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DEPARTMENT OF NATIONAL DEFENCE
CANADA

OPERATIONAL RESEARCH DIVISION

ORD INFORMAL PAPER NO 67/P10

EIGHTEEN YEARS OF MILITARY OPERATIONAL RESEARCH IN CANADA

BY

G.R. LINDSEY

OTTAWA

DECEMBER 1967

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FOREWORD

This document provides a brief historical review of post-war military operational research in Canada. The descriptions of individual activities as given in this text are not classified, so that excerpts or selections may be used for such purposes as describing operational research to uncleared audiences or to prospective recruits.

The complete document reveals enough of the overall direction of today's research program that it must be protected to the extent of the RESTRICTED security classification - i.e. it must not be published, or communicated to anyone except for official purposes.

A more complete account at the security level of CONFIDENTIAL, has been prepared as ORD Informal Paper No. 67/P9 with the title "Military Operational Research in Canada, 1949-1967.

This paper represents a compendiumof the work of many groups, and the material has been collected from many sources. Much of the text has been supplied by those who performed the studies themselves, so that the undersigned is more editor than author. The material in the Appendix was supplied by Dr. N.W. Morton.

It would be a difficult matter to give due and complete credit by name to the officers (both military and scientific) who carried out the studies, and instead the account has been left completely anonymous.

A perusal of the paper will show the very large number of important military activities to which operational research has made a contribution.

G R Lindsey

G. R. Lindsey
Director General of Operational
Research

EIGHTEEN YEARS OF MILITARY OPERATIONAL RESEARCH IN CANADA

1. INTRODUCTION

In the eighteen years since its post-war reincarnation in the Department of National Defence, operational research has become involved in a very large number of the activities of the Canadian Armed Forces.

There is always trouble over the definition of what constitutes operational research. In its broadest sense, practitioners of the military profession have been employing it for centuries. For the purposes of this paper it will be taken to include the activities sometimes defined as systems analysis, but to exclude management engineering (with organization analysis, work study, etc.) and technical research on human resources.

To a greater extent than most other defence scientific activities, operational research has been practiced by comparatively small groups in many units. There has been a large participation by serving officers (amounting to approximately one-quarter of the manpower involved). The control of the research programs and the use of their results has been exercised by military commanders at various levels.

Over the eighteen years there have been numerous changes in the organization of the operational research units. In the earliest days they included research on human resources, with emphasis on personnel selection and military psychology. But in 1952 this work was transferred to other parts of the Defence Research Board (DRB).

In the maritime area a large fraction of the effort (nearly one-half) has been based in the operational units (Atlantic Command, Maritime Air Command, and their successors, including small sections at the Maritime Warfare School, Operational Evaluation Unit, and with Pacific Command).

Operational research on air activities other than maritime was also conducted by placing a substantial fraction of the personnel (about one-third) in operational commands (Air Defence Command, Tactical Air Group, NORAD HQ, NORAD Northern Region, 1 Air Division, Air Transport Command). In the mid-1950's, when joint plans were being prepared for the air defence of North America, an O.R. team was based in Washington.

With the exception of two small field O.R. teams (in Korea and, for a short time, in Germany and a recently formed ORS at Mobile Command) army operational research has been based in Headquarters. The Canadian Army Operational Research Establishment (CAORE) began in Kingston, but was organizationally part of Army HQ. Prior to integration CAORE was the largest O.R. unit in Canada.

Canadian O.R. scientists have filled exchange postings with corresponding British organizations, and have served with various NATO formations (AAFCENT, SHAPE, SHAPE Technical Centre, SACLANT ASW Research Centre).

The chief role of the Defence Research Board has been to supply the professional civilian scientists who constitute the core of the operational research effort. Although there are transfers of personnel with DRB HQ and laboratories, the majority of the scientists engaged in operational research are transferred from one O.R. team to another, and build up over the years the expertise and continuity which comes with long experience in the various aspects of one profession.

