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# AN INTRODUCTION TO MILITARY OPERATIONAL RESEARCH IN CANADA

by

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# ABSTRACT

This monograph on military operational research in Canada consists of five chapters dealing with an introduction to operational research, operational research methodology, military operational research, examples of military operational research projects, and professional considerations, respectively. It is intended to provide practical information on operational research to serve as guidelines to young scientists embarking on military operational research work. It should also be interesting and informative for the more experienced operational research scientist. While details and examples of operational research methodology are not presented at length the many references enable the reader to supplement this introduction by consulting them. Special features of military operational research are cited and relations to military sponsors are discussed. Several examples of military operational research and general analysis projects done in the Operational Research and Analysis Establishment are described and suggestions are given for presenting the findings of such studies. The monograph also offers comments on the characteristics and attributes required for a successful career in operational research, on training and careers in military operational research and analysis in Canada, and portrays relations with defence research establishments and agencies in Canada and elsewhere. Information about the Canadian Operational Research Society and some suggestions for further reading are also included. A number of annexes deal with specific matters of methodology and an extensive list of references and a bibliography are provided.

## RÉSUMÉ

La présente monographie sur la recherche opérationnelle militaire comporte cinq chapitres, soit une introduction sur la recherche opérationnelle, un volet sur la méthodologie en recherche opérationnelle et un autre sur la recherche opérationnelle militaire, des exemples de projets de recherche opérationnelle militaire, ainsi que des considérations d'ordre professionnel. Le document vise à fournir des renseignements pratiques sur la recherche opérationnelle afin d'aider les jeunes scientifiques qui se lancent dans le domaine de la recherche opérationnelle militaire. Les scientifiques plus aguerris pourront également y trouver une foule de renseignements utiles. Même si l'auteur n'aborde pas en détail le volet sur la méthodologie, les lecteurs pourront, grâce aux nombreuses références données, en apprendre davantage sur ce sujet. Certains aspects de la recherche opérationnelle militaire y sont abordés et on y explique les rapports qui existent entre les chercheurs et les organismes militaires qui parrainent les projets. L'auteur décrit plusieurs exemples de projets de recherche opérationnelle militaire et d'analyse en général entrepris au Centre d'analyse et de recherche opérationnelle (CAR Op) et suggère certaines méthodes de présentation des résultats. La monographie traite aussi des caractéristiques et des qualités que doivent posséder les personnes intéressées de faire carrière dans les domaines de la recherche opérationnelle et de l'analyse et explique les rapports qui sont entretenus avec des établissements et des organismes de recherche en défense au Canada et à l'étranger. En outre, le lecteur peut trouver dans ce document des renseignements sur la Société canadienne de recherche opérationnelle et des suggestions d'autres ouvrages connexes. Les annexes au document traitent de différents aspects liés à la méthodologie et comprennent une imposante liste d'ouvrages de référence et bibliographie.

## ACKNOWLEDGEMENTS

The authors gratefully acknowledge the assistance given by members of the staff of the Operational Research and Analysis Establishment of the Department of National Defence in preparing this report, in discussions, and by constructive comments and suggestions. Material in some of the many references, and in particular in several of the textbooks cited, has been very useful in putting the report together and the authors acknowledge the contributions from this material with thanks and appreciation.

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# INTRODUCTION TO MILITARY OPERATIONAL RESEARCH IN CANADA

## CHAPTER I - INTRODUCTION

### INTRODUCTION

1. Operational research is a relatively new branch of applied science which provides a scientific approach to the study of operations. Its basic purpose is to make available to operators, managers, and decision makers a quantitative basis for directing, controlling, and improving operations.

2. As a recognized scientific activity operational research (OR) was introduced in Great Britain in World War II (WWII) to undertake the study and quantitative investigation of operational aspects of military systems, originally those of Fighter Command of the Royal Air Force (RAF). The first application of OR was to the process of plotting, filtering and passing aircraft track information provided by the recently introduced chain of radar stations. The time was the period 1938-1939. The original OR section at Headquarters Fighter Command was set up specifically to study and investigate operational problems, rather than technical ones. Information concerning the introduction and early history of OR is available in References (Refs.) 1, 2, 3, 4, and 5.

3. There are many definitions of OR. The one given in Ref. 1 is "numerical thinking about operations, with the aim of formulating conclusions, which applied to operations may give a profitable return for a given expenditure of effort". Another general one is "a scientific method of providing executive departments with a quantitative basis

for decisions regarding the operations under their control" (Ref. 6). A shorter definition is "quantitative common sense applied to solving operational problems". A somewhat humorous definition which contains more than a germ of truth is "a method of providing bad answers to operational problems to which otherwise worse answers would be given". In any case, two important factors characterizing OR are its basic concern with improving operations, and its emphasis on quantitative research. The main characteristics and tools of OR are discussed in a later section.

4. Although this report is concerned primarily with military OR in Canada, it first presents a general introduction to OR and OR methodology and then, in Chapter III, discusses military OR. This Chapter includes a section on military OR in Canada which is performed by the Operational Research and Analysis Establishment (ORAE) of the Department of National Defence. Chapter IV contains examples, and references to, projects and studies that have been done by ORAE. Chapter V presents some professional considerations pertinent to OR analysts in general and to ORAE scientists in particular.

## DEVELOPMENT OF OPERATIONAL RESEARCH

5. After its introduction in Fighter Command of the RAF, OR spread rapidly into other RAF Commands, the Royal Navy and the British Army. A little later, OR sections were formed in the Armed Services of the United States and Canada. And at the end of 1943, military OR had been introduced into the Armed Forces of the United KINGDOM (UK), the United States of America (USA), Canada, India, Australia, and New Zealand (Ref.4).

6. The introduction of OR in the Canadian Armed Forces has been documented in several places (Refs. 3, 4, 7, 8, 9, 10, 11, 12) and will not be repeated here. The references just cited also present many examples of military OR work both in wartime and in peacetime since WWII. The first OR units in Canada were established in September 1942.

7. Since its early use in military applications, OR has become recognized as an important input to decision making in business, industry, governments, and institutions (13). For example, in Canada, OR is currently being used in at least 30 federal departments or agencies, 50 provincial ones, and in 20 or more city or municipal governments. It is being used in many Canadian management and consulting companies, in Canadian banks, insurance and trust companies, in councils, foundations, and research institutes (Ref. 4), where it is often done under some other name such as policy analysis or systems analysis.

## REASONING AND THE SCIENTIFIC METHOD

### Logical Reasoning

8. Logic may be defined as the study of the general conditions of valid inference. Briefly, inference is the act or process of passing from one proposition, statement, or judgement, considered as true, to another whose truth is believed to follow from that of the former. Inferences are of two kinds: inductive and deductive.

9. Inductive inference, or induction, is reasoning or inference from the particular to the general or universal. Deductive inference or deduction is reasoning or inference

from the general or universal to the particular, or from postulated or axiomatic statements to logical conclusions. It may be noted that mathematics proceeds mainly by deduction whereas scientific methodology is based primarily on induction. Operational research as a form of applied scientific research is based on induction, but it also makes considerable use of mathematical models and deductive inference.

10. There are many ways of acquiring new knowledge. Among these are clairvoyance, intuition, revelation, chance, serendipity, history, experience, experiment and analysis. The last two of these are included in scientific methodology, which has been by far the most productive asset in our technological development and in our understanding of the universe and its functioning. Science is concerned with the establishment of verifiable laws and principles chiefly by induction. Since induction consists in reasoning from the particular to the general, one can never be absolutely certain that conclusions are universally true. It is important that conclusions be put in some quantitative form and that standardized testing procedures be followed in order that others can reproduce or disprove them. Strictly speaking, mathematical precision is not possible in induction so that, in general, science depends on inference that is statistical in nature, that is on statistical inference based on probability.

## The Scientific Method

11. The essential elements of the scientific method may be described as: (i) An examination of what is already known about the phenomenon of interest; (ii) The formulation

of a hypothesis that may explain or account for the phenomenon; (iii) The design of an experiment to test the hypothesis; (v) The collection and recording of observations or data representing the results of the experiment; (v) Analysis of the data leading to the acceptance or rejection of the hypothesis.

12. Not all these steps are always apparent in performing scientific investigations and sometimes they are employed unconsciously. And sometimes one or more of these steps may be missing, frequently unwittingly. It may also be noted that statistics contribute to the last three phases of the scientific method as described above (14) and, that since OR is a form of scientific research, it is not surprising that statistics plays a very important role in OR. As defined in Ref. 15 statistics may be considered as the science and art of the development and application of the most effective methods of collecting, tabulating, and interpreting quantitative data in such a manner that the fallibility of conclusions and estimates may be assessed by means of inductive reasoning based on the mathematics of probability.

13. As used above the term experiment has its normal meaning of test, or trial, or an operation carried out under controlled conditions in order to discover or verify an unknown effect or law, to test or establish an hypothesis, or to illustrate a known law. An experiment may range from a simple laboratory or other test to a complex computer model. In particular, in OR applications the practitioner may not realize that an experiment is being designed, conducted, and used to test an hypothesis. But he should be aware of the relationship of his procedure to the scientific method.

# PROBLEMS AND PROBLEM SOLVING

## General

14. From an operational point of view, a problem is generally concerned with the level of performance in some complex operation. It may be merely a problem of measuring the level of performance, or of finding out why the observed level is not as high as was hoped or desired.

15. A major difficulty in many problems lies in defining the boundaries of the problem. If the problem can be isolated as a function of very few parameters it is generally easy to solve with measurable accuracy. However many problems involve a large number of factors whose effects it seems desirable to separate in order to solve the problem but no way can be seen to do so. Some authors of OR papers designate this as a mess which cannot be solved. The serious OR worker should refrain from doing so. There are many ways of tackling such complex problems where there is a measurable outcome but the factors contributing to that outcome cannot be separately assessed. The methods include simulation, Monte Carlo technique, and war gaming. Of course, if the separate problems involved in one complex large problem are indeed separable it is best to tackle them separately. The OR worker should always attempt to break up a complex problem or 'mess' into separate individual problems each with its own cause which requires identification.

16. In military OR the problem to be solved, or the project to be studied and solved, may be specified by the military sponsors. It is however, the responsibility of the OR staff to convert the problem as specified into a

statement of the problem which can and will be solved. They may on occasion have to say it is impossible but will not until they have exhausted all their intellectual resources. It may be noted that in some cases OR scientists, who have been involved in or studying military operations, identify problems and initiate action to solve them.

## TYPES OF PROBLEMS AND THINKING

### General

17. In general problems may be considered as being of three types. The first type requires for its solution more information or improved techniques for handling and processing information. The second type may or may not require new information or data but it does require a rearrangement of information already available - an insight restructuring. The third type is the hidden problem. The problem in this case is to realize that there is a problem - to realize that operations or things need to be improved and to define this realization as a problem to be resolved.

18. The OR worker can expect to encounter problems of all three types, and it is important to know which type of problem is being faced. For the first type, which is by far the most common in military OR, the general approach to a solution is to assemble all relevant information and then to decide what else is needed for a solution.

19. In attacking problems of all types, recourse may be had to what is called lateral thinking. Lateral thinking is the process of using information to bring about creativity and insight, i.e. a restructuring. In thinking about any

problem it is, of course, desirable to think in all directions; backwards into the history of the problem; forward into its future impact; and sideways into the environment or context of the problem and to more-or-less related problems. That is the kind of lateral thinking that OR workers have always been aware of. The new popularity of the term does not imply that a new OR technique has been discovered.

20. However, the term is used in this report to mean structuring or restructuring a problem within a wider context. The interested reader will find further information about lateral thinking in Refs. 16, 17, and 18.

21. An example of lateral thinking in solving an elementary problem may be of interest. The problem is to take 3 empty styrofoam coffee cups and put 10 coins in them so that there is an odd number in each cup. The solution lies in thinking laterally of putting one cup inside another. There are 15 solutions in all of which the set 1, 2, and 7 coins is one, with the cup with 1 coin inside the cup with 2 coins, so that this cup has 3 coins in it. Some readers may explain the insight as arising from a good visualization of the problem or from performing an actual experiment; these also are ways to transform a problem into a more convenient form for solution.

22. Another example of a problem of interest to a military OR worker is the following. A mine field of area A has N mines distributed at random within it. The mines are identical and detonate if a heavy object approaches within a distance r. An army tank is driven into the area a distance S. What is the probability that the tank does not detonate a mine? There is then an area $N\pi r^2$ within which the tank

will detonate a mine and the probability that an object dropped at random in the area A will detonate a mine is $N\pi r^2/A$. But the tank is not placed at random in the area. The key to the solution is to think of the tank as carrying with it a 'swept path' of width 2r+W, where W is the width of the tank, so that the effective area swept out by the tank is $A_p=(2r+W)S$. Now the total area of the minefield is A and the area favourable to the event "detonating a mine" is (2r+W)S. Then the probability that any one mine will be detonated is $P_d=A_p/A=(2r+W)S/A$. The probability of not detonating this one mine is $(1-P_d)$, and the probability of not detonating any of the N mines is $(1-P_d)^N=[1-(2r+W)S/A]^N$. The contribution of lateral thinking here is considering the so-called 'swept path' of the moving tank as an area (2r+W)S within which a mine would be detonated. It should be noted that even in this relatively simple problem, several assumptions are involved in getting the solution. These are that the tank makes no crossings of path or sharp turns, that S is much greater than r, that the length of the tank is immaterial, and that the mines are sowed independently at random. All these insights and assumptions derive from initial knowledge of how tanks behave and how minefields are designed, i.e. they depend as much on vertical as on lateral thinking. Incidentally, using $1-P_d$ instead of $P_d$ in the final stage of the solution, is a well-known device in certain probability calculations.

23. It should be observed that, in general, an OR problem or study involves much more than providing a simple leap of insight that is one of the characteristics of lateral thinking.

## Problems in Operational Research

24. It will be found in practice that all OR problems require more information in one form or another. Problems in OR may be considered as being of three types depending on how this additional information is required: by collecting more data and information, by constructing or reconstructing data, and by imagining or postulating data.

25. For all these types, as for the first type of general problem mentioned above, the general approach to a solution is to gather all available relevant information and evaluate each possible combination. However, assembling all relevant information may involve thought processes which discover relevant information in unlikely places. These thought processes are sometimes called lateral thinking as mentioned above. Similar processes have been used from the earliest days of OR, often to devise surrogate measures for variables which are difficult to measure directly.

26. Attention should be drawn to the distinction between OR problems and OR projects. In general, in OR Practice a project is a major study which may involve solving several problems. In the Annual Program of Work for the Operational Research and Analysis Establishment, the program is organized by projects which may have sub-projects or sub-studies each entailing one or more problems.

27. There are, of course, various classifications of types of problem. For example, one other, given in a textbook on OR, considers certainty problems, risk problems, and uncertainty problems (19). An OR Scientist does not speak of impossible problems - these are merely problems which cannot be solved with the available resources.

Problem Formulation

28. Formulation is the process of converting a rather vaguely stated problem into a structured form that can be worked on logically to produce a quantitative answer from the available data. Occasionally the process is reversed to explain how an answer arrived at intuitively can be derived logically. Formulation of problems is perhaps the single most important skill in OR work. It is probable that some natural aptitude in problem solving is the best qualification for problem formulation. Given that, greater facility in formulation will come with experience.

29. The reader who has had a course, or courses, in OR or who is acquainted with OR methodology, will have been introduced to the process of problem formulation. Textbooks on OR generally have a chapter or several sections dealing with problem formulation and it is assumed that the reader has some familiarity with treatises on the subject such as those given in Refs. 19, 20, and 21. For example, Ref. 20, Chapter V deals with an idealized procedure for problem formulation and Ref. 19 states in Chapter 2 that to formulate a problem the following information is required:

a. the identity of the decision maker;

b. the decision maker's objectives - from these and other data a measure of effectiveness or performance is derived for evaluating the alternative courses of action;

c. the aspect or factors of the situation that are subject to the decision maker's control (the controllable variables Xi) and over what ranges these variables can be controlled (the restrictions or constraints);

d. other aspects or factors of the situation that can affect the outcomes of the available options (the uncontrollable variables Yj).

30. With such data the relationships can be expressed symbolically in mathematical form as $E=f(Xi,Yj)$ where E represents the effectiveness, or performance, of the operation or system under consideration.

31. The idealized procedure for formulating the problem set forth in Chapter 2 of Ref. 19, is a long one, requiring much time and ingenuity, and sometimes some lateral thinking. It will not be discussed here but the reader is referred to the above references (which are concerned with non-military OR) for more information on problem formulation. However, some general comments on the procedure follows.

32. First, anxiety to get on with the research often leads to a reduction in the time available for formulating the problem. Here the old military dictum that time spent in reconnaissance is seldom wasted is particularly pertinent. Secondly, for military OR analysts it is generally not easy to determine the identity of the decision maker and in general they have to deal with a sponsor, who has to pass the results further up the line of command for a decision, or his project officer. Thirdly, it is important to be sure of the sponsor's objectives and his view of the criterion for decision making i.e. the appropriate measure (or measures) of effectiveness. Also, in the Operational Research and Analysis Establishment (ORAE) the problem or project will be at least partly formulated in the standard form used in presenting projects in the Annual Program of Work. Finally, the junior ORAE analyst should never be hesitant

about conferring with one or more senior OR analysts, the OR director concerned, or the military sponsor of the project to clarify any aspect of the proposed work that causes any concern or doubt. In particular, the problem formulation and the construction or selection of a model, about which more later, may well be stages of the OR work which the novice will wish to discuss with others before proceeding with the study.

## The Statement of the Problem

33. As noted in Ref. 21 (Chapter 2, pp. 12-13), unlike text book examples, many practical problems and projects are initially presented to an OR team in an unclear, imprecise, and woolly way. Thus the first step is to examine the relevant system and develop a well defined statement of the problem. To do so requires that, among other things, the appropriate objectives, the constraints that are involved, interrelationships between the area to be studied and other areas of the organization concerned, and possible alternative courses of action be determined and specified. The statement of the problem or project should then be discussed with the sponsor, and agreement reached on it. Remember that it is not easy to get the "right" answer to the "right" problem and it is almost impossible to get the right answer when working on the wrong problem. Hence the statement of the problem must be set forth with much care. The original statement should be rechecked and modified if necessary during later stages of the work. Any such changes should be referred to the sponsor and his full agreement and understanding should be sought.

34. In the case of ORAE much of the military OR is done by staff members who study and understand military operations and the identification and formulation of problems is often done in the light of this understanding. Indeed the initial identification of a problem is often done by an OR scientist of ORAE.

35. Determining the right objectives to appear in the work statement is very important and these must be obtained in consultation with the sponsor and his staff. To do so may require a number of discussions and some compromises. There may well be hidden objectives which are not immediately apparent and considerable questioning may be required to discover them. There may also be some objectives that the sponsor or decision maker may want to retain or maintain as well as some that he wants to obtain. When multiple objectives are known or suspected, the sponsor should be asked to place them in order of priority.

## Representing the Problem

36. When the sponsor's problem has been formulated, the next step usually is to simplify the problem into a form that is convenient for analysis but which in some way retains what may be termed the essential operational aspects of the system or organization under study. Generally this is done by constructing a model that represents the essential operations of the process, system, or organization in such a way that the model can be used to provide numerical measures or quantitative data about these aspects. In a sense the model must be, in its essential aspects, the operational equivalent of the subject being studied. In the following Chapter further information is presented about types of models used in OR and; how they may be constructed.

Approaches to Problem Solving

37. Perhaps the most important comment about approaches to problem solving is that any such approach should be quite objective - at least on the part of the OR analyst or team. It should be recognized that the sponsor of an OR problem or project need not necessarily be objective, although analysts would prefer him to be. Only in special cases can the OR analyst know the full range of the sponsor's concerns. It is critical however that analysis be completely objective even if the analysts are aware that the sponsor or decision maker can introduce his own bias when making a decision on the future results of the analysis.

38. As already mentioned, the approach to problem solving should involve both logical or vertical thinking and lateral thinking. In OR for example, lateral thinking may be needed in seeking an appropriate payoff or utility function, or a measure of effectiveness. Devotees of lateral thinking should, however, beware of moving too far sideways. One of the most important restraints in problem solving is to keep the problem bounded, i.e. of a manageable size, by excluding possible relationships that do not affect the answer. This is in accord with the principle described below.

39. A general principle that warrants attention in problem solving and making hypotheses is known as Occam's razor, named for a British philosopher William Occam (or Ockham, 1290-1349). A literal translation of the original Latin version is "Essences are not to be multiplied without necessity". The principle states that a person should not increase, beyond what is absolutely necessary, the number of entities required to explain anything, or one should not make more assumptions than the minimum required (22). It

has sometimes been termed the principle of parsimony. For the OR scientist, Occam's razor has two obvious but important applications. First, in judging between two or more hypotheses it is usually best to choose the simplest one that explains the observed phenomena, and, secondly, in making assumptions that are normally necessary as the basis of any OR study, the minimum number of necessary assumptions should be used. It is always worthwhile to try to determine what is the minimum number of basic assumptions. In a sense the 'keep it simple' principle is a sort of modern form of Occam's razor. But, here again, simplification should not be carried to excess.

40. In concluding this section on approaches to problem solving, it is pertinent to draw attention to three other points. First, Ref. 23 discusses an approach to solving mathematical problems and the reader will find it profitable to make use of it as mathematical problems arise in OR work although most military OR problems involve much more than mathematics. Secondly, Ref. 24 observes that it is "a real possibility that the scientific or academic approach to problem solving is not providing individuals who have either the background or the expertise to solve the kind of problems facing society today". This article will be of interest to all OR practitioners if only to show the attempts of some social scientists to denigrate the scientific methods which they seem incapable of applying. Thirdly, Ref. 25 deals with the problem of teaching problem solving using what the author calls "the studio approach". It, too, is pertinent to the above and will prove interesting and instructive to OR workers.

## CHARACTERISTICS AND TOOLS OF OPERATIONAL RESEARCH

### Characteristics

41. The chief characteristics of operational research that, collectively, are its distinguishing features are:

a. The use of the scientific method;

b. Concern with the whole system or organization under study;

c. It is inter-disciplinary;

d. The use of the team approach, where necessary;

e. It seeks optimum operational decisions for an organization, i.e. those which are best in some sense for the organization as a whole;

f. Its heavy use of mathematics, mathematical models, and statistical theory in solving problems;

g. It is primarily concerned with processes rather than systems;

h. It provides input to decision making but is not the only input, and final decisions rest with the managers or those in control of operations, not with the OR people.

Tools of Operational Research

42. The tools and skills of OR include most forms of pure and applied mathematics particularly those forms that have proved useful in the physical sciences and those that are now being formulated for use in the social sciences. The mathematical tools include probability theory and the calculus, but also various applied forms such as queuing theory, linear, dynamic, and stochastic programming, and the theory of games, statistics, mathematical modelling, war gaming, design of experiments, simulation, the Monte Carlo technique, risk analysis, and computer science. As well, knowledge of, and training in, such fields as economics, engineering, the behavioural, management, and social sciences, and organization theory are often required for undertaking OR projects. In fact other techniques of many sciences not directly of mathematical form are employed whenever it seems appropriate to do so.

