every innovation needs a period of incubation to develop its potential, and it requires sustained development efforts during that period. This reminder may be necessary, because present efforts are limited to an initial <u>exploration</u>. Within the scope of the present investigation only some initial and major and important possibilities could be identified. Due to constraints on the scope of that exploration it could go no further than to characterize the issues for further research and development leading to potential operational applications. These issues could not be resolved within the present exploratory effort.

The following sections of this report proceed to the exploration of formal data structures erected on the quasi-algorithmic TS. As in all cases of mathematization, the abstraction into symbols of the underlying verbal formulations inevitably entails a loss of some information. At the same time symbolic forms make for mathematical tractability, i.e., manipulability of the data toward rigorous solutions of certain problems. Tractability of mathematical models has long been recognized to be directly related to the degree of abstraction they represent (see, e.g., Ackoff, 1962, pp. 109 - 110). Below it will be seen that some inversion of the information loss can be obtained by making explicit some characteristics or attributes of operations within TS. The logical and mathematical methodology outlined here below, incidentally, is a general one. While it is illustrated here in terms of operations within tasks, it is equally applicable to tasks within jobs or duty positions and to still more inclusive elements, and this should be kept in mind.

Representing a Task Specification in Terms of Attributes

Each of the task specifications given in Part I can be viewed as an ordered list of operations. To begin the mathematical formulation, let the operations in a task specification (TS) be symbolized by the small letter "o" with subscripts. Then the operations in a TS can be written as the ordered set,

where m is the number of operations in the TS. It is convenient to represent this ordered set by the capital letter "O".

Then

1)

$$0 = (o_1, o_2, \dots, o_m)$$

will represent the ordered set of operations in an arbitrary task specification. When a particular task specification is under discussion, the notation TS with a subscript is used. The subscript is the Index Number of the task specification given in Part I. The associated set of operations bears the subscript with the same index number. Thus, TS_{053000} and 0_{053000} are the beginning of the task specification and of the set of operations of Task 053 of Part I titled, "Plot Target by Shift from a Known Point". For our purposes, no ambiguity results if the O's are not included in the subscript. Thus, TS_{053000} and 0_{053000} become TS_{53} and 0_{53} , respectively. With this notation, expression (1) for TS_{53} is written,

2)
$$0_{53} = (0_2, 0_3, \dots, 0_{13}).$$

Operations o_1 and o_{13} of TS₅₃ are not included in the set 0_{53} because they are decision points. Task specification 053000 is the main example used in what follows to illustrate the concepts developed and the issues surrounding these concepts.

To establish data structures and derive information from them requires a fundamental assumption to be made. This is the assumption that each operation in a task specification can be described in terms of attributes from a pre-selected set of attributes. Operations may be described by their possession of all or some of the attributes in the set. Let capital A designate the total set of attributes and the small letter "a", with subscripts, denote the individual attributes in A. The set A is an ordinary (unordered)

Table 3					
Attributes for Illustrative	e Example				
Hypothetical Attributes	Abbreviation				
Short Term Memory	a ₁				
Reading Skill	~_ *^2				
Visual Acuity	a ₃				
Geometric Skill	^a 4				
Finger Dexterity	^a 5				
Orientation Skill	^a 6				
Numerical Skill	^a 7				
Eye-Hand-Finger Coordination	^a 8				
Precision/Accuracy	^a 9				
Color Discrimination	^a 10				
Form Perception	^a 11				
Stamina	^a 12				

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set and, as is customary, is written as

3) $A = \{a_1, a_2, \dots, a_n\},$

where n is the number of attributes in the set A. To illustrate, Table 3 shows 12 attributes the operations in 0_{53} may possess. In our judgment, based on the experience gained in deriving the TS of Part I, the 12 attributes in Table 3 are some of the attributes required to perform some of the operations in all of the TS. The number of attributes is small to permit hand computations to illustrate the theory. By no means is the list of attributes to be considered a definitive statement of attributes required to describe all of the operations in the set of TS. Their only purpose is to illustrate properties of the general model by a reasonably practical example. No particular relevance should be sought or seen in the results to be obtained by assuming the attribute set of Table 3.

The attributes in Table 3 are concisely represented by the set,

 $A = \{a_1, a_2, \dots, a_{12}\}.$

The exact explication of each attribute is not important for our present purposes. Most of the attributes are hypothetical and self-explanatory, but a_6 and a_9 require some explanation. "Orientation Skill," attribute a_6 is a short way of stating the attribute associated with reading a map. It includes, for example, the ability to distinguish cardinal directions, read and plot coordinates, read and plot angles, etc. "Precision/Accuracy," attribute a_9 is an hypothetical measure of how well a_9 has to be performed.

Table 4 shows which attributes of Table 3 characterize each of the 12 operations of TS_{53} . As in the selection of the attribute set, this assignment of attributes to operations is hypothetical and for illustrative purposes only. However, the assignments are presumably not altogether unrealistic.

<u>Table 4</u>							
Attributes	of Operations	in TS ₅₃					
Operation	Hypothetical	Attribu	tes				
°2	^a 1' ^a 2						
°3	^a 1, ^a 2,	^a 3, ^a 4					
°4	^a 4, ^a 5						
°5	^a 3, ^a 4,	^a 5, ^a 9					
°6	^a 3, ^a 4,	^a 5, ^a 6,	^a 9				
°7	^a 3, ^a 4,	^a 5, ^a 7					
°8	^a 3, ^a 4,	^a 5, ^a 6,	a ₈ , a ₉				
°9	^a 4, ^a 5,	^a 8					
°10	^a 5						
°11	^a 1, ^a 3,	^a 4, ^a 8,	^a 9				
°12	^a 1' ^a 3'	^a 4, ^a 8,	^a 9				
°13	^a 3, ^a 5,	a ₉					

So far, two sets have been defined for a TS, O and A. Set O has m elements and A has n elements. Our fundamental assumption is that every operation o_i (i = 1, 2,..., m) possesses some amount of attribute a_j (j = 1, 2,..., n). Let r_{ij} represent the amount -- in some sense -- of attribute a_j possessed by operation o_i . For example, r_{23} is the amount of attribute a_3 required in operation o_2° .

