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A Survey of Operations Research Techniques Used in U.S. Army Research*

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In this paper we consider the topics presented at the Twenty Seventh Annual Army O.R. Symposium and the projects proposed in the 1988–89 military research topic book. The purpose of our study is to try to determine the quantitative skills that are most in demand in certain parts of the U.S. Army. Such a listing may prove useful in determining the skills that Operations Research analysts need to be taught. The detailed comments on the topics give some idea of the breadth and scope of OR applications in the U.S. Army.

INTRODUCTION

BY ANALYZING various studies either proposed or performed by Army personnel we hope to discover which quantitative techniques are of most importance to an OR technician working for the U.S. Army. Such information can be useful in determining what techniques to include in various training programs. Analysis of the studies should also provide insight into the practice of OR in the U.S. Army.

Operations Research is defined in the Joint Chiefs of Staff publication 1 as 'the analytical study of military problems undertaken to provide responsible commanders and staff agencies with a scientific basis for decision on action to improve military operations. Also known as Operations Analysis'. The U.S. Army has a specialty designated as Operations Research/Systems Analysis (OR/SA). An officer serving in an OR/SA assignment frequently bridges the gap between military science and management activities. Tactics doctrine and the organization and employment of new weapons systems are typical examples of study areas which require OR/SA officers to be proficient in their basic combat skills. Thus OR/SA is not an entry level skill. All individuals with this title have previous experience in at least one of the many fields in the Army (such as Infantry, Armor, Finance, etc.). The ability to employ officers with training in various fields is commonly referred to as 'putting mud on the numbers'. OR/SA officers are expected to apply the 'mud' or their experience to any problems they tackle.

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SELECTING THE DATA

The U.S. Army has OR/SA specialists conducting studies around the world. After reviewing the studies performed at several sites it became apparent that each site employs a narrow range of techniques applicable to that specific organization. For example, an organization primarily concerned with logistics will predominantly use methods from queueing and transportation theory. For such cases, a taxonomy of the important quantitative skills would be redundant. Instead we decided to try and find sources that would give a more general picture than that provided by groups with a very specific, well-defined mission.

The data used for this paper was derived from two primary sources. The first is a listing of proposed research topics prepared by the military for use by military OR students.[1] These projects are earmarked as low priority and submitted from OR agencies throughout the Army. OR students seeking thesis material are invited to tackle these projects as opposed to assigning them to a full time OR/SA officer. This source represents a very broad cross-section of activities throughout the Army. Our second source of information was obtained from the 27th Annual Army Operations Research Symposium (AORS XXVII) 11–13 October 1988. This consisted of completed research papers presented from various organizations throughout the Army and its contractors. The above two sources produced a listing of 177 research topics. In what follows the proposed research topics and completed research papers will be referred to as 'proposals' and 'papers' respectively.

[1] Military Research Topic Book, School Year 1988–89, Functional Area 49 Proponency Office, Fort Leavenworth, KS.

COMMENTS ON THE DATA

There are some potential deficiencies with our choice of data sets. First the projects in the military research topic book are likely to misrepresent the Army's real OR needs, since, in the judgment of military management, other missions have a higher priority. Therefore the proposed research topics have been left for students, while full time OR analysts tackle the more pressing problems. Secondly, the completed papers presented at the Symposium are of broad interest to the Army. Many papers which are not as glamorous may not be presented at the Symposium. Also many projects were undertaken which could not be evaluated for security or other reasons. However, even with the above deficiencies we feel that our data sources are about as good as one could reasonably expect for the kind of survey we conducted.

Studying the proposals and completed papers sometimes revealed obvious methodologies and techniques. However, sometimes, even though the concept was clear, the specific methods applied to derive the results were not mentioned. In other cases several different techniques were applied. In this latter case all methods employed were tallied.

RESULTS OF THE SURVEY

Table 1 contains a breakdown of the skills required for the 177 research topics that were investigated. The results from each of our data sources are displayed separately. As might be expected the category Model Development is more important for the data sets consisting of proposed research rather than the one consisting of completed papers. A perusal of the other categories in Table 1 shows that there are no overwhelming differences between the two data sources. This somewhat validates our claim that our two data sets are fairly representative of the broad range of skills required by an Operations Research generalist in the U.S. Army.

