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Operations research in national defense services

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ABSTRACT

To provide the right (required) number of the right (qualified) personnel at the right (specified) time at the minimum cost" is the goal for any workforce planning, or military training more specifically system. This paper gives an outline of the areas of Operational Research where the work in the defense domain has been successful and it brings out the role it can play in decision making. This paper looks into the strategies and developments made in Military, Navy and Air Force using operations research since World War II where it was first used to enhance the effectiveness of weapons and other limited resources available.

Keywords— *Defense, Army, Navy, Air Force, Operation Analysis*

1. INTRODUCTION

Operations research is an advanced analytical method of solving problems that is useful to make better decisions and improves the management of organizations. Operations research arrives at optimal or near-optimal solutions to complex decision-making problems. In Operations research problems are solved in steps through mathematical analysis. Initially OR was used for defense purposes during the world war but now the use OR ranges from health care to financial engineering. Nowadays OR has become a part of everything and is important in making key decisions as it helps in further analysis of the situation.

Each country desires to become the most powerful nation and thus spends a very large portion of their budget on acquiring weapons. This requires high expenditure and so it is important for the military decision-makers to make a correct decision keeping in mind the long term perspective. Here Operations Research (OR) plays an important role in determining the best possible solutions and the most feasible options. OR is a very efficient method in planning defense situations. OR has been in use for a long time to plan and analyze the military requirements. Operations ensure stability and discipline in the management of the forces.

2. OVERVIEW

The modern field of operations research (OR) arose during World War II in an effort to enhance the effectiveness of weapons and equipment used in the battlefield. Since then, OR techniques have been used to solve many sophisticated and complex defense-related problems not only limited to combat operations but also encompassing logistics, manpower planning, equipment procurement, training, infrastructure defense, and many other areas.

Some major milestones in the use of OR in defense are mentioned below:

- Improvement of the depth charges used by the USA in WWII.
- Removing disparities in General Staff Qualitative Requirements in the Ministry of Defence.
- Use of Quantified Judgement Method of Analysis and WEI/WUV method using the Analytic Hierarchy Process to answer specific queries by the top management of the MOD/DRDO/Service Headquarters.
- Development of computer algorithms to help solve larger managerial problems.
- Visual Interactive Modelling, in which OR models and MIS/Graphics are interfaced through interactive algorithms.

- Introduction of systems analysis and planning, programming, and budgeting in the Pentagon, with a consequent shift of emphasis to force level and procurement decision making.
- In the 1990s, computer simulations, computer-assisted war games, and other forms of computer programming began to dominate the practice of OR.
- The Cyclops study conducted in 1963, whose objective was to keep the Atlantic sea lanes open to NATO allies if war broke out in Europe.
- Operations analysis assisted the fleet toward better war plans, operational efficiency, and tactical effectiveness.
- The 1967 MFE Study was a rare success in decision making by systems analysis and only possible because there was already a consensus that it must succeed.
- Numerous studies led to the establishment of formal techniques of command and control of fighter versus bomber operations in the Battle of Britain.
- It allows the air force to find out at what rate the transition to a new model of aircraft or the retirement of an old fleet can be accomplished, how many new recruits can be absorbed in a squadron, how fast can experience be acquired through mentoring.

3. RESEARCH OBJECTIVES

- To understand the problems faced in the military and how Operations Research is used in order to tackle these problems and find a solution for the same.
- To find the optimal solution to the problems faced by the organization.
- To improve the fleet readiness and scarcely notice the loss in quality
- To educate a stream of future leaders about the optimal solutions to any problem that may arise in the future.
- To elaborate upon the various decision-making criteria and the factors that affect the decision-making process.

4. RESEARCH METHODOLOGY

The research methodology that has been adopted here is a detailed qualitative analysis of secondary data adopted from published research papers. Numerous papers by international as well as Indian authors have been studied and in-depth analysis has been done from the same. In these papers various OR techniques had been applied in modeling of workforce and training systems and the same have been understood and studied.