Three sets are now defined, 0, A, and the set of r_{ij} values. Their interrelation can be displayed as an m by n matrix as shown in Figure 2. This matrix is defined as the Operations/Attributes (0/A)



matrix associated with a TS. The notation $(0/A)_{53}$ means the O/A matrix corresponding to TS₅₃. Each of the rows in the O/A matrix of Figure 2 is a linear vector. If o_i is an arbitrary operation of the O/A matrix, it can be written as,

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$$o_i = (r_{i1}, r_{i2}, \dots, r_{in})$$

where i can take on any one of m values. The linear vector is defined as the <u>description</u> of operation o_i in terms of the attribute set A. Therefore, each of the m rows in the O/A matrix is a description of an operation, and the sequence of m rows is a description of the entire TS.

The $(0/A)_{53}$ matrix is not shown at this point. However, its row labels would be the 12 elements of the set 0 given by (2), and its column labels would be the 12 elements of the set A given by (3). Its r_{ii} values for the attributes would depend upon the type of attribute scale used.

Expression (4) was defined as the description of an operation. However, it can be considered also as the description of the attributes required by an individual person to perform the operation. This dual interpretation of a description is important in interpreting some of the results obtained later. Because of the duality, it is occasionally necessary to identify what the description refers to -- an operation or an individual. When this is not necessary, the word "description" applies to both interpretations.

Up to this point a single O/A matrix has been the topic of discussion. However, a set of O/A matrices are present in the empirical situation of interest to us. Some of the operations are similar in any TS, but the majority of operations are different. This is also true for the set of O/A's. In addition, the number of operations can be different in each O/A in the set of O/A's. Generally the r_{ij} values in all of the O/A's are different. The attribute set, however, is assumed to be the same for each O/A. This assumption is not restrictive. If each O/A had a different attribute set, a new attribute set could be defined by combining all the attribute sets and calling this the common attribute set.

Before proceeding with the development of the model, a few general comments are appropriate on some of the issues involved in selecting attributes for the attribute set.

General Criteria for Selecting Attributes

4)

It was pointed out in Part I that elementarity of operations is relative to a defined population. Elementarity is also relative to what we wish to accomplish with the TS. The number of operations in a TS is, practically speaking, determined as soon as the level of elementarity for operations has been selected. The only way the number of operations can be changed significantly in a TS is by altering the

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elementarity of the operations. Selection of the number and nature of attributes is interrelated with the selection of operation elementarity, and both selections are governed by the objectives of the study.

In addition to the above considerations a number of other general and interrelated factors are involved in selecting attributes. These factors are considered desirable features for an attribute set to possess. These factors are here discussed only in general terms.

1. <u>Measurability</u>: An attribute can be measured very precisely and objectively, e.g., the height of a person in meters and centimeters, or it can be measured with no precision and only subjectively, e.g., "must have a sense of humor." However, the question of whether an attribute is measurable or non-measurable has to be answered by including time and cost considerations. For example, "must have a sense of humor" might well be a desirable attribute for people to have in nearly all group activities. It may be particularly desirable when the group is expected to perform in stress situations such as, combat operations. However, the attribute may be impractical (non-measurable) because of the time and cost involved in its determination, and because the attribute varies with ethnic and cultural background.

2. <u>Relevancy</u>: The relevancy of an attribute depends upon its importance or its criticality in the performance of a task. An attribute may be extremely relevant to accomplishing one task and totally meaningless when applied to another. Apart from this distinction, certain attributes have no relevance for any task. For example, "blue eyes" is an attribute for which it seems impossible to think of a task (in the Army) for which it might be required. Other attributes are non-relevant by law or regulation. Thus, the attributes "sex" and "race" are not permitted as descriptors for most or all Army tasks. On the other hand, the set of attributes should be large enough to describe every operation in a TS. For example, TS₃ "Constructing Azimuth Indexes", includes 55 operations. It does not appear reasonable to expect a set of three or four attributes to describe adequately all of the operations in this TS. Most questions about selecting relevant attributes are more subtle than the examples given above and are not easy to answer. One interesting method for obtaining answers to these questions is the Delphi-like technique of Roberts (1972). Clearly, relevancy is dependent on the purpose to which the TS descriptions are to be put, or the intent of the user.

3. Independence: In the model to be developed the attributes are assumed to be logically independent. The reason for this is that if attribute a_i and attribute a_j are not independent, then the presence of a_i and the absence of a_j in an operation amounts to a logical contradiction (Carnap, 1962). Independence is a logical requirement and sometimes difficult to achieve in practical situations. To illustrate the difficulty suppose one attribute to be "reading comprehension" and another "years of education." It is not immediately obvious whether these two attributes are logically independent or mutually dependent.

4. <u>Interpretability</u>: This factor is more of a requirement on the data structures derived from the O/A matrices than a requirement on the set of attributes. In other words, an extremely large set of attributes may be handled with the help of a computer, but the resulting data structures may be too large, complex and difficult to interpret and use.

The four desirable requirements interact with each other. One important relationship can be pointed out by considering the effect on relevance and interpretability caused by increasing the number of attributes. Certainly, increasing the number of attributes makes the descriptions of operations more complete and, hence, more relevant. But, doing this also makes the end results more difficult to interpret. In the extreme case the data handling requirements may come to exceed the capacity of even a large computer.

Issues raised in this section pose difficult problems, but no attempt can be made to resolve them within the present exploratory effort.

Attribute Scales

5)

An attribute scale for each attribute is required before the r_{ij} values in an O/A matrix can be determined. If a binary scale is used, then an attribute is either present in a description or absent. With a binary scale each attribute has associated with it an arbitrary value (a cutting score) to determine whether a description does or does not possess the attribute. To illustrate, suppose the attribute is "arithmetic skill," and a value of 80 (on some scale) is the cutting score. Then a symbol -- say l -- is placed in the O/A matrix in the arithmetic skill attribute column for those desriptions requiring a score of 80 or higher. A different symbol -- say 0 -- is used when the description does not require a score of 80.