One surprising aspect of Table 1 is the omission of topics such as Multiple Criteria Decision Making, Quality Analysis, Reliability and other economic analyses. These clearly are important topics. The lack of these categories is probably due to the deficiencies in the data sources that we have already described.

COMPARISON WITH OTHER SURVEYS

A number of surveys on the use of quantitative techniques in business have appeared in the literature. It is difficult to compare the results from the various surveys since the methodologies and type of data collected are often different. However, such a comparison is important in order to obtain some picture on how the usage of OR techniques varies among different sectors. Towards this end, Table 2 summarizes some of the data contained in a number of survey articles.

For purposes of comparison, we have collapsed some of the categories used in these papers so that they more closely resemble those in Table 1. Table 2 does not contain categories such as 'Dynamic Programming' and 'Game Theory' that appeared in some of the articles but not in the present survey. Similarly, classifications such as 'Model Development' that appear in Table 1 but not in the other surveys we investigated are also excluded from Table 2. Some of the surveys report the percentage of respondents using each OR technique (e.g. [1]). Others report the frequency of use for each method (e.g. [2]). To cope with these and other differences, our table simply contains the rank ordering of the various techniques.

The Forgionne [3] study looked at a random sample of 500 of the 1500 largest American operated corporations listed in the *EIS Directory*.

Table 1. A breakdown of the quantitative skills required for both proposed and completed projects of the U.S. Army

Skill required	Proposed topics		Completed Papers		Total	
	Number	%	Number	%	Number	%
Statistical Analysis	27	28.72	18	21.69	45	25.42
Simulations	13	13.83	14	16.87	27	15.25
Model Development	21	22.34	5	6.02	26	14.69
Qualitative Techniques	4	4.26	8	9.64	12	6.78
Artificial Intelligence	3	3.19	6	7.23	9	5.08
Decision Analysis	1	1.06	8	9.64	9	5.08
Linear/Non-Linear Programming	5	5.32	4	4.82	9	5.08
Stochastic/Queueing Theory	9	9.57	4	4.82	13	7.34
Inventory Theory	5	5.32	3	3.61	8	4.52
Network Analysis	2	2.13	5	6.02	7	3.95
Forecasting Methods	3	3.19	2	2.41	5	2.82
Other	1	1.06	6	7.23	7	3.95
Total	94		83		177	

Table 2. Ranking of categories from previous surveys

	(1)	(2)	(3)	(4)	(5)
Statistical Analysis	1	1	2	1	4
Simulations	2	2	3	3	2
Linear/Non-linear Programming	3	3	1	2	1
Stochastic/Queueing Theory	5	5	4	5	5
Network Analysis	4	4	5	4	3

(1) Table 2 from Forgionne, 1983.
(2) Table 3 from Thomas and DaCosta, 1979.
(3) Table 1 from McClure and Miller, 1979.
(4) Table 1 from Ledbetter and Cox, 1977.
(5) Table 8 from Gaither, 1975.

Thomas and DaCosta [1] surveyed a mix of 420 corporations selected from *Fortune*'s 1975 list of the top 500 industrial corporations in the United States and the largest industrial firms, financial institutions, banks and savings and loans in California. McClure and Miller [2] surveyed the 100 largest commercial banking companies while Ledbetter and Cox [4] looked at 176 *Fortune* 500 firms. Finally, Gaither [5] used a proportional stratified random sample of 500 firms selected from all manufacturing firms with 250 or more employees in Arkansas, Colorado, Kansas, Missouri, New Mexico, Oklahoma, and Texas.

As can be seen from Table 2, the category 'Statistical Analysis' is very important in all but the Gaither study. This latter paper considered the OR techniques used in manufacturing problems where there may be less need for the use of statistics since specific models such as linear programming ones are directly applicable. The most striking difference between Tables 1 and 2 is the importance of the 'Linear/Non-linear Programming' category. This agrees with the results found by Thomas and Mitchell [6], who surveyed officers in the U.S. Marine Corps. They found that 'Linear programming was reported to be used by only about a third of the Marine Corps respondents, falling quite a bit short of the apparent wide spread usage reported by private firms (where LP-amenable problems are possibly more numerous and better defined)'.