5. LITERATURE REVIEWS

5.1 Operations Research in military

Jaiswal discusses how OR techniques were used in the selection and acquisition of weapons. Initial studies were based on evaluation of guns vs rockets based on the 'Measure Of Effectiveness' (MOE) and the Total Systems Cost (TSC). In order to calculate MOE, many mathematical and simulation models had to be developed. This activity resulted in a lot of research on effectiveness, area coverage and damage assessment. The calculation of TSC included procurement cost, maintenance cost, ammunition cost, personnel cost, training cost, etc. Subsequently, the cost-effectiveness ratio was derived (MOE/TSC). The lowest value here determined the most cost-effective weapon and that weapon was recommended for acquisition. However, after the 1971 Indo-Pak War, focus of OR studies shifted more towards systems rather than specific weapons.

Jaiswal also talks about how OR was used in tactical planning. One of the earliest examples of use of OR in tactical planning is the depth charge in World War II. Initially, depth charges were set at a depth of 100ft, but this did not prove to be very useful. Scientific analysis revealed that if the charges were placed at a depth of 25ft, the number of submarines destroyed would increase by one and a half times. This finding, when implemented, increased the number of enemy submarines destroyed significantly. After the 1965 Indo-Pak War, the defense forces were more concerned about their prevalent operational tactics, thus they asked OR scientists to analyze their plans through scientific operations analysis.

He also talks about the design and development of weapon systems. The design and development of weapons in the Ministry Of Defence (MOD) are initiated by designing General Staff Qualitative Requirements (GSQRs) which specify the operational characters that the users want in the proposed weapons. This work is divided into different subsystems and these usually require help from other R&D agencies, universities and public/private institutions. Thus, weapon development requires a great deal of effort, involving the use of project management techniques like PERT/CPM and technical reviews. Some other areas where military OR has been useful are:

- Removing disparities in GSQRs,
- Performance evaluation of systems,
- Reliability evaluation.

Jaiswal then goes on to describe how OR was used in threat assessment and strategic planning. Long-term identification of threat on our borders and measures to counteract them on a timely basis constitute the most important decision-making problem particularly to executives in MOD and Service Headquarters. This needs an evaluation of the force strength/potential of a country and its adversaries quantitatively to assist in answering questions like If a war breaks out, what is the chance of country A winning under different scenarios? If two countries have come to some settlement on their boundary dispute, what should be done as a confidence-building measure by a country by pulling back some of its forces from border so that both countries can live peacefully, but at the same time be in a position to meet any aggression by the other country if it betrays the settled agreement. All these questions have been answered by military analysts and several techniques like Quantified Judgement Method of Analysis and WEI/WUV method using Analytic Hierarchy Process, have been used to answer specific queries by the top management of the MOD/DRDO/Service Headquarters.

He then talks about war games. Training of Service officers to appreciate a threat situation and plan for remedial measures within the available resources effectively is an important activity in defense. For this purpose, military field exercises are conducted regularly. The large military field exercises are very expensive and time-consuming. However, these are necessary in order to re-evaluate and ascertain the effectiveness of the existing manpower and weapon systems in a conflict scenario. The Chief of the Army Staff of Pakistan, during the military exercise 'Zarb-e-Momin', observed that many of his Generals and Brigadiers did not have the requisite experience of war, because most of them were very young during the 1965 and 1971 wars with India. There has been no war since then, and the technology and war scenarios have changed considerably thereafter. In India, a study team under the former Chief of the Army Stat; General K Sundarji took up the task of creating a computer-assisted war game for a Brigade level at the College of Combat, Mho w, in collaboration with Military College of Telecommunication Engineering, Mhow, in May 1980. This team used the Quantified Judgement Method of Analysis (QJMA). The team found QJMA useful for war games at Brigade/Division/Corps levels, but not for games at lower levels like regiment. The computerized war games were initially developed to meet this objective, i.e. development of war games at regiment level. The structure chart of a regiment level war game for tank-to-tank battle is shown in Fig. 1. The game has been designed to be played in three rooms called Blue Room (friendly force), Red Room (enemy force) and Umpire Room (also called Higher Command or HICON). The Umpire or HICON presents a scenario defining the background and the objective of the game, area, terrain, and environmental conditions during gameplay and availability of weapons and resources on both sides. The Blue and Red teams are asked to prepare their plans and forward them to the Umpire. The Umpire executes the plans under given rules and provides casualties of personnel and equipment. Revised game status is obtained and is made available appropriately to the Blue and Red sides who are permitted to revise their action plans. The game continues until the termination conditions are satisfied.

