AD NUMBER
ADB951281
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RESEARCH MEMORANDUM 60-19

An Allocation Technique Applied To Current Aptitude Input

NOVEMBER 1960

PERSONNEL RESEARCH BRANCH

Research and Development Division
The Adjutant General's Office
Department of the Army

Army Project Number
2L95-60-001

Combat Allocation a-00

(9) Research Memorandum 60-19

(6) AN ALLOCATION TECHNIQUE APPLIED TO CURRENT APTITUDE INPUT.

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(10) Robert F. Boldt, Martin F. Wiskoff and David J. Fitch

(14) AGO-PRB-RM-60-19

Accession For
NTIS GRA&I
DDC TAB
Unannounced
Justification
By
Distribution/
Availability Codes
Dist. | Avail and/or special
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Submitted by

Samuel H. King, Chief
Research Group III

(11) November 1960

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JOB

AN ALLOCATION TECHNIQUE APPLIED TO CURRENT APTITUDE INPUT

The Combat Allocation task of the Personnel Research Branch was established in response to USCONARC's concern that an insufficient supply of able personnel was reaching combat units. The ultimate objective of the task is to provide a method of assigning men to advanced training so that the resultant distribution of available aptitudes is adequate to the needs of combat units as well as to needs of combat support units and other branches of the Army.

BACKGROUND

In an early survey (1957-58) the manpower being supplied to combat divisions was found to be of lower aptitude levels than that being supplied to the rest of the Army (King, Boldt, and Brown, 1959). Relatively more men in the combat division than in the Army as a whole had scores below 90 in the combat aptitude areas which were operational at the time of the survey. Further analysis of the survey data indicated that the problem was not primarily one of assignment to combat units, but rather one of assignment to combat MOS (MOS with first digit = 1). In the combat units sampled, among men initially assigned noncombat MOS (MOS with first digit other than 1), the proportion who scored below 90 on the combat aptitude area was no larger than in the rest of the Army. However, among personnel in the combat units initially assigned to combat MOS, there was a considerably larger proportion of personnel scoring low on the combat aptitude area than there was in the rest of the Army. Since combat MOS make up a large share of combat unit personnel, the low scores among them accounted for the relatively high proportion of combat aptitude scores below 90 found for the combat units as a whole.

The overall conclusion was that the allocation problem would best be solved not by focusing research on distribution of personnel to combat units, but by focusing on the distribution of personnel to MOS with first digit of 1 at the time of assignment to advanced (MOS) individual training.

Since the study was conducted, the Department of the Army has instituted a machine allocation method which has decreased the relative frequency of assignment of personnel to areas on which they scored below 90. One of the advantages of this improved system is that MOS assignment is determined through use of the individual's aptitude area scores, physical profile, and other specific requirements of the entry MOS. There remains, nevertheless, a tendency toward imbalance of talent among the ten occupational areas, since prerequisites for entry MOS vary considerably. The problem is most pronounced in the technical occupational areas and in those requiring combat skills. Major operational problems in the Army allocation system revolve about making assignments which meet prerequisites of different MOS training programs while maintaining a balance in the distribution of talent across the occupational areas.

During FY 1958, known approaches to the statement and solution of the allocation problem were examined as a part of Combat Allocation Project A-21, Survey of Allocation Research and Theory (Research Memorandum 58-21, December 1958). One result of this research was adoption of the "allocation sum" as the measure of the value of a set of assignments. The allocation sum is calculated as follows: (1) Add the IN scores for all men assigned to infantry MOS; (2) to this sum add the AE scores of all men assigned to armored or engineer MOS; (3) to that sum add the EL scores of all men assigned to electronics or electrical maintenance MOS, and so forth through the occupational areas. A set of classifications is said to be optimal when this sum is at a maximum within the restriction of personnel quotas for occupational areas. Another result of the investigation was choice and partial development of a technique by which allocation is actually carried out. The technique chosen is called the Method of Optimal Regions (Dwyer, 54). Its mathematical basis is partially given in an article by Brogden (1954).