One of the contributions of operational research to the Armed Forces has been intimate cooperation in the conduct of their daily business. Most of the staff work and decisions in a military HQ demand the efforts of a considerable number of people, and the results are to a large degree anonymous. In many cases the contribution of a scientific point of view can be of great value, but it is not possible to isolate this contribution from all of the others.

In organizational trees the O.R. unit normally appears as part of the military staff, often reporting to the senior officer responsible for operations. Before the three Service HQ were integrated into Canadian Forces HQ (CFHQ) in 1964, there were five O.R. Sections (ORS) in Ottawa; CAORE, Directorate of O.R. (Navy), and ORS under the Chief of Air Operations, Directorate of Systems Evaluation under the Chief of Operational Requirements in Air Force HQ (AFHQ) and the Systems Analysis Group which worked for the Joint Staff and for DRB. After integration the Operational Research Division was created, reporting to the Vice Chief of the Defence Staff. It inherited the scientific and military officers and some of the support staff of the five sections. For purposes of personnel administration the civilian component (both scientific and support) is also organized into the Defence Operational Research Establishment (DORE) which is one of the main units of the Defence Research Board. DORE also supplies the civilian scientists to the field ORS's. The Director General of the Operational Research Division in CFHQ is also Director General of DORE in DRB.

2. OPERATIONAL RESEARCH IN THE FIELD OF MARITIME WARFARE

Operational research has played a key role in the design and analysis of operational trials and exercises involving the performance of anti-submarine detection and attack systems. The tactics used by ships and aircraft are continually evolving in order to exploit the improved performance of their equipment, or to offset the improved performance and tactics of the submarines.

Canadian maritime forces have shown great initiative in development of equipment and tactics in the AS role, outstanding examples being the variable depth sonar, the use of explosive echo ranging with air-dropped

passive sonobuoys, and the employment of helicopters and of sonobuoys by ships. In these cases, and many others (especially in connection with the Argus aircraft) the operational research sections have been instrumental in the combination of the technical, operational, and statistical knowledge which is necessary in order to devise and improve appropriate tactical procedures. To supplement mathematical studies and the analysis of actual trials, research on tactics has employed the synthetic trainer in the Maritime Warfare School.

In addition to the improvement of tactics, operational research employs the analysis of maritime trials and exercises to assess the performance of various units, the significance of weather conditions, and a host of other factors which must be measured at sea and understood if the art of anti-submarine warfare is to progress.

In the early 1960's a plan was studied for the measurement of overall fleet effectiveness. Although never implemented in toto, parts are now used for the assessment of ship and squadron effectiveness.

A statistical summary was made of the effects of weather on maritime operations in the North Atlantic. This has been widely used in the planning of exercises and operations.

Prior to the selection of the American SQS-5 as the basis for the Canadian SQS-503 an operational analysis was made of the relative merits of the medium-range hull-mounted sonar sets available at the time.

Studies were made and procedures improved in connection with the selection and training of sonar operators.

Studies on the performance required of hydrofoil craft in the anti-submarine role have been made in several of the O.R. sections, as well as by the systems group at the Canadian Armament Research & Development Establishment (CARDE).

In addition to anti-submarine warfare, operational research has been directed to air defence of the fleet. AA guns have been evaluated from firing trials, and assessments have been made of the effectiveness of various surface-to-air missiles and of fighter aircraft operating from a carrier.

Other naval studies have included mine warfare, under way replenishment, and the capability for sealift of troops.

The type of aircraft best suited for Canada's continuing role in shore-based anti-submarine patrolling has been the subject of a long series of O.R. studies.

Considerable O.R. work has been done on the evaluation of airborne anti-submarine radar, using both controlled experiments and operational exercises. This and other work has led to useful conclusions regarding the best tactics for use of radar and of passive radar intercept receivers for detecting submarines.

The success of low frequency free-floating air-dropped sonobuoys for ASW has led to suggestions for fields of moored buoys. The concept has been investigated by computer simulation and sea trials.

One of the major operational research contributions to maritime effectiveness has been made in the field of command and control. It is axiomatic in all maritime actions that there will never be enough ships and aircraft to thoroughly cover the huge areas of ocean involved in the search, and hence it is necessary for the Commander to try to concentrate forces where the intruders are. Conversely, if ships and aircraft can be moved from where there are no targets to regions where targets are, the effect is the same as increasing the size of the effective force at no cost.

