

# The US Army Uses a Network Optimization Model to Designate Career Fields for Officers

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In 1999, the United States Army instituted a new career-progression pattern for its officers. This pattern assigns, or designates, Army officers to specialized roles in which they must serve. Such roles include, for example, foreign area officer and operations research analyst. Manually designating officers into these roles under the new system is impossible because the problem is very large. We developed a network-optimization model, the career-field designation model, that makes these designations in minutes on a personal computer. The US Army has used this system four times since June 2001 to designate a total of approximately 10,500 officers and expects to continue to use the model to designate about 1,500 officers each year.

*Key words:* military; personnel; networks/graphs; applications.

*History:* This paper was refereed.

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The United States Army personnel system determines the way in which approximately 500,000 US soldiers in 100 countries are assigned to jobs, promoted, educated, trained, and separated from the Army. One of the system's tasks is to match enough qualified soldiers to career tracks to meet staffing requirements. We developed a network-optimization model, the career-field designation (CFD) model, that aids the Army in assigning its 49,000 senior leaders (officers) to jobs.

The Army assigns officers to many fields of specialization, for example, the infantry, which has a "...mission to close with the enemy by means of fire and movement to defeat or capture him," and military intelligence, which has a mission to "...manage and direct all facets of intelligence planning and operations at the tactical, operational, and strategic levels of war" (United States Army 1998).

An officer's career typically lasts 20 to 30 years (Figure 1), during which he or she serves two to three years in each of various jobs, including postgraduate education.

The battlefield is changing. In the future, combat will be "multi-dimensional, noncontiguous,...

and simultaneous [because] the increasing potential of adversaries, coupled with access to accurate, real-time information, will produce a different operational environment" (United States Army 2001). To address the changing nature of warfare, the Army is reengineering its structure, doctrine, and weapons and has correspondingly developed a new method for advancing officers through their careers, which the Army calls a career-progression pattern. In 1999, the Army's deputy chief of staff, personnel directed the United States Army's Total Army Personnel Command (PERSCOM) to develop a program to match its officers with the new career-progression pattern.

Under the officer professional management system prior to 1999, OPMS II, the Army assigned officers to one of 16 basic branches, or primary "muddy boots" career tracks, and the officers served in those basic branches for at least six years: infantry, armor, field artillery, air defense, aviation, special forces, engineers, military intelligence, military police, signal corps, adjutant general, finance, ordnance, transportation, quartermaster, and chemical corps. Then, the Army assigned each officer to a functional area (FA), or secondary career track, for a maximum of seven



Figure 1: The United States Army promotes officers through the ranks during their 20- to 30-year careers, typically for the service years shown.

years: psychological operations and civil affairs (FA 39), comptroller (FA 45), public affairs (FA 46), foreign area officer (FA 48), operations research and systems analysis (FA 49), Army acquisition corps (FA 51), nuclear research and operations (FA 52), and information systems management (FA 53). However, the Army promoted officers based on their performance in their basic branches and specifically in branch-qualifying (BQ) jobs. The universal requirement that officers serve in BQ jobs had a twofold effect: (1) Officers who were interested in serving solely in basic branch jobs could do so only for a limited amount of time, and (2) officers who wished to serve in functional-area jobs for most of their careers were spending time in BQ jobs that did little to develop their skills in their functional areas. The Army concluded that OPMS II produced unfocused officers (United States Army 1999).

In 1999, the Army created a new system for developing officers' careers—the officer professional management system for the 21st century (OPMS XXI or OPMS III). Under OPMS XXI, the Army produces more focused officers by requiring officers to serve seven to 10 years of their careers in a basic branch and then requiring them to develop and maintain proficiency in either that basic branch or in a functional area for the remainder of their careers. In addition, with OPMS XXI, the Army created several new functional areas in emerging and growing fields: information systems engineering (FA 24), information operations (FA 30), strategic intelligence (FA 34), space operations (FA 40), strategic human-resource management (FA 43), force management (FA 50), and strategic plans and policy (FA 59). The Army seeks to assign (*designate* in Army terminology) all officers to career fields after promoting them to major; about two-thirds of them remain in their basic branches, and the remainder serve in their functional areas.