In general terms, the assignment of the symbols "l" and "O" to the r_{ij} values of the O/A matrix of Figure 2 is made by the following rule:

$$r_{ij} = \begin{cases} 1 & \text{if operation } o_i \text{ possesses attribute } a_j \\ 0 & \text{if operation } o_i \text{ does not possess attribute } a_i. \end{cases}$$

When assignment rule (5) is applied to the operations and attributes of TS_{53} , as given in Table 4, the O/A matrix shown in Figure 3 is the result. This matrix is termed a binary O/A matrix, since a binary

Attributes													
		^a 1	^a 2	a3	^a 4	^a 5	^a 6	^a 7	^a 8	^a 9	^a 10	^a 11	^a 12
0,		1	1	0	0	0	0	0	0	0	0	0	0
0 ₂	[1	1	1	1	0	0	0	0	0	0	0	0
د ^٥	ł	0	С	0	1	1	0	0	0	0	0	0	0
ч °5		0	0	1	1	1	0	0	0	1	0	0	0
°6	Į	0	0	1	1	1	1	0	0	1	0	0	0
°7		0	0	1	1	1	0	1	0	0	0	0	0
°8	ł	0	0	1	1	1	1	0	1	1	0	0	0
°9		0	0	0	1	1	0	0	1	0	0	0	0
°10		0	С	0	0	1	0	0	0	0	0	0	0
011	1	1	0	1	1	0	0	0	1	1	0	0	0
°12		1	0	1	1	0	0	0	1	1	0	0	0
°13		0	0	1	0	1	0	0	0	1	0	0	0

Figure 3. Binary O/A Matrix for (TS)53

attribute scale is used to construct it. To illustrate how this matrix is to be read consider operation o_5 as an example. It has a 1 in the four attribute columns a_3 , a_4 , a_5 and a_9 . Thus, o_5 is said to be described by these four attributes. The absence in o_5 of the remaining eight attributes is descriptive, also, of the operation, but in a non-affirmative manner. It should be noticed that attributes a_{10} , a_{11} and a_{12} do not occur in any of the operations of TS_{53} . They occur in other TS, because we assumed that the 12 attributes were sufficient to describe all of the operations in the set of TS. The last three columns are dropped in versions of $(O/A)_{53}$ below, because they are redundant for TS_{53} .

Using a cutting score in descriptions creates a serious problem when applied to an 0/A. A single cutting score has to serve for all the descriptions. This is a severe requirement, because it is not reasonable to expect a single score to be appropriate for all of the descriptions in the 0/A.

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A binary cutting score divides the attribute scale into two intervals. Thus one solution to minimize the problem is to divide the attribute scale into several intervals, that is, by introducing attribute levels (see, Kingsley and Kopstein, 1977). The refinement obtained is at the expense of adding attribute values and not by adding new attributes. Practical considerations may limit the size of the attribute set in an actual situation. If a size limitation exists, then finer attribute levels may require the elimination of desirable attributes from the attribute set.

A method allowing attributes to range over a possibly non-discrete set of values can overcome some of the defects of a binary cutting score. The theory of fuzzy subsets, developed by Zadeh (1965, 1973, 1977), offers an intuitively attractive basis on which such a method could be constructed $\frac{10}{}$. A few of the basic concepts of fuzzy subset theory are discussed in a later section of this report. Some ideas are also given on how the theory could be applied to empirical problems.

Problem Definition and Approach

In addition to other interests our concern is with inferring the structural properties of the information contained in an O/A matrix. More accurately, we are concerned with devisiing methods for detecting relations between the descriptions in an O/A matrix.

By definition the serial listing of descriptions in an O/A matrix exhibits the relation f descriptions being sequentially chained, and this is an example of a structural property. Other relations may exist, but their discovery is not as obvious and requires a sophisticated approach.

The approach adopted is to construct a mathematical model of the empirical situation represented by an O/A matrix. First, some simplifying assumptions are made and translated into mathematical terms. This approach has been initiated by our definitions of the sets 0, A, the set of r_{ij} values, and by the definition of a description given by expression (4). Mathematical reasoning is then employed after these assumptions and tranlations have been made.

The information contained in an O/A matrix does not permit the use of statistical techniques to discover its structure. Statistical methods may possibly be used only to determine the r_{ij} values in the matrix.

The model presented in the next section is based on a simple binary scale. That is, the r_{ij} values in the O/A matrix are either 1 or 0. A model of this type has a number of advantages: (1) it can be used for the study of many empirical problems; (2) it is tractable and, thus, it provides insights to properties that are difficult to detect when a more complex model formulation is used; (3) it can be easily extended to include refinements of attribute levels; (4) it can be easily programmed for a digital computer.

The model presented is a first stage model. With it some problems are solved, others are not, and some ideas for a more refined version of the model are suggested.

 $[\]frac{10}{10}$ Kaufmann (1975) gives a detailed summary of the development and status of research in the theory of fuzzy subsets.

THE BINARY VECTOR MODEL

The model to be discussed in this section was originally formulated in the language of set theory, symbolic logic and Carnap's (1962) concept of Q-predicate descriptions. However, to reach a wider audience the model is now presented in terms of binary vectors of a certain type. All of the concepts and results of the original formulation are preserved. In addition, the binary vector formulation is almost directly programmable for a digital computer.

Designation Vectors as Descriptions

Expression (4) was defined earlier to be the description of the arbitrary operation o_i in the general O/A matrix. When the r_{ij} values are binary, the descriptions are called binary vectors. For example, operation o_3 of Figure 3 is the binary vector with 9 components $\frac{11}{2}$,

Let $d(o_3)$ represent this vector so that

$$d(o_2) = (1,1,1,1,0,0,0,0,0).$$

No ambiguity results if the customary parentheses and commas of vector notation are eliminated. With this notational simplification, $d(o_2)$ becomes

$$d(o_3) = 111100000.$$

An arbitrary operation -- say o_i -- described by n binary attributes is designated by $d(o_i)$ and is a string of n 0's (zeros) and 1's. Following Homer (1967) such descriptions are termed designation vectors $\frac{12}{}$. With this notation the descriptions contained in Figure 3 for TS₅₃ are written as designation vectors and shown in Figure 4.