PURPOSE

The purpose of the developments and research reported here was to solve problems encountered in conducting research on the method and technical problems of application of the Method of Optimal regions to current input insofar as problems of implementation were anticipated.

CURRENT DA ALLOCATION PROCEDURE

The organization currently accomplishing assignment of Basic Combat trainees to advanced individual training is Replacement Branch, Personnel Division, TAGO. Each week, the Branch develops training recommendations for a block of basic trainees. The trainees in a block are those expected to complete basic training during a given week. During the second week of basic training, an IBM detail card is submitted to Replacement Branch for each trainee in a block. The card carries all information used in allocation. The information on the man is then related to personnel requirements with respect both to quality and number. The procedure is essentially a series of card sorts, by which individual qualifications given on the detail card are compared with advanced training prerequisites given on the selection card for a given MOS to determine the number of people qualified for the MOS. The information punched in the selection card is a coded version of regulations for school courses as stated in AR 611-201, and in DA Pamphlet 20-21, plus notations of other desirable characteristics not specified in the regulations.

The current system, then, attempts to get as many qualified people as possible into the various MOS, within priority restrictions by a method of "cut and try." This system is a considerable improvement over the former system where very limited information was available about the personnel supply. Under the former system the only information available for the assignment personnel was (1) most appropriate aptitude area (field assignment recommendation), (2) score level of the man on that aptitude, and (3) physical profile recorded as A, B, or C. For example, it might be reported that at Fort Dix six men will be graduating from basic training whose most appropriate aptitude area is GT, whose score on this area is between the ranges of 100 to 110, and who are B profile. The names of the men would not be reported. Today, with machine processing and more complete information, a much more adequate job of allocation can be done.

However, despite the improvement of this machine system, the Army still lacks a method of allocation which rests entirely on variables of proven validity, and which considers all quotas and scores simultaneously. The Method of Optimal Regions is a means for basing assignment decisions on the Aptitude Area score to as great an extent as possible and for approaching the allocation job with one clear, Army-wide goal in mind, namely, to maximize across all jobs the aptitude levels of the individuals for the jobs in which they are placed.

TECHNICAL PROBLEMS ENCOUNTERED

SIMULATION OF THE APTITUDE AREA SCORE DISTRIBUTION

The goal of the allocation technique is to maximize across all jobs the aptitude levels of the individuals for the jobs in which they are placed. The statistic which it is desired to maximize is the allocation sum obtained in terms of aptitude area standard scores. However, these scores are available on the detail card only in extremely broad interval form. The card must contain many items of information, and columns are at a premium. Only one column is used for each aptitude area, necessitating coding of scores. The following intervals are used.

Score Interval	Code
130 and above	1
125 - 129	2
120 - 124	3
110 - 119	4
100 - 109	5
90 - 99	6
80 - 89	7
below 80	8

If a finer breakdown of aptitude area scores were to be obtai[illegible], expensive data collection methods would have to be employed. [illegible] is therefore economically advantageous to use simulation procedures The technical problem is one of estimating, from aptitude area scores coded in broad interval form, the allocation sum which would obtain if aptitude area standard scores were used. The solution to this problem is to construct a multivariate frequency distribution of classification variables using summary parameters estimated from the broad interval data. In the discussion of this problem, consideration is restricted to the aptitude area scores.

The simulation problem can be stated more specifically as follows: Given an input on which there is incomplete test score information, how can a set of numbers be generated which has the same multivariate frequency distribution as would have obtained had the actual scores been supplied? The point of departure is to assume that the joint aptitude area distribution 1/ can be well approximated by one which is normal in form. This assumption being made, it follows that the marginal

1/ A "joint aptitude area distribution" is the frequency distribution of combinations of scores on more than one variable. For example, the bivariate frequency distribution is also rightly called a joint frequency distribution of two variables. Fundamentally, the idea is that with each combination of scores there is associated a relative frequency of occurrence such that the sum of the relative frequencies over all combinations of scores is equal to one.

distribution[2] of any particular aptitude area is normal in form. This normality of the marginals is something that can be tested, and which, if reasonable, allows estimation of the scores and sigmas as follows:

If the marginal distribution of scores on a particular measure is normal, then the proportion of cases lying below a given score value is given by the cumulative normal distribution. For all aptitude areas except RC, the proportion of scores lying below the interval boundaries given on page 4 can be calculated. These proportions can be transformed into unit normal deviates and equated approximately (allowing error or departures from normality) to the difference between the cut score and the mean divided by the sigma. That is,

Let: T_i be the top score of the i^{th} interval,

Z_i be the proportion of cases in the i^{th} interval and below,

e_i be an error of fit,

μ be the mean of the test,

σ be the standard deviation of the test,

Then:

$$Z_i \cong \frac{T_i - \mu}{\sigma}$$

and:

$$Z_i \sigma \cong T_i - \mu$$

or:

$$e_i + Z_i \sigma = T_i - \mu$$

Consequently we have:

$$T_i = Z_i \sigma + \mu + e_i$$

But this is the equation for the regression of T on Z so that:

$$\sigma = r_{TZ} \frac{\sigma T}{\sigma Z}$$

and:

$$\mu = \overline{T} - \sigma \overline{Z}$$

[2] A "marginal frequency distribution" is a frequency distribution derived from a joint frequency distribution, which contains a smaller number of variables than does the joint distribution from which it is derived. For example, a bivariate frequency distribution, i.e., the joint distribution between x_1 and x_2 say, implies a frequency distribution of x_1 without regard to the level of x_2 and vice versa.

Further, the r_{TZ} is the measure of fit in the usual sense that a correlation coefficient is a measure of fit. Correlations were calculated in this way on quite a large number of samples of nonearmarked enlisted input to which the allocation procedure would be applied. The coefficient was never less than .995. However, some caution should be observed in interpreting this figure, since this means of testing goodness of fit is quite weak.

The means and sigmas provide all the parameters of the joint distribution except the correlation coefficients. These coefficients can be estimated with tetrachoric coefficients. All parameters for all tests except RC could be provided. The complications introduced by RC will be discussed later.

The next point of information is a theorem in Anderson, (1958), which states that if a set of variables are jointly normally distributed with covariance matrix Σ, and if these variables are subject to linear transformation T, such that $|T| \neq 0$, then the resulting variables are normally distributed with covariance matrix $T'\Sigma T$. If there is available a set of jointly normally distributed variables, with known covariance matrix, and if a jointly normal set of variables with some other known covariance matrix is desired, then the set at hand can be transformed into a set with the desired characteristics. The proof is as follows:

Let: Σ be the covariance matrix of jointly normally distributed scores on hand.

S be the covariance matrix of the desired scores, obtained from tetrachoric intercorrelations and standard deviations whose estimation is described above.

The problem then is find T so that:

$$T'\Sigma T = S \qquad (1)$$

Σ and S may be factored as follows:

$$\Sigma = P'P$$

$$S = Q'Q$$

Equation (1) then becomes:

$$T'\, P'\, PT = Q'Q \qquad (2)$$

If T can be found so that:

$$PT = Q,$$

then equation (2) will be satisfied and hence equation (1). The solution then is:

$$T = P^{-1} Q$$

Consequently, when normality is reasonable, and when some jointly normal sample of the right number of variables is on hand, the desired distribution may be obtained.

PROBLEM OF RADIO CODE APTITUDE MEASURE

The treatment discussed above required the ability to calculate means, sigmas, and intercorrelation coefficients of the joint aptitude area distribution. This problem is complicated in the case of the Radio Code Aptitude Area, a composite of the Verbal Ability test and the Army Radio Code test:

$$RC = \frac{VE + 2\ ARC}{3}$$

The problem arises from the fact that ARC scores below 100 are recorded simply as UNSATisfactory. However, many examinees score below 100 on ARC, well over half the cases being missing. The distribution of Radio Code as compared with the other occupational areas has thus been rather violently altered.

It was hoped that the top two intervals of the RC score range could be used to estimate mean, standard deviation, and intercorrelation coefficients. The approximations may be close to the true values, but must necessarily lead to parameters which do not match the empirically obtained distributions. In addition, means and sigmas obtained in this way do not always take on reasonable values. The solution to this problem is being sought under Combat Allocation subtask d-00, Experimental application of Allocation Techniques, since it has proved to be intractable under the present subtask.