43. It is, of course, not expected that every OR practitioner should be able to use all such tools but by having all OR staff members competent in one or more of them, and using the team approach, an OR group is able to bring a wide range of tools and skills to bear on any particular problem. By including military officers on the teams undertaking military OR, desired military inputs and a balanced approach can be obtained. However, not many military officers today have actual wartime experience so that, as far as convenient, military officers with special practical experience or OR training, or both, are selected for serving tours of duty with ORAE.

44. It may be noted that in OR terminology the ways in which such tools and skills are used are often referred to

as "techniques" of OR. The plan or design for utilizing a model or the technique is usually referred to as the "method".

## OPERATIONAL RESEARCH AND SYSTEMS ANALYSIS

45. Frequently, one encounters some confusion about the meaning of operational research as compared to systems analysis. The application of scientific methods and quantitative analysis to the design and evaluation of mechanical and man-machine systems is called "systems analysis" or "systems evaluation" by some writers. These terms are also used by some to mean the analysis and evaluation of the effectiveness or cost-effectiveness of future systems, that is ones that are in the design or bread-board stage, rather than of systems already in use or operation. Those who use these terms in this sense usually consider OR as applying to the study and analysis of present systems already in operation.

46. In some cases the terms OR and systems analysis are used synonymously and interchangeably. The definitions of OR presented above are quite general in nature and are not restricted in terms of the type of system or its time of operation. Accordingly, they may be considered as being sufficiently general to include systems analysis or evaluation. In any event, only the term operational research will be used in the present paper. Also, it should be noted that in the United States (US) and elsewhere, the term operations research is used instead of operational research.

## REMARKS AND SUMMARY

47. This introductory Chapter presents in abbreviated form some information pertinent to OR that is not found in most textbooks and formal courses on the subject. It notes that OR is more concerned with operational problems than with technical ones, that OR is only one of several possible inputs to decision making, but that OR is based on quantitative analysis and the scientific method.

48. It discusses briefly such basic concepts as logic, logical reasoning, inference, induction, deduction, and types of problems and thinking. It attempts to show the relationship between reasoning, thinking, problem solving, and the scientific method. The basic terms used are defined to avoid misunderstanding. Approaches to problem solving and some relevant basic principles are discussed. It introduces the concept of lateral thinking and notes that lateral thinking is required to some degree in solving many of the problems found in OR practice, but that it can be overdone.

49. The chief characteristics and tools of OR are mentioned with several relevant remarks. And the meanings of the two terms operational research and systems analysis are discussed and related.

50. The intention of this Chapter is to review and discuss basic concepts underlying the scientific approach in general, and of interest to OR in particular. Familiarity with these matters will enhance the reader's comprehension and appreciation of the material presented in the following chapters.

51. In the next Chapter on OR methodology the treatment given this topic in References (19), (20), (21), (26), and (27) has been closely followed and is hereby acknowledged. Care has been taken throughout to cite references whenever appropriate.

# CHAPTER II - OPERATIONAL RESEARCH METHODOLOGY

## BASIC PRINCIPLES OF OPERATIONAL RESEARCH

### General Basic Principles

52. As already observed a clear and explicit definition of the problem is an essential feature of an OR study, and ensuring that such a statement is available at the outset is a basic principle of OR. It is also important that the sponsor and the OR analyst have the same interpretation of the statement of the problem. When this is done a mutually agreed aim or set of objectives should be prepared.

53. It may warrant observation here that often the origin of an OR study is merely a vague feeling of perplexity, vexation, or unease on the part of some interested person, such as a manager, operator, or military officer, who wants to find the cause of what is, or appears to be, wrong and correct it. In such cases the initial action of the OR analyst is to study the operation concerned and determine whether there actually is a problem that can be defined and formulated.

54. In general, before a start can be made towards deciding how to approach the problem it is necessary to specify a set of assumptions on the basis of which a methodology may be developed. In some cases the analyst devises a suitable model and has to make assumptions which will allow him to use it. Again, a basic principle is that such a set of assumptions be prepared and agreed with the sponsor or tasking authority. In doing so Occam's razor should be applied as suggested in Chapter I.

55. All operations depend on several factors or parameters and it is always worthwhile to eliminate from initial considerations the less sensitive of these, i.e. those that have the least impact or effect on the operation concerned. These can often be identified by a statistical examination of past operations, by observing present operations, or by discussing them with experienced operators of the system or organization under study. Good examples of the need for detailed understanding of the operation and of finding sensitive parameters are given in Ref. 26. The principle here is that the influential factors or parameters should be determined early, or as soon as convenient, in the analysis of an OR problem or project. This principle is, of course, related to the previous one as assumptions concerning non-sensitive parameters may not be necessary and the principle of parsimony (Occam's razor) may eliminate them.

56. Irrespective of the aim, objectives, or desired outcome of the project, or the type of problem solving to be used, it is necessary that some measure or measures of effectiveness, pay off, objective, or utility function be determined before the solution methodology or model to be used is decided.

57. An interesting example of choosing a measure of effectiveness is given in Ref. 26. This case involved the question of equipping merchant vessels with anti-aircraft guns for operations in a war zone in WW II. It was estimated that the guns available would have very small probability of shooting down enemy planes and would not warrant being installed in view of this and the attendant cost. This conclusion was based on the probability of an enemy aircraft kill as the measure of effectiveness. However, the objective of the guns was not to shoot down enemy planes but

rather to give protection to the merchant vessels so that the proper measure of effectiveness was the probability of the merchant vessel not being sunk. It could be shown that this probability would be considerably increased by installing the guns as the attacking aircraft would then be obliged to release their weapons from greater heights or distances, thereby decreasing the accuracy of delivery and increasing the probability of the vessel not being sunk or damaged. The choice of the proper measure of effectiveness is crucial in OR problems. This fact will be made apparent when the examples given in Chapter 3 of Ref. 28 are noted. These concern aircraft operations and will be of special interest to military OR workers. Other examples, from OR and general analysis studies in the military environment, are given in Chapter IV below.

58. While the preceding remarks concern measures of effectiveness, similar comments are applicable to such related criteria as cost-effectiveness, cost-benefits, pay-off functions, and utility measures. In many OR projects cost is a vital factor and one may wish to determine the particular system or alternative that would maximize effectiveness within an overall given cost ceiling, or provide a given level of effectiveness for the minimum cost. In some cases it may be appropriate to compare the effectiveness per unit cost of a number of competing systems, procedures, or organizations in order to determine the best course of action for the sponsor or decision maker.

59. In socio-economic studies the OR worker or analyst will often be concerned with cost-benefit analyses rather than with cost-effectiveness. But in principle the two concepts are similar and provide yardsticks or measuring devices for judging the relative merits of alternative systems or courses of action.

60. The basic principle involved here is that the choice of the proper criterion such as the measure of effectiveness, cost-effectiveness, or payoff function is critical and must be made with great care.

61. It should be noted that in some cases it may be useful or mandatory to have more than one criterion of performance or behavior, e.g. two or more measures of effectiveness. *One method of dealing with such problems is to conduct* the analysis using each of the measures in separate solutions, and present the findings to the sponsor in terms of the separate measures of effectiveness.

62. Further information on multiple criteria in OR and on problems involving more than one objective wherein a method of assigning relative values or weights to the objectives is required may be found in Ref. 19 and Chapters 5 and 6 of Ref. 20, respectively. Ref. 29 represents nineteen references pertinent to this topic of measures of effectiveness. It may be of interest to the reader to note briefly some of the less usual types of ordering or measurements. A shorter description of these is given in Annex A.

63. Three other basic general principles that warrant being mentioned again are that OR is based on the scientific method, the OR analyst must strive to maintain objectivity at all times, and that timeliness in providing OR results and conclusions is often important to the sponsor. With regard to timeliness it should be remembered that a less than perfect analysis, and a conclusion that influences a decision of the manager or sponsor in the right direction, is much more valuable than an elegant analysis with the 'perfect' solution that comes after the decision has been made. But it may also be disastrous if the hasty conclusion

that influences the manager turns out to be wrong. Thus, in providing timely solutions, great care should be taken to ensure that the answer given is in "the right ball park".

64. The first step in undertaking a research study, once the problem has been satisfactorily defined, is often a comprehensive literature search. Today the military OR analyst may well carry out both a literature search and a search or check of available computer programs that could be used or adapted to ensure that the wheel is not being reinvented. But it is equally likely that the analyst with experience will be able to think up his own approach to solving a problem without the necessity of searching for other people's solutions.

65. Finally, it should be noted that the ORAE possesses a vast amount of data in various forms on a wide variety of subjects. One obvious example is, of course, the many OR reports issued over the years. Not so obvious examples are the detailed descriptions of the so-called ground environment of the North American air defence system which are available in a computer program, and the data stored in computer files and on record in documents relevant to the conduct and play of war games.

## Phases of Operational Research

66. Another OR principle that is more specific in nature is that certain steps or phases are involved in all OR projects. There is general agreement that the major phases are:

a. Formulating the problem;

b. Constructing a model to represent the operation of the system under study;

c. Deriving a solution from the model;

d. Testing the model and the solution;

e. Establishing controls over the solutions or outputs;

f. Implementing the solution or conclusions reached in the OR study.

67. The formulation of the problem has been discussed in Chapter I and it has been noted that in doing so a measure or measures of effectiveness must be specified and their appropriateness must be confirmed. The general idea of the functional relationship between effectiveness and controllable and uncontrollable variables in mathematical form as $E=f(X_i, Y_j)$ has also been introduced in Chapter I.

68. The following sections deal with the other five phases and related matters, but before discussing them it should be remarked that in some cases Phases e. and f. are often omitted in carrying out an OR study, although they should be covered in all OR projects. The beginning OR worker will not be concerned with the final phase which will normally be the responsibility of the project leader or director, who should follow up on the study and see that its results are put to use.

69. The steps or phases listed above are not necessarily performed in the order presented. Some or all of them may take place at the same time and there often is continuing

interaction between the phases during the course of the research. It should be observed that the availability of usable data is a prerequisite for conducting OR studies and that the experienced OR analyst soon develops an ability to make all kinds of information "usable".

## MODELS IN OPERATIONAL RESEARCH

### Types of Models

70. The second phase of an OR project is to recast the problem into a form that is convenient for analysis. The usual OR approach for doing so is to construct a mathematical or symbolic model that represents in terms of mathematical symbols and equations, the essential properties and operational features of the system under study. A short description of the most common types of models is given in Annex B.

71. Elementary examples of models are the well known relationships $F=ma$ and $E=mc^2$. In military OR a typical example of a simple mathematical model for a weapon system is $E=P_d.P_L.P_K$, where $P_d$ is the probability of detection, $P_L$ is the probability of locating, $P_K$ is the probability of kill, and E is the measure of overall effectiveness. This model, or modifications of it, may be used to measure the effectiveness of a weapon system for attacking submarines, tanks, or aircraft.

72. In many cases in OR one encounters equations with both determined or controlled variables and probabilistic or uncontrolled variables. For example, consider the well

known situation of a newsboy who must decide how many newspapers to order to maximize his expected profit. If we let:

x = the number of newspapers ordered per day;

g = the gain or profit on each paper sold;

l = the loss on each paper returned (not sold);

y = the demand, i.e. the number that could be sold per day if $x \geq y$;

p(y) = probability that demand will be y on a randomly selected day;

P = net profit per day (where negative P represents a loss),

then it is easily shown that the expected net profit per day is given by the equation:

$$P = \sum_{y=0}^{x} p(y) \cdot [yg - (x-y)l] + \sum_{y=x+1}^{\infty} p(y) \cdot gx$$

In this formula P is the measure of effectiveness or performance, x is the controlled variable, y is an uncontrolled variable, and g and l are uncontrolled constants. To solve this model one must find the value of x that maximizes P.

73. Mathematical models are idealized representations which can be manipulated, which indicate relationships, and facilitate analysis. It may be said that they represent the essence of the problem in mathematical terms by means of equations. In the general form E = f(Xi,Yj) restrictions on values of the variables may be expressed in a supplementary set of equations or inequalities, often called "constraints". With such a model, the problem is to choose the values of the variables so as to maximize the function E subject to the specific constraints. Such a model, and

variations of it, are typical of the models used in OR. Further examples of OR models will be presented in later chapters and information on military modelling can be found in Refs. 30 and 31.

Recurring Processing and Problems

74. As the practice of OR developed it became evident that the techniques and methodology employed could be considered as falling in certain classes depending on the type of process or problem to which these techniques and methods were applicable. The more common classes and processes and related problems may be described as follows as is done in Chapter 1 of Ref. 20.

a. Inventory Processes -- In these processes one or both of the following problems arise: (i) how many or how much to order, produce or sell; (ii) when to order, produce, or sell. The main question in such cases is how to balance inventory carrying costs with the other associated costs such as order costs, production run set-up costs, shortage, or delay costs, etc.

b. Allocation Processes -- These arise when: (i) there are a number of activities to perform and there are alternative ways of doing them; (ii) resources or facilities are not available for performing all activities simultaneously in the most effective way. The problem then is how to combine activities and resources to maximize the overall effectiveness.

c. Waiting Time Processes -- These involve the arrival of units which require servicing at one or more service units. Waiting is required of either the units to be serviced or the servicing units, or both. Costs are associated with these waiting times. The general problem is how to minimize the sum of these costs, which in such a case corresponds to maximizing the effectiveness of servicing.

d. Replacement, Maintenance, and Reliability Processes -- These arise when equipment deteriorates, becomes obsolete, or fails and maintenance involves replacement of one or more parts or sub-units. Again, the problem is to minimize the sum of the associated costs of making the equipment serviceable.

e. Competitive Processes -- A competitive situation is one in which the effectiveness of a decision of one party can be decreased by a decision of a second party or by variations of a random factor such as the weather. Examples of such situations are games, duels, wars, marketing, etc. Again, models and theory have been evolved or adapted to assist in the solution of the associated problems.

f. Combined Processes -- In many cases real situations do not fall neatly and completely into one of the classes of processes described above. Rather, they involve two or more such processes thereby leading to more complicated problems.

g. Sequencing Processes -- In contrast to waiting time processes, a sequencing process arises in a situation where the facilities are fixed and arrivals, and the sequence of servicing the waiting customers, or both, are subject to control. The problem is to schedule the arrivals, or sequence the jobs to be done, so that the sum of the associated costs is a minimum.

h. Search Processes -- In the typical search problem one is attempting to use resources to track down, or locate a target or missing object or vehicle. The basic decision to be made in such cases is how much search effort and attendant cost and time should be expended before calling off the search. A different but also common search problem is looking for something which is not there but that it is feared may arrive unexpectedly one day, such as an enemy missile attack. Then the decision required is how to maintain the search indefinitely at least cost.

Remark

75. In large measure, the development of OR techniques and methods has been in conjunction with devising models for the various processes just described and determining solutions to the models. It should be noted that for any one of these processes there may exist many different models although by now textbooks on OR have made considerable progress towards standardizing these models. Even so it may still be desirable to modify existing models or develop new

ones for specific problems. The success of OR is largely due to the fact that it does not offer standard solutions - it goes for something better.

## Models for Recurring Processes and Problems

76. For each of these classes of processes, characteristic models and methods of solving them have been developed. In Ref. 20, for example, six elementary inventory models, as well as more complicated ones and their solutions, are described, and examples given. The technique which is most often applied in allocation problems is linear programming and the related procedure called mathematical programming.

77. Waiting time processes are generally addressed by constructing queuing models and invoking queuing theory to solve them. Similarly, models of repair and maintenance have been developed for representing replacement processes. Competitive problems are usually of three types: games, bidding, and duels against nature. The theory of games may be used for the former as well as for simple bidding problems, and analytic methods may be applied to less simple bidding problems. Sequencing and other models are described in such References as (19), (20), and (21).

## Construction and Use of Symbolic Models

78. Examples of models and their construction for problems in military OR are given in Chapter IV below, and in the references cited in the reports summarized in these examples.

79. In building a model, conflicting objectives may confuse the issue. One wishes to make the model as easy to solve as possible and as accurate as possible. It is always necessary to simplify reality but with care it may be done without significant loss of accuracy in the area under study. Good judgement and practical experience are required to maintain the proper balance. This topic warrants more consideration than is given here and the interested reader may wish to refer to Chapter 3 of Ref. 19 for more information on this subject and on model construction in general. Refs. 20 and 21 also provide many directions for mathematical model construction.

80. Perhaps not much more need be said here about the use of models in OR. Their use is very general and, as noted above for each of the recurrent processes and problems that have become recognized in OR work, models have been devised and used with success.

81. In concluding this section, for the sake of more complete coverage, passing mention is made of dynamic and integer programming and of coordination problems which are generally referred to by the names of the techniques used to solve them - PERT (program evaluation and review technique) and critical path. Definitions, descriptions, and examples of all these techniques may be found in Refs. 19, 32, and 33.

## Limitations in Modelling

82. A mathematical model is necessarily an abstract idealization of the system under study and its mode of operation. Approximations and simplifying assumptions are usually required if the model is to be usable and useful.

Accordingly, great care must be taken to make sure that the model is an acceptable representation of the real world situation or system. The determining factor here is whether or not the model predicts the relative effects of alternative courses of action with enough accuracy to permit a right decision. While this statement is easy to make, in practice it is not easy to determine when sufficient accuracy will be obtained. But, in general, it is not necessary to include unimportant details or factors that would have approximately the same effect for the various alternative courses of action being considered. Also, it is not always vital that the absolute magnitude of the measure of effectiveness be obtained or is even obtainable for various alternatives. It is the relative values provided by the model for alternative systems or courses of action that are consequential and meaningful in most cases. The relative measures of effectiveness calculated by similar means are generally satisfactory for ordering options even if the absolute values cannot be accurately calculated. In other words, the real requirement is that the predictions of the model are sufficiently good to order the alternatives and that there is a reasonable correlation between these predictions and what may be expected to happen in the real world. It may be obvious that these requirements are met, but occasionally it has to be demonstrated and then it is necessary to do considerable testing and perhaps to modify the model. Doing so is discussed briefly in a following section.

83. Two comments may be apropos here. First, in view of the above remarks on accuracy and precision, the reader may wish to consult Ref. 34 for more information on these terms. Secondly, there has been some concern recently about the relationship between the manager with the problem and

the OR professional who is modelling the problem situation. This concern raises questions about the relation between the real world and the model world in OR. A thoughtful article on this issue is found in Ref. 35.

## DERIVING SOLUTIONS FROM MODELS

### General

84. In discussing solutions to OR problems, it is assumed that the OR analyst has been able to represent the problem in the form of a mathematical model which may be a very simple formula or a complex computer program. For purposes of this discussion even the simplest formula representing the measure of effectiveness or objective function is referred to as a model.

85. The two basic methods or procedures for deriving a solution, preferably an optimal one, from a model are analytical and numerical. Analytical methods make use of mathematical deduction, and may involve any branch of mathematics such as the four fundamental operations, calculus, differential equations, algebra, matrices, or linear, dynamic, or integer programming.

86. Numerical methods consist basically of trying various values of the control variables in the model, comparing the results obtained, and determining that set of values of these variables which yields the best solution. The procedures may vary widely from simple trial and error to complicated iterations.

87. Some model formulations cannot be evaluated numerically with accuracy because of either mathematical or practical considerations. In most such cases the so-called Monte Carlo technique can be used to get approximate evaluations of the expressions. The essence of this technique is that mathematical formulation can be avoided. It is necessary that a few relevant parameters be known and that one has some means of measuring the outcome for different values of those parameters. Rather than beginning with a model, statistical relationships are developed between parameters and outputs by replication. In general this technique is rather expensive and time consuming.

88. Before discussing methods of solving the various models discussed above, it is fitting to make some remarks concerning dimensions. In general the way that fundamental quantities such as mass, distance, time, and cost enter into a compound quantity or a model result in what are called dimensional formulas. In physics, for example, the dimensions are expressed in terms of L, M, T for length, mass and time. Thus the dimensions of velocity are $LT^{-1}$, of area they are $L^2$, and for density, $ML^{-3}$. In setting up formulas and formulating models the OR scientist should always check to make sure that the two members of all equations have the same dimensions.

## Solving Inventory Models

89. The military OR practitioner may encounter inventory problems and models in various forms, particularly in the general area of military logistics. There are many different types of inventory problems and models, most of which are concerned with inventory control. Textbooks on OR classify these in different ways.

90. For example, Ref. 20 provides solutions to several types of inventory models. Ref. 21 has a chapter (Chapter 12) titled Inventory Theory and gives examples of deterministic inventory models and stochastic inventory problems with known demand, probabilistic demand, and probabilistic demand with known lead time.

## Solving Allocation Models

91. Allocation models are frequently used in OR to solve problems that arise when there are a number of activities to be performed and there are alternate ways of doing them, and when resources or facilities are not available for doing each activity in the most effective way. In general, solutions to allocation problems are obtained by the techniques known collectively as linear programming (36, 37, 38, 39).

92. There are special types of linear programming problems which have been called the transportation problem, the trans-shipment problem, and the assignment problem. Refs. 20 and 21, for example, provide examples and methods of solution. The military OR analyst may have occasion to deal with such problems from time to time.

## Solving Waiting-Time Models

93. A waiting-time problem occurs whenever the demand for a service may temporarily exceed the available capacity for providing that service. Three possibilities are: Customers are waiting; facilities not fully utilized; facilities fully utilized but no customers waiting. The usual situation is

that servicing facilities are fully utilized as long as there are customers to be served and customers queue up for service in the order of arrival.

94. Generally, such problems and their models are considered as either of two distinct types. One of these consists in there being arrivals which are randomly spaced or service times being of random duration. The second type is concerned with the sequence or order in which the service is provided by a set of servicing stations.

95. Modelling queuing situations may involve complex models but these are usually solvable by standard methods. It is also the case that a Monte Carlo approach can be used instead of developing a model, provided one has records of the input to, and output from, a suitable service facility.

96. Sequencing problems generally require combinatorial analysis for their solution. Models for such problems and their solutions can be found in Refs. 19, 20, and 21 and elsewhere in the published literature.

## Solving Replacement and Maintenance Models

97. Replacement and maintenance problems and models are generally quite similar since maintenance is usually interpreted as the process of replacing components or subassemblies in order to keep equipment operating. For example, replacing an unserviceable track on an army tank is replacement as far as the track is concerned, but it is maintenance insofar as the tank is concerned. This brief section, accordingly, deals with replacement only.

98. In considering replacement for major capital items, two cases arise: items or equipment that deteriorate and those that fail. The normal measure of effectiveness in the first case for comparing optional replacement policies is the discounted value or present worth of all expenditures for capital and future running costs. For these cases the solution of models usually requires only the use of the principles of the mathematics of investment.