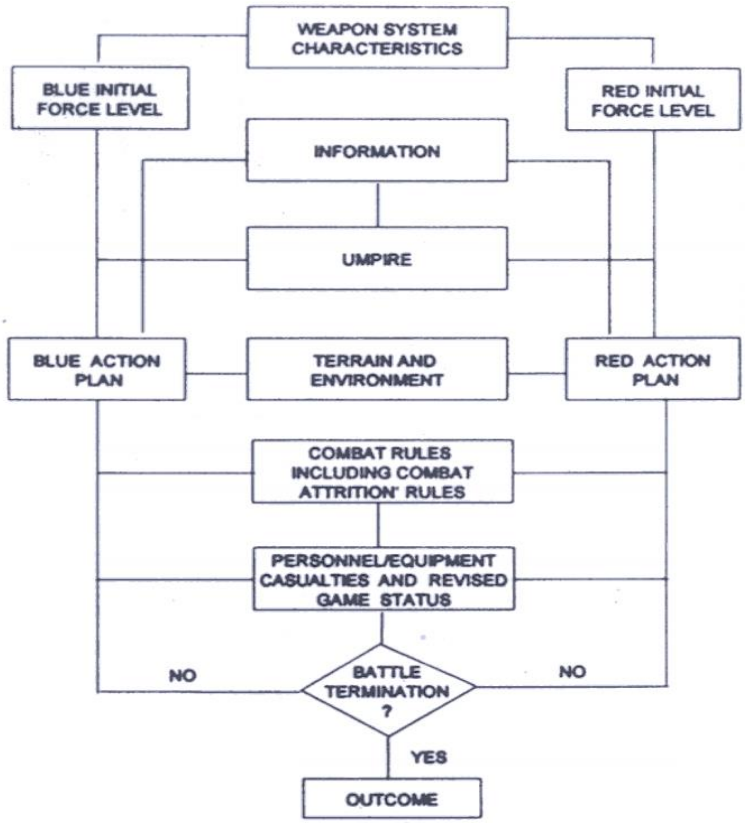

Fig. 1: Structure chart of regiment level computerized war game

The penultimate topic Jaiswal discusses is OR and Computer Interface. OR was initially defined as 'quantitative common sense' since the problems tackled were very simple, and the answers arrived through scientific analysis looked as if these could have been obtained using common sense. However, with larger managerial problems, the analysts had to invent newer tools and techniques and use them to undertake more complicated studies. The developments in computer systems provided support to such studies and also to the development of algorithms to handle large problems. The most significant impact on OR came with the advent of personal computers (PCs). The following advantages in OR implementation resulted from the introduction of PCs:

- Machine independent transportability,
- Interactive computing,
- Graphics capability.

Finally, he moves on to the future aspects of OR in military. Advances in OR and computer science and their interface are bringing in new developments in scientific decision making. A more recent concept is Visual Interactive Modelling in which OR models and MIS/Graphics are interfaced through interactive algorithms. A visual interactive model helps in increasing the mutual understanding between the analyst and the executive by providing a dynamic animated view of the model. Military OR has been applied to many vital issues such as the complex problem of scheduling the airlift of 3,50,000 troops and hundreds of thousands of tonnes of cargo in more, than 11,500 missions before and during the Gulf War, military stability in a multi-polar world, effect of command, control and communication on combat dynamics, etc. Military OR will be more in demand in future owing to the need for quick and rational decision making. There have not been any serious compulsions in our context but with increasing

competition, constraints, uncertainties, and global dependencies to affect decision making, there will be a greater need to involve an interdisciplinary team of analysts including Military OR experts and computer scientists. The need for bringing in cost-effectiveness in our decision making, quantification in place of qualitative appreciation, and better interaction between analysts and management through the growth of computer technology is being appreciated. It is a real challenge to Military OR analysts and computer professionals to provide defense executives with rational cost-effective solutions and to present their analysis in a format that defense executives can appreciate.