 $\frac{11}{Recall}$ that attributes a_{10} , a_{11} , and a_{12} are not present in TS₅₃.

F

 $\frac{12}{1}$ Homer's designation vectors are an application of Ledley's (1960, 1962) "designation numbers."

Basic Operations with Designation Vectors

Components of the designation vectors (the 0's and 1's) are not ordinary integers but Boolean symbols, and the usual arithmetic properties do not hold. Three Boolean operations are used: addition, multiplication and complementation. These three operations are defined as follows:



The symbol " \oplus " is used to indicate Boolean addition, and the symbol " * " to indicate Boolean multiplication. These special symbols are used to emphasize the distinction between Boolean and ordinary arithmetical operations.

Operations on designation vectors are defined in terms of these three basic Boolean operations. The general definitions are given first and then followed by an example using the designation vectors of Figure 4.

<u>Complementation</u>: The complement of a designation vector is obtained by replacing all 1's with 0's and all 0's with 1's in the vector. The complement of $d(o_1)$ is denoted by $\overline{d(o_1)}$ -- the bar being the Boolean operator NOT ().

Example: If

$$d(o_0) = 00110010,$$

then the complement of $d(o_q)$ is

 $\overline{d(o_9)} = 11001101$

<u>Union</u>: For a 1 to appear in the ith place of the union of two designation vectors $d(o_j)$ and $d(o_k)$, a 1 has to appear in the ith place of $d(o_j)$ or $d(o_k)$ or both. Or, using Boolean arithmetic, add the two designation vectors component by component. The union is denoted by the symbol V -- the Boolean operator OR (V)

$$d(o_4) = 000110000$$

$$d(o_6) = 001111001,$$

then

$$d(o_4) \bigvee d(o_6) = 001111001.$$

<u>Intersection</u>: For a 1 to appear in the i^{th} place of the intersection of the two designaion vectors $d(o_j)$ and $d(o_k)$, a 1 must be present in the i^{th} place of, both, $d(o_j)$ and $d(o_k)$. Or, using Boolean multiplication, multiply the two designation vectors component by component. The intersection is denoted by the symbol \wedge -- the Boolean operator AND (\wedge).

Example: If

$$d(o_{11}) = 101100011$$

 $d(o_3) = 111100000$,

then

$$d(o_{11}) \wedge d(o_3) = 101100000.$$

<u>Cardinality</u>: The cardinality of a designation vector is the number of 1's in the vector and is denoted by $|d(o_i)|$.

Example: If

then

 $d(o_7) = 001110100$

The above basic operations on designation vectors are used to define more complex relations between them.

 $|d(o_7)| = 4.$

The Difference and Distance Between Two Descriptions

For a set of operation descriptions such as, the set of Figure 4, it is useful to be able to determine whether two descriptions are identical, and, if they are not identical, to determine the extent of their difference. By inspection, $d(o_2)$ and $d(o_3)$ differ in all but the first two components. Also by inspection, it is easy to see that $d(o_{11})$ is identical with $d(o_{12})$. Although the difference between any two operations of Figure 4 is easy to determine, such determinations become rapidly more difficult when the attribute set or the set of operations is large. It is almost impossible to accomplish when both sets are large. However, a function can be defined for determining the difference between two descriptions.

Before defining this function, to avoid cumbersome notation, let d_i represent the designation vector $d(c_i)$. No ambiguity results by adopting this notation, and the expressions to be developed are easier to read, because fewer parentheses are present.

With this notational simplification let

represent the function that determines the difference between the two designation vectors d_i and d_j and call this function the <u>difference function</u>. The function is given by the following formula,

6)
$$\text{Diff}(d_i, d_j) = (d_i \bigvee d_j) \bigwedge (\overline{d_i \bigwedge d_j}),$$

where all the operations are Boolean. From this definition it is evident that $\operatorname{Diff}(d_i, d_j)$ is again a string of 0's and 1's. The following properties can be shown to hold for this string. If the k^{th} symbol is 1, then either the k^{th} symbol in d_i is 1 and the k^{th} symbol in d_j is 0, or the k^{th} symbol in d_i is 0 and the k^{th} symbol in d_j is 1. In other words, the symbols in the k^{th} place of d_i and d_j do not match. If, on the other hand, the symbol in the k^{th} place in $\operatorname{Diff}(d_i, j)$ is 0, then either the k^{th} symbols in d_i are both 0 or both 1. In other words, the symbols in the symbols in the k^{th} place of d_i and d_j and d_j are both 0 or both 1. In other words, the symbols in the symbols in the k^{th} place of d_i and d_j match.

Two examples of the use of formula (6) are given to illustrate its use.

Example 1: If,

$$d_3 = 111100000$$

 $d_{11} = 101100011$,

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then

$$d_3 \bigvee d_{11} = 111100011,$$

a∎d

$$d_3 \wedge d_{11} = 101100000$$
,

so that

$$d_3 \wedge d_{11} = 010011111.$$

Writing $\overline{d_3 \wedge d_{11}}$ underneath $d_3 \vee d_{11}$ makes it simpler to form this intersection. Thus,

$$\frac{d_3 \bigvee d_{11}}{d_3 \bigwedge d_{11}} = 010011111$$

so that

In other words, the attributes a_2 , a_8 and a_9 do not match in the two descriptions. The cardinality of $Diff(d_3, d_{11})$ or $|Diff(d_3, d_{11})| = 3$ is the number of attributes not matching.

Example 2: If,

$$d_5 = 001110001$$

 $d_6 = 001111001$

then, proceeding as in the first example,

$$\frac{d_5 \bigwedge d_6}{d_5 \bigwedge d_6} = 001110001$$

$$\frac{d_5 \bigwedge d_6}{d_5 \bigvee d_6} = 110001110$$

$$\frac{d_5 \bigvee d_6}{d_6} = 001111001$$

Diff(d_5, d_6) = 000001000

In other words, the only mismatched component in the two descriptions is attribute a_6 . Finally, to finish the example,

$$\operatorname{Diff}(d_5, d_6) = 1.$$

The complement of the difference function, denoted by $\overline{Diff}(d_i, d_j)$, is the vector that shows which attributes match. The cardinality of $\overline{Diff}(d_i, d_j)$ gives the number of matching components. Using the last two examples,

$$Diff(d_2, d_{11}) \approx 101111100$$

with cardinality 6, and

$$\overline{\text{Diff}(d_5, d_6)} \approx 111110111$$

with cardinality 8.

