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Growth of Military Operational Research in India

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ABSTRACT

Operational Research has contributed substantially to decisions on cost-effective induction of weapon systems, evaluation of tactical plans, development of computerised war games for training, realistic formulation of General Staff Qualitative Requirements, performance and reliability evaluation of military hardware under design and development, force structure planning and other tactical and strategic issues in Indian defence. This paper reviews the work in Military OR initiated by Professor DS Kothari, the first Scientific Adviser to the Ministry of Defence, and brings out the role it can play in defence decision making.

1. INTRODUCTION

The birth of Operational Research can be attributed to the pioneering work of Professor PMS Blackett, who along with a team of scientists and engineers, was asked by the British Government to advise the Royal Air Force on the problems arising out of induction of new weapons and equipment during World War II. This group observed that, in many cases, improvement in a system could be achieved by merely carrying out a scientific analysis of its operating policies and identifying a better policy for system operation. This led to the birth of Operational Research (Operations Research as it was later called in the USA and the countries following American English).

It is a mere coincidence that Professor Blackett, who was the main founder of Operational Research (OR), was called upon to advise the Government of India to set up the Defence Science Organisation (DSO), which finally came into existence with Professor DS Kothari as its first Scientific Adviser, in May 1948. Professor Kothari was a great visionary who could foresee the immense potential of the emerging field of OR. The importance that he attached to OR can be assessed from his own statement (Professor DS Kothari Memorial Lecture by A Nagaratnam at Defence Laboratory, Jodhpur, 6 July 1993): "As resources are limited, it is all the more necessary to thoroughly understand the science and the design parameters underlying the weapons in order that within the limitation of our resources, we can choose them wisely and produce them economically. The poorer a country is, the harder is the thinking it needs to do."

At the Second Defence Science Conference held during 21-26 April 1952, Professor Kothari devoted a considerable part of his address[1] to the importance of OR in Defence Science, need of close interaction between OR teams and the Services, examples of OR from World War II and effectiveness of weapons (or weapon economics as he preferred to call it). He created a small OR Cell in the Defence Science Laboratory (now Defence Science Centre) in 1949. The first impetus to OR came from the CACDS (Commonwealth Advisory Committee on Defence Science) conference organised in March 1953, at New Delhi. Professor Blackett was invited to this conference which discussed OR problems pertaining to operations of weapons and equipment in the Eastern theatre, reliability of airborne radio equipment, traffic accidents involving army vehicles, storage and deterioration of rubber goods used by the armed forces and countermeasures for mines in the battlefield. This conference provided sufficient stimulus to the OR activity not only in defence but also in other sectors.

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In 1959, DSO was expanded and reorganised by merging a number of Service/technical institutions, and the Defence Research and Development Organisation (DRDO) came into existence. Professor Kothari, in consultation with Army Headquarters, created the Weapons Evaluation Group (now Institute for Systems Studies and Analyses) on 1 June 1959. The Group was primarily responsible for carrying out OR studies and analysis of weapons for the three Services. Operational Research was also undertaken in the Offices of the Scientific Advisers to the three Services for meeting the Services' immediate requirements. This could be considered as the beginning of Military OR (OR applied to military problems) and also as a concrete step towards induction of OR in Defence decision making, which Professor Kothari emphasised in his speeches to scientists and Service officers. 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.

This article is dedicated to Professor Kothari, whose inspiring and thought-provoking lectures and discussions had a considerable impact on the author, who as a young defence scientist, was trying to understand the role that OR can play in rational decision making in defence.

Operational Research is an applied science and is therefore related to the prevailing environment in the sector in which it is being applied. Hence, the growth of Military OR has been related to the needs of management in the defence sector. Before 1980, when the Defence Research and Development Organisation had not embarked upon major weapon development programmes, the emphasis in the Ministry of Defence (MOD) was on the selection of weapons and equipment and in the Services on the evaluation of tactical plans. In addition there was interest in studying the procedures and practices in vogue with a view to modifying them to meet new challenges. Thus system improvement and modification became an important activity of OR. After 1980, DRDO management was more concerned with performance evaluation of systems under design and development, reliability evaluation, etc. Owing to the induction of computers, Services became keen on acquiring computer war games for their training purposes and MOD's interest shifted to larger strategic issues. Some of the important areas in Military OR are discussed in subsequent sections of this paper.