99. In the case of components that fail after a period of use, the real difficulty with most repair and maintenance problems lies in estimating future failure rates where there has not been enough experience with the equipment to measure them. For these cases probability theory, life or mortality curves or tables, and mean times between failures may be required in solving the models. Again, most textbooks on OR give many examples of replacement models and their solutions, e.g. Refs. 19, 20, 21, and 27. Other pertinent References are (40) and (41).

100. Two other relevant comments may be made. First, some problems associated with staff recruitment and promotion are similar in certain respects to replacement problems and can be solved by approaches similar to those just mentioned (27).

101. Secondly, reliability is generally associated with the problem of the failure of equipment as a function of time. Since most industrial and military equipments are complex systems consisting of many components, the failure of any one of which may cause the failure of the equipment itself, such problems can be quite complex.

102. Actually, the most complex systems are those involving both sequential and parallel components. Here the failure of some single component may cause the whole system to fail, but in other cases it may require the simultaneous failure of two or three components for the system to fail. Examples and solutions are given in most OR textbooks and in such published articles as Refs. 42 and 43.

## Solving Competitive Models

103. Competitive models represent situations in which two or more individuals are in conflict or competition and are trying to make decisions when the outcome is controlled by the decisions of all the individuals involved.

104. Many of such situations involve chance or games against nature, or duels with nature intervening, as for example the weather over the target area during a bombing raid. But in all competitive situations it may be assumed that each opponent acts in some rational manner and tries to resolve the competition in his own favor.

105. A game theory originally developed by von Neumann (44) makes use of the basic concept of minimization of maximum loss (i.e. minimax strategy) and is applicable to the solution of some competitive evaluations and models. In military OR practice, game theory has not been found to be widely applicable. Again, the theory of games with examples and solutions of the associated models are presented in many textbooks. The reader will find much relevant information in Refs. 37, 39, 44, 45, 46, and elsewhere in the literature.

## Solving Sequencing and Coordination Problems

106. To date most large sequencing problems, which are usually encountered in a production department, have been solved through simulation although simple cases have been solved by use of the Gantt Chart (19, 20). More sophisticated methods of solution (e.g. integer programming) have been tried (19) with limited success. The complexity of sequencing can be appreciated by considering a situation in which three jobs must be done each requiring the time of four machines. There can be $(3!)^4$ or 1296 different sequences.

107. Coordination problems have given rise to techniques for their solution known as PERT and critical path. These techniques have been well treated in such references as (19) and (20) and will not be described here. PERT is a development of the flow chart.

## Solving Search Problems

108. The original work on searching was done on submarine hunting during WW II. The basic reference here is (26) which presents some search models and analytical solutions thereto. The basic concept concerns the probability of locating, or damaging, or colliding with some object, called the target which is positioned somewhere at random within the area A. It is shown that the probability of success, or of a 'hit' is given by the formula (model) $P = 1 - e^{-z}$, where $z = a/A$, and a is the area covered at a given time by the searching system. The target may not be confined to an area but be in a volume, e.g. as in anti-submarine (A/S) warfare.

109. In search problems a decision that often has to be made is how much search effort should be expended. The return from the effort is usually very uncertain. The decision to call off the search effort can be very difficult to make because it is always possible, even if not apparently very probable, that a little more effort may yield a great return, e.g. success in the search. These factors apply in search and rescue efforts by aircraft and search parties, and in A/S warfare.

110. In general the solutions to the formulas and models used in search theory and applications involve relatively simple mathematics such as probability and the calculus. Many examples are given in such references as (19), (47), (48), (49), and (50).

## Other Methods of Solving Problems

### General

111. In this section some comments are offered on other methods of solving OR problems. In some cases the problems are quite minor ones; in others the problems are projects or major studies rather than simple problems. The treatment is brief in each case and not intended to be exhaustive.

### Simulation

112. A model in the sense used herein represents reality whereas simulation imitates reality. Simulation always involves manipulating a model, usually it is a technique for carrying out sampling experiments on the model of the system

being represented. The experiments are done on the model rather than on the system itself because to do the latter would be too inconvenient, time consuming, or expensive. The experiments are done on a computer when a large amount of calculating is required.

113. In OR, simulation is used to derive solutions from models, usually symbolic models, to evaluate a mathematical expression in an equation, or the equation itself, where one or more of the elements are stochastic variables. The latter is a variable whose value at any given time is a random selection from some probability distribution. Examples of such applications are found in Refs. 19, 21, and elsewhere.

## War Gaming

114. In military terminology a war game is a form of simulation in which decisions are made by two or more competing real commanders or decision makers. In industrial and civilian government applications such simulations are referred to as operational gaming.

115. War gaming has had a long and interesting history, and is widely used by both military and OR staffs in the study of complex military operations. For example, war gaming in the Directorate of Land Operational Research (DLOR) of the Operational Research and Analysis Establishment (ORAE) of the Department of National Defence (DND) is primarily, and was originally, a research tool. It is operated mainly by the military staff of the War Game Section in support of much of the research of the Directorate and to provide data and information on questions of interest to the Canadian Land Forces.

116. The war gaming facilities in DLOR are used for several purposes: to study tactics and strategy; to assess weapons systems, logistic support, and command and control facilities; to train military staff, and familiarize personnel with various aspects of military operations with new weapons and equipment.

117. An essential feature of war gaming is the set of rules for conducting the game, making decisions, and assessing outcomes of engagements. The preparation of the rules involve the translation of existing or proposed capabilities into game terms, the introduction of probabilities into force capabilities, and the coordination of military judgement and opinions with the results of scientific analysis.

118. The first war game in Canada was played in what was then called the Canadian Army Operational Research Establishment in May 1959. It was a hand played game with Blue and Red forces and a control staff. This facility has evolved and developed over the years and is now a computer assisted game. Present facilities permit more than one game to be played at the same time. A very informative account of war gaming army operations is given in Ref. 51. Further information and references are presented in Ref. 19.

## Graphical Solutions

119. The use of graphs and graphical methods in solving problems is well known and widespread. Most of us probably encountered graphs first in algebra and analytical geometry. Recently, graphs have been used in the so-called theory of graphs, and in network analysis. All these, i.e. graphs, the theory of graphs, and network analysis, are

useful as tools of OR. In the planning and control of programs of various kinds, perhaps particularly of research and development programs, a technique involving network analysis called PERT has been developed and has proved quite useful.

120. To connect the concepts of graph theory and networks it may be noted that in this relevant terminology a "graph" is a configuration consisting of a set of junction points called "nodes" with some pairs of the nodes being joined by lines called "branches" or "links". A "network" then is a graph with a flow of some type in the branches. For more information on network analysis and examples, see Refs. 21 and 52.

121. In OR, graphical solutions may be used in a wide variety of problems including those in game theory, linear programming, and sequencing. Some examples can be found in Ref. 27.

122. Also, graphical methods can be used to calculate numerical answers and to display answers in a convenient form to sponsors and others. In fact, graphics are becoming an increasingly useful tool particularly for presenting answers to multi-criteria problems.

## Approximate Solutions

123. Occasionally the OR scientist comes under some attack from so-called pure scientists on the grounds that his work and output does not measure up to scientific standards in all respects. The claim is sometimes made that OR analysts use ball-park estimates or figures and make use of back-of-an-envelope calculations. While it is true that

they do, usually because of lack of time or lack of accurate data, the solutions or results obtained by these imperfect methods can be very valuable and indeed vital inputs to decisions.

124. A most pertinent example of a "quick-and-dirty" solution which was based on rough estimates made on the 'back of an envelope' occurred in the early days of OR at HQ Fighter Command of the Royal Air Force. The head of the recently established OR section there (Mr. Harold Larnder), was at the HQ on a Sunday morning in May 1940 when Sir Hugh Dowding, the Air Officer Commanding, called him into his office regarding a recommendation he had to make to Prime Minister Churchill and the Cabinet that afternoon (5). The decision concerned whether or not the British should reinforce the French by sending over and maintaining six additional fighter squadrons in France to help to blunt the German blitzkrieg. Sir Hugh's military judgment was that the reinforcements should not be sent. But he asked whether the OR scientists could give him a paper on the topic and have it ready in two hours.

125. Rough calculations based on the number of aircraft available (900), the lowest number of them that could be accepted (300), the production rate of fighter aircraft per day, and the expected daily losses if six more squadrons were committed showed that the aircraft inventory would fall below the minimum acceptable reserve in 4 weeks rather than the 7 months it would take with the current rate of commitments. On receipt of these "ball park" estimates the British Cabinet decided not to commit the six additional squadrons of fighters (1, 5). Incidentally this bit of work was the first case in which OR was applied to the planning of operations. Prior to this, the OR section had been

confined to researching into the Command's operational system on technical and tactical problems not into actual operational staff policy matters.

126. The message here is that "quick-and-dirty" solutions and approximate calculations are often warranted when they can have significant impact on decisions that have to be taken before a full-scale study can be done.

127. A further use of approximate solutions can often be very helpful in OR as in other applications. This procedure consists simply of putting into a formula, or model, values of parameters and variables that are known to be approximately accurate and computing the result. This approximate output will usually provide an answer that is of the right order of magnitude or better. It can then be used as either a first approximation to the right answer or as a check on the size of the correct answer to be expected from the proper solution.

## Other Types of Solutions

128. Merely as a matter of definition it may be worthwhile to distinguish between what are sometimes called feasible and optimal solutions.

129. Consider, for example, the linear programming model: maximize the function:

> $Y = f(x_1, x_2, \ldots, x_n)$ subject to a set of restrictions represented by $F(X_i)$. Then a feasible solution is a value of $(x_1, x_2, \ldots, x_n)$ for which all the restrictions are satisfied. An optimal solution is a feasible solution which maximizes the objective function Y.

130. In general, an optimal solution is the best solution, in the sense of being best for the system or organization as a whole. It should be noted that solutions such as those mentioned above are optimal only with respect to the model being used. Since the model is an idealization of the real problem there is no guarantee that the optimal solution for the model will be the best possible solution for the real problem.

131. Because of this fact, and related considerations, it has been suggested that the goal of an OR study should be to "satisfice" rather than optimize. That is, the goal should be to find an acceptable answer that the decision maker considers a satisfactory guide for taking action in a reasonable period of time, rather than to spend time and money trying to find an optimal solution which may not be the best one for the real problem.

132. Other types of solutions involve such sophisticated mathematical tools as integer, non-linear, and stochastic programming and combinatorial and network analysis. These techniques are not discussed here but the interested reader will find information about these in such references as (19), (32), (33), (53), and elsewhere.

### Ranking

133. Occasionally it may suffice for the OR analyst to provide the decision maker with a ranking of alternative courses of action or systems in terms of some common characteristic such as magnitude, cost, timeliness, or effectiveness, or in terms of more than one of these such as cost-effectiveness.

134. The necessary approach in such cases is to assess each of the competing items, e.g. by solving the basic symbolic model for each of them, then rank the outcomes in ascending or descending order. An advantage of this type of solution is that the basic model need not be particularly sophisticated or complex since absolute differences in, and absolute values of, the measures of effectiveness are not critical factors in making the decision. If two or more of the alternatives yield approximately the same values, the analyst would normally list them as equal in performance and leave it to the sponsor or decision maker to make a choice between them on other grounds, as would probably be done anyway.

135. Of course, the OR analyst would have to determine in advance whether or not a ranking of the several alternatives would be acceptable to the decision maker. Normally this matter should be sorted out in the early planning stages according to the agreement and understanding reflected in the assumptions underlying the study.

## *COMPUTERS AND THEIR USE IN OPERATIONAL RESEARCH*

### General

136. The advent of what has been termed the computer revolution has contributed to the growth, development, and acceptance of OR and computers are now used widely in OR. The rather complex problems often encountered by operational researchers may require vast amounts of computation that would be too time-consuming to be done by hand. Accordingly, the development of electronic digital computers has been a real asset to OR.

137. Computers are, of course, useful wherever considerable computation is required and in OR they are particularly useful in solving problems and models in linear programming, allocation, sequencing, replacement studies, simulations of all kinds, and in applying such techniques as simplex and Monte Carlo.

138. There was a time, perhaps somewhat brief, during the early days of the widespread use of computers when managers and decision makers, including those in the military, may have been awed by the rapidly increasing recognition of the great computational capabilities of computers. In those days for the scientist or engineer to say 'that's the answer the computer gave us' may often have been enough to convince some of them, irrespective of inputs. But such is no longer the case and management is now well acquainted with the GIGO (garbage in, garbage out) aphorism and quite aware that computers are merely tools. The latter fact, unfortunately, is sometimes overlooked by OR people who become obsessed with the process of programming itself and unless checked will spend time and effort writing a computer program when it is not required or where a suitable program, with or without some modification, is already available.

139. There is also a growing body of opinion that most computer programs are over-optimized. Unless a program or algorithm is to be used for a very large task or very many times, a relatively simple implementation running only a very little longer than the best possible version will often suffice. The implication for the OR analyst is clear: do not write a computer program when it is not needed or a suitable one is available, and do not spend time and effort in trying to develop the best possible program when a less sophisticated version will do the job. Here again, we see a possible application of Occam's razor.

140. It may be worthwhile to note a few features of the use of computers that are pertinent and should be helpful in practice.

a. A model should be devised and developed before considering whether or not to use a computer.

b. Certain steps in a model may be deterministic and might be dealt with separately by a computer while other steps are not.

c. A computer program perforce follows a set or sequence of steps and is not easy to change if some important factor has been omitted from the sequence.

d. The speed of computers is an asset that can be exploited to advantage, particularly in the re-use of well-tested models previously dealt with manually.

e. The pace of some military operations is such that human reactions are too slow to control the sequence of events. In these cases, control can be exercised by computers and the model of the operation must be a computer model.

f. The write-up of a computer program is not a substitute for a detailed description and explanation of the actual model which has been developed (cf.a. above).

g. Operations actually carried out with computer assistance may sometimes best be analyzed by use of a computer model; but equally it is often advantageous to look at the same operation without using a computer to ensure that a result or output is improving the operation and not just using the computer more.

141. In an article entitled Hooked on computing (54), it is pointed out that obsessive use of the computer may be detrimental to the social development and perception of reality of the computer "junkie", the "compulsive programmer", and the "hacker". This modern fixation can afflict the OR worker and result in much loss of valuable time and talent. It may require a conscious effort to prevent becoming a compulsive programmer and the OR analyst contemplating a computer program should always check out the implications noted in the preceding paragraphs.

142. It is probably not necessary to provide the reader with references to computer use in general. However, a few references (55, 56, 57) are supplied in the interests of completeness.

## Computers, Information, and Security

143. One of the major benefits ascribed to the computer is its ability to provide access to relevant information on the subject under study from a wide variety of sources, and indeed the claim is sometimes made that it can provide all known information on a particular topic. There is enough truth in this to cause great concern that information is too easily available to persons who have no need for it or who want to use it for illegal or nefarious purposes. The security of computer information is a major problem at the

present time and seems likely to continue to be one, especially in the military field where protection of classified information is a continuing pre-occupation. It is still difficult to find fully secure computing facilities, and where they exist they remain secure only by imposing stringent restrictions on access, programs, and output. As a result there is much less exchange of complete computer analysis of secret military problems between countries and establishments than research staff would like, and more emphasis on developing one's own programs for one's own problems.

144. The way out is, of course, the use of models. Models can use the parameters of classified systems without recording the connections to the real system, and can exploit the calculating capabilities of the computer to the full without revealing the significance of the results. With their own programs analysts can be, and indeed must be, aware of the real implications of the figures they produce and be able to explain them to sponsors and others with a need to know. Analysts must resist the temptation to conclude that since they can't explain their results to everyone, there is no need to explain them to anyone; clear exposition of one's work is always a necessity.

## TESTING MODELS AND THEIR SOLUTIONS

145. The fourth phase of an OR project, as mentioned above, is testing the model and its solution. As noted in the preceding section, the validity of a model depends on how accurately it predicts the relative effects of the possible alternative courses of action and it is not usually

easy to determine what is sufficient accuracy. Accordingly, there is always a requirement to test the model and its solution or output.

146. There are several ways in which a model may not be adequate. A model is inadequate if it gives the wrong answer or cannot be induced to give answers at all, and, in the former case the analyst must be able to recognize a wrong answer. Some of the reasons why a model may be inadequate are as follows. It may include factors or variables which are not relevant or significant, or it may fail to include one or more that have a significant impact on the system's effectiveness. It may not express the right functional relationship between E, the measure of effectiveness, and the pertinent or significant variables, or certain input parameters may not have been evaluated properly. It is important to ensure that as far as possible these sources of error are eliminated or reduced.

147. Possibly, preliminary checks can be made, including making certain that no obvious errors or oversights have been allowed in formulating the problem or designing the model. A second useful check is to verify that all mathematical expressions are dimensionally consistent in the units employed. Another helpful course of action is to vary the input variables and parameters of the model to see if the results behave in a reasonable and desired manner. If it is judged that they do not, some modification of the model is indicated.

148. What is sometimes called a retrospective test can be used as a check. It involves using historical data in the model to see what would have happened if the model had been used to predict what solutions or outputs would have been

given at that time. Comparing the results with what actually happened may then indicate where the model needs to be modified and whether the model tends to give satisfactory performance.

149. If there is reason to think that the model is a good one, we can begin by testing the model as a whole. If we do not have high confidence in it, we can first test those aspects which give us cause to doubt the value of the model. If the test of the model as a whole indicates that it is not adequate, then more testing is required to determine which of the four types of deficiencies mentioned above is, or are, present. The techniques that can be used for testing for these types of deficiency are usually statistical in nature. For example, to test whether a certain variable has what the statistician calls a "significant" effect on the measure of effectiveness one can use correlation or regression analysis or analysis of variance or covariance (15).

150. In many cases it is convenient to carry out sensitivity analysis to determine how sensitive a model or formula is to small changes in the values of input parameters. The main concern here is that the model may give large variations in the solution when the parameter values are changed slightly. If such is the case, these values must be estimated with great care. Indeed they probably indicate some new problem and a need for re-modelling. Such sensitivity analyses are of particular concern in linear programming and allocation problems, but should be applied whenever convenient in testing OR models.

151. If the model is going to be used repeatedly, it is necessary to check it and the solution after the initial use or implementation to make sure that they continue to be valid. Establishing such control is discussed in the next section.

152. Further information on testing models can be found in Refs. 19, 20, 21, and 58. In particular Ref. 20 discusses at some length the kinds of data that may be available for making the necessary tests and how the data should be collected.

## ESTABLISHING CONTROLS OVER OUTPUTS

153. Having developed an acceptable model and solution, or output, it may happen that the output is to be used frequently, although in many cases a model may be used only once. It is clear that the output will remain valid for the real problem only as long as the model remains a satisfactory representation of the system or operation involved. But conditions are always changing in the real world and some of these may seriously affect the model, e.g. the values of input parameters may change enough to invalidate the model. Therefore, use of the model must be controlled so that it is not used with invalid or inadequate inputs as otherwise any outputs or solutions will be invalid and worthless. If the model is used for future situations, the validity of the future inputs must be explored.

154. To exercise such control, a general overall surveillance of the whole problem and situation should be maintained and systematic procedures for checking the model and solution should be established. To do so the critical input

parameters have to be identified using sensitivity analysis. Then procedures are required for detecting statistically significant changes in each of the critical parameters. In many cases, control charts such as those used in statistical quality control (59) can be used for this purpose. Whenever such changes are detected the model, solution, and resulting course of action must be adjusted accordingly, or a new model developed. In practice the need to update a model may not often arise, but it is important to check and determine whether or not the need exists.

IMPLEMENTING THE SOLUTION

155. The last phase of an OR study is to implement the solution reached, or the conclusions made, in the study or the report. Too often the OR analyst or team does not consider implementation of their findings a matter of direct concern to them but it should be for the following reasons.

156. First, when the solution, or preferred course of action is put into operation, certain shortcomings may become apparent and the OR people are those best qualified to suggest the proper adjustments or modifications. Secondly, when the solution is translated into a workable procedure, it should be as accurate a translation as is feasible, and again the OR analysts can best see how to minimize the loss in solution effectiveness resulting from the translation. Thirdly, on occasion there may be a tendency on the part of the sponsor or decision maker not to use the solution, or not to give it sufficient weight in arriving at a decision. It is important that the results of an OR study be taken into proper account if the benefits of the OR study are to be realized. The OR workers frequently position to see that

the results of their work are used and used properly, but they should be concerned that they are used and do what they can about it. There are normally several inputs to a major decision and the value of that OR input should not be lost in the decision making process.

157. The OR team should encourage the active and ongoing participation of the sponsor of the OR study in all stages of the work, including evaluating the solution. By doing so, the results of the OR work will have more impact on the relevant decision and enhance implementation of the findings.

158. Implementation, of course, occurs more readily when an acceptable solution that is understood by management is reached. It is the responsibility of both the OR analysts and the sponsor or management to see that the findings are translated into workable procedures, but the major responsibility lies with the sponsor and the management. Further information on testing, controlling, and implementing solutions and outputs of models may be found in Chapters 15 and 16 of Ref. 19 and in Part IX of Ref. 20.

## SOME LIMITATIONS IN OPERATIONAL RESEARCH

159. Some limitations and difficulties in the theory and use of OR have been mentioned earlier. And some others should be noted before finishing this chapter.

160. The problems involved in constructing models and ensuring that, as far as conveniently possible, they are adequate representations of the real situation under

investigation are often quite numerous and difficult. It is also not easy to determine whether a model is adequate and how adequate it should be. Also, even when one is satisfied with the model, or method of solution, there are often limits to getting acceptable input data to use in the model. Particularly in assessing the relative merits and performance of systems not yet in operation, no actual performance data are available. In such cases the OR worker may have to make use of manufacturer's specifications regarding performance characteristics to have any reasonable data. Such inputs may well be somewhat suspect so that the robustness of the models being used, that is their lack of sensitivity to small changes in input values, becomes very important.

161. Frequently, OR solutions are satisfactory in a comparative sense but have real limitations with respect to how good they are in absolute terms. Unfortunately this rather general limitation is often overlooked by the OR analyst, and unless proper care is taken to avoid it, by the manager or decision maker as well.

162. An interesting discussion of limitations of operational data and of expert opinion in OR work is given in Ref. 26. In a different context, limitations in the form of fallacies in OR are considered and debated in Ref. 60.

163. Limitations of and fallacies in OR are referred to here merely to note that they do exist and to alert the OR practitioner to them. As a creation of imperfect human beings, OR as practised does have its shortcomings, imperfections, and deficiencies. The OR worker ignores them at his peril.

REMARKS AND SUMMARY

164. This Chapter deals with principles of OR, discusses models and their use in OR, and presents information on deriving solutions from models, and other matters of interest to the OR practitioner. Eight general principles and one specific one are noted. The general ones are: the need for a clear and explicit definition of the problem; a mutually agreed and understood aim or set of objectives; an agreed set of assumptions; elimination of unnecessary factors; a choice of a measure of effectiveness or objective function; scientific methodology; objectivity; and timeliness.