Before proceeding two special designation vectors need to be defined: the null vector and the unit vector. Let $d(\emptyset)$ represent the null designation vector. By definition $d(\emptyset)$ consists entirely of a string of 0's. The complement of $d(\emptyset)$, denoted by d(U), is the unit vector and consists entirely of a string of 1's.

It can be shown that two designation vectors, say d_i and d_j , are equivalent <u>if and only if</u> their difference is the null designation vector. In symbolic notation, $d_i = d_i$ if and only if

$$Diff(d_i, d_j) = d(\emptyset) = d_{\emptyset}$$

The theorem is illustrated by using (6) to compare d_{11} and d_{12} ,

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 $d_{11} = 101100011$ $d_{12} = 101100011.$

Thus,

$$\frac{d_{11} \wedge d_{12}}{d_{11} \wedge d_{12}} = 101100011$$

$$\frac{d_{11} \wedge d_{12}}{d_{11} \wedge d_{12}} = 010011100$$

$$\frac{d_{11} \wedge d_{12}}{d_{11}} = 101100011$$

and

$$Diff(d_{11}, d_{12}) = 000000000$$

so that

 $d_{11} = d_{12}$.

The equivalence of d_{11} and d_{12} is readily established, but this example does not illustrate the power of the theorem given by expression (6). It is important, at least for simplification purposes, to identify equivalent descriptions in a TS. Equivalent descriptions occur in a TS in two ways. First, an operation may be repeated a number of times. For example, the operation denoted verbally as "place pin into firing chart..." occurs very frequently in the TS associated with FDC activities. Second, two or more operations may be denoted with different verbiage but have the same descriptions in a TS can be obtained by considering TS_{04} "Constructing Deflection Indexes," which contains 59 operations. If each operation is described in terms of attributes by a designation vector, then $59^2 - 59 = 3422$ pairwise comparisons are required to identify equivalent descriptions. Clearly, this number of comparisons cannot be done manually even if the number of attributes is small. The difficulty becomes increasingly worse as the cardinality of the attribute set increases.

The difference between two designation vectors is closely related to the concept of the distance between two designation vectors. In fact, it can be shown that the cardinality of the difference function of two designation vectors has the essential properties of Euclidean distance $\frac{13}{}$. That is, if d_i , d_j , and d_k are three arbitrary designation vectors, then the following three properties hold. First, $|\text{Diff}(d_i, d_j)| = |\text{Diff}(d_j, d_i)|$ and this is the symmetric property of distance. Second, $d_i = d_j$ if and only if $|\text{Diff}(d_i, d_j)| = 0$, and this is the identity property of distance. Third, $|\text{Diff}(d_i, d_j)| +$ $+ |\text{Diff}(d_j, d_k)| \geq |\text{Diff}(d_i, d_k)|$, and this is the triangle property of distance. In topology these three properties define a metric, i.e., the cardinality of the difference function has the essential properties of distance (Sierpinski, 1952; Kuratowski, 1962).

The Concept of Dominance

By inspecting the descriptions given by the designation vectors in Figure 4 it is easy to see that certain operations require more attributes than others. This is readily determined by comparing the cardinalities of the designation vectors. What is not so easy to determine is illustrated by the two descriptions,

$$d_3 = 111100000$$

 $d_2 = 110000000$

from Figure 4. Description d_3 has the same attributes as description d_2 plus two more. Thus, an individual who can perform operation d_3 has attributes a_1 , a_2 , a_3 and a_4 and can certainly also perform d_3 which requires only two attributes a_1 and a_2 . The terminology d_3 dominates d_2 is used to describe this situation, and the notation d_3 Dom d_2 will be used to represent it symbolically. This

 $\frac{13}{}$ See Restle (1954) for another psychological application of the cardinality of the difference function.

intuitive concept is more precisely defined by saying that $d_i Dom d_j$ if and only if the designation vector d_i possesses all of the attributes of designation vector d_j plus at least one more. To determine visually whether one designation vector dominates another is impossible when the attribute set is large. However, the comparison can be done by using the following theorem. Designation vector d_i dominates designation vector d_j if and only if,

8)
$$\operatorname{Diff}(d_i, d_j) = d_i \sqrt{d_j}$$
.

Descriptions d_3 and d_2 are used to illustrate the application of expression (8). The left side of (8) is evaluated as,

$$\frac{d_3 \wedge d_2}{d_3 \wedge d_2} = 11000000$$
$$\frac{d_3 \wedge d_2}{d_3 \wedge d_2} = 00111111$$
$$\frac{d_2 \wedge d_3}{d_3} = 111100000$$

so that

 $Diff(d_3, d_2) = 001100000.$

The right side of (8) is evaluated as,

$$\frac{d_3}{d_2} = 111100000$$
$$\frac{d_3}{d_2} = 001111111$$
$$\frac{1}{2} \int d_3 = 001100000,$$

and this is the same as $Diff(d_3, d_2)$ so that d_3 Dom d_2 .

It can be shown that the dominance relation induces a partial order on the set of descriptions. That is, the dominance relation is irreflexive, asymmetric and transitive. In other words, if d_i , d_j and d_k are three arbitrary descriptions, then it is false that d_i Dom d_i (Dom is irreflexive); if d_i Dom d_j , then it is false that d_j Dom d_i (Dom is asymmetric); and if d_i Dom d_j and d_j Dom d_k , then d_i Dom d_k . The partial ordering of the set of descriptions by the dominance relation is an important result. It is the first structural result derived from the model, and with it the set of descriptions can be arranged into a pattern.