2. SELECTION AND ACQUISITION OF WEAPONS

In his address on 21 April 1952 at the Second Defence Science Conference, Professor Kothari stated: "The problem of evaluation of weapon efficiencies, or weapon economics for brevity, arises at all levels. One may ask : Is it an advantage to change from say Rifle A to Rifle B, and if so what will be the relative advantage gained? Is it worthwhile, and if so, to what extent, to replace TNT with RDX in shells?" Similar questions continued to be asked of Military OR specialists since the decision makers in Defence were mainly concerned initially with identifying suitable weapon systems for acquisition.

Initial studies were concerned largely with evaluation of guns and rockets on the basis of a ' measure of effectiveness (MOE)' and the total cost of the system to be inducted. Calculation of MOE required the development of mathematical or simulation models, e.g. the effectiveness of an artillery gun measured in terms of the coverage or the proportion of the area damaged of a specified target during the mission time. This activity led to a large number of studies on effectiveness, area coverage and damage assessment. The determination of system cost involves the procurement cost, maintenance cost, ammunition cost, personnel cost, training cost, etc. After determining the MOE and the total system cost (TSC), the cost effectiveness ratio of each proposed weapon system is evaluated by dividing TSC by MOE. The lowest value of TSC/MOE determines the most cost-effective weapon and is recommended for acquisition.

After the 1971 war, the paradigm of OR studies in weapon evaluation shifted to systems rather than specific weapons, e.g., anti-tank missiles, ground attack missiles, suitability of nuclear submarine for the Indian environment, maritime reconnaissance aircraft, comparison of heavy guns vs free flight rockets, deep penetration strike aircraft (DPSA) vs guided missiles, rockets vs anti-ship missiles, proportional damage to targets by conventional, prefragmented warheads, etc.

The cost-effectiveness analysis continued to dominate the selection and acquisition of weapons. More recent studies concern air defence guns, missiles, radars, etc. The modelling approach has been more sophisticated partly due to complications in weapon systems and partly due to enormous mathematical and computational methods available with the analysts. It may be emphasized that Military OR studies on weapon evaluation, which were earlier conducted by comparing a few important characteristics of the weapon, have been later evaluated with a larger number of variables in related combat scenarios using analytic models or simulation. As a result, the studies were more realistic and helped in enhancing the confidence of the Services in such studies.

3. EVALUATION OF TACTICAL PLANS

Is the existing deployment of a weapon most effective in achieving its intended mission? Can the effectiveness of an operation be improved through scientific analysis? Can tactical plans be evaluated without conducting a field exercise? These questions have been posed to military operational researchers since World War II and have been satisfactorily answered.

The classical example of depth charge in World War II is one of the earliest of this kind. The initial depth setting of 100 ft ($\simeq$ 30.5 m) of the depth charge did not produce the desired effect in killing enemy submarines and therefore Professor Blackett and his team were entrusted with the responsibility of designing a more powerful depth charge. While this was being done, a scientific analysis revealed that if the depth setting is made 25 ft instead of 100 ft, the number of submarines killed would increase to two and half times. This finding, when implemented, improved the number of submarines killed significantly. This study and many similar studies in World War II brought out clearly the role that scientific analysis can play in improving operational effectiveness.

After the 1965 war, the Defence forces became more concerned about their prevalent operational tactics. Thus they consulted OR scientists to analyse their plans/scaling norms on the basis of scientific analysis, e.g., minimum effective scale of anti-aircraft guns required in a given mission, effective scales of war wastage reserves, etc. Several important studies were undertaken in the seventies on deployment patterns of various weapons for defence of some vulnerable areas, search schemes for an area, etc. A number of tactical problems such as optimum spacing between ships in a search and attack unit, optimum aiming strategy for target coverage, optimum distance to lift artillery support during an infantry attack, optimum number of AD guns controlled by a radar, and optimum mix of AD guns and missiles have been analysed after 1980.

4. SYSTEM MODIFICATION AND IMPROVEMENT

The effectiveness of an organisation or system may change owing to changes in the operating environment and may call for new policies to be implemented in place of the existing ones. Generally these changes are done on an ad-hoc basis which need not be optimal. Also, many systems can be improved by using the capabilities of modern computer systems.