DETAILED COMMENTS ON TABLE 1

Statistical analysis

Clearly statistical techniques figure predominantly in both data sets. Many of the OR tasks appear to only need statistical analysis for completion. This category in Table 1 covers a wide range of techniques, since no specific statistical method appeared often enough to warrant a separate category.

Although many of the proposals are related to a statistical analysis of large volumes of data, some required a detailed knowledge of various statistical applications. For example, one proposed project was to develop an automated tool for generating experimental designs.

The papers that used statistical analysis involved the use of cost analysis, sensitivity analysis, experimental design, regression and other analytical techniques. Many of these papers resulted in a detailed analysis of problems facing Army leadership. Through regression techniques, simple models were developed at all levels of command to determine such things as logistical needs, manpower staffing requirements and even soldier performance in relation to expected combat conditions. Other studies evaluated the effectiveness of specific recruitment programs, maintenance programs and training programs. These detailed studies are critical to management in their decision making process.

Simulations

There is a significant use of simulations by military OR analysts. Some of the proposals dictate the use of Monte Carlo simulations while others imply applications of Lanchester's Square Law. The vast majority of the proposals in this category hope to provide additional detail to existing combat simulation models. Many of the existing simulation systems in place today provide scenarios for a wide variety of combat operations. Research is being performed to specifically model military sub-unit operations, such as military police tactics in theater-level operations. It is hoped these simulation sub-models will provide military leaders with a detailed view of the simulated battle field and the interaction between the myriad activities.

The majority of papers in this category also use Monte Carlo simulations of combat scenarios. The military uses these models for a multitude of planning requirements. Analysis of the output of these models helps to determine the effectiveness of the equipment and force mix in a variety of scenarios. It seems that the use of simulation for 'war gaming' is becoming more prevalent as computer speed and availability increases.

Model development

The proposals have a higher percentage of model development problems than the completed papers. This is because the methodology on the completed papers is easier to discern while the

proposals are left open to the imagination and judgment of the analyst. Many of the proposals which were ambiguous toward the methodology to be employed have been included in this category.

One of the proposed topics involves the development of a model for optimizing tank and gaugement ranges. Another requires development of a model to determine the number of initial entry no-shows for the recruitment program. Another suggested development of an analytic model for determining the effectiveness of a unit or weapon. Finally, some proposals dealt with areas where the military has previously not applied OR methods. For instance, one recommends discussion of appropriate OR tools for the analysis of systems safety and risks associated with various systems. One completed model assists in determining the impact of winter environment on operations while another models the performance of directed energy weapons. From a marginal point of view one of the most valuable of the completed papers appears to be the one dealing with development and application of the Army command and control evaluation system. This model assists management in the assessing of divisional command and control performance. Unfortunately, no information was available regarding the methodology the OR/SA officer used in developing this system.

Qualitative techniques

This category is less analytical than it is 'common sense'. It contains cases where methods were used to evaluate perceptions and feelings regarding various programs. The Army's use of experienced officers in OR/SA positions is an asset wherever this method is needed. The intimacy of an OR/SA officer with his basic branch of training (e.g. Infantry) may lead to significant insights unavailable to another analyst.

Proposals ranged from the evaluation of retiree's perceptions of the Army's transition program to the survivability of the quartermaster units in combat. Almost 10% of the completed papers fall in this category. One particular example is a study on conventional arms control. Although the study uses other OR techniques, it appears to primarily depend on qualitative methods for its conclusion. The paper's findings show the impact of withdrawal and redeployment of U.S. forces under recent reduction treaties.

Artificial intelligence

Artificial intelligence techniques are not considered OR related in most universities curricula. However, an OR/SA officer may have this designated as a special skill identifier in addition to his OR skills. The merger of these fields produces some very interesting discussions.