Representations of the Dominance Relation

Two representations are used to exhibit the structure in a set of TS implied by the dominance relation, a matrix representation and a graph representation. Figure 5 is the first step in constructing the matrix representation. It is actually Figure 3 slightly rearranged. The descriptions are now listed in descending order of magnitude of their cardinalities. Cardinalities of the descriptions are shown in the column on the right-hand side of the matrix. The matrix of Figure 6 is obtained by using expression (8) on the descriptions in Figure 5. A total of 78 applications of (8) are required. For example, using (8), d_8 is compared with 11 descriptions to determine dominance, d_6 is compared with 10 descriptions, etc. If in these comparisons d_i dominates d_i , a l is placed in the ith row and jth column of the matrix. Descriptions d_{11} and d_{12} , being identical, are grouped together in the matrix. Thus the descriptions in the left-hand column dominate the descriptions in the top row if and only if a 1 appears in the corresponding row/column cell of the matrix. For example, d_8 dominates d_6 , d_5 , d_9 , d_{13} . d_4 and d_{10} ; d_7 dominates d_4 and d_{10} , etc. The matrix of Figure 6 is termed the dominance matrix associated with a TS. In particular, Figure 6 is the dominance matrix associated with TS_{53} . Row sums and column sums are given in Figure 6 as well as the cardinalities of the descriptions. A row sum is the number of descriptions dominated by the row description (e.g., d_8 dominates 6 descriptions, d_7 dominates 2 descriptions, etc. A column sum is the number of descriptions dominating the column descriptions

							Att	ribute	9 9						
				^a 1	^a 2	^a 3	^a 4	^a 5	^a 6	a7	^a 8	^a 9_	Card	inality	
		d ₈		0	0	1	1	1	1	0	1	1		6	
		d ₆		0	0	1	1	1	1	0	0	1		5	
D	ı	d ₁₁		1	0	1	1	0	0	0	1	1		5	
e		d ₁₂		1	0	1	1	0	0	0	1	1		5	
s i	V	d		1	1	1	1	0	0	0	0	0		4	
g	c	d ₅	1	0	0	1	1	1	0	0	0	1		4	
n	t	d ₇	1	0	0	1	1	1	0	1	0	0		4	
t	r	d _o		0	0	0	1	1	0	0	1	0		3	
i	s	d13		0	0	1	0	1	0	0	0	1		3	
n	1	d ₂		1	1	0	0	0	0	0	0	0		2	
		d,		0	0	0	1	1	0	0	0	0		2	
		d ₁₀		0	0	0	0	1	0	0	0	0	(1	
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	Dom	ł			d										
	Г		^d 8	d ₆	^d 12	d ₃	^d 5	ď7	d۹	^d 13	d_2	d ₄	^d 10	Cardi- nality	F
	dg	T		1			1		1	1		1	1	6	
	d ₆						1			1		1	1	5	4
d ₁₁	d12													5	0
11	d,										1			4	1
	d ₅									1		1	1	4	'n
	d ₇											1	1	4	2
	d _o											1	1	3	2
	d, 3												1	3	1
	d ₂													2	0
	d,												1	2	1
	d10												1	1	0
Co	lumn			1			2		1	3	1	5	7		•
					Figu	e 6.	Domi	inance	e Mati	rix fo	r TS	53			

e.g., no descriptions dominate d_{11}^{11} , d_{12}^{12} , but five descriptions dominate d_4^{11} .

Not all descriptions are comparable. It is possible to have two descriptions, say d_i and d_j , where d_i is not equivalent to d_j , d_i does not dominate d_j , and d_j does not dominate d_i . That is, the two descriptions cannot be compared for dominance. This always occurs when the two descriptions have the same cardinality, or when expression (8) is not satisfied. Non-comparable descriptions are indicated by empty row/column cells in the matrix of Figure 6.

Figure 7 shows the dominance relation of Figure 6 as a graph. To construct the graph the procedure is first to plot descriptions of equal cardinality as points on the same level in descending magnitude and labeled with the appropriate d_i 's. Then two points, d_i and d_j , are connected with a line if and only if a 1 is in the ith row and jth column of the dominance matrix. The graph of Figure 7 is called the dominance graph of TS_{53} . Such graphs, when a large number of descriptions are involved, can be extremely complicated, difficult to draw and difficult to read. Fortunately, some simplification





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can be made by taking advantage of the transitivity of the dominance relation to remove redundant lines from the graph. For example, in Figure 6, d_8 dominates d_3 and d_3 dominates d_{10} so that by transitivity d_8 dominates d_{10} . Thus the line joining d_8 to d_{10} is redundant. An algorithm for removing such redundant lines from a transitive graph is given in Kingsley and Kopstein (1977). Applying this algorithm to the dominance graph of Figure 7 yields the simpler dominance graph shown in Figure 8.

The dominance matrix of Figure 6 and the dominance graphs of Figures 7 and 8 are different representations of the same underlying relation, namely the dominance relation. Each representation shows the relation in a different way. Dominance graphs show the relation graphically, and thereby dramatically depict the dominating descriptions and their interconnections. However, such depictions become extremely complicated to draw and interpret for large data sets. Dominance matrices are relatively easy to produce and can be manipulated mathematically, but they do not readily show the interconnections. Unlike graphs the matrices can be stored in a computer and then easily manipulated to produce any result of interest.

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an approximation of a

APPLICATIONS

A number of requirements are placed on the analyst who applies the quasi-algorithmic approach outlined in Part I of this report to establish TS and to use the model developed in Part II. First, he is forced to identify specifically the operations in the task being analyzed. Second, describing the operations forces him to select a specific set of attributes. Third, from the set of attributes he has to select exactly those attributes associated with each operation in the set of TS. However, the clarity forced on the analyst by these requirements is almost totally negated, if the analyst does not know in quite precise terms just what problem he is being asked to solve.

Some preactical interpretations of the mathematical model have been given as the model was being developed. The choice of terms used to describe concepts in the model was not arbitrary. The <u>exclusive</u> <u>sum, metric</u> and <u>partial order</u> are the customary terms used technically (in mathematics) to describe what we have termed <u>difference</u>, <u>distance</u> and <u>dominance</u> respectively. Our choice of terms to describe concepts reflects implicit applications of the concepts. Since we are here not solving a <u>particular</u> problem of application, we cannot give a detailed application of the model. In other words, the last requirement for clarity is violated (missing). The best that can be done under these circumstances is to discuss briefly and in general terms some possible uses of the model.