## Literature Review and Other Assignment Policies

Klingman and Phillips (1984) developed a network model to assign enlisted Marines to prioritized jobs with differing quotas or requirements. Liang and Thompson (1987) developed the large-scale personnel-assignment model, which assigns groups of Navy sailors to jobs. Bausch et al. (1991) developed a network model for assigning Marine officers from peacetime to wartime jobs. Sweeny (1993) developed a network model, the officers staffing goal model at the Naval Post Graduate School, to assign groups of Marine Corps officers to jobs. Krass et al. (1994) developed a model to assign enlisted personnel to combat units to maximize readiness. Reeves and Reid (1999) created a multiobjective linear-programming model for assigning Army Reserve officers to various posts, for example, to military school. Baumgarten (2000) used an integer-programming model to determine how many Marine officers should follow each career path. Sweetser et al. (2001) described a family of statistical, simulation, and optimization models for assigning soldiers to jobs and redistributing them among jobs based on projected Army requirements. Armacost and Lowe (2005) developed a model that the Air Force uses to assign graduating Air Force Academy cadets to career fields.

Of these models documented in the literature, only Sweetser's and Armacost and Lowe's are currently in use. Other undocumented models, however, are currently in use. The Army uses a greedy (myopic) algorithm to assign its West Point graduates to basic branches, for example, infantry or field artillery, based on their class rankings. The Navy uses a greedy algorithm to assign Naval Academy graduates to career paths, for example, naval surface warfare officer, based on their class rankings (Henry 2003). The Navy may soon use the assignment policy matching system

to match enlisted personnel to jobs within particular Navy communities (Cunningham 2003).

The Marines use a Markov model to determine probable manpower requirements for Marine occupational specialties. It then uses an optimization model to determine how to constitute each Marine occupational specialty. It assigns individual officers manually to specialties (Grant 2003). The Marines use a heuristic to assign their enlisted personnel to Marine occupational specialties and corresponding school start dates while accounting for Marine capabilities and the required number of Marines in each specialty (Bicknell 2003).

Our problem is related to the classic problem of stable marriage, which seeks a stable matching, or pairing, of individuals such that no individual, say  $A$ , who is paired with  $A'$ , would prefer to be paired with someone with whom he is not, say  $B$ , while at the same time the latter ( $B$ ) would also prefer to be paired with the former ( $A$ ) rather than with his current partner,  $B'$ . Gale and Shapley (1962) address the similarities between this problem and that of admitting prospective students to colleges, while others apply the stable-marriage problem to pairing (a husband and wife pair of) medical residents with hospitals (Roth 1984, Aldershof and Carducci 1996) and rabbinical students with congregations (Bodin and Panken 2003). Unfortunately, solutions to the stable-marriage problem suffer from asymmetric satisfaction between elements of the two mutually exclusive groups that are matched. Romero-Medina (2001) addresses this shortcoming with a “sex-equal” matching algorithm to minimize the “envy difference” between the groups while retaining stability.

## Career-Field-Designation Data and the Selection Board

To help it to designate officers into career fields, the Army asks officers to submit three preferences for branch or functional area or both during their 10th years of service. To be considered a fully qualified officer in a branch or functional area, an officer must possess certain minimum qualifications, which are described in a document, DA-PAM 600-3 (United States Army 1998). If an officer asks to serve in a functional area in which he has not served before, according to the guidelines, he or she must show sufficient

aptitude and background to serve in that job. The Army also sets hard upper and lower bounds, or a range, for the number of officers it requires in each branch and each functional area; this range is referred to as officer requirements and can be affected by attrition and the availability of jobs.