3. O.R. IN THE CANADIAN ARMY

Operational research has been applied to the assessment of the effectiveness of army weapons ever since the trials in 1949 to test the lethality of three-inch mortar bombs bursting in various types and depths of snow. Some of the other weapons tested or evaluated include artillery weapons (together with a study of the optimum size of fire unit), VT-fuzed projectiles, flame throwers, CW weapons, heavy machine guns, infantry small arms and tank, anti-tank and anti-aircraft weapons (both ballistic and guided). An investigation of the divisional weapons systems carried out with the US and UK compared direct and indirect fire weapons for their effects on personnel and armoured units.

An extensive study was made of the body dimensions of the Canadian soldier, and the results used in the design and positioning of the butt and sight of the C1 rifle.

In addition to the data on anti-tank warfare obtained from war gaming, considerable analytical work has been done on anti-tank operations.

A parametric computer model has been developed, which permits the rapid evaluation of the effectiveness of future anti-tank weapons as soon as the quantitative estimates of their capabilities are available. The result of these studies, which cover several cost-effectiveness analyses of several different weapons for various types of terrain, have had a direct effect on the choice of anti-tank weapons for the Canadian land forces. For example, there was the decision to provide a family of such weapons, and, recently, to procure the KARL GUSTAV medium anti-tank weapon. A study of the requirement for anti-tank ammunition resulted in an alteration in the stocks held.

Other cost-effectiveness studies have been done on comparison of anti-aircraft guns with one another, with surface-to-air missile systems, and with the REDEYE weapon with and without an infra-red acquisition device. One such study contributed to the decision to obtain ET-316 RAPIER.

Throughout the period of this review a vital and very important contribution has been made by O.R. in assisting the Armed Forces and DRB, but particularly the land forces, in the design, conduct, and analysis of field trials and experiments. The work has been directed towards efficient experimental designs and the deriving of valid conclusions. It can be said that this contribution has been one of the major ones, which has had a cumulative effect in improving the quality and standard of field trials and experiments throughout the Department of National Defence. One of the main subjects requiring continuing field trials has been the design of combat clothing and equipment.

In the period up to 1955, when one of the main defence roles was the maintenance of a mobile striking force, operational research was done on many aspects of operations in the Arctic regions. Subjects studied included methods of detecting enemy lodgements, ground navigation, transport and logistics. O.R. personnel jumped with the paratroops and participated in the exercises. One result was the introduction of in-flight feeding in order to reduce fatigue. Comprehensive investigations were conducted on the effects of different air weapons on military defences constructed in winter from locally available materials. A study was made on the savings that could be effected by standardization of vehicles and engineering equipment on the Northwest Highway System. A detailed analysis was undertaken of certain Arctic battles in Finland during the winter of 1939-40.

During the Korean War a small O.R. team was attached to HQ 25 CIB, and worked on problems concerning the effectiveness of artillery fire and infantry weapons, the collection and analysis of medical statistics, and the calculation of wastage rates and reinforcement flow.

Assessment of the implications of tactical nuclear weapons on the conduct of land warfare is a large subject, in which calculation and analysis must take the place of actual experience. Operational research has been applied to this problem since 1950. An early study demonstrated that a nuclear battle will be highly mobile, and fought over wide frontages and considerable depths. An increased requirement for armoured personnel carriers was identified.

A study of the reliability of Centurion tanks concluded that it has been quite high, and there is no apparent decrease in reliability with the number of times that a tank is rebuilt.

In recent years the largest single activity in land operational research has been in tactical war gaming. War gaming has been used mainly as a research tool for generating data about various aspects of land operations. The settings have covered both conventional and nuclear war, at various levels between corps and battalion. Theatres have varied from Northwest Europe to undeveloped areas of Africa or South America. Roles have included the NATO central front, the ACE Mobile Force, peace restoring, peacekeeping, and internal security. The results of these games have contributed to changes in army tactics, organization, and equipment, such as the procurement of the Honest John SSM, increases in the number of 106mm recoilless rifles and tanks in 4 CIBG, and the introduction of tanks into the infantry battalion as anti-tank weapons. The vital importance of

collection and dissemination of battlefield intelligence has been emphasized, with a consequent impetus to the Periscopter and Reconnaissance Drone projects. Lessons concerning logistic supply have been learned from the war games.