Such modification programmes involve a variety of tasks such as provisioning, stocking, maintenance of stores, costing of projects, manpower policy evaluation, monitoring performance of ordnance factories, and maintenance of war wastage reserves and spares. Military OR has also been used in comparing the cost of indigenous production vs license production vs import of weapon system and specifying the requirement of spares over the life cycle of weapon systems being acquired. Within the scope of logistics management, OR studies have also been undertaken to improve the movement/transportation of forces in narrow mountainous terrains, transshipment of supplies from base to forward units, positioning of communication radio sets in order to ensure a sufficient signal strength for communication in unfavourable terrain, and scales for authorisation of these equipment to Army units.

The task of the OR practitioners in this sphere of activity was not simple. Besides the modelling work, they were faced with an uphill task of acquiring data, knowledge about the procedures by actually visiting the forward areas and later generating the users' confidence in their solutions which, although scientifically valid, may not be acceptable to the traditionalists. It is only by gradual interaction and persuasion, the users' confidence was won to accept recommendations arising out of these studies.

Development of cheaper, inexpensive computer systems has added another dimension. Many problems which were earlier tackled in a routine manner by mechanical means have been improved by using the computer capabilities of PCs and work stations. Such studies include stores management, database management, mission planning studies, ship navigation studies, map digitization, etc., where the main emphasis is not on mathematical modelling but on the use of computers as an aid to systematize and improve the existing procedures.

5. DESIGN AND DEVELOPMENT OF WEAPON SYSTEMS

The design and development activity of the weapons in the MOD is initiated by the Services by defining the General Staff Qualitative Requirements (GSQRs) which specify the operational characteristics that the users (Services) desire to have in the proposed weapon system. The work in a large system is usually divided into subsystems and each of these may need the help of other R&D agencies, universities and other public and private organisations depending upon the capabilities/facilities available with them. Thus, hardware development invariably requires a great deal of coordinated effort calling for the use of project management techniques like PERT/CPM and appropriate technical reviews at different levels.

Besides project management, the following are some of the areas in which Military OR has been helpful:

(a) Removing disparities in GSQRs,
(b) Performance evaluation of systems, and
(c) Reliability evaluation.

5.1 Removing Disparities in GSQRs

As discussed above, GSQRs define the characteristics that the system/subsystem should have in order to meet the users' requirements. While a great deal of care is taken in defining these characteristics, some ambiguities may arise because the users' requirements are generally based upon the *best performance characteristics* available in similar systems elsewhere. In this process, it is possible that certain QRs (qualitative requirements) can be met, while others may be too difficult to achieve at the current state of technological development. As an example, consider the QRs of a tank gun specifying the first round hit probability under different operational conditions, e.g., a static tank firing on a static target (tank), static tank firing on a moving target and a moving tank firing on a moving target.

In order to assess the hit probability one needs to study the type of errors. These errors can be studied for each subsystem and their reasonable limits assessed. For example, for a static tank firing on the static target, the errors such as those of sensors for giving inputs to the ballistic computer of the gun control system, errors of the ballistic computer itself, gun laying errors and the ammunition errors are important in affecting the hit probability. The hit probability can then be evaluated analytically or through simulation by superimposing the errors appropriately.

The hit probabilities in the three cases mentioned above can thus be evaluated without carrying out field trials. If there is a mismatch in the estimated hit probabilities for static-static, static-moving and moving-moving cases against figures defined in GSQRs, the same can be identified and resolved in consultation with the users.

5.2 Performance Evaluation of Systems

A weapon system can be subjected to simulation to evaluate its performance much before it has been completely designed and developed. Such analysis helps in identifying alternative designs of the weapon system for its optimal performance. Consider a situation in which the project manager wishes to determine the survivability of the tank and study the trade-off between the weight and the survivability of the tank.

The probability of kill by an anti-tank weapon for a given hit depends upon its penetration capability, which in turn depends on the thickness of the plates, the angle of attack as well as the nature of the armour. Thus, for different plate thicknesses and their inclination, one can evaluate the kill probability and consequently the survivability of the tank, and also the weight of the tank, even before the tank prototypes have been fabricated. This approach can thus be helpful in deciding design issues without actually developing the prototypes, and will obviously save the time and cost of development. Computer helps in this process very effectively since one may use Computer-Aided Design (CAD) packages to depict the weapon/equipment on the computer terminal and study various design ideas even at the conceptual stage.