165. The more specific principle is that six steps or phases are involved in all OR projects. These phases are each treated at some length. The OR analyst should always check to make sure that these phases have all been adequately covered, as appropriate, in all OR studies and projects. These phases are: formulating the problem, constructing a model, solving the model, testing the model and its solution, controlling the solution or outputs, and implementing the solution, conclusions, or findings.

166. Processes, problems, and models frequently used in OR are discussed and reviewed. These are inventory, allocation, waiting-time, replacement, competitive, combined, sequencing and coordination, and search processes, and associated problems. Some discussion on models and their construction is presented along with comments on certain limitations and deficiencies in modelling.

167. The section on deriving solutions to models mentions the two basic ways, analytical and numerical, gives some

general description and directions for solving the various models, and also discusses other methods of solving OR problems including simulations, war gaming, graphical methods, approximate and "quick-and-dirty" solutions, feasible and optimal solutions, and ranking. There is also a short section on computers and their use in OR in which some possible misuses of computers are mentioned.

168. The last three phases of a properly conducted OR project (Testing the Model and Its Solution, Controlling the Output, and Implementing the Solution) which are sometimes overlooked in OR practice, are discussed briefly. Attention is drawn to the responsibility of the OR analyst or team in implementing the solution, that is having the solution applied to the original problem and having it included in the decision making process.

169. The Chapter closes with some comments on limitations in operational research.

# CHAPTER III - MILITARY OPERATIONAL RESEARCH

## SPECIAL FEATURES OF MILITARY OPERATIONAL RESEARCH

### A Basic Difference Between Civil and Military Operational Research

170. In the typical civil OR problem the activity to be examined is already in operation, or being carried out in some form, so there is relatively little difficulty in collecting the information and data necessary for analysis. Thus, in general, major effort can be devoted to devising suitable models and methods for analysis and optimization rather than in searching for relevant data. As a result, OR literature contains many elegant models for non-military OR problems which are usually quite inapplicable to military OR problems.

171. On the other hand, many military OR problems are concerned with equipment or tactics for a military operation some years in the future. The form that such operations may take, and exactly when they will occur, are unknown. But unless the military planner makes a serious attempt to forecast future change in military activity he will be accused of incompetence and of preparing to fight the last war over again. The difficulty is that most of the information for making forecasts comes from the last war, previous ones, or recent ones that may not be representative of future ones. The military OR analyst must find some acceptable way of updating or adapting such information, determining the parameters of the operation applicable to the future, and then

making a forecast of the outcome at some future date. Moreover, it may be wrong to select what appears to be the most likely future operation and to optimize performance in it, since doing so may lead to inadequate performance in other future operations which are almost as likely. In fact, the most useful general concept in military OR may be that of "satisficing" (19) rather than optimizing, that is making sure that there will be 'adequate' performance over the whole range of possible future operations rather than top performance in only one.

## Defining the Problem

172. The importance of developing a well-defined statement of the problem has already been emphasized and doing so is particularly important in military OR, for several reasons. First, most military OR problems require solutions as inputs to policy or procurement decisions which usually have to be taken on, or before, a fixed date so that it is essential that no time be wasted by starting work on the wrong problem. Secondly, the point of view of the military officer and of the OR scientist, and their interpretation of the meaning of terms in a statement of work can be quite different, so that the statement should be as clear and unambiguous as possible. Further, the posting of military staff, the military project officer or sponsor, or both, may change during the course of an OR study, so that again the problem definition and work statement should be precise, clear, and as unambiguous as possible to avoid a change in direction and aim before the study is completed.

173. As already noted (Chapter I), it is critical in military OR to understand and be sure of the objectives of

the military sponsors and also be certain that they really want a study or investigation undertaken. It may be necessary, in some cases, for the OR team or analyst to discover an area or problem that should be studied and bring it to the attention of the responsible or responsive military personnel. If this can be done in such a way that the military personnel are convinced of the need, or feel that they are aware of, or have recognized the problem and the need, so much the better.

174. Other features of military OR which apply to OR field units, and those at military headquarters, are the tendency for the senior OR analyst to be called on to act as a scientific advisor to the respective Commander, and the fact that numerous small tasks often of a mathematical or statistical nature arise almost on a weekly, if not daily basis, which the OR staff can assist the military staff by solving. If working relations are congenial and mutually supportive, as they should be, many opportunities for such assistance will come up and the OR staff should always respond positively. Similarly, OR staff can gain much knowledge and assistance from military personnel which may be required to understand the nature of military problems.

175. The general considerations and caveats presented in Chapter I, in the sections on problem formulation and statement of the problem, are particularly applicable in military OR. Similarly, the section on approaches to problem solving is pertinent in military OR and should be kept in mind in preparing to work on any military problem.

Agreement on Assumptions

176. Decisions concerning how to do the work, i.e. formulate the problem and construct a model for its solution, should be rigorously reserved by the OR analysts. However, the sponsor or military project officer should be informed of the proposed measure of effectiveness or the kind and dimensions of the expected outputs. Also, it is essential that agreement be reached between the OR people and the military sponsors or management about the basic assumptions that are to be used as the underlying substructure or postulates for the study. It is not uncommon in military OR to have some assumptions altered during the course of a study because of a change in sponsor, tactics, or some unforeseen political development. Accordingly, it is wise to check the basic assumptions with the appropriate military authority before the study is completed, especially if it is a prolonged one. There is perhaps nothing more frustrating and disappointing to the military OR scientist than to have the results of good work discarded because military decision makers state that they do not agree with one or more of the underlying assumptions.

Obtaining Data

177. A feature of military OR that often causes concern and difficulty may be termed the lack of 'hard' data. While data on the performance of men and machines can be more or less readily obtained in peacetime exercises and trials, data from wartime experiences are not easily had. As well, performance data of new equipment not already in the field or in operation are not available, even in peacetime, although data in the form of manufacturer specifications are

often at hand. In some cases, data can be obtained from current wartime situations in which new equipments not previously used in combat are being employed. However, in general, such data are not representative of data that would be available in a war in which Canadian forces and materiel were engaged. Thus, much care and judgment must be exercised in selecting and using such data in OR studies.

178. Data from such sources as peacetime exercises and trials, ongoing or recent armed conflicts, manufacturers' specifications, or from previous wartime experience (i.e. historical data) must always be treated circumspectly by the military OR workers. And it is important to identify the origin of any data that are used from such sources. It must always be kept in mind that, almost invariably, performance in battle is degraded relative to that expected on the basis of peacetime experience. But just how great the degradation will be is not easy to determine.

179. Other possible sources of data for military OR problems are the use of such techniques as simulation, the Monte Carlo technique, war gaming, and computer programs. All of these are only approximate representations of the actual wartime situations and the caveats mentioned above about models and fallacies in OR apply particularly to military studies.

180. The use of what are generally termed 'field trials' is a special area of military activity. As used here, field trials refer to tests, trials, or experiments carried out by any element of the Armed Forces on land, in the air, or at sea. The purpose of such trials is to gather data on one or more aspects of the particular activity for later study and analysis. Military exercises on the other hand are mounted

to practice and train service personnel in assigned roles or in preparation for combat. Both field trials and military exercises may provide the OR people with opportunities for gathering data and statistics for simulated military operations.

181. During active operations in wartime, it is usually possible to say whether an operation was successful or not, but there is little opportunity to determine how and why. This is because it is seldom possible to record what is going on in an engagement without interfering with the engagement itself or, perhaps, just appearing to do so. This kind of consideration applies, of course, not only to active wartime operations, but is also present in exercises and trials; it has therefore been a continuing concern in military operational research to collect factual information on military activities without introducing an observer bias. An early example of this was the recording van used to monitor anti-aircraft artillery engagement in the United Kingdom (UK). Before their use the artillery battery had little idea of its own performance; with a van even the accuracy of fire could be measured. In general, however, measurement of operational performance during combat was, and is, seldom possible. But on the cessation of hostilities it became possible to send teams over the battlefield to examine damage, interview participants, and compare actual results with what had been expected on the basis of previous knowledge of weapon performance. This was done in Europe and elsewhere at the end of WW II and produced a vast amount of factual information on the actual performance of weapons in battle which has been a mine of information for military OR ever since. In many cases there was a great difference between actual and expected performance and usually the reasons for the difference could be determined.

The importance of this information is clearly illustrated by US experience in Viet Nam where the theoretical expectation of damage produced by heavy US raids was wildly different from the damage which actually resulted, a fact which should have been known but was not appreciated until it was too late to correct the error.

182. The outstanding example of post-war collection of information is the report of the team sent to examine the effects of the nuclear explosions at Hiroshima and Nagasaki which provided what is still (fortunately) the only direct information on the effects of nuclear weapons on highly populated areas in war. The value of such information retrieval operations is well recognized and is still a factor in the concept of field teams. Such teams are set up by some defence departments to accompany military forces on active operations, to record events, and assess performance as well as to provide technical advice.

183. It is no exaggeration to claim that information and data gathering and its interpretation are the main activities of operational research staff. It is pointed out elsewhere in this chapter that the typical military OR problem is concerned with creating an adequate defence for the medium to long-term future - it would be more accurate to say that this is a continuing preoccupation of the military planner. The acquisition of major items of new capital equipment such as ships, aircraft, tanks, and artillery is a very expensive business which can produce major crises in the defence, and even the national, budget. So it is not surprising that a great deal of effort is devoted to producing detailed, factual, and, hopefully, convincing studies of why there is a requirement for the capital equipment in question. Such problems are relatively few in number but

very persistent; the analysis can last for years, particularly if new criteria are introduced from time to time as is frequently the case. These major projects are usually the responsibility of ORAE as a whole or of a team. The individual analyst will normally be producing information documents relating to some particular aspect of the study. Even if an acquisition of a major item of equipment is approved and undertaken it will be some years before it is actually deployed. There is a considerable gap in time between the present unsatisfactory state and the hoped for future in which the Forces will be re-equipped and restructured, and an even longer gap from the time that current force structures and procedures were developed and the current equipment was acquired. It is this period that is the main sphere of activity of military OR. Required activities include:

a. Tracking the changes in external conditions, which include changes in the threat, technical developments, development in management concepts, changes in the strategic picture, and changes in social attitudes to military activities.

b. Studying how to maintain defence capabilities with existing, and perhaps obsolescent, weapons and equipment, with diminishing resources of men and material, and in the face of a possibly increasing threat.

c. Assessing the effects of improvements in performance, and new developments in equipment and tactics as a guide to future re-equipment.

d. Monitoring the force structure to ensure that a capability is retained for future expansion in the event of war.

184. Almost all the work done on these activities can be classified as military OR. Sources of information relevant to these activities include the following, some of which have already been mentioned:

Historical reviews of warfare;
Military records and war diaries;
Military indoctrination pamphlets;
Accumulated military experience of active operations;
Military exercises;
Development and user trials of equipment;
Past operational research studies; and
Information on current problems and new difficulties from active military commands.

All this is useful information to provide a starting point in researching current problems and future difficulties but it seldom provides a clear guide to future analysis. For this, military OR analysts must look elsewhere for what they consider relevant information and adapt it where necessary to the military milieu through what is recognizably a preliminary OR study. To a great extent the military OR study provides the basic data for investigating the future and improving on present performance. Examples of the kind of information which can be developed are:

a. General models of system performance which allow us to predict the performance of a new system from its physical characteristics even before a prototype exists. There is a wide variety of such models from the simple, e.g. the normal distribution as a model of firing accuracy, to the very complex, such as the "Effects of Nuclear Weapons", by which the effects of a nuclear warhead can be scaled (61). It also includes operational systems, such as air-interception, airlift, tank combat, etc.

b. Limiting studies (of which the book "The Limits to Growth" (62) is a well-known example) which derive limits to the development of new systems because of known physical limits to such factors as size, weight, speed, detection capability, accuracy, range endurance, in the light of the present state of the art.

c. General parametric models which determine performance as a function of several physical variables for which a range of possible values is known or can be estimated (these are models well suited to the computer age).

d. Threat evaluation studies are very necessary for problems related to planning future defences or future force composition generally. They may involve collection of data relating to world-wide technological development and international relationships.

e. Few things change so much between war and peacetime as social relationships involving the military. These changes affect many peacetime military activities such as peacekeeping, dealing with terrorism and security, and studies may be necessary to set new limits to the acceptable use of force. Other changes, such as affirmative action for women, may be pertinent. It is difficult to determine trends since some changes may arise merely from the wartime-peacetime transition, others may be permanent social developments.

f. Analysis of failures. Problems arise when normal operations are found difficult or impossible to carry out for some unidentified reason. Often the reasons for the failure are suspected and can be tracked down and analyzed. This is frequently the first stage of an OR study which can sometimes be more useful than speculating on possible solutions to the problem.

g. Re-evaluation of historical data. A comprehensive review of military activities over a period of years has been found to be of considerable value in providing a reliable basis for forecasting the likelihood of similar events in the future, by providing both data for OR studies and general information for military planners. Examples are the ORAE Review of Arms Control Proposals and the Compendium of Conflict (63, 64).

h. Alliance Studies. Canada's military structure is, to a great extent, influenced by Canadian commitment to international alliances and groupings which make their own plans for co-operative action, notably NORAD, NATO, and various United Nations groupings such as the Eighteen Nation Disarmament Conference (ENDC). Military OR is recognized as a valuable source of data and information for such plans, and this is one area where Canada endeavours to participate to the full in Joint studies. In doing so, Canada not only helps the alliance, it receives a great deal of information on developments in the world, for example on strategy and the application of technological developments.

i. In many countries, military management is one of the largest management operations in the economy. It is no accident that many new management techniques have originated in the military environment. As a result there are many techniques available which, however, often need considerable further work to adapt them for practical use, and there is still scope for the development of new ones. Operational research affords a good approach to such problems, and among other things it can help to discourage a tendency to overmanagement.

j. Civil OR. Although military and civil OR have to a considerable degree developed separately over the last 20 years, there is still a considerable overlap and some commonality of methodology. Specific areas of overlap are in OR related to management, social and economic studies, and decision theory. Military OR specialists should not neglect the general literature on these topics.

It frequently happens that the collection of data will provide a sufficient answer to the sponsor's request without extensive analysis.

## Determination of Methodology

185. The particular model to be constructed in seeking to solve a military OR problem, or the method of solution, will depend on the type of problem and the OR analyst's knowledge and experience. If the problem can be clearly identified as

one of the several problems or processes described in the preceding Chapter, then the method of solution will follow from the appropriate one discussed briefly in the section on deriving solutions from models, with further details being available in the quoted references.

186. Although one should be prepared to take advantage of computers in solving military OR models and problems, the OR analyst should decide early in the process whether a computer program or simulation is really required. Many military problems do not require sophisticated mathematics or vast amounts of calculation. Often the careful formulation of the problem will reveal that some elementary mathematics or statistics, and quite limited calculations, are all that is needed. The example quoted above about the RAF Fighter Command problem in World War II is a good case in point.

187. Again, in debating on the methodology to be used, it will be helpful to apply Occam's razor, or the parsimony principle, in respect to both the assumptions to be made and the method of solution to be used. The OR practitioner should also always be aware of the 'keep-it-simple' principle and not try to baffle the sponsor with unnecessarily complicated mathematics or sophisticated models and solutions where they are not really required.

188. The matter of timeliness will always have a bearing on the methodology to be used in attacking a military OR problem. If the problem has to be answered in a very short time, recourse may have to be had to a 'quick-and-dirty' approach or a 'back-of-an-envelope' analysis and calculation. Discriminating judgment and great care must be exercised in applying such short cuts and approximations. And the fact that the results are at best rough estimates should be made known to the sponsor or proper authority.

189. Assuming that the problem has been clearly defined and is understood unequivocally by all concerned parties, the OR team or individual scientist must go about formulating the problem, choosing an appropriate measure of effectiveness and, in effect, constructing a model or procedure for solving the problem. Having done so, it is advisable to check these steps with a senior experienced OR scientist such as a director or section head before embarking on solving the model and testing the solution. Much valuable time and effort can be saved by validating these early stages of work before proceeding further with what may be a somewhat inadequate model and plan of action.

190. Further relevant comments on OR in solving military problems in DND are given in Refs. 65 and 66.

## TYPES OF PROBLEMS

### General

191. Types of problems for military operational research are conveniently defined in relation to the fundamental defence problem which is summarized in the following terms:

a. What defence will be necessary for Canada in future years?

b. What force structure and equipment will be required to provide that defence?

c. What information is necessary to determine those requirements and implement the necessary changes?

d. How can that information be obtained, analyzed, validated, and utilized in support of the general aim of determining the future defence structure?

e. What gaps and deficiencies in defence now exist and how can they be filled until a long-term solution is reached?

f. How can management best cope with current deficiencies and facilitate the transfer to a new structure?

These questions are a perennial concern to the defence organization as a whole, and naturally to the military OR element as part of the defence organization. ORAE does not have the sole responsibility for solving these problems, although it is frequently asked to present its views of what the solution might be. But it does have a unique role to play in the generation of solutions.

192. Any of the types of processes and problems discussed in Chapter II under recurring processes and problems may arise in a military context. Other types of problems including searching for targets, problems requiring opinions and reactions from users or experts, strategical and tactical problems either political or military in nature, problems involving the design and analysis of field trials and military exercises, and war gaming may also be encountered in practicing military OR.

193. More specifically, the military OR analyst may often be called on to conduct cost-effectiveness studies to provide inputs to decisions concerning force composition, or the procurement of new detection, avionics, weapons,

communications, or logistics systems. Still other problem areas in which military OR may be requested to provide analyses, studies, and inputs arise in manpower and personnel, social, economic, and policy issues and concerns. Military OR work can also involve addressing such problems as how existing military equipment may be better used, how tactics can be improved, and how military performance can be measured and assessed.

194. Another area where the OR staff may be asked for analysis and inputs is defining desirable characteristics and specifications for new military systems to be procured in the future. Here, the OR people can provide data on performance characteristics, reliability specifications, quantities required, and on other quantitative aspects of the system under study.

195. Mention has already been made of the many small tasks, mainly of a mathematical or statistical nature, that may arise fairly frequently at the request of the military staff with whom the OR people are serving and working. Many of these will be the sort that can be quickly solved by the trained scientist. They should be welcomed as opportunities for useful assistance and for establishing credibility and acceptance. However, the OR staff must be careful not to allow themselves to be drawn into or involved in a lot of trivial small tasks that the military staff may be quite capable of handling themselves.

196. It is clear from the above that the OR analyst may be expected to undertake analyses and studies on a very wide range of problems. Many of these will be concerned with present and future operations and OR staff may investigate past operations and conflicts as a source of data or as a

guide to military operations in general. They can also expect to get involved in economic, personnel, social, strategic, and policy matters. Thus, they will need to be knowledgeable about approaches to problem solving, and capable of devising models for many different processes and situations. On the operational side, appreciation of, and familiarity with, military operations are a prerequisite for the proper formulation of problems and modelling operations of personnel, equipment, and machines. The best way to gain these attributes is through field postings, by participating in live exercises and field trials as observers, and by collecting information while so participating. It will be helpful to study reports and histories of campaigns and past military exercises.

## Field Trials and Surveys

197. Problems being studied by conducting military field trials require sound knowledge of the design and analysis of experiments such as may be found in Refs 67, 68, 69, and elsewhere. Perhaps four essential general principles in designing experiments of any kind should be noted. First, the experimenter who does not anticipate any inferences but merely waits to see what will turn up in the data, cannot support any conclusion whatever by a confidence probability statement. The second principle is closely related to the first: the method of analyzing the data obtained from the experiment should be determined before conducting the experiment. Thirdly, there must be an element of randomization in the experiment if any statistical inference, i.e. quantitative reasoning from the sample in the experiment to the population, is to be made. Finally, non-observance of

these principles may make it impossible to derive any supportable conclusions, inferences, or generalization from the findings of the experiment. Unfortunately, this fact is not always recognized and sometimes erroneous and invalid conclusions are made which can have disastrous effects on the decisions that are based on the results of the experiments.

198. From time to time attempts have been made to standardize the terminology of field trials and tests. Such terms as troop trials, acceptance trials, engineering trials, technical trials, and others have been used by different nations to describe field experiments of different kinds. Irrespective of the terms used or the purpose of such trials with troops and equipment or clothing, they should all be planned, conducted and analyzed in accordance with the principles of the statistical design of experiments. A short account of terms used in military field trials with definitions and examples is given in Annex C.

199. Unfortunately, it is often thought that any scientist or engineer can readily plan, conduct, and report on any field trial. Perhaps the worst aspect of this misconception is that such persons are not aware that special knowledge and skills are required for doing trials properly and usually reach conclusions about the results that, unknown to them, are completely invalid. It is to avoid such errors that ORAE established the Directorate of Mathematics and Statistics to design experiments and analyze the results and provide mathematical support to other ORAE directorates and the Canadian Forces.

200. Survey methods are used in connection with many military problems as a means of obtaining information on a variety of topics. Some of these are: personal reaction to

new equipment or clothing; feedback from service personnel and the public about policies and the impact of military bases on socio-economic aspects of communities; and opinions about the acceptability of proposed changes and other existing or new items.

201. It is frequently thought that anyone with reasonable common sense can conduct a satisfactory survey. While common sense is important, the carrying out of a good survey requires an understanding of statistical theory, familiarity with sociological and psychological methods, and sufficient mastery of computing techniques to plan for handling large quantities of data. To avoid the many possible pitfalls which too often occur in conducting surveys, both training and practical experience in the social sciences are useful and desirable.

202. It is not possible in this brief report to discuss all the phases of a survey which include:

- Design of the questionnaire content;
- Questionnaire construction;
- Deciding on questions to be asked;
- Deciding on those to be questioned and interviewed, and how many;
- Determining method - interviewing or mailing;
- Recruiting, training, and controlling survey personnel;
- Preparing raw data of survey for analysis;
- Defining and selecting categories for analyzing that will assist interpretation;
- Analyzing the returns.

203. Information on, and discussion of, these phases and survey research methods in general will be found in such references as (70), (71), and (72). It should be noted that

surveys can produce only approximations, never precise measurements, and that criteria have been developed for preparing questionnaires and conducting interviews. A set of these is presented in Annex D.

## Problems Solved by War Games

204. War gaming has been used to provide data, insight, and training in all three armed forces elements - land, sea and air. A main reason for war gaming is that conducting exercises with military personnel and equipment is generally very costly in time, money, and personnel. War games can be played with only a few military players or civilian scientists, or preferably with a combination of both.

205. War gaming is a type of simulation involving real decision makers. Types of war games vary from a fully manual game, that is, one that imitates war and is played by hand on a stylized layout to fully abstract models that represent war mathematically or in a computer program. There are also manual games that are computer assisted. It is not possible in this report to give a detailed description of war games. Relevant information is available from many sources, for example Refs. 19 and 73.