5.2 Operations Research in Navy

In many ways, the experience parallels the growth of OR in the Navy. For about 20 years, the emphasis was on improving fleet performance and readiness for combat. Then in the 1960s, Defense Secretary of United States Robert McNamara introduced systems analysis and planning, programming, and budgeting in the Pentagon, with a consequent shift of emphasis to force level and procurement decision making. By the 1970s, these procedures had been adapted and, in some respects, strengthened by the Navy. Meanwhile, the methods of OR had spread broadly into business, finance, and transportation. These commercial methods were then reflected back into Navy logistics, training, and human resource management. During the 1980s, hand-held and desktop computers began to have strong effects, largely but not entirely positive, on Navy analysis. In the 1990s, computer simulations, computer-assisted war games, and other forms of computer programming began to dominate the practice of OR. Today, most Navy analysts are employed in two ways: They participate in the formal and elaborate process of decision making and they develop and employ an extensive array of powerful computer programs for resource management and analysis.

The Cyclops Study of 1963: The study objective was to appraise America's leaders of their capacity to keep the Atlantic sea lanes open to our NATO allies if war broke out in Europe. The Soviet submarine force was very numerous, and its first nuclear submarines—the November-class SSNs—were just entering service. When the Cyclops Study was underway it was evident that a screen optimized against several hundred diesel subs in the forward 120-degree sector should not be weakened by spreading the limited number of escorts through 360 degrees just to guard against a few SSNs

FLEET OA: Operations analysis assisted the fleet toward better war plans, operational efficiency, and tactical effectiveness. Prominent contributors have been the Operations Evaluation Group, a history of which has been written by Tidman (1984), the Submarine and Destroyer Development Groups, and the VX air squadrons for tactical experimentation and technology development.

The 1970s CPAM Process: The biggest benefit of Navy analysis in Washington was not in justifying a new system or rationalizing a force level. The 1967 MFE Study was a rare success in decision making by systems analysis and only possible because there was already a consensus that it must succeed. The enduring benefit of OR in the Pentagon was in educating a stream of their best officers about the state of the Navy and the cost-constrained possible states of a future Navy.

5.3 Operations Research in Air Force

Operations Research and Air Force go back together in a long way. In fact, the use of OR for the first time was in the Royal Air Force. To defend Britain against an attack from Germany, the British government established radar installations along the coast to provide the Royal Air Force (RAF) with early warning of incoming German strikes. Numerous studies led to the establishment of formal techniques of command and control of fighter versus bomber operations in the Battle of Britain. Studies in navigation accuracy, radar performance, and the employment of chaff contributed to improved bombing accuracy and aircraft survivability during the area bombing of German cities. And thus, Operations Research was born in the Royal Air Force.

In India, a 'System Analysis Group' for attending to problems of Air Force was started in 1972, which was later renamed as Aeronautical Systems Analysis Group. This Group became the Centre for Aeronautical Systems Studies and Analyses (CASSA) on 3 October 1984 and was made responsible for carrying out performance assessment, evaluation and cost-effectiveness studies mainly relating to Air Force systems using quantitative techniques of OR and Systems Analysis.

The Air Force needs to train highly specialized personnel such as pilots, navigators or electronic sensor operators. In essence, this is accomplished as in any other school or college by sequentially marching instructors, students, and physical resources to complete a required program. Pilots generally go from undergraduate training to operational training units and on to squadrons. They go from learning how to fly to learn how to fly types of aircraft (helicopters, multi engines or jets) and finally how to fly specific aircraft. To become operationally qualified, pilots are required to acquire flying hours on specific aircraft and this is accomplished through mentoring with experienced pilots.

However, in this military environment several major characteristics make the problem quite different. The specialized resources used (pilots, planes, simulators) are very expensive and thus used to capacity if not lacking. The ability to use planes is dynamic due to failures, maintenance, and weather. The availability of instructors is also dynamic due to sickness, leave and secondary duties, which delays individual classes.

Coupled with the limited number of resources, the delays generate competition for the resources and sometimes for several consecutive days, which means that a priority scheme has to be used to decide who gets the resources. Individual classes often require two or four instructors. For example, for each flight, a specific number of instructors and students are required in addition to pilots and the aircraft. There are many failure points for the students but a limited number of retests are allowed. While a student is retested, the whole class waits. Similarly, if a student is sick, the class is idle until his return. The objective here is to find out at what date to start each course and minimize their time span. Finding out the bottlenecks is a secondary objective.