5.3 Reliability Evaluation

Weapon systems have to operate under varying environmental conditions and have, therefore, to meet stringent reliability requirements. Such requirements can be met by enforcing the reliability concept from the initial stages of equipment design. The apportionment of reliability to various subsystems, prediction of reliability from fault tree analysis for alternative designs and estimation of reliability of various subsystems based on laboratory/field trial data help in cutting down the cost of development as well as in ensuring the desired reliability of the system in actual operations. There has been a significant contribution by OR practitioners in reliability evaluation of missiles, communication systems, radars, torpedoes and several electronic systems.

6. 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 the following types of questions: If country A has acquired certain technological capability either indigenously or through procurement, what should country B do so as to have a cost-effective alternative to meet the enhanced capabilities of A? 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 tackled by Military OR analysts and several techniques like Quantified Judgement Method of Analysis[2,3] and WEI/WUV method using Analytic Hierarchy Process[4], have been used to answer specific queries by the top management of the MOD/DRDO/Service Headquarters. This area has been progressively developed in India and the users' confidence is well reflected by an increasing number of studies which are now being tackled by Military OR analysts.

7. 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 defence. For this purpose, military field exercises are conducted regularly. The large military field exercises (such as 'Brasstacks' conducted by India in 1987 in the Rajasthan sector or 'Zarb-e-Momin' conducted by Pakistan in December 1989 in the Indus-Jhelum-Chenab corridor) 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.

Some important alternatives for military training are map exercises, telephone battles, sand model exercises and computer war games. Comparatively, these are easier to conduct and have a relatively higher degree of abstraction than military field exercises.

In India, a study team under the former Chief of the Army Staff, General K Sundarji (then Lt General and Commandant, College of Combat, Mhow) took up the task of creating a computer-assisted war game for a Brigade level at the College of Combat, Mhow, 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 computerised 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 (see Jaiswal and Jethi[5]). 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 game play 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

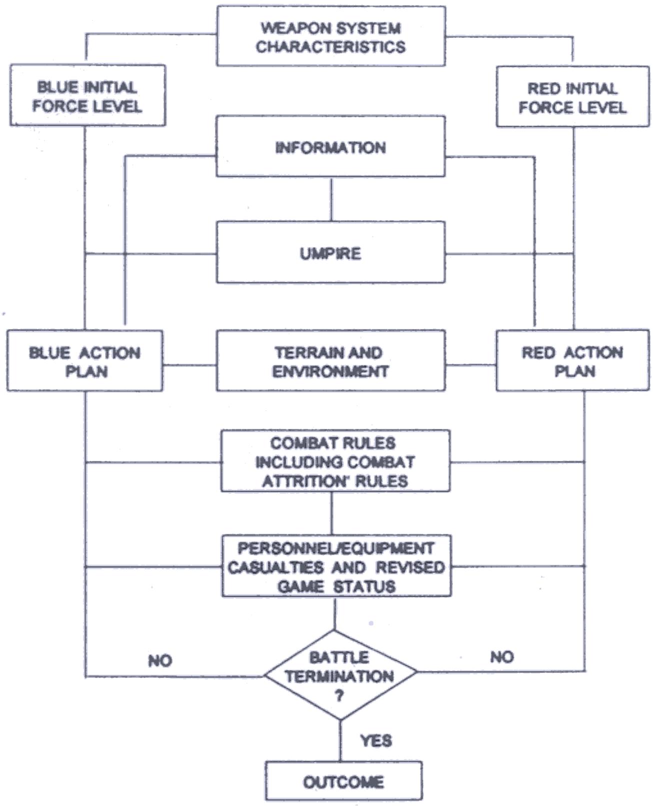

Figure 1. Structure chart of a regiment level computerised war game.

rules and provides casualties of personnel and equipment. A 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 till the termination conditions are satisfied.