206. In the Canadian Department of National Defence, war gaming at present is limited mainly to gaming for the Land Forces, although gaming in one form or another is sometimes done for the Air and Maritime Forces also. The games are sponsored by the Chief Land Doctrine and Operations and are played mainly in support of the Directorate of Land Combat Development. Games may be played at different levels, e.g. battalion, brigade, division. The games are designed to

preserve detail, be manually operated with computer assistance, and have a high degree of flexibility. Actual play of the games is by Armed Forces officers who are posted to the Directorate of Land Operational Research (DLOR) for the purpose. Scientific members of the Directorate staff cooperate with the military staff particularly in developing rules and assessing the findings.

207. The war games are used primarily as a research device to investigate such issues as:

- Testing operational doctrine, concepts, plans and tactics;
- Assessing weapons effects and equipment performance;
- Evaluating organizations or force compositions;
- Providing data for the Land Combat Development staff to use in making recommendations to higher authority.

The war gaming facilities are also used in Command post exercises for training military personnel in conducting field operations.

208. As mentioned earlier a vast amount of effort is involved in preparing and testing the rules of the game which control the development and outcomes at each and every decision point. How the rules are developed, how a game is played, how records are maintained, and how problems are solved by war gaming are beyond the scope of the present treatise. Only by considerable reading and actual practice in playing in a war game can one become familiar with the many aspects of, and inputs to, a war game. The interested reader will find relevant information in the above-mentioned references and in Refs. 74 and 75.

Information for Future Defence Planning

209. The unique role of military OR is to play the leading part in obtaining, validating, and utilizing information required in support of the general aim of determining future force structure. This can be expressed in other words as *providing the basic factual information for future defence planning*. The whole activity centres in the military operation, and the structure of ORAE is designed to generate the necessary information about it. The main categories of information and the ORAE directorates involved are as follows:

a. The context of future operations, including types, magnitude, location, participants, degree of sophistication, arms limitations, public attitudes and morale, and economic limitations (Directorate of Strategic Analysis (D Strat A), and Directorate of Social and Economic Analysis (DSEA)).

b. Evaluation of future operations. This is primarily the development of measures of effectiveness of equipment and performance of military formations or systems allowing for variations in conditions and tactics. Quantitative comparison of performance of different force structures, tactics, and weapon systems is made possible by using these measures (Director General Operational Research (DGOR), DLOR, Directorate of Maritime Operational Research (DMOR)), and Directorate of Air Operational Research (DAOR).

c. Analysis of gaps and deficiencies. This is usually the study of how to carry out operations in the face of shortages in manpower and inadequate equipment, which sometimes also leads to the definition of new requirements. There is also the definition of requirements for operational roles not now carried out, but which may be expected to arise in future hostilities. If the deficiencies occur in current military activities, the studies will involve the field sections; if they relate to new activities, they involve the DGOR directorates, primarily.

d. Management problems under conditions of limited resources and during transition to new structures, including wartime mobilization (Directorate of Manpower Analysis (D Man A), Directorate of Logistics Analysis (D Log A)). This also involves the improvement of management techniques and is the one area in which the results of OR studies may be directly implemented. Field sections may also be involved in studying local management problems and conflicts with central management.

The above categorization affords a general guide to the type of work done in each directorate and field section in ORAE. The categorization is not absolute and major problems can, of course, involve two or more directorates and field sections. Such problems may be dealt with by the formation of special project teams. A reference to the ORAE General Analysis and OR program of any year will confirm this categorization. Thus, the programs of the DGOR directorates (DAOR, DLOR, DMOR) each contain at least one project relating to future requirements or future force structure, but their main effort is devoted to the study of particular types of military operations and the development of models and techniques for evaluating performance in these operations. D Strat A devotes a great deal of its effort investigating questions of nuclear strategy and deterrence and assessing developments in force postures and arms control in terms of their implications for deterrence and the stability of the nuclear balance. However, such context studies are usually less amenable to modelling than is combat evaluation when the nature of the combat is known. This means there is more scope for the development of new and better models than exist now. D Log A and D Man A spend most project time in improving general management procedures for regular operations in the expectation that good management procedures will largely eliminate the need for "crisis" management, will facilitate transition to a future state of the system, and will save money in peacetime, while improving or not adversely affecting performance in war. DSEA is concerned mainly with social and economic aspects of military life and operations and with their interactions with the civilian society and economy. The Directorate of Mathematics and Statistics (DMS) provides mathematical and statistical support to the other directorates and to the military as required.

210. Defence planning is an extensive and multi-faceted exercise which at National Defence Headquarters and Field Commands involves much more than military OR and analysis. The interested reader will find much pertinent information on defence planning in such references as (76), (77), and (78).

## RELATIONS WITH SPONSORS

### General

211. In military OR projects and studies are normally undertaken for some military sponsor or interested authority. In principle the relationship between the OR analyst and military management is not different from that in the non-military environment. But there are certain subtle differences.

212. In the first place it may be quite difficult for the military OR analyst to determine who the real decision maker is and what his or the sponsor's real objectives are and develop a well-defined, mutually understood statement, of the problem. As a result, problem formulation may be more difficult in the military context than in the non-military one and great care is required to make sure that there is no misunderstanding at the problem formulation stage of the work.

213. Secondly, the military sponsor or officer may not be well acquainted or conversant with the scientific approach to problem solving, nor have had previous experience with OR people, and may be somewhat apprehensive and cautious in dealing with them. This reserve may cause difficulties in defining the problem or task and in getting agreement on objectives and assumptions. Despite many years of productive OR support for the military, there are still many military personnel who have not heard of OR, or, if they have, do not know what it is or what it can do for them, and are therefore not very kindly disposed towards military OR. There is a continuing need for education and this can be better advanced by deeds than by words. But in order to

produce the needed evidence of useful OR work, projects must be initiated and an environment of mutual respect, trust, and understanding is necessary. OR workers at all levels should seek to foster this atmosphere and gain increasing credibility.

214. On the other hand, the newcomer to military OR may feel self-conscious and inept in the presence of military staff and attempt to compensate with simulated self-assurance or professional jargon. In either, or both cases, it may not be easy to establish an atmosphere of mutual understanding and respect, but without it the OR workers will be unable to be really successful. They may, indeed, find themselves trying to solve the wrong problem or have the findings not accepted by the sponsor because of some misunderstanding about an objective or assumption.

215. If the military sponsor, project officer, or staff has had little or no previous experience with OR work, they may feel threatened in the sense that they should have been able to undertake the problem themselves or that they reckon that their responsibility is being encroached upon or eroded in some way. It is very important that the OR analysts dispel this feeling by making it clear that they are helping, rather than competing or threatening, and in particular that at best they are providing a quantitative input to a decision and not trying to be the decision makers.

216. It is important that the OR analysts make sure that they study the operation involved until they really understand it and that there is no misunderstanding about the problem or project under consideration insofar as its statement, objectives, and basic assumptions are concerned. It is also relevant that OR personnel do not give the

impression that they know more about the operation than military personnel do. They must exercise tact and discretion in discussions and dealings with the military.

217. One other general comment should be made. It concerns writing reports on a project, either as progress reports or as the final account. Most OR organizations have a more or less standard format for the various kinds of reports they issue. The concern here is with the writing rather than what is written. In most cases in military OR the audience is the military sponsor or officer and their staffs, and they must be kept in mind while writing for them. The main text of a report should be as short as conveniently possible and contain what may be called 'the minimum amount of essential information' required to present the basic conditions of the study and the findings. Mathematical and other details should be put into annexes or appendices. In any event the junior OR analyst should consult the team leader, section head, or director for directions about how to prepare the OR report.

218. In may also be observed that over the years, the military have developed rather special writing styles and use many special military abbreviations. Military OR staff must become acquainted with these abbreviations which are now NATO standardized. This manual of abbreviations is Ref. 79.

## Levels of Sponsorship

219. The question of sponsorship is of course much broader than the sponsorship of individual projects. At least four levels of sponsorship can be distinguished:

a. Overall sponsorship;

b. Functional sponsorship;

c. Program sponsorship;

d. Project sponsorship

Overall sponsorship is concerned with the continued existence of the military OR activity as a whole. Initially sponsored by the Defence Research Board as an independent scientific activity, OR is now sponsored by DND as a whole through the Policy Branch and the Deputy Chief of the Defence Staff (DCDS). This sponsorship has two major advantages. The Assistant Deputy Minister (Policy) has a voice in all future activities of the Department and can support ORAE involvement in virtually any DND activity and the DCDS is concerned mainly with doctrine and operations. Secondly, as a scientific activity OR does not work with expensive items of equipment and is relatively cheap to carry out. Moreover, through its concern with cost-effectiveness it is a force for economy in military expenditure; its own cost-effectiveness is therefore relatively high and this is a strong factor in favour of its continued existence.

220. Functional sponsorship covers the question of who military operational research is done for, and is the controlling factor in the internal structure of ORAE. All ORAE directorates, and field sections, with some exceptions, have a specific sponsor who will fight for the continuation of the directorate or section and to maintain a fair share of the OR resources. DMS is sponsored by ORAE itself to provide a service for the other directorates, but it can also do work for other elements of DND which do not have direct links to other OR directorates.

221. Program sponsorship is where one gets down to details. The program of a directorate is worked out by direct consultation between the director and his principal sponsor in advance of the ORAE annual program review. It is done in the light of the sponsor's priorities and the director's resources. This is not done for field stations, but in this case the heads of the stations must provide a sufficient listing of, or rationale for, their activities to justify their continued operation at the Command.

222. In the process of defining and approving the program the principal sponsor nominates a project officer for each project who will act as sponsor for that project. The director will nominate the analyst or analysts responsible for working on it, and the important sponsor-analyst relationship can continue to operate.

223. While the directors of ORAE must necessarily concern themselves with all levels of sponsorship, individual analysts in directorates need only maintain contact with the project officer or sponsor of the project they are working on and follow the guidance of their director. The head of a field station has a much more difficult problem. In this case the sponsor is considered to be the commander, and the incumbent must act as a local director to sort out the Commander's priorities and the OR station's own resources. In practice the sponsoring is usually done by officers at the working level, who reconcile their tasks with the Commander's priorities. The field station is also, to some extent, sponsored by a director in ORAE and must ensure that its program is not in conflict with other work in the related directorate. The head of the field station needs all the tact that he can muster in sponsor-analyst relationships.

Access to Sponsors

224. It may not always be possible or politic for junior OR workers in a military environment to have direct or frequent access to the sponsor of a project, or to the decision maker. Indeed, such access is seldom needed and the newcomer should not expect to enjoy direct access at will. The importance of having direct access to senior military officers when it is deemed necessary is emphasized by the fact that at some field stations direct access to the local commander on special occasions is written into the terms of reference of the senior OR analyst. Normally a senior OR officer, such as a director or director-general, will have access to senior military and civilian personnel as required. The junior OR analyst will have occasion to meet sponsors of projects and should always cultivate good working relations with the military project officers for the project on which he, or she, is working.

225. An excellent way to become acquainted with senior military staff and to learn much about many facets of military organization and operations is to participate in exercises and trials, troop concentrations, and manoeuvers. These are the best possible peacetime vehicles for understanding actual wartime operations and becoming familiar with most phases of military activities. The newcomer to military OR should welcome any opportunity to take part in any of these activities and in joint study groups or task forces concerned with military operations. To become an effective and productive military OR worker, it is not enough to be well acquainted with all OR textbook techniques (80).

226. There are two other factors that may affect the relations between military sponsors and new military OR staff. The first is a very general one: the fact that the background and training of military staff are quite different from those of civilians. Military personnel are more accustomed to rather rigid discipline, are more conscious of rank structure, and have a more developed sense of esprit de corps than is generally the case with civilians. As a result, civilians coming to work closely with military staff for the first time may find the environment rather strange, strained, and constraining, and encounter difficulty in becoming comfortable with it. However, they should realize these differences, understand the reason for them, and learn to adjust to ensure harmonious working relations. The second factor is the requirement for stringent security measures which must be observed although they are quite restrictive. But one gets used to security regulations, particularly those concerning handling classified material, and observing them becomes a readily accepted habit.

## The Team Approach

227. As mentioned in Chapter I an important characteristic of OR is the team approach. This characteristic is particularly important in military OR and associated general analysis studies. The use of teams of civilian scientists or engineers and military officers has proven very productive. In some cases the military officer can bring both training in science or engineering and military experience to supplement the knowledge, skills, and experience of the civilian OR and analysis people. Even if the military members do not have any special training in science, or

experience in actual warfare, they are able to provide important military insight, experience, knowledge, and judgment to the team effort.

228. Combined military and scientific teams have proven very productive in military OR on formal OR projects, in war gaming, and in general analysis investigations such as strategic, logistic, manpower, and socio-economic studies. A recent recruit to military OR, working on such a team, can profit greatly from the experience of working closely with military officers on a common project. The Operational Research and Analysis Establishment (ORAE) has, for many years, made good use of joint teams of military and civilian members, teams of scientists and engineers, and teams of scientists and personnel trained in the humanities. Such teams can be very effective, as they provide stimulation to all team members, and ensure that several approaches and points of view are brought to bear on a problem.

229. In many cases it is necessary for the analysts to work alone on a study, but they should never work in complete isolation, particularly if they are newcomers to military OR and analysis. Occasionally, analysts may find themselves working on more than one project or as a member of more than one team. This practice can be quite a fine learning process for the newcomer.

## MILITARY OPERATIONAL RESEARCH IN CANADA

230. In Canada all military OR is conducted by the staff of the ORAE or by outside agencies under contract to ORAE. The great majority of it is done internally in ORAE. The present ORAE has evolved over a period of more than 40

years. Accounts of the origins of OR in Canada, which began with the military, are given in Refs. 3, 4, 7, 8, 9, 10, and 12.

231. Suffice it to note here that action on organizing OR in Canada began in August 1942 and the first OR office was set up in Air Force Headquarters in September 1942 and consisted originally of one scientist, Dr. J.O. Wilhelm. The first OR field unit at a military headquarters was also set up in September 1942 at Eastern Air Command in Halifax, Nova Scotia. The complement of this section was never more than three in number.

232. The interested reader will find detailed accounts of the origin and development of OR for the Canadian Forces in the references mentioned above. In particular, Ref. 4 describes the growth of OR in Canada from the origins in 1942 to the early 1980s. After WW II OR for the military was provided by scientists and engineers who were employees of the Defence Research Board. The organization of military OR resources went through a number of changes before assuming its present status as the ORAE, whose complement of staff is 150 personnel consisting of 82 defence scientists, 21 military officers, 6 military other ranks, and 41 support staff.

233. A comprehensive outline of ORAE is given in Ref. 81 which described the organization, staffing, and work of the establishment in broad terms and includes an organizational chart. All personnel joining ORAE should become well acquainted with this guide to ORAE as soon as possible. Since this document is readily available in ORAE its contents will not be repeated in the present report.

234. In brief, it is remarked that ORAE is divided into two main operating parts, the General Analysis Division (GAD), with five directorates, and the Operational Research Division (ORD), with three directorates and one special unit, the Electronic Warfare Operational Research Team. In addition, six small sections, called field sections, are stationed at military commands. These are tasked by their respective military commanders, but each is associated with an ORAE directorate mainly for career and personnel matters and can call upon ORAE for scientific or other support.

235. The directorates of the ORD are the Directorates of Air Operational Research (DAOR), Land Operational Research (DLOR), and Maritime Operational Research (MDOR). Those of the GAD are the Directorates of Mathematics and Statistics (DMS), Logistic Analysis (D Log A), Manpower Analysis (D Man A), Social and Economic Analysis (DSEA), and Strategic Analysis (D Strat A).

236. The field stations are the Operational Research Division at Maritime Command (ORD/MARCOM), the OR Branch at Air Transport Group (ORB/ATG), and OR sections at Maritime Forces Pacific (Victoria, B.C.), Air Command (Westwin, Manitoba), at Air Defence Group (North Bay, Ontario), and at Headquarters Canadian Forces Europe (Lahr, Federal Republic of Germany). At present there are also four special postings of ORAE personnel to Mobile Command (St. Hubert, Quebec), North American Air Defence Headquarters (Colorado Springs, Colorado, USA), SHAPE Technical Centre (The Hague, Netherlands), and to the SACLANT Centre (La Spezia, Italy).

237. The general nature of the type of research work carried out by the ORAE directorates is indicated by their titles. Thus, the three directorates of the ORD conduct OR for the Air, Land, and Maritime Forces respectively.

238. The titles of the directorates in the GAD give a general indication of the work undertaken by each of them. However, the inclusion of an organization described as doing general analysis in a manual dealing with military operational research deserves some comments. At the time the GAD was named there were some people who felt that the work done in the directorates making up GAD was not operational research. This was rather clever of them since there was, and is, no generally accepted definition of operational research. Whatever the general view may be, the definition preferred by ORAE for military OR is research into operations involving the military. By this definition a lot of the work in GAD is military OR and a fair amount of the work in ORD is not. Thus D Log A and D Man A study real operations of logistic supply and manpower allocation, whereas DLOR, DMOR, and DGOR may be studying weapons which do not now, and may never, exist; such studies can hardly be described as "operational". The authors of this manual have had no hesitation in including examples of the work of all ORAE directorates in their Introduction to Military Operational Research and are prepared to defend the choices they have made.

REMARKS AND SUMMARY

239. This Chapter discusses some special features of military OR, the types of problems often encountered in doing OR for military sponsors, and offers comments on relations between the OR people and military sponsors and their staffs.

240. The special features include the difficulty in obtaining data, the particular importance of clearly defining the problem and getting agreement on objectives and

basic assumptions. Comments are offered on initiating projects, performing short-term tasks, and acting as scientific advisors. As well, emphasis is placed on the general considerations and caveats presented in Chapter I.

241. Some problems in obtaining data for military OR studies are mentioned and some helpful suggestions are made regarding sources of data, including field trials and exercises. Methodology used in military OR may be any of the standard OR models, elementary mathematics or statistics, or some quick-and-dirty solutions.

242. Types of problems considered include recurring problems, search problems, those requiring opinions and reactions from users or experts, and strategical and tactical problems. Others requiring the design and analysis of field trials and military exercises, and war gaming are mentioned and discussed. In all, eight different types are discussed. Four essential principles in the design and analysis of field trials are cited and criteria for preparing surveys and conducting interviews are presented in Annex C.

243. Some comments on relations between military sponsors and OR workers are submitted that should provide some guidance for newcomers to military OR. Also some remarks are made about report writing, access to senior military officers, and about the use of joint military/civilian teams for performing OR or general analysis studies. The Chapter also has a short description of military OR in Canada.

## CHAPTER IV - EXAMPLES OF MILITARY PROJECTS

### INTRODUCTION

244. The purpose of this Chapter is to present some examples of actual OR projects that have been done by the directorates and field stations of ORAE. In choosing the examples, the only criteria were to select projects that are representative of different kinds of military OR work done in Canada, that involve different methodologies, require different models or methods of solution, and that are practical rather than theoretical. A common requirement was that all projects selected had to be completed and reports on them prepared and published.

245. The general approach in presenting these examples has been to give a brief description or statement of the problem concerned, state the aim of the project, mention the measure of effectiveness or cost-effectiveness used, outline the methodology employed, and note the results obtained, and any implementation that may have taken place. The reports on all these projects are available in ORAE and the reader will need to refer to them for details and full descriptions of the projects.

246. The examples chosen from the work of the ORAE directorates are presented below under the two operating divisions of the establishment.

EXAMPLES OF PROJECTS OF THE OPERATIONAL RESEARCH DIVISION

## A Weapons System Cost-Effectiveness Study

247. A good example of a weapons system cost-effectiveness study was published in an ORD report in May 1965. It was a comparison of anti-aircraft (AA) guns. The problem was how best to defend Canadian ground troops against low-flying enemy aircraft. The aim of the project, which was done by DLOR, was to determine the most cost-effective weapons system for the defence of a Canadian brigade in an European theatre against low-flying aircraft, using AA weapons available at the time, which in 1964 were AA guns.

248. A total of 46 AA systems, comprising the guns plus their sighting devices or fire control systems, were considered. Ten guidelines were agreed with the sponsor as the basic assumptions underlying the study. Certain criteria were used to reduce the number of available systems to be studied to ten. These were of four different calibres, eight different gun barrel configurations, and two different types of fire control - visual or radar.

249. Six different hostile aircraft and three height-speed combinations for each were selected as the enemy vehicles in consultation with the sponsor and Intelligence advisers. The vulnerable areas of these aircraft were then estimated in a manner described in detail in the report.

250. A computer model was used to calculate the probability that an aircraft would be shot down by one gun of each type and the combined effect of a group of guns deployed in a brigade area was determined. In calculating kill probability, account had to be taken of degradation in gun

capability by terrain masking of the aircraft target from the weapon, by imperfect detection of exposed targets, and by gunner reaction times. A model of detection was used to determine where during the exposed segments of flight the aircraft is detected by the gunner. Having determined where the enemy aircraft is both exposed and detected, a simple firing doctrine was assumed to find the beginning and end of an engagement. When these were defined, it was possible to calculate the kill probability based on weapon characteristics (type of fire control, rate of fire, accuracy, projectile size, and velocity, etc.) and target characteristics (aircraft size, vulnerability to projectile being used, height and speed combination, etc.). For each weapon the single pass kill probability was determined for each of eight crossing distances, each of three height and speed combinations, and each of six aircraft targets. The single engagement kill probability was the basic factor in calculating the effectiveness of the AA guns against aircraft targets.

251. A measure of effectiveness for each weapon against each type of aircraft over a range of crossing distances was needed to permit a comparison of the effectiveness of the different gun systems. The measure used was the so-called equivalent lethal diameter. This term may be new to the reader but it is, in effect, the kill probability over the complete range of the weapon, and is described more fully in the report. A detailed description of the computer model used and the method of applying it is given in the report.

252. Equivalent lethal diameters were calculated for the ten gun systems selected for each of the aircraft heights and speeds, and summarized in a table. Taken together with the number of guns in a battery these results were the basic effectiveness figures required for the cost-effectiveness comparisons.

253. For costing purposes the three principal components were procurement costs, additional capital costs (basic equipment, war stores, service equipment), and operating costs (services to the AA unit, maintenance costs, training costs, and personnel costs). Estimating personnel costs involves consideration of organizations that would be used for deploying the various gun systems. Indeed, making reliable costs estimates for weapons systems in operation is quite a complicated matter. Again, details of the costing procedures used are given in the project report.

254. In presenting cost-effectiveness results in such a study the exact nature of the threat is a most important parameter. For example, it may often happen that, in a cost-effectiveness comparison of two gun systems, one will be better against slow speed targets, while against faster targets the second system will be superior.

255. In this study a threat composed of equal numbers of each of the target aircraft types and each height-speed combination was selected as the basic representative enemy attack configuration. But material was provided in an Annex of the report which could be used for making comparisons between the systems against many other types of threat should it be desired to do so.