For many years, the Army has used a selection board to promote officers. This board consists of 16 colonels led by a major general (a two-star general). For the purposes of OPMS XXI, this group is divided into four panels of four officers each, at least one of whom has held jobs in the basic branches or functional areas for which the panel is responsible. The board evaluates each officer based on his or her personnel record, consisting of performance evaluations, awards, education, and job experience. To rank officers, each board member of the four-person panel assigns a score to each officer who has at least minimum qualifications to serve in a branch or functional area. The lower the score, the more desirable the selection of an officer for a particular basic branch or functional area. The board bases its order-of-merit list (OML) on this OML score, which is totaled across all board members.

The board compiles an OML for each branch or functional area and for each preference level. For example, the board compiles an OML for officers who give operations research and systems analysis (FA 49) as their first preference, another OML for officers who give FA 49 as their second preference, and another for officers who give foreign area officer (FA 48) as their first preference. The board orders each list by increasing officer score.

We can state the career-field-designation (CFD) problem as follows: How do we designate the most willing and best-qualified officers into career fields to meet officer requirements while ensuring that we designate no officers into careers for which they are unqualified?

## Do We Need a Model for Designating Officers into Career Fields?

Because the Army wanted to designate officers into career fields on a case-by-case basis, the board resisted using a mathematical model. Indeed, prior to 1999, the Army manually designated officers into career

fields. This was possible because, under OPMS II, designating officers into career fields was a simple task with obvious feasible solutions. It had twice the number of officers it needed, and it assigned very few officers at or past the rank of major to one functional area for the remainders of their careers. By contrast, under OPMS XXI, the number of officers the Army needs for each basic branch or functional area more closely matches the number of officers who are qualified, which, in turn, leaves the board with little latitude in designating officers and complicates satisfying range and qualification requirements.

To demonstrate the necessity of a model, a practice board, consisting of key decision makers in the Army personnel community, convened at PERSCOM, Alexandria, Virginia in early 2000. For several days, the board tried to designate a subset of officers manually but found that the requirements and the supply of officers were so closely matched that it could not find a feasible solution even though one existed. To understand the problem, consider the roughly 1,500 officers designated annually. In the worst case, the number of possible designation combinations is four times the total number of officers, that is, an officer could be designated into one of three functional areas or back into his or her basic branch. Even if the board gives most of the officers their first preferences, it is not known a priori which officers these are. The remaining fraction of officers still leaves hundreds of designation combinations, which cannot be sorted through manually. The practice board conceded that the Army needed a mathematical model to help it to designate each officer into a basic branch or functional area.

## The Career-Field-Designation Model

To designate each officer into a basic branch or functional area, if the possibility exists, we calculate a score that accounts for both officer preference and qualifications yet weights preference over qualification (appendix). These scores correspond to the utility scores for (officer, branch or functional area) pairs. To mitigate the subjectivity that is inevitable in human evaluation of officers' records, we designed the utility score to preserve a relative ordering of the officers being evaluated by a given panel, and the board normalizes the evaluations across panels and basic

branches or functional areas. That is, we give the most qualified officers for each basic branch or functional area the same score. The board considers the individual merits of each officer carefully and gives each officer a distinct utility score; doing this precludes ties in officer scores and prevents designating officers in aggregate.