The three rooms (Blue, Red and Umpire) are equipped with workstations/PC-ATs which are connected through a Local Area Network (LAN). A database of weapon characteristics is created which contains details such as detection, hit and kill probabilities as functions of range and environmental factors. Using digital cartography the realistic features of a map including terrain can be brought into the game play. Extensive combat rules are incorporated to simulate actual battle drills followed by the two sides. The combat rules also include attrition rules for which combat/attrition models are developed to assess casualties in specific encounters, replacing the gut judgement of the Umpire in sand models/map exercises. The early models on attrition were largely based on Lanchester equations which have some limitations. These limitations have been eliminated by including spatial effects, reserve planning and battle termination rules[6,7]. Though these combat studies have remained largely theoretical, practical applications of the theory are being attempted for development of large-scale war games.

The philosophy of developing air and naval war games is similar to what has been explained above for the land war games. These computer war games are being usefully played in training establishments of the Services.

8. 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, the term 'quantitative' is significant and brings out the real focus of an OR analysis. 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.

8.1 MIS, DSS and Expert Systems

The concept of Management Information System (MIS) was an important development in providing executives with information in desired formats. However, MIS did not provide any decision-making capability and an interface of MIS with OR models through a dialogue module, called Decision Support System (DSS) was developed in early 1970s. A decision support system is an interactive system that provides the user with access to decision models and data in order to support semi-structured tasks[8]. Another significant interface arose in terms of Expert Systems which are defined as follows: A computer program that exhibits, within a specific domain, a degree of expertise in problem solving that is comparable to that of a human expert. Both DSSs and Expert Systems have enriched the interface of OR and computer science significantly.

8.2 Role of Personal Computers in OR

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:

(a) *Machine Independent Transportability* : Software developed on mainframe computers were dependent on the specific machine. The development of software on PCs and its transportability through floppies has provided the OR analyst with the facility to demonstrate the results on a PC in the room of the executive, thus enhancing communication between the analyst and the decision maker significantly.

(b) *Interactive Computing* : Another capability on PCs is the ease with which the data and even assumptions can be interactively modified. This helps the decision maker to validate the model from his experience, and improves mutual understanding with the analyst.

(c) *Graphics Capability* : The availability of graphics on PCs helps the analyst in explaining and convincing the decision maker about the results of his study. A graphical presentation is obviously more acceptable to the manager for appreciating the results of a study.

8.3 Computationally Efficient Algorithms

One more important advantage of computers came up when the size of an OR problem became sufficiently large. The requirement in such cases is to develop computationally efficient algorithms which take lesser time so that the managers can get answers to their complex decision-making problems in a reasonable time.

A large number of decision-making problems are optimisation problems in which the analyst has to maximise or minimise an objective function. Owing to the complex interdependencies between its variables, an optimisation problem may not be amenable to classical OR techniques like Linear Programming or Dynamic Programming, or may require enormous computer time to arrive at the results. For solving such problems, heuristic optimisation techniques grew predominantly in the eighties. These are random search procedures in the feasible solution space. They have the advantage of tackling problems more easily and at reduced computation time. However, the results obtained from heuristic techniques are approximate or near-optimal. Very large scale problems, e.g., Weapon Targeting Problem[9], involving a number of weapons, targets and sites have been solved using Simulated Annealing technique. Other heuristic optimisation techniques include tabu search[10], neural networks[11], target analysis[11] and genetic algorithms[12]. These need to be used/developed further for applications in Indian defence.

9. FUTURE OF MILITARY OR

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[13] 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[14], military stability in a multi-polar world[15], effect of command, control and communication on combat dynamics[16], etc. (For additional applications of OR to Gulf War, see Schuppe[17] and Roehrkasse & George[18]).

It seems that considerable potential exists for using Military OR in our own context than what has been done so far. Presumably, greater understanding between the Military OR analysts and the users and an environment for mutual interaction has to be created in order to boost the profession of Military OR.

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 defence executives with rational cost-effective solutions and to present their analysis in a format which defence executives can appreciate.

Earning users' confidence is still an important task for the OR profession. There is still resistance to accepting the results of scientific analysis. OR practitioners should therefore concentrate on behavioural aspects also in order to evolve a steady support from the initial stages of a study when they interact with the users for problem definition, data collection and analysis, and finally for implementation of the study. Perhaps, a stiff attitude on pure optimisation may not be helpful and one may have to look for 'satisficing' solutions rather than 'optimising' solutions.

The best tribute that one can pay to Professor Kothari's dream of using OR in defence decision making is to create an environment conducive to OR development that will not only make India militarily strong but also save enough money and resources without jeopardising national security.

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