256. Using the effectiveness results and the chosen representative threat the main findings were presented in the form of two graphs. The first of these shows the procurement cost in millions of dollars as a function of effectiveness (number of guns multiplied by equivalent lethal diameter). The second shows total system cost over 10 years as a function of effectiveness. Thus either the most

effective system for a given procurement or total 10 year cost, or the least costly system that would give any desired level of effectiveness can easily be read off the graphs.

257. An interesting feature of this study is that the results are presented in such a way that they could be used in answering many possible questions concerning the cost and effectiveness of AA guns. In fact, the results were so used and were an important input to a decision that was made regarding the air defence of Canadian troops in Europe. Other noteworthy features were the large number of relevant factors (terrain masking, imperfect detection, reduced reaction times, firing doctrine) that were taken into account. None of these were subjected to sensitivity tests for significance of their effects on outcome (kill probabilities) as it was known from previous work that they were indeed significant factors.

258. In outlining this example and following ones, no mention is made about the important matter of defining and formulating the problem, nor is this matter discussed at length in the respective reports. However, in each case considerable thought, discussion, and negotiating took place before the statements of the problems and their aims were reached and agreed.

259. A related study concerning an AA weapon system done by ORD staff is described in Ref. 82.

## A Maritime Air Defence Study

260. The defence of a convoy of merchant ships against enemy air attack is a matter of continuing concern to Canadian maritime planners and operators. In 1983 a study was undertaken by DMOR to assess the effectiveness of certain air defence systems in the role of convoy protection. This study formed part of a major maritime air defence project and was reported on in a DMOR Staff Note.

261. The basic problem was to evaluate the effectiveness of a set of air defence systems defending unarmed merchant ships crossing the Atlantic Ocean in convoy, assuming that the navy escort vessels carrying the defence systems were not themselves objects of attack.

262. The convoy consisted of a fixed number of merchant ships and the threat was assumed to be posed by enemy missiles. The defensive system comprised four missile types for which some thirteen characteristics were known or assumed. These characteristics which governed the missile capabilities imposed both temporal and spatial limitations on performance, which had to be taken into account. The threat was assumed to consist of raids of waves or ripples of five enemy missiles, each ripple varying in azimuth, with attacks being equally likely from all directions. The five missiles in any ripple were assumed to come from about the same direction, but each ripple from a different direction. Three generic attack profiles were considered but these were assumed not to be mixed in any single raid.

263. Four distinct steps were used in the analysis:

a. Footprints - A computer program was used to evaluate the capability of each weapon system against each threat. The results were presented as contour maps or 'footprints'.

b. Convoy Coverage - The convoy was introduced and using the 'footprints' a manual operation determined the azimuthal coverage against a single threat for a chosen target.

c. Ripples - Using a Monte Carlo analysis, ripple and random effects were generated by a computer program. A sector by sector analysis gave, from the convoy coverage, the number of penetrators in a wave (each sector was 60 degrees).

d. Raid Analysis - The single ripple data were used to give the result for a series of ripples or waves, i.e. a raid.

Details about developing the contour diagrams or 'footprints', for each defensive missile system modelled against each threat profile considered, are presented in the report as are details on convoy coverage, waves of missiles, and raid analyses.

264. The measure of effectiveness used in the main air defence study was the percentage of ships in a convoy of a given number of ships that survived when attacked by a raid of a given number of missiles. Results and comparison of various alternatives are not given in the report described here but can be found in the main maritime air defence study report.

265. A large number of assumptions was made in undertaking this study and these are spelled out in the Staff Note. Many of these were made to simplify the analysis, a common practice in OR work.

266. The discussion section of the Note describes the advantages of the methodology used and limitations of the methodology and of the analysis in general. It is interesting to observe that the methodology was selected primarily to respond quickly to the project whose general nature was known, but for which parameters and systems were not immediately available. This situation is not uncommon in military OR and the OR analyst must be adept to devise methodologies that may be quite innovative and involve some lateral thinking. In this case a method or model involving four steps was developed that allowed re-examination of, or changes to, any of the steps without affecting the manner of treating the other steps.

267. It will be clear from the above that the results of the assessment methodology used in this study were incorporated in the more general study of which this one formed a part. Such an OR study which is done to provide quantitative inputs to a task force or study group is frequently undertaken by ORAE staff.

## An Evaluation of Ground Based Interceptors

268. This project is reported in a DAOR Staff Note (83) which states that the "Basic Interceptor Evaluation Model" (BIEM) was developed specifically for the New Fighter Aircraft program to assess the basic abilities of the contending aircraft as ground-based interceptors.

269. There were in DAOR many previous programs and models for assessing the capabilities of ground-based interceptors which would have been used to answer questions about aircraft capabilities. Why then develop a new program? It was not that the previous programs were unsatisfactory; they had already proved themselves capable of giving reasonable answers. It was rather that it was now realized what specific information was essential for the relative evaluation of the fighter option in the air defence role and that it was worthwhile to construct a new model to provide that information as quickly and economically as possible. The author provides a "nutshell" description of the model from which the following can be quoted:

> "Given a number of flight profiles for an interceptor and some assumptions about ground radar coverage, the model tests the aircraft's ability to attack bomber raids flying in a series of parallel tracks at varying offsets progressing outward from the committed base. Time, distance, and fuel parameters are all monitored within the model, as are missile kill probabilities, detection and redetection probabilities, combat tactics, etc., in order to generate the bottom line for each simulated intercept the expected bomber kill by the fighter."
>
> "Ground radar coverage is modelled in two separate ways..." (A continuous band across Canada, or the coverage of actual radar sites.)
>
> "This model ... accumulates the probabilities involved during the intercept to obtain the final kill. The fighter's tactics and hence the sequence of missile firings by the fighter are predetermined."

270. Some of the significant features of the model are as follows:

a. The "given" flight profile for aircraft options are in fact available from earlier studies relating performance to design characteristics;

b. The modelling of radar coverage is simple but known to be adequate from many previous air defence studies;

c. It is known that the number of interceptors to be available will never be enough to destroy a mass raid before penetration. The primary criterion of defence effectiveness is coverage, i.e. the ability to engage a single aircraft on any path, which at least has a deterrent value, provided there is an appreciable chance of a kill in the engagement;

d. "Predetermined" fighter tactics have no sinister implications; it merely means making the assumption that the fighter uses the time of contact to the best advantage in carrying out repeat attacks.

271. This project provides an excellent example of the effective use of the computer in OR. The following points are noted:

a. The mathematical formulae are deterministic so the calculations required are done extremely quickly. The variation comes in the conditions of intercept, choice of mid-path, particularly the offset of interceptor and radar sites and interceptor bases. Consequently, there are a very large number of individual calculations.

b. The computer output can be designed to organize the extensive output so that all the essential information regarding a specified bomber-interceptor combination can be displayed on one sheet. This sheet gives the coverage of an interceptor base in terms of the maximum effective distance to bomber track that can be covered and the kill probabilities associated with different offsets. The use of the standard "band" radar coverages in each case then allows for direct comparison of interceptors by comparing the corresponding output sheets. From these sheets it is possible to decide whether the present layout of interceptor bases can provide full coverage given a particular interceptor option or whether additional bases might be needed. Again, comparison of the band radar and actual radar results indicate whether present radar coverage is adequate.

272. Finally, it is noted that the choice of a new fighter aircraft is not the responsibility of ORAE; there are very many considerations that must be weighed and tradeoffs considered. It is ORAE's task to provide information to help in the decision process, and the more clearly and unambiguously the information requested can be provided the better. It also helps if the work can be done at short notice. In that this project represents improvement in the operation of providing information to the sponsor rather than just an improvement in a model or computer program, it is undoubtedly good operational research.

## EXAMPLES OF PROJECTS OF THE GENERAL ANALYSIS DIVISION

### Introduction

273. In the ORAE OR program, there is a tendency for projects to encompass themes such as "studies of air defence operations" rather than to list individual projects in air defence. On the general analysis side the same tendency occurs and is even reinforced by the fact that major projects develop in parallel with the methodology to solve them and it may take several years before the means of solving problems is developed to the point where it is really useful to the sponsor. Having reached this stage the project may be continued indefinitely. In describing an example of such a project it is necessary to show the process of development. Often the project does not pose a specific problem but requires answers to a variety of questions arising in the field of interest and frequently allows the OR investigator the freedom to select what he considers the most appropriate areas for study. It is more informative to describe the project as a whole rather than the separate studies as if they were independent.

### A Nuclear Weapons and Arms Control Study

274. This problem in the form of ballistic missile defence was the problem which led to the formation of D Strat A, and it is still active. The problem is that there is a declared policy not to deploy nuclear weapons in the Canadian forces, but that Canada through its alliance commitments may have to fight in nuclear conflict. In effect the environmental force elements have no responsibility for nuclear weapons, but they are a matter of great concern to military planners

and policy makers. The project is essentially to provide information and analysis on possible wartime situations involving nuclear weapons to military planners. This includes assessment of the likelihood of nuclear conflict, which in turn requires an assessment of the prospects for nuclear arms control.

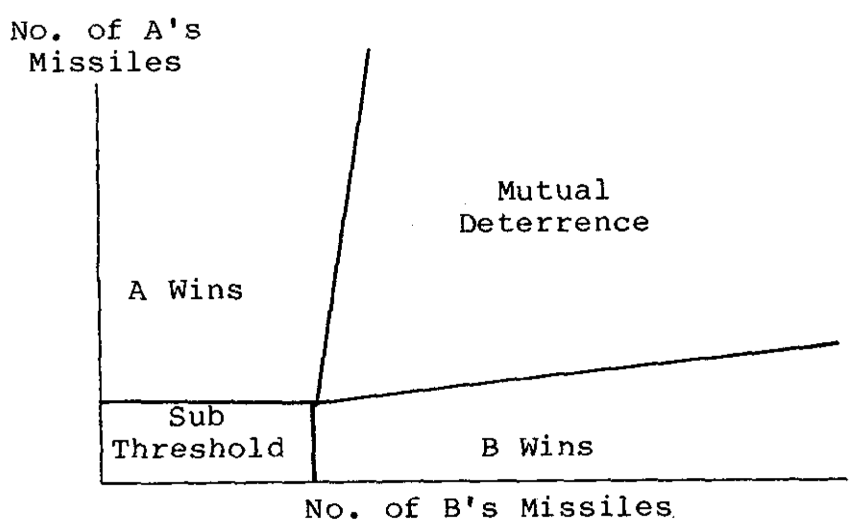
275. In a complex and rather vague project, definition of the problem at the various steps in its progress is very important. In this project the first definition is that a nuclear weapon, although very powerful, is a weapon like any other with measurable limits to its destructive power. It therefore becomes possible to consider the outcome of nuclear engagements in a similar way to conventional engagements. Consequently, when there are two nuclear powers in confrontation, it is possible to regard the conflict as a duel. Moreover, since the two superpowers control more than 90% of all nuclear warheads between them, any agreement to limit or control nuclear weapons must be acceptable to both superpowers. Other countries like Canada can submit proposals for control but have no means of implementing such proposals. In spite of this, Canada and other countries have made proposals for control from time to time.

276. The starting point for all methodology for assessing nuclear weapons is the book "Effects of Nuclear Weapons" (84), the official source of statistics on the damaging effects. Although a nuclear weapon explosion is a complex event releasing several damaging agents simultaneously, representation of its effects against a specific target is generally simple, consisting of a circle centred on ground zero (the point directly below the burst) with a radius corresponding to the greatest distance from the burst that

any of the various damaging agents can destroy the target. In the case of ground-based missile sites the important damaging agent is blast pressure. The other factor in weapon performance is accuracy of weapon delivery and estimates of this can be made for any delivery vehicles used.

277. The basic material on effects and delivery accuracy can be used directly to assess the performance of new weapon variants such as the so-called "neutron bomb" or the cruise missile. But it must be remembered that damage produced is not necessarily the measure of effectiveness or success and that further steps may be needed to complete the weapon evaluation.

278. Development of a "Duel" model depends on the fact that one side's land-based missiles are simultaneously that side's attacking weapons and the other side's targets. Combining this concept with the effectiveness measures of missile warheads against land based missile sites leads to a semi-quantitative model with a "set theory" display as in the diagram below.



279. This model has proved very useful in assessing possible weapon developments to see whether they are destabilizing or not. It can be modified to allow for mixtures of different weapons on each side to some degree, but it is not needed in the present situation where each side has enough submarine launched missiles, (whose location cannot yet be determined accurately) to destroy all the other's vital targets. In this situation, mutual deterrence automatically exists. Further information about this model will be found in Ref. 85.

280. For many years the concept of deterrence has been the central tenet of defence policy. The necessity for maintaining deterrence has effectively ruled out any acceptance of unilateral reduction of nuclear weapons and has led to a good deal of international competition to put forward arms control proposals acceptable to both superpowers and other countries. A further step towards understanding and possible agreement in arms control, initiated by OR workers rather than by a sponsor, was to review and classify all arms control proposals that could be found in the records of official bodies such as the ENDC and in academic literature. This rather lengthy operation produced approximately 300 different proposals of which over 40% related to nuclear weapons. The primary method of classification of these proposals is by the verification technique proposed to monitor compliance with the proposal. Very few of the proposals have been adopted and enforced by treaty so the valuable information contained in the proposals collectively was in danger of being lost. The result, published as a "Compendium of Arms Control Verification Proposals" (63) has been widely circulated internationally and generally acclaimed. Beyond its value as an information source of factual data, it can, and does, serve as a starting point

for other studies and evaluations related to Canadian defence policy. The operational research worker who works on or writes up such a compilation may not be doing high powered original research, but he is undoubtedly enhancing the reputation of ORAE as a source of information and results.

## An Equipment Replacement Study

281. An interesting example of an OR study on the replacement of a major equipment item is reported on in Ref. 86. The study was done for the Director of Land Requirements (DLR). The problem was identified and formulated in conjunction with the DLR staff and the many assumptions involved were agreed with them. The problem was defined in terms of its aim which was "to determine the optimum size and load carrying capacity of the heavy cargo vehicles which are to replace approximately 700 5-ton trucks within the next few years". In addition to estimating costs, the objectives of the study were to utilize available supply simulation models to:

a. identify the number of 5-ton vehicles needed to lift a given tonnage of material;

b. compare that figure with those obtained for a range of vehicles of larger capacities;

c. identify the savings in time and manpower, if any, accruing from the use of larger capacity vehicles.

It was decided also to examine the benefits of the selected vehicle having a built-in self-loading capability or a demountable rack off-loading and pick-up system (DROPS).

282. It was agreed that four possible replacement vehicles would be considered, and compared with the 5-ton vehicle in use at the time, in respect of life cycle costs, requirement for brigade resupply, and delivery time relationships.

283. A large number of relevant assumptions concerning costs (both capital and recurring operating and maintenance), and loading times had to be made. These are given in detail in the report along with the respective sources. Current estimates for a fleet of 700 trucks for both capital and basic operating and maintenance costs were taken as the base line case. Assuming that capital expenditures were fixed at $157.8 million, the figure for the base case, the fleet sizes for other types of vehicles were readily determined.

284. To determine the resupply capability of each fleet the number of vehicles of each type required to deliver the daily supply requirements of a brigade group was calculated using an available computer simulation model. It was also necessary to postulate a war scenario. The one selected and agreed was based on a war game played by the Directorate of Land Operational Research. The simulation of the resupply of an independent mechanized brigade group as used in this study is described in detail in an annex to the study report. The same procedures were used in determining the costs and capabilities that would apply if the vehicles studied had a built-in self-load capability or were equipped with DROPS.

285. The measures of effectiveness used were cost per metric ton-kilometer, cost per ton mile, and cost of a service battalion fleet. These costs were based on an average vehicle usage of 7,000 kilometers per year at full load for a period of 15 years. Other measures were timings, personnel required, and fleet life capacity. Special features of this project are the very short time available for the study (1 month), the ready adaptation of simulation models and data previously developed, the detailed tabulation of cost data on a yearly basis for each of the candidate vehicles, and the use of a wartime scenario to provide realism and permit estimates of vehicles lost in action.

286. At the time of writing (December 1984), no decision has been taken on a replacement vehicle. Further work and field tests of candidate vehicles will be required. But this study has provided valuable data for the decision and has contributed to a tentative decision to procure a replacement of greater load carrying capacity than the 5-ton truck.

287. The results are summarized in four tables showing respectively the life cycle cost summary, brigade resupply data (vehicles, personnel, tonnage delivered, timings, and cargo space), cost data, and capability figures.

288. Other ORAE studies on replacement, repair, and life cycle units are described in Refs. 87 and 88 and in papers listed in the Bibliography.

The Social and Economic Impact of a Canadian Forces Base on Its' Host Community (or Environment)

289. The economics of the Canadian Forces in relation to the national economy is a main area of study for the Directorate of Social and Economic Analysis. The impact of a particular base on its local region may be thought to be a very small part of the total economic effect, but it can be very important locally, and being small in relation to the total is something that can be fought for by local politicians with some chance of success. Moreover, the locations of Canadian military bases are a product of history; they may not be best locations for today's force structure. Consequently, the question of closing or re-locating a base comes up fairly frequently. When it does, the critical question is whether what is gained by the change is sufficient to compensate for what was lost by the closure of the base concerned. This project was originally set up to measure the social and economic benefits provided for the locality where a base is situated, as an indication of what the locality would lose if the base closed.

290. Initially it was hoped that a common formula, or at least a common methodology, could be applied to all such cases. There is indeed some commonality in the factors examined; thus in each case it is necessary to determine the boundaries of the local region affected by the base, its population, its economy in terms of public services, health and education. But there is so much variation in these factors between locations that no common formula is possible. It is usually necessary to decide during the course of analysis of a particular case which are the factors of greatest importance and interest and to adjust the method accordingly.

291. The particular example discussed here is "The Impact of CFB Comox on the Comox-Strathcona Regional District" described in Ref. 89. This is a special case because although the impact of the base itself is in question, the problem to be addressed is a reduction in personnel of the base by approximately 25% which would amount to around 2% of the total population of the region. In this case most of the social impacts of the base are hardly affected appreciably and the major impact is economic, although even here the effect is probably marginal. The methodology is therefore selected to examine the effect of the reduction on employment in the region in some detail. The report indicates three types of data:

a. Secondary source material - This includes data on social interfaces with the community, and social and economic statistics relating to the region from government sources.

b. Economic accounts of the base, through the base comptroller with additional breakdown requested by questionnaire.

c. Sample survey of selected base personnel by questionnaire covering education, income, occupation, family data, expenditure, etc.

Analysis of these questionnaires provided basic quantitative data for input-output analysis of the region's economy, the determination of economic multipliers, and the output dollar amount per job in the province (British Columbia).

292. The outcome of the study is a reasonably convincing demonstration that a reduction of 476 jobs on the base would

mean 90 less civilian jobs in the region of the base. The 566 jobs lost represent only 2.1% of the district's total employment and as a result the conclusion is that "the total impact would not be very big". Provincial and local authorities may not agree, but at least there is a factual basis for the decision. It is now becoming almost routine to carry out an impact analysis for any proposed closing of a base or major reduction in staffing, but because of the variety of locations, and varying significance of the base's economic output compared to the rest of the region in which it is located, it is often necessary to devise new or modified techniques for each particular case. A more general study of this type is discussed in Ref. 90.

A Manpower Planning Study

293. The Directorate of Manpower Analysis carries out analyses in support of the Personnel Branch of DND. The essence of manpower management is to ensure that the required numbers of personnel with the right qualifications are available to fill the various positions established for the efficient functioning of the Armed Forces, and that they will continue to be available as staffing changes occur. DND like other organizations cannot find trained staff ready to hire, nor can they fire excess staff without notice. Personnel moves must be designed to keep the established positions staffed, but they must also be made as far as possible in accordance with recruiting rates, attrition rates, promotion rates, etc., which are laid down in policy or are expected from past experience.

294. A basic tool of manpower analysis is the manning model which starts from the present with a set of filled positions in a particular classification, and tracks the

problem of keeping them manned in the future as rates of attrition, transfers, and promotions take effect according to established practice. There are two types of model, the long term one where the objective is to determine rates of attrition, etc., which if maintained would keep the staffing system operating effectively, and the short term model where the objective is to make adjustments to rates to compensate for unexpected divergences from the planned manning level. There are many variants of these models depending on the context of the problem to be solved.

295. A good example of the use of the long-term model is given in Ref. 91. As well as solving a specific problem, this report provides a clear exposition of the building of manpower models and their uses, including a thorough discussion of the variables involved. Moreover, although such models are written as computer models, the report concentrates on the meaning and function of the model rather than the details of the computer program.

296. The particular application in this report is to career planning for specialist officers, whose training and qualifications differ considerably from those in the general service officer classification. A three-tier career development plan, i.e. a plan with three control points in a full officer career, had been developed for general service officers, and the problem for the analyst was to determine whether similar plans could be designed for the various specialist officer classifications. In each model the main variables to be considered were preferred manning level, attrition rates, promotion policies, reassignment rates, and conversion rates at the control points. Perhaps the most difficult part of the work lies in deciding on appropriate values for these variables for each classification, and in

by-passing some complications due to the nature of data records, e.g. avoiding the use of both age and length of service as working parameters. The values of the variables to be determined are steady state values, that is values which if held constant from year to year will result in satisfactory manning levels being maintained over that period.

297. The study did indicate that a three tier career plan could be established for the various specialist officer classifications without requiring any unacceptably extreme values of the control variables, and the feasibility of a change to the three tier career plan was demonstrated to the sponsor's satisfaction. However, in view of certain practical considerations not yet examined, the change has still not been made.

## EXAMPLES OF PROJECTS AT ORAE FIELD STATIONS

### Introduction

298. Projects undertaken at ORAE field stations are conducted on behalf of the local Commander and his staff. There is a great variety in the kinds, complexities, and extent of these projects. An example of an OR investigation conducted at the Maritime Command OR Branch (MC/ORB) is given below and others are listed in the Bibliography.

Surveillance of Fishing Activities in
the ICNAF Areas of Canada's East Coast

299. The abstract of Ref. 92 which has the above title, states:

> "This report presents the results of a fisheries surveillance study which had the objective of bringing the problem into focus and providing more information about this topic, particularly for the benefit of those who are involved in fisheries surveillance."

The study was initiated with the objective of explaining the requirements for surveillance, not only to Maritime Command, but for the Canadian fishing industry and those organizations responsible for regulating fishing in waters adjacent to Canada's eastern coast. In listing organizations involved in surveillance later in the report the following appears:-

> "Maritime Command which conducts surveillance of a variety of activities and conditions along our coastline and out to sea, is probably the principal air observer of fishing operations."

This is sufficient reason for issuing the report under the aegis of Maritime Command, but a considerable demand for copies show that it has been very useful to the other organizations involved. The general information on fishing activities which occupies much of the report is of general interest; the more detailed estimate of air surveillance requirements is of special interest to Maritime Command. In the provision of general information, the following questions were addressed:

a. Why is the surveillance required?

b. What should surveillance cover?

c. Where should the surveillance be carried out?

d. When should the surveillance be conducted?

e. How should the surveillance be accomplished? and

f. Who should conduct and carry out the surveillance?