THE PROBLEM OF TANGENTIAL CHARACTERISTICS

Many variables or attributes other than aptitude area scores are prerequisites for entrance into Army jobs (AR 611-201 and DA Pam 20-21). Included among these tangential requirements are MOS cutting scores and possession of certain attributes. Problems posed by the existence of these requirements are:

> Must they be met without fail?
>
> Is the input population adequate to meet them?
>
> If the population is adequate and they must be met, will Optimal Regions meet them?
>
> If Optimal Regions is not adequate to meet them, can the method be modified successfully?

The answer to the first question is that not all requirements must be met without fail. That this is so is indicated by the fact that not all variables and attributes referenced in AR 611-201 and DA Pamphlet 20-21 appear on the detail card. For example, neither depth perception nor night vision abilities are recorded or even assessed. Further, certain variables appear on the card which are not needed in the differential classification procedure specified in the regulations, such as race and officer candidate test score. Evidently there is flexibility in consideration of tangential requirements.

Principal problem areas anticipated in tangential consideration are term of service, physical profile, cut scores, education requirements, preferences, and field training recommendations. These areas will be handled statistically under another subtask in the application of the allocation procedure to simulated data. Many of the tangential requirements--particularly negative requirements such as color blindness, a 3 in the S (psychiatric) component of physical profile, and conscientious objector status--refer to attributes which occur vary rarely in the input population. Examples of positive requirements are language ability and specified usable civilian skill. Negative conditions may be dealt with through a censoring process, with only a slight reduction in the bulk of manpower subject to optimal allocation. For example, a color blind man can be utilized in all occupational areas except electronics and combat; it is possible to exclude him from assignment to those areas merely by arbitrarily using zero as his EL and combat scores in the classification procedure.

Adequacy of the input population to meet tangential requirements is, of course, hard to determine when the requirements themselves are somewhat flexible. However, with respect to multiple requirements, a test of adequacy can be applied. In the case of the EL occupational area, for example, a random 10% sample of the input for November 1958 through April 1959 was checked against quotas based on multiple requirements--EL cutting score of 100, 3-year term of service, and high school algebra (Table 1).

Table 1

EL QUOTAS BASED ON MULTIPLE REQUIREMENTS AND AVAILABLE TALENT COMPARED FOR 6-MONTH PERIOD

Month	Quota	Uncommitted Personnel Qualified for EL	Committed Personnel Qualified to EL	Number Available Above Quota
Nov 58	525	410	590	+475
Dec 58	370	370	400	+564
Jan 59	556	570	420	+424
Feb 59	381	620	870	+1109
Mar 59	300	540	640	+380
Apr 59	141	260	960	+1079

It appears from the results of this six-months analysis that EL job quotas with multiple requirements can be filled. In fact, with the exception of January 1959, all quotas could have been matched with committed personnel only.

PROPOSED ALLOCATION CARD LAYOUT

Allocation on aptitude area scores rather than interval scores introduces card space problems. The present method of recording personnel data, through utilization of IBM coded cards, has facilitated allocation of enlisted personnel. However, for classification efficiency the card should be revised, taking as a major consideration the substitution of aptitude area scores for aptitude area interval scores. The inclusion of actual scores rather than interval scores would involve the use of eight extra columns on the card. Appendix A shows how these columns can be made available through reorganization of the card.

In a proposed revision of the card, additional test and tangential information may be provided through fuller utilization of columns and high punches. Three variables--citizenship, term of service, and officer candidate test score--may be placed in dichotomous form as high punches, eliminating the necessity for column usage. All three of these variables operate as restrictions on possible allocation of the individual. Aliens may not be allocated to certain MOS with security requirements. Certain assignments may not be given to EM with only two-year term of service because of the extensive training period involved. Therefore, term of service could appear on the card as a high punch, being recorded only when it is over two years. Similarly, the OCS test score need be recorded only if it is 115 or above.