One of the proposals seeks to merge AI technology with simulation techniques to produce combat models with better emulation of planning and conduct of combat missions. Another proposal was to develop an expert system to determine the best mix of weapons systems necessary to combat a specified threat.

One of the presentations by the U.S. Army concepts analysis agency discusses an interesting approach to transportation systems. This technique uses an object-oriented rule-based scheduling program. Using heuristic reasoning based on local problem conditions this computer program solves problems of a highly complex non-linear nature. Another example of OR/SA artificial intelligence research focused on understanding on how U.S. Army Corp level planners perform operational planning. This paper discussed an approach attempting to solve operational problems using concepts from AI and cognitive sciences.

Decision Analysis

Decision analysis techniques (such as decision trees and tables, cost benefit analyses, etc.) were a minority in the proposed research topics. Only one of the 94 proposals suggested this type of analysis. However, 8 of the 83 papers presented at the Symposium used some form of decision analysis methodology. Most of the methods employed were highly tailored to specific problems. One example that may enjoy a broader application was a paper suggesting decision analysis models for determining weather effects on operations.

Linear and non-linear programming

These methods were occasionally needed in the proposed research topics. Based on this sample it seems that OR/SA analysts apply these techniques primarily to transportation or distribution systems. One paper however, illustrated creativity and imagination in applying integer linear programming to help evaluate modernization policies for Army Aviation equipment.

Stochastic processes and queueing theory

One of the proposals required the use of Markov process theory to model fuel capacity requirements. Another research topic that may use queueing theory involves analyzing the number of recruiting stations necessary to cover a given area.

One of the completed papers discussed the use of Poisson distribution to determine the probability of damage given a hit in a fragment distribution application.

Inventory

Most of the topics in this category dealt with typical inventory problems. One challenging research proposal related to supply requirements for ice. In addition to determining ordering quantities the OR/SA officer is expected to recommend policy for production storage and issuance of this highly perishable item. This example illustrates the breadth of knowledge expected of an individual fulfilling these duties.

Only 3 of the 83 completed papers involved inventory theory. These studies will be used by

Army leaders to insure adequate personnel and equipment quantities are available to perform the missions of the U.S. Army.

Network analysis

One of the proposed research topics for which network analysis skills may prove useful was to develop a model for unit movements and routes selection.

The papers requiring network analysis primarily involved optimization of distribution and communications networks. One of the completed papers analyzed the effects of varying unit mobility rates on war gaming simulations. This analysis specifically makes use of the shortest path and maximum flow algorithms to improve the Army's mobility models.

Forecasting methods

One proposal was to forecast future force requirements by analyzing force sizes, battle duration and other quantities of war and to also identify other trends or interesting patterns that may occur during the course of war. Forecasting is used extensively to predict personnel needs. One proposal hopes to determine the best forecasting method for officer attritions. Other papers focused on forecasting items such as ammunition consumption.

CONCLUSION

After evaluating the 177 items in the survey some remarks about training requirements are offered. Because of the preponderance of the papers using statistical analysis techniques this is obviously an important skill required of an OR/SA officer. Evaluating the type of analysis required shows these papers to be of a very basic level. Thus this type of skill is primarily needed at an entry level. Some similarity with simulation also seems to be needed at the entry level for an OR/SA specialist. Many of the survey items involved various simulation models and their adaptation to particular problems facing the Army today. It is imperative for the OR/SA officer to be familiar with simulation techniques to effectively research the problems. Beyond entry level skills a broader range of techniques are required. A significant amount of the papers in the survey involved the development of models with no specification of particular techniques. This implies a broad knowledge of various methodologies to determine the approach.

At upper levels of management familiarity with advanced techniques is all that is necessary. It appears the OR requirements at this level become more qualitative. Whenever the research involves a detailed analysis it normally is delegated to lower levels of management. This leaves upper levels of management available to evaluate the more pressing problems it faces.

Due to the merger of OR and Systems Analysis minimal training should include several information systems topics. One topic may be artificial intelligence. At a minimum the training should include systems analysis techniques. Overall the primary uses of OR skills have been the improvement of the Army's planning capabilities.

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