300. The division of waters of interest to Canada was made according to sub-areas defined by the International Commission for the Northwest Atlantic Fisheries (ICNAF). These sub-areas are aggregated into two groups, Maritime areas and Newfoundland areas, the former including the in-shore areas of the St. Lawrence estuary and the Atlantic areas south and southwest of Nova Scotia. In the Maritime areas the Canadian catch is approximately two-thirds of the total catch, whereas in the Newfoundland areas the Canadian catch is roughly one-third of the total.

301. Difficulties in tackling the problem lay first in finding the appropriate sources for statistical data and having done so to bring the problem of surveillance down to a manageable size. One factor is the distribution of vessels according to size and national ownership. Thus of 49,068 registered fishing vessels 46,431 are vessels less than 25 tons, divided almost equally between US and Canadian ownership with very few from other countries. Most of these are near the coast and it was suggested that the Canadian vessels, given suitable communication, could monitor the activities of foreign vessels in near coastal areas. The remaining 2,637 vessels are over 25 tons and distributed 1,741 foreign, and 896 Canadian. These fish the deep-sea areas further from the coast, are in many cases much larger

than 25 tons, and relatively thinly spread in the area where they fish. These are the vessels requiring air surveillance to ensure that they comply with fishing regulations. Further, certain sub-areas are fished only during certain months of the year, or are fished mainly by Canadian vessels during certain months. It was suggested that surveillance is required only in those months and sub-areas where the foreign take exceeds the Canadian. When these various considerations are taken into account, it becomes possible to calculate the number of surveillance sorties required per year and the flying hours required for adequate surveillance of each sub-area. Although this is the main quantitative result, it is by no means the only useful output of the report. By collecting most of the relevant data concerning fishing activities in one place, it has provided basic data for planning the monitoring of foreign fishing activity and it has made a number of practical suggestions for extending surveillance and coordination of all sources of information to provide a central service.

302. The monitoring of fishing activities is a subject that recurs with more prominence whenever fish catches are low. *Further work will be done on the surveillance problem*, but perhaps not in DND, which has merely a back-up responsibility for monitoring fishing activities.

COMMENTS AND OTHER EXAMPLES

303. The preceding examples of military OR work done in ORAE will give the reader some idea of the variety and scope of the studies being done by the Establishment. A complete list of current and ongoing projects is given in the annual General Analysis and Operational Research Program. A full

understanding of the examples just described will require careful reading of the reports and, in some cases, of the references given in the reports.

304. Other field section reports the reader will find instructive are listed in the Bibliography.

305. All ORAE completed studies and projects are written up in formal and informal publications. Copies of all these documents are available in the ORAE library or in the directorate or field section concerned. A list of titles of all publications is held by the editorial staff, and partial lists are given in Refs. 93 and 94.

306. A very interesting and informative article dealing with experiences encountered in learning how to apply formal quantitative analysis techniques learned in university to 'the real world' is given in Ref. 80. This article includes an account of developing and selling a new information system (The Aircraft Maintenance Management Information System) in the Canadian Armed Forces. It concludes with a list of twelve lessons learned in doing so. It is a good example of military OR work which military OR staff will find instructive and rewarding.

DEFINING, CONDUCTING, AND SOLVING ORAE PROJECTS

307. In ORAE it is convenient to recognize two stages in defining an OR or general analysis project. The first is getting the problem. This is not necessarily the concern of the individual researcher although it often is. There is in ORAE an established procedure for suggesting, sponsoring, and accepting new projects and deciding which directorates

will be responsible for them. This procedure involves discussion and negotiation with interested directorates and officers of National Defence Headquarters, or of the field Command concerned. It terminates in the annual General Analysis and Operational Research Program. This program consists mainly of major projects of considerable scope, some of which are of a continuing nature. Within these projects specific sub-projects or studies may be identified, defined, and conducted. About seventy percent of ORAE resources are assigned to the annual program. The remainder is reserved for projects which arise on short notice and for ORAE initiated research of an exploratory nature.

308. The second stage is the formulation of the problem. This subject and related ones have been discussed in Chapters I and II but is so important that further remarks directed specifically at military OR are warranted. The following is a listing of the considerations involved which was originally drawn up specifically for military OR workers in Canada and is still pertinent to present day activities:

a. How is the end result to be measured? Are we concerned with savings in cost, manpower, casualties, time, with increased damage to an enemy, or any other measurable quantity?

b. What is the scope of the problem, i.e. where do we stop in our investigations? For example, in weapon assessment can we stop at damage production, or do we face the further complication of measuring efficiency?

c. What criteria are to be adopted? Are we concerned with comparative or absolute effectiveness? Are we maximizing or minimizing some quantity or just looking for a reasonable increase in performance?

d. What are the variables or parameters involved, i.e. what factors influence the quantity to be measured as the end result?

e. Can we reduce the number of variables without appreciably affecting the end result?

f. What are the relations between the important variables and the end result? The definition of these relationships constitutes a "model" of the problem situation which can be used to evaluate results in different situations.

g. What is the range of values of the variables to be considered? Anomalous results can be produced by considering values outside the range that the equipment involved was designed to cover.

h. Can we evaluate those variables for which we have no direct information? If so, how? If not, can we get around the difficulty by reformulation?

i. Are there random variables (e.g. weather conditions) which affect the result? Can we ensure that the variations we hope to measure are sufficiently large not to be hidden by random fluctuations?

j. Is the model such that the process of calculating the end result from the variables involved is of manageable size? If not, can simplifications and approximations be made without sacrificing accuracy in the calculated result?

k. Is the end result of the analysis of direct practical application? If not, how are the practical implications to be explained to the user?

309. The answers to this list of questions and the availability of suitable data may well determine whether the problem can be solved at all. In practice, once given a problem, the OR analyst must endeavour to provide some kind of answer, but he should indicate when doing so whether his answer is firmly based or highly speculative. But the answer will provide an indication whether a quick-and-dirty solution is all that can be given, whether a detailed model should be designed, and whether it is best suited for computer programming or direct logical analysis.

310. There are a few general matters that merit attention in the conduct of an OR study. It is usually beneficial to prepare in advance a draft outline of the report that will be made when the work is finished. This outline normally would contain the titles of the several chapters and as many headings and sub-headings as can be envisaged. For example, the chapter headings might be Introduction, Aim (or Purpose), Assumptions, Methodology, Results, Discussion, Remarks, and Conclusions. Annexes or appendices should also be considered and titles and lists of contents drafted. All these would, of course, be subject to revision as the work progresses and should be checked by the project leader, section head, or director as may be appropriate.

311. It is also usually helpful to schedule times for completing the various stages of the work and writing up the corresponding chapters of the report. It may sometimes be useful to set weekly or monthly goals for completing specified portions of the analysis work and the written account of it. Time should also be allowed for reviewing the original draft by the analysts themselves, and by peers, or their leaders or directors as appropriate. Further time will be required for redrafting and processing the final version. Again, it should be noted that deadlines for finishing studies and reporting on them in written form or in briefings should always be met.

312. In the preceding treatment in Chapters I, II, and III considerable discussion and information on problem solving in general, and on solving OR problems in particular, have been presented. In the examples given in this chapter methods of solving practical military OR problems have been described and demonstrated. From these discussions and descriptions it will be clear that the solution to a military OR problem may vary from quite simple techniques to quite complex mathematical processes or simulations, from back-of-the envelope calculations to the use of sophisticated model formulation that cannot be evaluated numerically. Having devised, selected, or adopted a model or formula and a method of solution, either personally or in conjunction with others, and drafted a proposed methodology, keeping in mind the keep-it-simple principle and the principle of parsimony, junior analysts should have these proposals vetted by a senior OR analyst such as a section head or director. At the same time the basic assumptions should be checked by a senior analyst and the sponsor's project officer. Doing so will yield savings in time and effort, avoid possible embarrassment, ensure that the research gets off to a good start, and perhaps avoid a panic finish.

313. A simple precaution that is often overlooked is checking all entries, calculations, inputs, and outputs to ensure that the results make sense, in both a practical way, and in terms of dimensions and magnitude. A further comment is that having obtained the solution and results they should be reviewed, ordered, and presented concisely. In particular it is very important that the conclusions do not include any statements or judgments that have not been raised and substantiated in the text.

## PRESENTING FINDINGS AND RESULTS

314. The findings and results of military OR studies may be presented to sponsors and other interested agencies in several ways. The three most common ones are by means of formal and informal discussions, by prepared briefings, and in written reports of one kind or another.

315. It often happens that the findings of an OR analysis are required by the sponsor before there has been time to write up a report and get it approved and processed. In such cases the main findings may be communicated verbally in a discussion or meeting with the sponsor or his project officer and staff. In other cases it may be convenient and prudent to give the sponsor and his staff, and other interested personnel, a formal briefing on the work done and results obtained. In still other cases it may suffice to prepare a written report and distribute copies to the sponsor, his staff, and other interested agencies. Also, any two or all three of the above methods of presenting findings may be used or required. Although in all cases a written report of some kind is prepared, briefings and discussions are normally held at the request or wish of the sponsor and his staff.

316. In each of these cases the material involved should be carefully prepared and approved by the project leader, section head, director, or director general as appropriate. Normally, graphs, charts, or tables or all three will be required and care must be exercised in preparing these and choosing the best information and data to go into them. Again the junior OR analyst should get advice and guidance from more experienced personnel before deciding on how best to present the results of the OR work.

317. Reference to the reports mentioned in the above examples will acquaint the reader with the format of the various kinds of reports currently used in ORAE. Some discussion about drafting outlines of written reports has been given in the preceding section and further comments will be found in the following chapter. The quality of the written reports issued by ORAE is an important factor in the reputation of the authors and the Establishment as a whole, as is the quality of formal briefings. Accordingly, much care should be exercised in preparing reports and briefings and making sure that all aspects of the work are scientifically sound and the written record of it is clear, concise, and ready for critical inspection.

318. Two general types of written reports are in use in ORAE. These are the following formal and informal publications.

## Formal Publications

319. ORAE formal publications are reports and papers which are intended to receive formal distribution outside ORAE. There are four types:

a. ORAE Reports: These are formal publications which normally receive wide distribution. ORAE Reports include:

i. the final results of a formal study;

ii. a work of major significance; or

iii. other work that merits publication as an ORAE Report.

b. ORAE Memoranda: Memoranda are similar to ORAE Reports, but more latitude is permitted in the style of presentation. They may cover a wide range of subjects, including:

i. an interim report on a study;

ii. the final report on an informal study;

iii. a visit report;

iv. the text of a speech or lecture; or

v. in general, any work that deserves publication under the auspices of the ORAE, but is less than completely formal or authoritive.

c. ORAE Project Reports: These are reports prepared to describe work done on specific projects to their sponsors and can be either interim or final reports. They present the considered results of project analyses to sponsors and interested agencies in an expeditious manner.

d. ORAE Extra-Mural Papers: Extra-Mural Papers report on work performed in support of the ORAE program by outside agencies and individuals under contract. They are numbered consecutively in a separate series.

It should be noted that many ORAE publications are classified. No classified material has been included or referenced in this report.

Informal Publications

320. The principal informal publication is the Staff Note. Staff Notes are essentially working papers covering separate parts of major projects, descriptions of methodology, results of small studies, and individual contributions of various kinds. They are written as informal records of data, analyses, tentative views, comments, methodology, or briefing material which for one reason or another do not warrant or require formal publication. The contents are the responsibility of the author, and do not necessarily reflect the opinion of the Directorate concerned. Each Division and Directorate maintains its own numbering series.

321. Again, the junior OR staff member should check with a senior analyst for advice in determining which of these categories of publication is appropriate in any given case. At field sections any of these publications may be used but others such as Internal Working Papers are also in use.

322. All publications carry a disclaimer. The wording to be used in each case is given in Ref. 95 and can be found on

the various ORAE publications. The wording of the disclaimers varies with the particular type of document but, in general, they contain the statement that the document does not necessarily reflect or represent the views of the department of National Defence or one of its agencies. In the case of Reports and Project Reports the agency is the Department itself; for Memoranda it is any Departmental agency; for Staff Notes it is the Directorate; and for Extra-Mural Papers it is ORAE.

# CHAPTER V - PROFESSIONAL CONSIDERATIONS

## CHARACTERISTICS AND REQUISITES

323. The characteristics, attributes, and requisites for a successful career in OR and military OR cannot be stated precisely and comprehensively. However, many of them can be identified on the basis of experience and these are presented here as general characteristics common to all good or promising OR analysts, along with other attributes and requisites that pertain to military OR workers.

### General Characteristics

324. Some of the more important of these are:

a. An inquiring, reflective, and imaginative mind and the capability of approaching problems and questions objectively;

b. Interested in science and problem solving and regards problems as challenges;

c. Versatility, flexibility, and willing to change work interests and undertake new projects in different areas;

d. Ability to discuss and negotiate and express ideas lucidly and fluently;

e. Ability to acquire new knowledge quickly and understand the formal and informal organizational structure of the company or business;

f. Ability to communicate easily and effectively, with proper appreciation of the value of other people's time;

g. Recognition of when to talk and when to listen;

h. Background in science, including mathematics, probability, statistics, economics, and management science;

i. Some acquaintance with behavioral and social sciences;

j. Ability to engender good relations with co-workers and clients.

k. Aptitude for 'selling' oneself and the output of OR studies;

l. Having good writing and briefing skills

m. Some knowledge of, or experience in, research work and procedures;

n. Willingness to keep up-to-date on advances and developments in own field of academic interest and in similar fields related to OR research techniques, and in management science;

o. Ability to explain matters and principles to non-technical personnel;

p. Good knowledge of OR techniques which, of course, can be acquired.

325. Among these the personal skills are important (96) but are not covered in formal courses in OR, systems analysis, or management science. In some cases graduates with advanced degrees have never learned, or been taught, to write clearly and succinctly with a good command of grammar and syntax. This deficiency is a real handicap in OR as well as elsewhere. Fortunately this handicap can be redressed or alleviated by study and practice using such an aid as Ref. 97, or by taking courses in writing at a local university. In drafting or writing reports and other papers it is always helpful to have a good dictionary and thesaurus (e.g. Ref. 98) at hand.

Attributes Needed for Military Operational Research

326. In addition to some or all of the above characteristics, an OR worker with the military should have certain special attributes or develop such capabilities as those listed below:

a. Knowledge of the military organization, chain of command, roles, and the national defence program;

b. Knowledge of military ranks and ready recognition of rank insignia;

c. Acquaintance with military authorities requesting and sponsoring OR studies;

d. Familiarity with, and experience in, military exercises and operations, and knowledge of weapons and equipment, and how they are employed;

e. Interest in military matters, plans, and intelligence;

f. A liking for Armed Forces personnel and operations;

g. Behavior must be such that military staff do not see OR and OR workers as a threat to their duties or responsibilities;

h. Willingness and ability to discuss work and projects with senior military staff frankly and openly without excessive assertiveness;

i. Ability and disposition to discuss OR work with military staff without using scientific or professional jargon;

j. Familiarity with military and defence terminology and using it in discussions with, and writings for, military personnel;

k. Willingness to accept postings and short-term work assignments at field stations such as Command Headquarters;

l. Ability to distinguish between real world problems and textbook problems and adjust and react accordingly.

327. For the new recruit to military operational research these attributes and requisites for successful and satisfactory work in the military environment will be developed over time. But the sooner knowledge and familiarity with

various aspects of military matters and concerns are acquired the more comfortable the OR analyst will be, and the more rewarding the work and associations will become.

Remarks

328. From the above list it will be clear that for a successful and satisfying career in military operational research many attributes and skills and considerable knowledge in scientific and socio-economic disciplines are required. In addition some rather demanding personal attributes and characteristics, while not necessarily being absolute prerequisites, are very helpful in generating congenial, harmonious, and productive working relations with co-workers, both military and civilian.

329. The newcomer to military operational research who does not have previous experience in OR may find the above list somewhat awesome and forbidding. He, or she, may take comfort from the fact that no one possesses all these desirable characteristics and skills to a high degree but that many of them can readily be acquired or developed with some exposure to the military-scientific complex and the will and desire to learn and grow.

330. Newcomers to military OR should find these lists helpful as indicators and guidelines as to how they can improve their professional capabilities and personal attributes and thereby render their careers in the field more productive and rewarding. To succeed in military OR requires some special skills and attributes and the work can

be quite demanding. But it can also be very challenging and rewarding and give a real sense of professional accomplishment and personal gratification.

## TRAINING AND CAREERS

### General

331. Academic training for employment in OR may be quite varied as different colleges and universities offer different courses, programs, and degrees in OR and OR-related disciplines. In fact courses in OR or related subjects have been given in Canadian universities by departments of mathematics, economics, business administration, commerce, administrative studies, computer science, applied mathematics, management science, quantitative analysis, industrial engineering, and computing and information among others (99). Accordingly, academic training in OR is quite varied and not confined to courses in OR, mathematics, probability, and statistics. A good background in mathematical sciences is usually looked for as part of the qualifications for OR work. However, formal training in OR is not an essential requirement for military OR work but it certainly is useful.

332. For military OR in Canada the General Analysis Division of ORAE requires analysts with academic training in such subjects as sociology, economics, history, or political science for employment in socio-economic and strategic analysis. Training in some of the fields mentioned in the preceding paragraph is also useful for such work. It is also interesting to note that many successful OR scientists have majored at university in such subjects as biology and

chemistry, so that proficiency in OR is not necessarily dependent on any particular type of academic background. However, in general, some facility in mathematics is a prerequisite and the personal skills and characteristics listed above are very important for proficiency in the practice of OR.

333. Normally, a newcomer to OR can expect to work on an OR team or under close supervision of an experienced OR analyst, section head, or director. The initial phase of work in effect constitutes on-the-job training and is a very important step in one's career. After a period of employment in one area, perhaps on a single large scale OR project, the OR analyst can normally expect to move on to work in another field of application, or another project which may not be closely related to the first one. In due course, he or she can expect to become a project leader, or director. There are many opportunities for advancement in OR work in both the public and private sectors in Canada and other countries. It is interesting to observe that many OR analysts have risen to senior management positions in business, government, and industrial organizations.

## Training and Careers in Military OR in Canada

334. In the case of new recruits to OR in the Operational Research and Analysis Establishment of the Department of National Defence the first two to three years are usually spent with one or more directorates in Ottawa and the next three years as a subordinate member of a field station. Then the employee returns to ORAE and spends another three years with one or more of the directorates at Headquarters. At the end of nine years, the employee can expect to return

to one of the field stations, possibly as the senior member of the unit (100). After three years there, he or she again returns to Ottawa and can expect to remain with one of the directorates there for a long period, although another field posting may be had later, particularly if requested.

335. This pattern of postings is not rigid, rather it is an idealized schedule. It should be noted that there are eight directorates in Ottawa, and at present, seven field stations at Command Headquarters of the Armed Forces in Canada and at Canadian Forces Europe. In addition there are three other possible postings for OR personnel at North American Air Defence Headquarters in Colorado Springs, U.S.A., the SHAPE Technical Centre at The Hague, and at SACLANTCEN La Spezia, Italy. Thus a wide variety of postings is available. Also, it is policy to rotate OR staff members to different HQ directorates and field stations to gain experience in different kinds of military OR with the three environmental elements and support services of the Forces. Further details of postings and careers for defence scientists in OR are set forth in Ref. 100 which discusses postings, moves, and careers for defence scientists in operational research in the Operational Research and Analysis Establishment. Another useful document that provides much relevant information is Ref. 81, which also describes briefly the kind of research done in ORAE, and gives further information on defence scientists, qualifications for ORAE staff, training and careers, and on the general function and structure of ORAE and its work. In some minor respects it is out of date but is still a very valuable and informative reference document.

# RELATIONS WITH DEFENCE RESEARCH ESTABLISHMENTS

## Introduction

336. The OR people in the Department of National Defence have always maintained close liaison and working relations with many defence research establishments in Canada and abroad. Indeed, in the early days (i.e. in 1949 and the fifties) much of the success of the Operational Research Group, the progenitor of ORAE, was due to assistance, advice, reports and publications, and visits from OR groups in the UK and USA. Several very capable and experienced OR analysts from the UK accepted postings in Canada to help military OR in the country get off to a good start. However, beneficial contacts and relations have not been confined to those with other OR groups and a short account of present relations with defence research establishments other than OR ones is given in the next two sections followed by another on relations with OR establishments and other agencies or organizations in subsequent sections.

## Relations with Defence Research Establishments in Canada

337. There are at present six regional defence research establishments (DRE's) other than ORAE in Canada. These are the Defence Research Establishments Atlantic (DREA), Valcartier (DREV), Ottawa (DREO), Suffield (DRES), Pacific (DREP), and the Defence and Civil Institute of Environmental Medicine (DCIEM) at Downsview, Ontario. All these relate to NDHQ through the agency of the Chief of Research and Development (CRAD). These six Establishments plus the ORAE constitute the research facilities of the former Defence Research Board which was disbanded in 1977.

338. These establishments carry out basic defence research in a wide variety of areas. DREA and DREP specialize in research for maritime defence. DREV carries out research in the development and evaluation of military equipment and weapons systems. DREO provides defence research support in protection against nuclear, chemical, and environmental hazards, in energy conversion in batteries and in engines using new fuels, in electronic warfare, electronics technology, communications systems, and radar. DCIEM is the national institute for human research and, on its military side, concentrates on the effective performance of man in the military role and does research in behavioral and bioscience studies relating to sea, land, and air operations. DRES specializes in problems of defence procedures against chemical and biological agents, applications of explosives and electronics to military engineering problems, and in studies of remotely piloted vehicle systems. DRES has the largest experimental range area in Canada and can conduct both laboratory-scale research and related large-scale field trials side-by-side.

339. It is clear from this brief statement of the main research areas of the DRE's that liaison and co-operation with them can be very helpful to the military OR staff in providing advice, technical and other information, and various inputs to OR studies. The new recruit to military OR should have a general acquaintance with the research programs of the DRE's and make sure to liaise through proper channels with the DRE staffs on any OR study that appears likely to benefit from DRE inputs. Further information on the work and programs of the DRE's can be found in Ref. 101.

340. Working relations, liaison, and co-operation in research work are particularly close and beneficial between

the maritime OR stations on the east and west coasts and DREA and DREP, respectively. Their physical proximity make such relations readily attainable. Other examples of close liaison and working relations are those of the Directorates of Land and Air Operational Research and DREV on equipment and weapons systems investigations, and the Electronic Warfare OR Team of ORAE with DREO (Electronic Warfare Division) and with DREV on infra-red and laser studies.