Proposed additions to the present card are age, and security clearance of the EM (if any). Each of these variables would involve the use of one card column. Other variables proposed for addition in dichotomous form are height and non-combat assignment. Non-combat assignment would be high punched when an EM is a sole-surviving son and may not be assigned to combat (AR 614-75). Height would be indicated as a high punch if the individual is less than 5' 7", since he is excluded from MP duty. Area commitment, the remaining addition, refers to the area of the world to which the EM has been promised assignment. This information could be important since certain MOS may not be represented in some areas and the MOS in which the man could be trained would be limited accordingly. Coding of area commitment could be effected through expansion of the enlistment commitment category.

The total number of card columns filled in the prepared revision is 77. The remaining three columns are needed for allocation data by DA. However, examination of DA MOS regulations indicates many requirements not found on the present assignment card--and, consequently, not used in current allocation procedures. A complete list of variables mentioned among current requirements, but omitted from the allocation card, follows:

1. Clearance
2. Age
3. Depth Perception
4. Night Vision
5. Swimming
6. School Training
    a. Geometry
    b. Physics
    c. Plane Geometry

7. Aptitude

   a. Pattern Analysis

   b. Verbal

   c. Arithmetic Reasoning

   d. Mechanical

   e. Radio

Measures of the several aptitudes listed under "7" above are all available in the form of ACB scores. However, as scores are not recorded on the allocation card, they are unavailable at the time of allocation. Two other variables that are presently on the assignment card and might be valuable for allocation under current DA doctrine are:

1. MOS recommended by field interviewer

2. Training Preference of EM

It is felt that the proposed changes could add significant information on which allocation may be performed. The final decision on the acceptability of these proposed changes remains with the DA. The proposed card layout is presented as Appendix A.

REFERENCES

1. Anderson, T. W., An introduction to multivariate statistical analysis. New York: John Wiley and Sons, Inc., 1958.

2. Brogden, H. E., A simple proof of a personnel classification theorem. Psychometrika, 19, 1954, 205-208.

3. Dwyer, P. S., Solution of the personnel classification problem with the method of optimal regions. Psychometrika, 19, 1954, 11-26.

Appendix A

PROPOSED IBM CARD LAYOUT

	Variables	Coding	Number Columns
1.	Name	alphabetic	14
2.	Service Number	eight digits	10
3.	Aptitude Area Scores	score	
	IN		
	AE		16
	EL		
	GM		
	MM		
	CL		
	GT		
	RC		
4.	Physical Profile	P-U-L-H-E-S	6
5.	Civilian Education	code for years	1
6.	Major College Subject	as in AR 330-409	3
7.	Major H.S./Voc S. Subject	code set up by DA	1
8.	Driver Aptitude	coded scores	1
9.	Basic Combat Training Unit	code set up by indiv. installation	1
10.	Language Proficiency	AR 611-201 and AR 611-6	2
11.	Enlistment Commitment (Area Commitment)	code set up by DA	4
12.	Installation Identification	code set up by DA	2
13.	Musical Ability (Bandsmen)	2d and 3rd digit of MOS, score on proficiency test, score on audition test	6

	Variables	Coding	Number Columns
14.	Civilian Occupation	DOT code and skill level	4
15.	Special Reporting	Professional and Engineering, Doctors, Dentists, High Aptitude Personnel	1
16.	Training Recommendation	to be supplied by DA	3
17.	Age	to be coded	1
18.	Clearance	TOP SECRET - SECRET - CONFIDENTIAL	1
19.	Date of Allocation	to be supplied by DA	3
			80

PROPOSED IBM CARD LAYOUT

Variables (to be included as high punches)	Variable Coded Under:
1. Color Blindness	Physical Profile (E)
2. Conscientious Objector	Physical Profile (S)
3. Typing Ability	Civilian Occupation, if speed greater than 35 wpm
4. Citizenship	at discretion of D/A
5. Police Record	at discretion of D/A
6. Officer Candidate Test	at discretion of D/A where 115 or greater
7. Term of Service	at discretion of D/A where greater than two years
8. Height	at discretion of D/A where less than 67 inches
9. Non-combat assignment	at discretion of D/A