Brothers (1951) reports there are many types of research topics that require the proper studying and implementation of Operations Research. They are: Offensive ones dealing with bombing accuracy, weapons effectiveness, and target damage; Defensive ones dealing with defensive formations of bombers, battle damage and losses of our aircraft, and air defence of our bases; Studies of cruise control procedures, maintenance facilities and procedures, accidents, inflight feeding and comfort of crews, possibility of growing vegetables on South Pacific islands, and a host of others.

This allows us to find out, among others, at what rate the transition to a new model of aircraft or the retirement of an old fleet can be accomplished, how many new recruits can be absorbed in a squadron, how fast can experience be acquired thru mentoring.

6. LIMITATIONS

The equations developed in the models used in national defense are restricted by many simplifying assumptions that do not take into consideration the complicated real-life combat scenarios. The researchers have been continuously trying to modify these equations so that they could handle such scenarios with readiness.

The decision-making techniques for problems observed in military organizations should consider the complex structure, multi-criteria nature, and high uncertainties involved in military operations. These factors dramatically complicate a lot of real-life military decision problems.

In the case of defense and security applications, the types of methods used and problems addressed have changed significantly over the years since these naturally reflect the strategic and military environment of the time. Therefore, a particular method cannot be used for extended periods and constant changes are supposed to be made to keep up with the dynamic defense domain.

7. FINDINGS

Composite Group	APPLICATION AREA	OR METHOD
I. STRATEGIC & DEFENSE	Strategic Operations Nuclear Biological Chemical Defense Arms Control and Proliferation Air and Missile Defense	**Deterministic Operations Research** Dynamic Programming Inventory Linear Programming Multiobjective Optimization Network Methods Nonlinear Programming
II. SPACE/C4ISR	Operational Contribution of Space Systems Battle Management/Command and Control ISR and Intelligence Analysis Information Operation/Information Warfare Countermeasures Military Environmental Factors	**Probabilistic Operations Research** Decision Analysis Markov Processes Reliability Simulation Stochastic Processes Queuing Theory
III. JOINT WARFARE	Unmanned Systems Land and Expeditionary Warfare Littoral Warfare and Regional Sea Control Strike Warfare Air Combat Analysis and Combat ID Special Operations and Irregular Warfare Joint Campaign Analysis	
IV. RESOURCES	Mobility and Transport of Forces Logistics, Reliability, and Maintainability Manpower and Personnel	**Applied Statistics** Categorical Data Analysis Forecasting/Time Series Multivariate Analysis Neural Networks Nonparametric Statistics Pattern Recognition Response Surface Methodology
V. READINESS & TRAINING	Readiness Analytical Support to Training Casualty Estimation and Force Health Protection	
VI. ACQUISITION	Measures of Merit Test and Evaluation Analysis of Alternatives Cost Analysis Decision Analysis	
VI. ADVANCES IN MILITARY OR	Modeling, Simulation, and Wargaming Homeland Defense and Civil Support Computing Advances in Military OR Warfighter Performance and Social Science Methods Warfighting Experimentation	**Others** Advanced Computing Advanced Distributed Systems (DIS) Cost Analysis Wargaming

8. CONCLUSION

- It can be concluded that Operations Research is a robust tool that helps improve the quality of investment decision making by throwing light on key issues, assumptions, and sources of information and its aim to optimally utilize the available resources with a nation for defense purposes.

- The distinguishing contribution of Operations Research in national defense has been and still is in helping executives make better, timely decisions by applying special art of quantitative analysis, and only incidentally in the fidelity of the models and other tools that are employed.
- The countries could shift much analytical talent to improve fleet readiness and scarcely notice a loss of quality.
- The benefit of OR was not so much informal decision making as it was in educating a stream of future leaders about the state of the Navy and cost-constrained possible future states
- Looking at the other aspect of it, it is realized that because of the increased importance of operations research in the eyes of the military, navy and air force, and the availability of both educated people and powerful computers, applications that for years seemed to be unquantifiable are now being modeled more and more and across a broader range of applications and therefore are being used to their fullest capacities and efficiencies. Creativity combined with computing power has always been vital to successful research, but never has it been more important to the continued growth of a process as it has become to operations research. The techniques which are proving to be the most useful include linear programming, network analysis, and structured systems analysis and design.

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