As an extension of the work on war gaming, a new technique has been developed to apply war game rules to forecast the probable results and (simulated) casualties in real field exercises, as they proceed day by day. It has proved to be possible to modify the exercises in order to ensure that situations develop which will provide maximum training. A manual describing the methodology and its application has been prepared for use in the field.

In addition to the use of the war game for research, and for control of field exercises, it has been found to have considerable value for training. A "Training War Game Handbook" has been produced, which details the organization, functions, and administration required to establish a training game, and provides the rules and procedures for play. Such a game exercises commanders and staffs in making plans and decisions when opposed by an uncontrolled malevolent enemy intent on frustrating their actions. Training games have been conducted at the Canadian Army Staff College with very favourable results, and it is considered that they possess a good potential for training of commanders and staffs in field force formations.

Considerable time and effort have been devoted to the development of land combat models and simulations to provide computer programs for the rapid calculation of data on various aspects of land combat such as the probability of success of attacks, the results of manoeuvre and exchanges of direct fire, rapid evaluation of changes in organization, equipment, and tactical characteristics of different formations, and the recording and rating of calculations for land-played games.

Over the last several years considerable effort has been devoted to studies on land force combat intelligence. These have included investigations of operations at night, and the effectiveness of various night vision and aiming aids. Large scale field trials have been conducted. Objectives of this work include the determination of which devices should be provided and on what scales of issue.

Two other important studies on combat intelligence involve the development of a computer simulation of a combat intelligence system at the brigade level, and an analysis of the cost-effectiveness of introducing automatic data processing into a brigade group in the field at different levels.

Related work includes analysis of terrain and intervisibility and investigations of photographic interpretation. In addition estimates have been calculated of the coverage of ground-based radars for the surveillance of vehicles moving on roads.

Operational research scientists have made a contribution to studies of the employment of helicopters for land force use.

4. O.R. IN RCAF ACTIVITIES

Maritime air was covered in section 2, and the early work on tactical air support of the Mobile Strike Force in section 3.

In the field of air defence, operational research has produced a considerable number of concepts and procedures that were accepted by the Canadian Forces.

Since the construction of the Canadian component of the North American Air Defence System (circa 1952), the Aircraft Control and Warning System has been the subject of intensive operational research. The performance of the radars has been studied from many aspects (coverage vs. various targets, calibration accuracy, heightfinding accuracy) and certain procedures such as selection of beam tilt angle were improved. A slide-rule type of computer was designed to predict the range at which various aircraft would be detected for different screening and tilt angles. It was discovered that the sun could be detected when it was low on the horizon, and the signal used to orient and calibrate the radar. The Defence Research Medical Laboratories (DRML) devised a procedure for the best adjustment of displays and of room lighting.

The passage of information through the air defence system was intensively studied during the period when manual plotting and voice transmission was used. Procedures were altered frequently as circumstances and installations changed. The DRML cooperated in these studies.

Before the SAGE system was adopted there was a great deal of preliminary study in Canada as well as the US. Canadian operational research analyses favoured a smaller and less ambitious system, matched to the air traffic and weapons density expected over this country. However the ultimate decision was to install SAGE throughout NORAD.

The process of identification of unknown aircraft occupied much attention. A system of "critical numbers" was devised in order to alert the commanders when the distribution of unidentified tracks reached an unusual pattern.

The importance of early warning was investigated by a joint US-Canadian study, which influenced the positioning of the DEW and Mid-Canada warning lines.