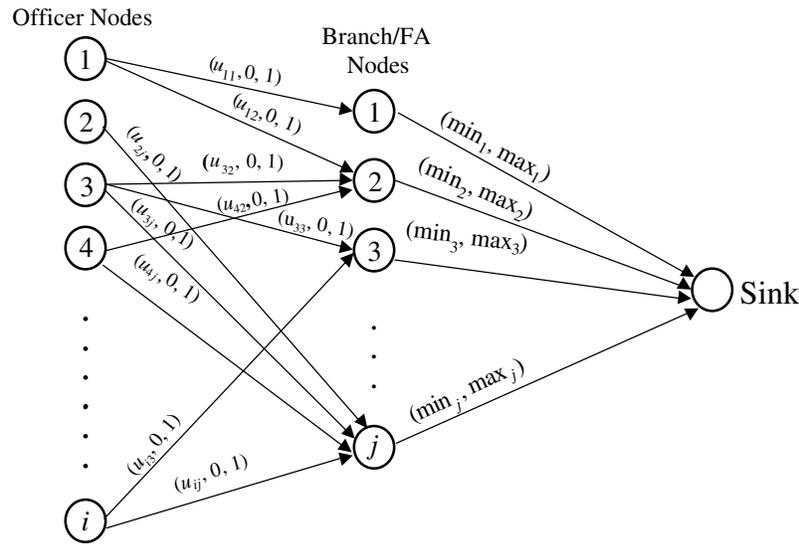
The CFD model is a network model (Figure 2) that minimizes the sum of the utility scores while meeting flow balance constraints to ensure that the required numbers of officers are designated into each career field. The model is composed of three sets of nodes. The first set consists of nodes with a supply of one, representing each officer,  $i$ . The second set contains a node corresponding to each branch and functional area,  $j$ . The last category consists of a single sink node. Flow emanates from the officer nodes and enters the branch and functional area (FA) nodes and from these nodes passes to the sink node.

An arc from an officer node to a branch or functional area node exists only if an officer has selected a branch or functional area as one of his or her choices (or is currently serving in a branch) and the board has assigned the officer an OML score. The cost on each of these arcs is the utility score,  $u_{ij}$ . A flow of 1 indicates that the officer is designated into the branch or functional area and a flow of 0 indicates otherwise. Army officer requirements define lower and upper limits,  $\min_j$  and  $\max_j$ , respectively, on the number of officers that can serve in each branch or functional area. While we have tailored the model to our application, other researchers describe similar models (Papadimitriou and Steiglitz 1982, Chapter 11; Sedgewick 1988, Chapter 34; Ahuja et al. 1993, Exercise 1.4).

Officer requirements may be too aggressive to be satisfied given the list of fully qualified officers for each branch and functional area. In this case, the board must consult the senior personnel officer for the Army or his representative to adjust the number of qualified officers.

## Running the Career-Field-Designation Model

The CFD model runs in a spreadsheet and has three major components: (1) a preprocessor and arc generator, (2) a network simplex solver, and (3) an output



**Figure 2:** The CFD model is a network model that minimizes the sum of the order-of-merit-list scores while meeting flow-balance constraints to ensure that the number of officers designated into each career field meets the requirements. Attributes on the first set of arcs are (cost, lower bound, upper bound), while those on the second set are (lower bound, upper bound); on the latter set of arcs, the costs are 0.

generator. The preprocessor and output generator are subroutines written in Visual Basic for Applications; the network simplex solver is an Excel add-in.

The preprocessor allows the board, with the assistance of the CFD officer (an Army major), to pre-designate officers for special cases not considered in the network model. Using preprocessing, the board can also reduce the problem size by making obvious designations. For example, the number of officers asking to remain in their basic branches is usually less than the number required. Because all officers under consideration are qualified to serve in their basic branches, the board can designate all those asking to remain there as a first preference into their first preference branches and remove them from further consideration. The preprocessor makes up to 50 percent of the designations and provides information as to whether these predetermined designations have rendered the resulting model infeasible.