Applications to Training and Evaluation

A number of uses of TS for FDC tasks have been described in Part I. These uses were based on the serial listing of the operations in a task specification. However, the structure given by the model disrupts the serial relation of the operations and replaces it with other relations. These new relations disclose properties not immediately evident from a TS. Some of them are discussed below.

The dominance graph of Figure 7 can be used as a diagnostic tool either during instruction in the task, or in monitoring task performance and mastery. To illustrate, the performance of operation o_5 directly requires attributes needed in performing o_6 . Thus failure to perform o_5 can be immediately compared with the performance of o_6 . If the difficulty is not resolved, then o_8 , which immediately dominates o_6 , can be used for comparison. Longer and more complex back-tracking may be required for other troublesome operations of lower cardinality. Isolated components of the graph such as, d_{11} , d_{12} and d_3 , d_2 of Figure 7 require special attention, because they are not dominated by or dominate other operations.

Use of the difference relation to identify equivalent descriptions has been mentioned earlier. The identification of equivalent operations is important, because it may be used to reflect the degree of practice in some particular facet of skill that is provided by a given task. Alternatively it can be used to pinpoint the repeated opportunities for observing this skill facet.

Cardinalities, row sums and column sums of descriptions are useful summary measures. From Figure 6, for example, it may be seen that o_8 dominates six other operations, and it also has the greatest number of attributes. Thus operation o_8 can be said to be critical for the performance of TS_{53}^{*} . Operation o_6 is the next most critical operation in the sense that it demands many attributes and influences a great many operations in TS_{53}^{*} . Column sums can be used, also, to identify critical operations. Those operations whose column sums are zero are critical, because they are dominated by other operations.

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Of course, it must be remembered that these deductions from the model are <u>hypothetical</u> and for purposes of illustration only, since the attributes in the designation vectors are themselves hypothetical.

Generality of the Model and Other Applications

It will be recalled that the difference between two designation vectors, especially the cardinality of the difference function equates with their distance. Thus the basis for a classificatory system -a taxonomy -- is provided. The greater the distance between two operations the less related they are, and vice versa. The degree to which two operations are related or similar is stated objectively and quantitatively by their distance. In principle, this way of stating relationships or similarities is parallel to the Linnaean taxonomic system applied in biology. The taxonomic classification is not limited to operations, but has a far more general applicability as explained below.

The model discussed here above is a specific application of a more general model. In this general model operations are replaced by "objects" and attributes by "characteristics." Thus the model includes <u>any set of objects</u> that can be described by the possession of characteristics from a pre-selected set of characteristics. (An object, in this sense, is a logical one and not necessarily a physical object.) As a result the areas of application of the model are diverse. Limits on its uses are those given pre-viously in the discussion of the problem of selecting a set of attributes. Some applications to other problems of Army interest are shown in Table 5.

	<u>Table 5</u>			
Potential	Applications	of	the	Model

Objects	Characteristics
Missions	Tasks
Duty assignments	Duty modules
Duty positions	Duties
Career fields	MOS's
MOS's	Duties
Teams	Activities

In summary, the model is applicable to any clearly defined set of objects that can be described in terms of a finite set of characteristics. What can be deduced from such a model (over and above what has been illustrated here) depends on the particular area of application and on the specific problems addressed.

The dual meaning of a description was mentioned earlier but not illustrated. It will be recalled that a <u>description can describe an operation or an individual</u>. This duality might be useful when considering a single operation, but it is more useful when the entire TS is considered or a cluster of TS. Unfortunately the binary model is probably too gross for sensitive analysis of the latter situation. In Figure 4 a description of TS_{53} can be deduced to be

$d(TS_{53}) = 111111111000.$

In this description, it will be recalled, the last three attributes of the attribute set were not found in TS_{53} . Another task description, say TS_i , might include some of the last three hypothetical attributes so that its description might be

$d(TS_{i}) = 111001100011.$

Similar descriptions can be derived for all of the TS in the set for any individual. Using this set of descriptions together with the model reveals structures of the set of task descriptions for an individual. This is a gross method. The more sensitive method based on fuzzy subset theory is outlined in the next section.

FUZZY SUBSETS

In the earlier discussion of the deficiencies of a binary attribute scale we suggested that the theory of fuzzy subsets appeared to be a method for reducing these deficiencies. An introduction to some of the basic concepts of fuzzy subset theory is given in this section along with examples of the concepts. In addition, an outline is sketched to show how the concepts can be applied to describe a TS and a set of TS.

It will be recalled that a primitive notion in classical set theory is that of an element being a member of a set. An element is either a member, or it is not. No other alternatives are permitted. In contrast to this notion most of the sets in the real, empirical world do not have sharp boundaries that separate those objects that belong to a set from those that do not. For sets with fuzzy (not sharply defined) boundaries an element may have a grade of membership that lies somewhere between full membership and non-membership. For example, the set of individuals who are tall is a fuzzy subset of some reference set of individuals. Fuzziness is introduced by the vague word "tall." Because no clear cut boundary is given, it is not possible to arrive at an absolute agreement about membership in this subset of an individual who is 5 feet and 11 inches tall. However, such a person would have a higher degree of membership in the subset than an individual who is 4 feet and 8 inches tall. Continuing this same example Figure 9 gives the heights (in inches) of a reference set of eight persons and the fuzzy subset of "tall individuals." It is seen that each individual is assigned a <u>degree</u> of membership in the fuzzy subset. Degrees of membership range from 0 (non-membership) to 1 (full membership). Assignment of grades of membership allows a mathematical structure to be established that can be used to manipulate poorly defined concepts (e.g., "soft skills") for which membership in a subset is somewhat hierarchical.