A great deal of operational research was devoted to the Mid-Canada Line, starting with the demonstration and selection of the Bistatic Doppler System and its early trials on test links in the Ottawa Valley. When installed, extensive flying trials were conducted to assess its coverage against very high and very low flying aircraft. Difficulties with false alarms necessitated extended study, as did the determination of the proper sensitivity settings. By systematic study of the pen signatures, and proper

training, it became possible to distinguish small fast aircraft from large slow ones, and to reject the signals caused by geese, lightning, and man-made interference.

Employment of the radar and MCL information for the best tactical use of interceptors was under constant review, by trials and exercises and by theoretical analysis. At one period the density of interceptors was so high that very careful tactics had to be used in order to avoid saturation of the control capacity. It was necessary to devise procedures agreed with the neighbouring air defence sectors in the US. It proved possible to use MCL reports to expedite the reaction, and as a result of operational research it was decided to redeploy some of the control and interceptor strength to stations where they could best be exploited.

In these analyses the combination of the various detectors and weapons was treated as one overall system, irrespective of nationality, and its effectiveness for air defence maximized. For considerable periods exercises were designed for research and improvement of tactics rather than for training alone, and the results subjected to close analysis by scope photography.

A number of the concepts and procedures for tactical employment of interceptors, counter-ECM activities and the evaluation of radar performance were adopted by the USAF.

Systems studies were made of weapons which were adopted (e.g. CF-100 with its various armament and fire control modifications, and Bomarc) and many which were not (e.g. Velvet Glove, Arrow with its fire-control and other avionics, Talos, Nike Ajax, Nike Hercules).

Another type of operational research study which originated in Air Defence Command and was later used in other flying commands concerned the relationship in a flying station between the amount of flying, the number of maintenance personnel, and the maintenance schedule. Using the theory, and after data have been accumulated on the incidence of unserviceability of a given type of aircraft, it is now possible to predict the number of aircraft that a squadron must possess to meet a given flying commitment, or the additional maintenance personnel required to meet a commitment when the aircraft strength is fixed. Such studies are under way for the CF5.

In 1 Air Division operational research has been applied to squadron training in the air-to-air firing of both guns and rockets. For example, after establishing the learning curve of firing performance with time on the firing range it became possible to make an informed judgement regarding the necessary length of the course of firing exercises. Considerable work was also done on the analysis of procedures for scoring pilot performance as related to rocket hit probability.

Photographic procedures were introduced to the Type 80 control radar, for checking routine performance and to assist in exercise evaluation.

Statistical analysis was able to isolate certain causes of accident rates.

When the Air Division converted to the strike-reconnaissance role, the ORS studied problems such as bombing accuracy and its measurement, vulnerability of bases to attack by air or IRBM and methods of reducing it, vulnerability of strike/recce aircraft to ground fire, and the choice of strike routes to minimize losses.

In Air Transport Command many practical problems arise in the scheduling and loading of aircraft which are amenable to operational research. Analysis of UN airlifts and exercises involves evaluation of command and control, transfer techniques, incidence of unscheduled maintenance, and many other facets of transport operations.

Interesting mathematical problems continue to arise out of these studies. Examples are transient queueing of messages in the communication system, combinatorial probability applied to refuelling under varying conditions of weather, temperature, and load, and the use of integer programming in the transportation problems (since a fraction of an aircraft cannot fly).

Data from actual experience have been used to develop a mathematical stochastic simulation model of long range airlift. This model promises to be useful for the planning of airlifts in Mobile Command and at CFHQ as well as at Air Transport Command. Naturally the planning of ACE Mobile Force, United Nations, and other overseas operations requires detailed and accurate knowledge of the capabilities of Air Transport Command.

Since the issue of the 1964 Defence White Paper, an O.R. team has been studying tactical air operations. When the CF-5 was selected, research was directed towards the evaluation of alternative avionics and weapons systems for this aircraft, and towards the desirable characteristics of a future tactical aircraft to follow the CF-5. Attention is being directed towards the possibilities of a multi-purpose aircraft capable of close support, interdiction, reconnaissance, and air-to-air combat. An important element in these studies is the assessment of the vulnerability of the aircraft to ground fire, and its dependence on the tactics employed.

Command and control of tactical air operations is also being studied.