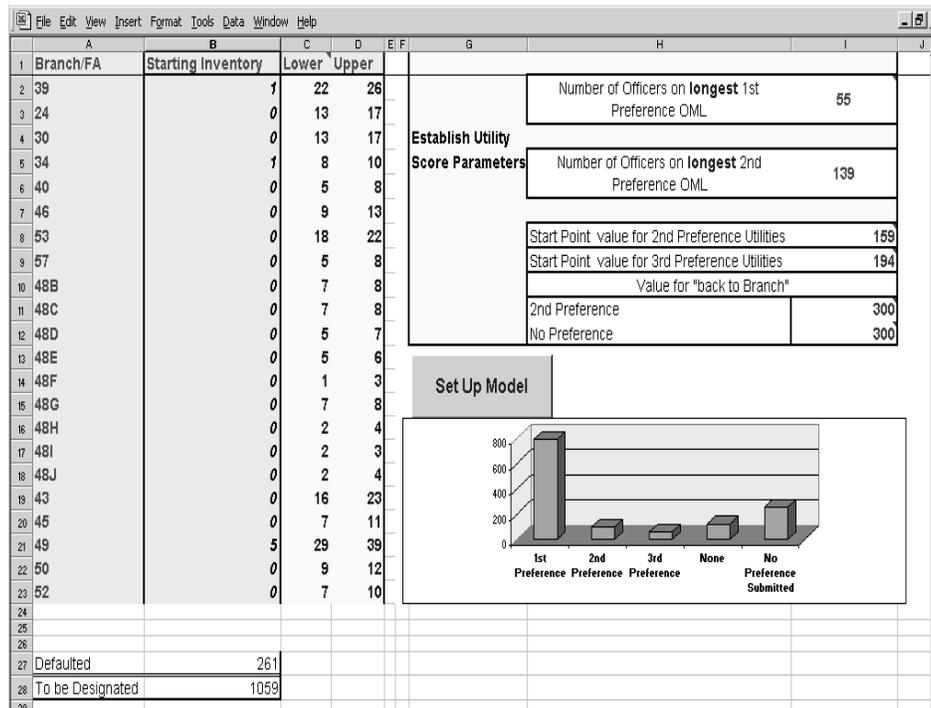
The key component in this model is a solver that employs the network simplex algorithm (Jensen 1999). This solver has an interface that allows the user to enter the data as assembled by the board; a Visual Basic program converts these data into the network format the solver uses. These data consist of nodes

and arcs along with the associated supplies, demands, upper and lower bounds, and costs. The model optimally designates 1,500 officers into 16 basic branches and 16 functional areas in less than 10 seconds on a 900MHz Pentium PC with 256 MB RAM.

The postprocessor merges the list of officers designated during preprocessing with the list of officers designated during the model run (Figure 3). It also summarizes the results for the board, for example, the number of officers who received their first preference or their second preference. The board reviews the recommended designations and makes changes that are necessary because numerical scores cannot fully delineate all officer attributes.

## Results

The Army has used the CFD model during four board meetings since June 2001 to designate a total of over 10,500 officers. The Army will continue to use the model to designate approximately 1,500 officers each year. Because the board cannot make a feasible set of designations under OPMS III manually, we cannot contrast solutions using the optimization model with prior efforts. However, we can measure the success of the model by the board's perception of the



**Figure 3:** This truncated screen shot depicts the primary inputs and corresponding outputs from the CFD model. Shown are the number of officers needing to be designated, along with their current branch or functional area (Columns A and B), and officer requirements (Columns C and D). The top right-hand corner contains information for determining  $u_{ij}$  scores. The bottom left-hand corner tallies the number of officers who are preprocessed from the model and the resulting number of officers that needs to be designated. Finally, the bottom right-hand corner depicts the designation output as the number of officers who were assigned their first, second, or third preferences. Officers not assigned to one of their preferences (fourth bar) usually did not submit their basic branch as one of their preferences. Only about 80 to 85 percent of the officers submit preferences; hence, we include a no-preference bar.

solution quality and the happiness of the Army’s officers. Board members have stated that the quality of the officers it has designated into the basic branches or functional areas has been superb. Board members have also been pleased with the graphical depiction of the network that gives them a conceptual understanding of the model; this understanding increases their confidence in the model. Attrition rates, commonly used to gauge officer happiness, will not be available for another five years. However, another measure easily speaks to the success of the process. Since it began using OPMS XXI, the Army has established an appeals process for officers who are unhappy with the board results. Fewer than one percent of the designated officers submitted appeals since June 2001, indicating that most officers believe that the process

is fair. In general, about 85 percent of officers have received their first preferences and over 90 percent have received their first or second preferences.