Reference Set	^a 1	^a 2	^a 3	^a 4	^a 5	6	<u>a7</u>	^a 8
Height (inches)	53	72	68	73	77	55	84	63
Fuzzy Subset	0	.9	.6	.9	1.0	• 2	1.0	• 3

Figure 9. Example of a Membership Functi
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A more rigorous definition of a fuzzy subset begins with a reference set A whose elements are a_1 , a_2 ,..., a_n . This set is not fuzzy and its elements are well defined. Following Kaufmann (1975) fuzzy subsets of A will be indicated by a wavy line under the symbol of the subset. A fuzzy subset g_1 of A is characterized by a membership function associating with each a_1 in A a number in the closed interval from 0 to 1 representing the grade of membership of a_1 in g_1 . Returning to the example shown in Figure 9, the last line shows individuals a_5 and a_7 definitely belong to the set of tall persons, and a_1 definitely does not. The remaining individuals have varying degrees of belonging to the subset.

All of the basic set theoretic operations of classical set theory can be reformulated for fuzzy subsets. To illustrate the potential of fuzzy subset theory we only need to define the operation of the union of two fuzzy subsets. Figure 10 is the example used to illustrate the definition. In this example

			^a 1	^a 2	^a 3	^a 4	^a 5	^a 6	^a 7	^a 8	^a 9
	d₂		.8	.7	.3	0	.1	• 2	.4	•1	.3
	d∕3		•6	.5	.7	• 7	.3	.1	• 4	.2	•4
	Union	Γ	•8	.7	.7	•7	.3	• 2	•4	•2	•4
F	lgure :	10.	Exa	ample	of tl	he Uni	lon of	Two	Fuzzy	Subs	sets

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the first two rows are operations of TS_{53} and are described by an assumed membership function. The two descriptions d_2 and d_3 are called fuzzy descriptions. If $d_2 \cup d_3$ designates the union of the two fuzzy descriptions, then the membership function of $d_2 \cup d_3$ is defined as the maximum of the two membership functions of d_2 and d_3 .

It is instructive to compare the fuzzy union of Figure 10 to the comparable operation $d_2 \bigvee d_3$ on the designation vectors of Figure 4, which is given by

$$d_2 \bigvee d_3 = 111100000$$

9)

The first four attributes in (9) all have the same value 1, but in Figure 10 there is a difference between these attributes. Likewise the last five attributes in (9) all carry weight 0, whereas the fuzzy union shows differences. This short example demonstrates the increase in sensitivity that is gained by using fuzzy subset descriptions.

The definition of the union of two fuzzy descriptions extends to any finite number of fuzzy descriptions. This suggests one way to summarize an O/A matrix of a TS when it is formulated in terms of fuzzy descriptions. Figure 11 is a hypothetical example to illustrate this summarization. The example is based on TS_{53} and the designation vectors of Figure 4. Assumed values of the membership function are chosen arbitrarily. The only rule followed is: where a 1 appears in the designation vector in Figure 4, a membership value greater than or equal to .5 is given to the corresponding location in the fuzzy description; where a 0 appears in Figure 4, a value less than .5 was selected for insertion into the corresponding location in the fuzzy description.

	^a 1	^a 2	^a 3	^a 4	^a 5	^a 6	<u>a</u> 7	^a 8	^a 9
^d 2	•8	.7	.3	0	.1	•2	•4	•1	.3
d3	.6	• 5	.7	.7	.3	.1	• 4	•2	•4
d ₄	•3	.1	•2	.6	.7	.3	•4	•3	• 3
d ₅	0	0	•2	• 7	1.0	•4	•1	0	.6
d ₆	•1	• 2	•6	• 5	.8	.9	0	0	.8
d ₇	.3	0	• 5	.7	.9	0	.5	•2	•1
d ₈	•4	.4	.8	.7	.9	1.0	•4	• 5	• 7
d9	.3	• 2	0	.6	.5	0	•2	۰5	•4
d ₁₀	0	0	0	•1	.9	•1	•2	•4	•4
d ₁₁	.9	0	.6	.7	0	0	•4	• 5	.8
d 12	.9	•1	.6	.7	• 2	•4	.3	.5	.8
^d 13	0	.4	.9	•3	.6	.2	•1	0	.5
Union	.9	.7	.9	.7	1.0	1.0	.5	• 5	.8

Figure 11. TS₅₃ Fuzzy Description and Summarization

In Figure 11 the union is a summary fuzzy description of the nine hypothetical attributes required to perform TS_{53} . Let $g(TS_{53})$ denote this description and $d(TS_{53})$ the summary description derived from Figure 4. These two descriptions are shown in Figure 12. In it exact matches exist only for a_5 and a_6 , and the remaining attributes differ in various degrees. This example illustrates the increased

	^a 1	^a 2	^a 3	^a 4	a 5	^a 6	7	^a 8	_ ^a 9
d(TS ₅₃)	.9	.7	.9	.7	1.0	1.0	• 5	• 5	.8
d(TS ₅₃)	1	1	1	1	1	1	1	1	1
1									

righte iz. comparison of bescription	Figure	12.	Comparison of Descriptions
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sensitivity made possible when fuzzy descriptions are used. The fuzzy union of fuzzy descriptions in Figure 11 allows us to list the attributes in order of decreasing value as,

$$(a_5, a_6), (a_1, a_3), a_9, (a_9, a_4), (a_8, a_7),$$

where attributes with the same value are grouped by parentheses. Critical attributes are thus identified in the order of their criticality.

The definition of the union of fuzzy descriptions also suggests a method for comparing one TS with another. This can be done by calculating $d(TS_i)$ and $d(TS_j)$. In addition, if $d(TS_1)$, $d(TS_2,..., d(TS_n)$ are n summary fuzzy descriptions of n TS making up the job or duty position of a single individual, they can be compared two at a time. Finally, the fuzzy union of the n fuzzy summary descriptions can be formed to describe the individual's job or duty position.

It is intuitively obvious that a fuzzy model, similar to the binary model, can be devised. Many of the concepts of the binary model are easy to formulate in terms of fuzzy subsets, but others appear to involve some difficulties. It is known, for example, how to define a fuzzy relation, and this will permit a definition of fuzzy structures. The concept of dominance does not translate directly into fuzzy formulation, but instead several different notions of distance are available as well as several notions parallel to dominance. In this exploratory effort it was not possible to pursue these potentially useful and sensitive formulations.

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