5. OTHER OPERATIONAL RESEARCH STUDIES

Survival Studies

Responsibility for civil defence has changed several times, and does not now rest with the Armed Forces. No very large expenditure has been made. Nevertheless a considerable amount of work has been done. Calculations have been made of the effects of nuclear weapons burst over Canadian cities, with estimates of the casualties and damage caused by blast, fire and radiation. Forecasts of the distribution of fallout over the entire country have been calculated for various types of attack on Canadian and/or US targets.

Assessments were made of the requirements for dissemination of warning, radiac instruments, blast and fallout shelters, and of the organization, training and equipment needed for reentry operations. Various features of the likely post-attack situation were analyzed.

Assistance has been given in preparing lists of possible targets in Canada, and of different attack patterns. A methodology was developed for estimating fire spread.

Ballistic Missile Defence

Canada has not participated in either the offensive or defensive side of the ballistic missile confrontation. However, it is important that some group in the Department of National Defence preserve an acquaintance with this field, which is of course central to the military strategy of the Super-Powers.

The fact that the US have announced their intention to install a light ABM system has made it all the more necessary for Canada to maintain up-to-date knowledge of this subject. Current studies are addressed to the hazards to Canadian population produced by ABM engagements over our territory.

Canadian operational research studies have examined the progress of active ABM defence through the years. They were able to predict that the early Nike Zeus system would not be successful because of the problem of discriminating decoys. As each technical change occurred, the significance of Canadian territory for the defence of the US was reconsidered.

A variety of studies have been carried out on ballistic missile trajectories, particularly in relation to accuracy and direction of attack.

Some operational research was involved in a study of the possibility of detecting ICBMs by reflected sunlight, using airborne detectors. Experimental work at CARDE was related to this investigation.

Some computational work done on BMEWS proved useful to the Americans in deducing the coverage and the ability to predict the impact points.

An analysis of the vulnerability of ICBMs and MRBMs led to an assessment of the value of road or rail-mobile deployment in Canada and in NATO Europe.

Military Use of Space

Shortly after the achievement of the launching of earth satellites, much concern was raised over their possible military potential. From the outset it was fairly clear that this type of operation, and more particularly of men in space, would be so expensive that only the major world powers could become seriously involved. But it was necessary to evaluate the possible threats to North America, and to identify what part the Canadian Armed Forces might have to play in defence against such threats.

Many aspects of potential space operations were analyzed with the help of computer simulation. These included simulation of a satellite-borne boost-phase ICBM detection system, a series of simulations of different phases involved in making a friendly satellite rendezvous with an enemy satellite, simulation of a system designed to intercept and kill enemy satellites, and analyses using intelligence input data to identify present Soviet enemy space activities and forecast future intentions.

Generally speaking, it was shown that a direct threat from space was unlikely, since it would be more costly and less effective than the employment of ballistic missiles.

The most attractive employment of satellites for military purposes was seen to be in the field of reconnaissance and communications. Without the use of classified information it was possible to show that the potential in both applications is very significant.

Throughout these investigations the significance of Canadian geography was under constant study. While it was obvious that Canada could not become unilaterally involved in a space program, there was the possibility that some activity could be attempted in partnership with the US. In the final event, the Canadian Armed Forces did not become involved. The Canadian studies were made available to various US agencies, who may well have made use of them in their own programs.

Arms Control

Contributions have been made to the methodology of analyzing measures of arms control. It has been demonstrated theoretically that a situation of stable deterrence cannot be transformed into one of disarmament without passing through a stage of very precarious stability.

Studies have also been made pertaining to the control of a nuclear test ban.

Logistic Studies

Integration and unification of the Armed Forces has made possible the creation of a single integrated supply system. Inventory management will be performed on a national level, using a computer-based automated information system. The program to plan and design the system (known as the "DEVIL" program) has raised a number of complicated problems of a mathematical and statistical nature which are amenable to the methods of operational research.

Studies have been made of inventory control policy, based on past data from the separate service supply systems but designed for the ultimate integrated operation. Using such techniques as marginal analysis it will be possible to program the initial computers to base reorder instructions on the patterns of demand, and to know with a fair degree of certainty what will be the probable frequency of stockouts.