Because we optimize utility across all officers and career fields, it is conceivable that the model has multiple optimal solutions in which a more preferable solution designates a greater percentage of officers into their first preferences. However, given the tight requirements, that the utility scores account for preference, that a very high percentage of officers receive their first preferences, and that the board makes final recommendations after it has thoroughly examined the solution, we are confident that the designation process produces excellent results.

In addition to the immediate and apparent benefits of a more focused armed force and a greater

degree of contentment among officers with the career-designation process, the CFD model also has long-term benefits. Attrition and unforecasted changes to the force structure can result in shortages or surpluses of officers in various career fields. In turn, this may result in designations that do not meet the expectations of the officers in all ranks of the Army, which hurts morale. The use of a rigorous quantitative process to make career decisions after 10 years of service helps the Army to adjust its designations so that its supply of officers better matches its requirements for officers in its career fields.

The Army now has an effective model for designating officers into career fields. One board member made a telling comment: “The model [is] not only useful, it [is] necessary.”

## Appendix. Determining and Characterizing Officers' Scores

For each branch or functional area  $j$  and first officer preference, we score officers in decreasing order of qualification (as specified by the OML) as  $1, 2, \dots, n_{j1}$ , where  $n_{j1}$  is the number of qualified officers who choose branch or functional area  $j$  as their first preference. Then, for each branch or functional area  $j$  and second officer preference, we score officers based on qualification as  $\max_j\{n_{j1}\} + 1, \max_j\{n_{j1}\} + 2, \dots, n_{j2}$ , where  $n_{j2} - \max_j\{n_{j1}\}$  is the number of officers who choose branch or functional area  $j$  as their second preference. Similarly, the rankings for third preference branch or functional area begin at  $\max_j\{n_{j2}\} + 1$ . These scores correspond to the utility scores for (officer, branch or functional area) pairs. We weight the utility score associated with assigning an officer back into his or her basic branch without that request about 1.5 times worse than the worst score of any officer on any OML list for any branch or functional area.

These scores produce a stable matching of officers to career fields. To see why, let  $n_{jk}$  be the number of qualified officers with branch or functional area  $j$  as their  $k$ th preference. Assume that we have an unstable solution. Without loss of generality, we may assume that we have at least two officers who were given their second preferences but, because they both received OML scores in their first-preference branches or functional areas, they were qualified to receive

their first preferences. For two arbitrary disgruntled officers, the best (lowest) their combined score could have been under the assumed (unstable) solution is  $2^*(\max_j\{n_{j1}\} + 1)$ . Consider a feasible switch of these officers, both to their first preferences. The worst (highest) the resulting score could be is  $2^*(\max_j\{n_{j1}\})$  (under a worst-case scenario of equal length OMLs in the branches or functional areas to which we switched the officers). Because  $2^* \max_j\{n_{j1}\} < 2^*(\max_j\{n_{j1}\} + 1)$ , minimizing the sum of all utility scores would never yield the hypothesized unstable solution. Hence, the original matching must have been stable.

## Acknowledgments

We extend special thanks to Colonel Peter Gibbons (retired) and Lieutenant Colonel Jack Kendall (retired) of the US Total Army Personnel Command for guidance and support, to Professor Paul Jensen of the University of Texas at Austin for supplying the solver free of charge, and to Professor Kevin Wood and Lieutenant Colonel David Olwell (retired) of the Naval Postgraduate School, Professors Frances Newman and J. Kevin Newman of the University of Illinois, and several anonymous referees for helpful suggestions on earlier drafts.

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- Ricardo Rivera, Lieutenant Colonel, US Army, Chief, Development Branch, Department of the Army, US Total Army Personnel Command, Alexandria, Virginia 22332-0411, writes: “I would like to verify that the Career-Field-Designation Model is currently in use by the United States Army in the selection of Officer Career Tracks. The Army has been using this model since 1999, resulting in the designation of over 20,000 officers. The Army’s Career-Field-Designation process, and the Officer Professional Management System III, which it is part of, could not work without this valuable model developed by Major Daniel Shrimpton and Dr. Alexandra Newman.”