341. There are, of course, other contacts, discussions, and liaison between the ORAE staff and the DRE's, on such matters as human performance under war conditions (DCIEM), and protection from chemical and biological agents or liaison on large scale field trials (DRES). While it may not always be easy for OR analysts to know when an OR project can benefit from the research work of the DRE's, they should always be alert to the possibility and prepared to explore it.

342. Occasionally joint teams of OR and DRE staff, or members of the CRAD organization, may work together on major projects as has been done recently in studying towed arrays for anti-submarine warfare operations, and air defence problems. In such cases it is usual that the team or task force will have military officers as members also. It will be recalled that the team approach to problems is one of the characteristics of OR, and such joint project teams have proven very effective and productive.

343. All the ORAE Directorates, except DMS and DSEA, have mutually beneficial working relations with one or more of the DRE's. For example, four of them (DAOR, DLOR, DMOR, D Strat A) liaise with DREO, three of them (DAOR, DLOR, DMOR) with DREV, three (D Man A, DMOR, DLOR) with DCIEM, and

two (D Log A, DLOR) with DRES. DMOR liaises also with DREA and DREP. As well, the DRE's and CRAD are interested agencies in many ORAE projects and most of them receive copies of the monthly activities reports and more formal publications of the ORAE Directorates.

344. The DRE's and ORAE are still related through the Defence Scientist (DS) group of the Public Service. All civilian scientists in these seven establishments belong to the DS group and DS's do not work in any other organizations or agencies of the federal government.

## RELATIONS WITH FOREIGN DEFENCE RESEARCH ESTABLISHMENTS AND AGENCIES

### Introduction

345. The Operational Research and Analysis Establishment has developed and maintains mutually profitable relations with many OR and other defence research establishments, institutes, and agencies, in several friendly countries. Practically all of these are in the so-called NATO countries, but a few are in Australia, and one is in Sweden.

### Foreign Defence Research Establishments

346. These contacts, exchanges of information, reports, and visits are quite numerous and five of the eight ORAE Directorates each have working relations in defence research with several different countries. Many, but not all of these relate to OR. Listings of these establishments by country for the five Directorates are given in Annex E. The fact that there are over 32 such establishments, institutes,

or agencies in six different countries shows that these relations are diverse, widespread, and provide the ORAE with many opportunities for profiting from discussions, meetings, and visits with other professionals in OR and defence research.

## The Technical Co-operation Program

347. The ORAE also benefits greatly from, and contributes much to, the Technical Co-operation Program (TTCP) conducted by Canada, USA, UK, Australia, and New Zealand. The chief study and working groups and panels of TTCP that ORAE Directorates participate in are shown below by Directorate.

| ORAE Directorate | TTCP Unit |
| --- | --- |
| DAOR | Sub-group on Air Attack Effectiveness |
| D Log A | Sub-group on Reliability and Maintainability of Military Equipment |
| DLOR | W6 Technical Panel on Generic Weapons Systems Effectiveness |
| D Man A | Sub-group U - Manpower Modelling |
| DMOR | GTP2 - Undersea Warfare |
| DSEA | Sub-group U-TP3 - Behavioral Sciences |

## NATO GROUPS AND PANELS

348. NATO study groups and panels in which ORAE members participate include the following:

Nuclear Planning Group - Chief ORAE (C/ORAE) and others;

Defence Research Group Panel VII - Military Applications of Operational Research - DGOR and others;

Maritime Systems Analysis Group on Campaign Analysis - DMOR and others;

Arms Control Talks - C/ORAE, D Strat A;

Discussion on Anti-Satellite Weapons - D Strat A.

## CONFERENCES, MEETINGS, SEMINARS, AND SYMPOSIA

349. The number of conferences, meetings, seminars, and symposia in which ORAE personnel participate is very extensive. Some of these are held regularly, e.g. annually, and others on an as required or ad hoc basis. A list of the main ones with the names of the Directorates usually participating is given in Annex F.

350. This list contains over twenty such gatherings of professionals and is not a complete list. It does, however, indicate the extensive and numerous occasions that ORAE staff have to attend, learn from, and contribute to meetings and conferences in their area of interest and work.

### Other Interactions and Relations

351. In addition to the quite extensive and varied relations mentioned above, the ORAE staff have numerous exchanges and working relations with many universities, institutions, and consulting firms, mainly in Canada but some abroad as well. Some of these are maintained by personal contact and some on a more formal institutional basis.

352. For example, many contacts with Canadian universities are maintained by individual ORAE members, particularly D Strat A staff, and with some universities in the UK and USA. As well, working relations exist with other federal government departments and agencies such as External Affairs, National Research Council, Ministry of Science and Technology, and the Royal Canadian Mounted Police (Solicitor General Canada). Other examples are discussions with the Canadian Institute of International Affairs, collaboration with Emergency Planning Canada, and some association with such societies as the Canadian Economic Association and the Canadian Political Science Society.

353. It should also be mentioned that ORAE contracts some of its research work to various consulting firms and selected contractors. These relationships provide opportunities for most ORAE staff to become acquainted with methodologies and approaches to problem solving that they would not otherwise have.

Remarks

354. It will be apparent from the foregoing that the ORAE has a great number and variety of beneficial working relations with other defence research and OR establishments, agencies, and study groups. These relations can be of particular benefit to newcomers to military OR by providing contacts and collaborative work with experienced professionals in their fields of interest and work. The opportunities thus presented for growth and learning are very great and quite unique.

# THE CANADIAN OPERATIONAL RESEARCH SOCIETY

## The Society

355. Since 1958 there has been a professional society in Canada which promotes the theory and practice of OR. At present its membership has about 1,000 professionals and managers from all across Canada. The society is called the Canadian Operational Research Society (CORS) and it includes as members leaders in research as well as OR workers who use OR methods on a wide variety of important problems confronting Canadians today. Information about the types of problems and projects that OR practitioners have worked on in business, industry, government and national defence will be found in Ref. 4.

356. The research that has been done in OR has led to new developments in mathematical programming, simulation, and the theories of reliability, scheduling, inventories, and queuing. Most, but not all, of the theoretical research work is done in Canadian universities and the results are published in various professional journals.

## Activities

357. As a society CORS works to advance the theory and practice of OR, and to acquaint all sectors of society with the potential and usefulness of OR. These aims are accomplished largely through meetings and publications. But personal contacts and discussions also assist in spreading the word.

358. To provide members opportunities to exchange information and views and establish contact with other professionals and managers interested in OR and its applications, local sections of CORS hold meetings at regular intervals throughout the year. The local section in Ottawa meets every third Thursday of the month from September to April, inclusive. Once each year a National Conference is held, with members attending from across the country and abroad to exchange information and discuss new developments, and other matters of common interest. From time to time conferences are held with other societies.

359. Three different publications are published by CORS. A journal called INFOR is published four times a year, jointly with the Canadian Information Processing Society. The journal provides papers and articles on many subjects, both applied and theoretical, and helps members to keep abreast of developments in theory and applications. The CORS Bulletin is issued ten times a year and keeps members informed of current events in OR and contains some articles and editorial comment. CORS also publishes a Directory of Society membership which is updated from time to time. From December 1963 to November 1970, CORS published the Canadian Operational Research Journal (CORS Journal). Since then the joint INFOR journal has been the official publication of CORS.

360. CORS has mutually beneficial relations with the International Federation of Operational Research Societies which publishes informative abstracts of OR papers distributed throughout the world in the International Abstracts in Operational Research. Also, through CORS, members may receive INTERFACES, an application journal published jointly by two societies in the USA.

Organization

361. CORS business is administered by a National Council consisting of an elected executive, appointed members, and representatives of local sections. It is concerned mainly with matters of policy, finance, administration, and liaison with other societies. There are now eleven local sections including a student one at the University of Waterloo. The local sections are centered at Halifax, Quebec, Montreal, Ottawa, Toronto, Southwest Ontario, Winnipeg, Calgary, Edmonton, and Vancouver. Each section is responsible for the local affairs of CORS, and is administered by a president and elected officials. Society officers are elected annually.

362. Membership in CORS is open to all persons interested in the theory and application of OR. Qualification requirements are based on education and experience; generally graduation from a recognized university in an appropriate discipline and at least two years experience in the practice of OR. All new members become associate members on joining the Society. Professional OR workers who satisfy the requirements of the Society's membership committee may attain full member status with the right to hold any national office in the Society.

Remarks

363. The founders of the Society were mainly people with military OR experience and throughout its existence of over 25 years ORAE staff have continued their support of its activities. Many of the ORAE staff have served as President or other officers of the Society. However, the military

element now represents only a small proportion of the total membership, so that there is much contact and interaction with OR personnel in industry and the universities and through them with OR activities across Canada (99).

364. Further information about CORS can readily be had from the many persons in the Operational Research and Analysis Establishment who are CORS members. In particular, the present Director of the Directorate of Mathematics and Statistics has been Secretary of the National Society for many years. He is well acquainted with all aspects of the Society and can make relevant literature available. A short history of CORS is given in Chapter X of Ref. 4 and in Ref. 102.

365. There are many advantages from being a member of CORS and new staff members of ORAE should seriously consider joining the Society. They will find membership beneficial, informative, and enjoyable.

## FURTHER READING AND BIBLIOGRAPHY

366. There is no lack of sources for further reading about operational research and general analysis methodology and techniques. Several countries now have national OR societies and publications. The principal journals of interest to Canadian scientists are probably the Journal of the Operations Research Society of America, the OR Quarterly of the UK, INFOR - the Canadian Journal of Operational Research and Information Processing, the Journal of Optimization Theory and Applications (USA), the European Journal of Operational Research, the Journal of Operations Management (USA), Management Science (USA), Interfaces, the

International Journal of the Institute of Management Sciences and the Operations Research Society of America, and the former CORS Journals.

367. The references cited in the text provide, in effect, a fairly extensive bibliography of textbooks and articles on OR and related subjects. In Chapter IV, twelve OR studies done in ORAE are described or noted with their individual references which contain other references as well. In addition to these references to and example of OR work, the Bibliography provided with this report lists a number of articles, papers, and books which the reader will find pertinent and informative. All of these publications are unclassified. No classified documents by ORAE staff or others have been referenced herein.

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## MEASURES

1. In devising a measure of effectiveness it may be noted that four types of measures can be recognized. The usual types are nominal, ordinal, interval, and ratio.

2. A nominal measure divides candidates into categories or sets but does not permit arithmetical manipulation. Examples of such sets are those obtained in the forms: yes/no, one/zero, with/without.

3. An ordinal measure ranks candidates in respect to each other and permits an ordering in terms of some preference criterion. Thus a set of ten candidates might be ranked in ordinal order 1, 2, 3 to 10.

4. An interval measure permits a ranking and an indication of how much better one item is than another. For example, the Fahrenheit scale enables temperatures to be defined in definite numbers whereby temperatures and differences in temperatures are given in quantitative form as degrees.

5. A ratio measure expresses the ratio of certain features, usually positive ones, to other features, which are often the undesirable or negative features. For example, cost effectiveness measures are sometimes expressed as ratios, e.g. in the form of effectiveness per unit cost. Ratio measures provide numerical measures that permit algebraic manipulation and facilitate quantitative comparison. In operational research we usually seek interval or ratio measures.

# TYPES OF MODELS

1. The three types of models that are generally used in OR and in science are called iconic, analogue, and symbolic. The latter are frequently referred to as mathematical models.

2. In general terms iconic models represent pictorially, visually, or with a change in scale certain properties or aspects of the real system or thing. Photographs, drawings, maps, and model airplanes, ships or tanks are examples. Iconic models are usually simple to conceive, and are the most specific and concrete of the three, but are difficult to manipulate for experimental purposes.

3. Analogue models use a set of properties to represent another set of properties of the system or thing being studied. For example, the flow of water through pipes may be taken as an analogue of the flow of electricity in wires. Contour lines on a map are analogues of elevation, and graphs are another example. In general, analogue models are less specific, but easier to manipulate than are iconic models.

4. Symbolic models use letters, numbers, and other kinds of symbols to represent variables and the relationship between them. They take the form of mathematical relationships, usually equations or inequalities that reflect the structure of what they represent. They are the most general and most abstract type of model and are usually the easiest to manipulate but most difficult to conceive or build.

5. The function of iconic models is generally descriptive rather than explanatory, while that of a symbolic model is usually explanatory rather than descriptive. Accordingly, a symbolic model is well suited to the prediction or determination of the effects of changes in an actual system. In OR, symbolic models are used wherever possible because they are easier to manipulate and generally yield more accurate results under manipulation than do iconic or analogue models.

6. It is worthy of note that models that contain controlled variables, in general, are explanatory and often exploratory, and those that do not are usually descriptive.

7. In some situations preliminary and tentative representations of a system are used in developing a model that is the one finally used to obtain a solution. These are often called conceptual models. They are frequently diagrams that reflect our conception of which variables are relevant and how they are related, e.g. a flow diagram of the sequence of activities in an operation. Nowadays, flow charts or diagrams are more common and better known than "conceptual models".

# FIELD TESTING AND EXPERIMENTATION

## Introduction

1. Field tests and experiments of military equipment, including clothing and general stores, if properly designed, conducted and analyzed provide one of the few methods of obtaining data on the characteristics and quality of military equipment in peacetime. Of course, testing and experimenting are not confined to peacetime. Such testing should be concerned with the performance of the item under test as an entity and with its performance in a system involved in military activity.

2. There does not appear to be any agreement on the terminology of the different types of field testing nor on definitions for the types. Such terms as troop trials, acceptance tests, user trials, field tests, engineering tests, technical, and laboratory tests abound, with no general international agreement on or use of such terms. But there has been for many years a perceived need for stricter definitions of types of field testing, and for their general acceptance.

3. Some time ago in preparation for a Commonwealth Conference two members of the Defence Research Board prepared a document on the subject of field testing by the military (103). It included proposed definitions of three types of field tests which are given and described below.

a. Technical Testing is the testing of the properties of an item, in the laboratory or in the field, by means of objective methods and observations.* In technical testing the objective is to determine, by measuring appropriate parameters, values of the significant inherent characteristics of the experimental item, and to assess the degree to which they conform to those defined in the formal statement of requirements.

b. Engineering Testing is the testing of the performance of an item, in the field, by means of objective methods and observations, supplemented by subjective methods. In engineering testing the objectives are to assess the validity of the interpretation of the requirement for the item, and to measure the operational performance of the item or its prototype.

c. User Testing is the testing of an item for acceptance by the user, in the field, by means of subjective methods, supplemented by objective observations. In user testing the objective is to discover whether the fully developed item is satisfactory in the eyes of the user.

4. At the time the above-mentioned document was prepared (1952), a draft manual entitled Field Testing of Clothing and General Stores (104) was written and submitted to the Fourth Commonwealth Conference on Clothing and General

* As used here, by observation is meant any kind of numerical recording of data or information.

Stores. Copies of this manual and the document mentioned above should be available in the Department of National Defence.

5. Other terms sometimes used are troop trials, acceptance trials, and training trials. The two former are similar to user tests or trials, and the latter to engineering trials or tests.

6. Field trials and testing of the types mentioned above may be conducted by any of the Force elements, air, land or sea. An item such as radar equipment, an armoured car, a sonar set, or a weapon system may undergo all three types of testing in the field. For example, the serviceman's personal weapon, the rifle, as a proposed new weapon might undergo technical testing to determine how well it conforms to the formal specifications set forth in the statement of requirement. It could also receive engineering testing to assess its performance in the field. Finally, it could be subjected to user trials or testing to decide whether it could be acceptable to the serviceman under field conditions. Similarly, a new item of clothing such as service boots or jacket would normally receive all three kinds of field testing before being accepted for service use.

# CRITERIA FOR PREPARING QUESTIONNAIRES AND CONDUCTING INTERVIEWS

## Introduction

1. Based on practical experience, trial and error, and studies and theories in psychology and the social sciences, a number of criteria to be observed in preparing questionnaires, and conducting interviews, have become recognized as being very important and indeed critical.

2. For the sake of brevity and easy reference several of these criteria are listed below without comment. Further information and rationale for their importance may be found in Refs. 68, 69 and 70.

ANNEX D Para. 2: for "Refs. 68, 69 and 70". Please read Refs. 70, 71 and 72.

## Questionnaire Criteria

1. Keep questionnaire as short as possible.
2. Questions to be short, simple, and worded positively.
3. Questions should be easy to read, understand, and answer accurately.
4. Answers should be readily recorded.
5. Leading questions should be avoided.
6. Answers should be easy to code, edit, and be made ready for analyses.
7. Questions should follow a logical sequence.
8. Some cross-checks for accuracy should be included.

9. Questions involving rating scales should have not more than seven levels and preferably not more than five.

10. Multiple choice questions are acceptable if carefully worded and choices are limited to five in number.

11. Where appropriate, all questions should be answerable by 'Yes' or 'No', or by a figure or a name.

12. Questions requiring private or confidential opinion should be kept to the end of the questionnaire.

NOTE: Questions should always be pretested by a pilot survey. The method of analyzing the data obtained from the questionnaire should be determined before the survey is conducted.

<u>Criteria for Conducting Interviews</u>

1. The risk that the interviewer may misunderstand a reply should be guarded against and minimized.

2. The risk of misinterpretation is greater with opinion questions and special care is required in recording replies to them.

3. Interviewers should receive training, attend briefings and conferences, and receive detailed instructions.

4. Interviewers should know when to add explanations, how to probe responses, and how to deal with difficult or unexpected queries.

5. Interviewers should be able to talk sensibly about the purpose of the interview although avoiding saying anything that could prejudice replies.

6. Interviewers must maintain a detached attitude, but ensure that the interview is relaxed and friendly.

7. Interviewers must be sure to ask all questions in a neutral straightforward way, and accept answers in the same manner.

8. A key interviewing skill is probing, encouraging the respondent to give an answer, or to clarify or amplify an answer.

9. Interviewers should record the answers during the interview as they are given.

10. Interviewers should record something beside every question they ask, e.g. don't know, don't remember, none, as appropriate.

11. The respondent's interest and goodwill have to be maintained throughout the interview.

12. In asking the questions, interviewers must always use the precise words printed on the interview schedule.

# RELATIONS WITH FOREIGN DEFENCE RESEARCH ESTABLISHMENTS

## Introduction

1. This Annex presents listings of defence research establishments and centres in countries other than Canada with which the Operational Research and Analysis Establishment has working relations such as exchanges of information, formal discussions, formal visits, exchange of reports, and collaboration on defence research work. The lists are not exhaustive but they do serve to show the extent and variety of professional contacts that the five ORAE Directorates have with defence analysts in other countries.

## Listings of Foreign Establishments by ORAE Directorates

| Directorate | Country | Establishment |
|---|---|---|
| DAOR | U.K. | Royal Aircraft Establishment (RAE)<br>Defence Operational Analysis Establishment (DOAE) |
| | U.S.A. | Foreign Technology Division Wright Patterson Air Force Base (AFB)<br>Defence Mapping Agency<br>US Army Engineers Waterways Experimental Station<br>North American Air Defence Command (NORAD - CANADA/US) |
| DLOR | U.K. | Royal Armament Research and Development Establishment (RARDE), DOAE, RAE |

| Directorate | Country | Establishment |
|---|---|---|
| | U.S.A. | Army Materiel Systems Analysis Activity (AMSAA)<br>Training and Doctrine Command Activity Naval Weapons Centre Eglin Air Force Base |
| | West Germany | Land OR Establishments (three) |
| | Australia | Ministry of Defence (MOD) |
| | NATO | SHAPE Technical Centre, The Hague |
| DMOR | U.K. | Admiralty Research Establishment DOAE |
| | U.S.A. | Centre for Naval Analysis<br>Naval Underwater Systems Centre<br>Directorate of Naval Analysis<br>Naval Weapons Centre |
| | Australia | Royal Australian Naval Research Centre |
| | NATO | SACLANT ASW Research Centre La Spezia, Italy<br>HQ Saclant, Norfolk, Virginia |
| D Log A | U.K. | DOAE, RARDE, MOD, U.K. |
| | U.S.A. | US Army Logistics Management Centre<br>US Army Concepts and Analysis Agency<br>US Air Force Logistics Branch Wright Patterson AFB<br>AMSAA<br>MacDonnell Douglas Aircraft St. Louis |
| | Australia | MOD, Canberra |
| | Holland | Physics Laboratory of the National Defence Research Organization |
| | NATO | SHAPE Technical Centre |
| D Strat A | U.K. | Institute of International Strategic Studies |
| | U.S.A. | RAND Corporation |
| | Sweden | Stockholm International Peace Research Institute |

CONFERENCES, MEETINGS, SEMINARS, AND SYMPOSIA

1. A listing of conferences, meetings, seminars, and symposia that ORAE staff members attend and participate in on a more or less regular basis is given below along with the Directorate involved.

Annual Conference of the Canadian Operational Research Society - All Directorates

Monthly Meetings of Ottawa Section of the Canadian Operational Research Society - All Directorates

Meetings of Canadian Economic Association - DSEA

Meetings of Canadian Association of Applied Social Research - DSEA

Seminars on the Armed Forces and Society - DSEA

Annual Conference on Design of Experiments in Army Research, Developing and Testing - DMS

US Army Conference on Applied Mathematics and Computing - DMS

US Conference of Army Mathematicians - DMS

US Conference on Numerical Analysis and Mathematics - DMS

US Army Operations Research Symposium - DLOR

ABCA Army Study Program Meetings - DLOR

Quadripartite Working Group on Army Operational Research - DLOR

General Science Symposium of Commonwealth Defence Science Organization - D Log A

Annual Reliability and Maintainability Symposium (USA) - D Log A

Symposium on Computer Graphics - DAOR

Symposium on Aerodynamic Fluid Flow - DAOR

Symposium of Association of Old Crows - DAOR

Symposium on Electronic Warfare (USA) - DAOR

NATO Maritime Systems Analysis Group Symposium on Campaign Analysis - DMOR

Meetings of Canadian Institute of International Affairs - D Strat A

Annual Conferences of Institute for International Strategic Studies (including local chapters) - D Strat A

NOTE: (See also NATO Groups and Panels in Chapter V of main text.)

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13. ABSTRACT This monograph on military operational research in Canada consists of five chapters dealing with an introduction to operational research, operational research methodology, military operational research, examples of military operational research projects, and professional considerations, respectively. It is intended to provide practical information on operational research to serve as guidelines to young scientists embarking on military operational research work. It should also be interesting and informative for the more experienced operational research scientist. While details and examples of operational research methodology are not presented at length the many references enable the reader to supplement this introduction by consulting them. Special features of military operational research are cited and relations to military sponsors are discussed. Several examples of military operational research and general analysis projects done in the Operational Research and Analysis Establishment are described and suggestions are given for presenting the findings fo such studies. The monograph also offers comments on the characteristics and attributes required for a successful career in operational research, on training and careers in military operational research and analysis in Canada, and portrays relations with defence research establishments and agencies in Canada and elsewhere. Information about the Canadian Operational Research Society and some suggestions for further reading are also included. A number of annexes deal with specific matters of methodology and an extensive list of references and a bibliography are provided.

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