Repair and overhaul offers another field for operational research. Considerable economies are expected in the original order of spare parts when large new systems are purchased.

The mounting and support of operations overseas is entirely dependent on logistics. Supply of both air and sea lift are being subjected to extensive operational research studies.

Operational Research in Personnel Problems

In addition to the work of the psychologists, which has been taken to be outside the area of operational research for the purposes of this paper, there have been a few studies of a mathematical or statistical nature.

When it was important to be able to assemble a given number of aircraft controllers on short notice in the event of a surprise air defence alert, it was the practice to maintain a roster of qualified officers who were not allowed to leave their quarters. This caused considerable personal inconveniences. A study of the habits of officers not on roster revealed that it was only on infrequent and predictable occasions (such as major holiday weekends) that the required quota could not be assembled in the time allowed. In most normal circumstances the roster was not needed in order to have a high assurance of being able to fill the controller positions.

The transfer of military tradesmen among the radar station of Air Defence Command used to consume a great deal of time of the personnel staffs, searching files in order to list and match a number of routine requirements. The process never ended, since the rules required tradesmen to be moved before their stay in one station exceeded a certain maximum. It proved possible to perform this process by computer, which would offer the solution which obeyed all the rules and also minimized the total travel cost. The staff could then study the computer solution and veto it if there was some objection not contained in the rules. In this event the computer would substitute the valid solution with the next lowest travel cost.

The career progress of military officers can be studied on an actuarial basis, and a mathematical model constructed to predict the progress through rank with age. Promotion policy can thus be related to future rank structure.

Application of Developing Operational Research Techniques to Management Problems

Although the work normally described as "management engineering" has been excluded from this paper, there are some other types of problems in the general area of management to which the newest techniques of operational research have been applied.

When the "PERT" technique for analyzing the various interlocking steps in a complicated process was very new, one of the operational research

scientists prepared an instructional manual subsequently published for use throughout the Canadian government service.

Many of the O.R. studies concerning the choice of alternative systems employ cost-effectiveness analysis, and improvements to the techniques are sought continually.

Many problems in planning reduce to assignment of priorities for the allocation of scarce resources. Research is being done on systematic methods for relating program priorities to the overall objectives.

Miscellaneous Mathematical and Statistical Techniques

Mathematics and statistics form the normal tools of most operational research. However, improvements in the methods are being made throughout the profession, and many of the practitioners rely on the advice of specialists when confronted with unusual problems. The same may be said of the use of electronic computers.

A small O.R. group specializes in these techniques, applying and improving them as required, and acting as consultants, advisors, and instructors to their colleagues and to other members of the Department of National Defence when requested.

Among the mathematical techniques applied to practical problems are linear programming, integer programming, dynamic programming, and queueing theory.

APPENDIX

STATISTICS CONCERNING THE CIVILIAN SCIENTIFIC PERSONNEL IN DEFENCE OPERATIONAL RESEARCH

The number of Defence Scientific Service Officers employed by the Defence Research Board and attached to the various operational research organizations has totalled about 155. The total strength of DSSOs at any one moment rose fairly steadily from 1949 to 1960, and then levelled off at about 60.

At the time of writing (November 1967) there are 59 on strength. About 30% of these have been on strength for ten years or more, about two-thirds for five years or more.

Of the 97 once but no longer employed in operational research, fewer than 30% stayed as long as five years; half left before three years.

The median age of the DSSOs on strength today is 42. 36 have been trained in physical sciences or mathematics, 14 in engineering, and 8 in other disciplines. 40% have a master's degree, 12% a doctor's.

About 20% of the present group had experience in operational research before joining.

18 of 59 have served at least one tour of duty outside of Canada while on strength.

One generalization which has been noted many times, and is confirmed by these statistics, is that a "typical" recruit comes into operational research without prior experience, and that it takes about three years to discover whether he is suited to it (and it is suited to him). About half of those who try it leave fairly soon, most of the other half remain to make a career of it.