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DEFENCE ANALYSIS AND OPERATIONAL RESEARCH

Lecture to Second Annual Canadian Armed Forces
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1. Introduction

It is a real pleasure for an operational research scientist to talk with communications and electronics officers. We have a great deal in common.

To understand your profession you must be familiar with several branches of engineering and be able to deal with radio tubes, wiring diagrams, generators, cooling systems, antennas, test equipment, and countless other pieces of hardware. But most of you, as you rise to more senior positions, will become increasingly concerned with organization, costs, system considerations, and the ways in which communications and electronics can best serve the overall needs of the Armed Forces, or perhaps even of Canada.

To be competent in operational research, it is necessary to have a certain technical background, including a working knowledge of several branches of mathematics and statistics, a practical outlook, and a taste for picking up the essentials of other peoples specialties. But the most interesting problems come when somebody wants to combine equipments in a new way, to choose the best of several competing systems, or to reassess basic purposes. The answers are not to be found in textbooks, and the methods often have to be devised for the job.

Operational research is generally considered to have started in the Royal Air Force just prior to the outbreak of World War II, after radar had been invented and at the time that it was necessary to devise a practical warning and control system to exploit the new device. Ever since these pioneer days, much of the best military O.R. has been done in connection with electronic apparatus and the systems associated with them. This is partly because the problems are generally well suited to scientific analysis, but also because the type of servicemen specializing in C & E have the same outlook as the O.R. scientist, are glad of his help, and find it easy to co-operate with him.

I shall use some of the time allotted to me this afternoon to describe a few of the operational research projects currently under way in the Defence Research Analysis Establishment that relate to communications and electronics. But before I come to these, I would like to speak about some of the trends apparent in the type of systems analysis getting the most attention today, and then say a few words about the extension beyond the more orthodox areas of operational research that we are attempting in DRAE.

2. Some Trends in Systems Analysis

In the literature on operational research one finds increasingly frequent references to decision theory. There is not unanimous agreement as to what this includes. Some of it embraces sections of statistics, such as the theory of statistical inference (which told one what would be concluded from a mass of statistics, and indicated the level of confidence that would be assigned to the conclusion). Acceptance sampling and quality control can be considered as part of decision theory.

There are three general types of situation under which decisions have to be made: certainty, known probabilities, and unknown probabilities. Many of the problems of decision making under certainty are simple in principle, but face too many possible permutations and combinations to be easy in practice. Examples come in scheduling, assignment, and allocation of resources.

When we face uncertainty, but know the probabilities of all the various events which may occur, the problem becomes more difficult, but is still essentially soluble as long as we can agree on how to measure the various outcomes and place them in an order of preference. Examples are found when we wish to schedule servicing facilities (e.g. repair, or stocks of spare parts) to take care of maintenance problems whose frequency and duration we can forecast on a statistical (though not an individual) basis.

But the worst problems come when we cannot assign numerical probabilities to the various circumstances under which we may wish to operate. What is the probability that a proposed new weapon system will have to be used on a nuclear battle field, a conventional battle field, or in a peacekeeping action? In your electronic apparatus you insist that the equipment be able to withstand extreme cold, extreme heat, shock, tropical fungus, extended storage, and many other stresses. It is possible to ensure this, but only at a very considerable price. In the larger sphere of the design of Canadian force structure, we just cannot afford to be 100% effective under all conceivable circumstances. We just might be able to afford to be 90% effective under the circumstances most probable to arise. But which are they? And if we could attain 80% for half the cost of 90%, would that be a better policy?

Many of the most serious problems facing the Canadian Armed Forces are those of allocation of resources. We know exactly how much we have to spend - i.e. $1.815 Billion for each of the next three years. We have men trained for the present activities, and weapon systems of various ages, generally rather older than newer. If we choose to continue all of the present activities, then virtually all of the $1.815 Billion will be needed for the costs of personnel, operation, and maintenance. But there remains the option of reducing some activities and using the resources that would have been devoted to them for the purchase of new equipment.

With our objective to get the best possible effectiveness for a given cost, it is natural to find cost-effectiveness analysis an active subject. It is a difficult subject, too. It is surprising how many complications arise in the sensible and appropriate allocation of costs. What should be included? How should one treat overheads shared with other activities? Which personnel costs need to be added? Would some of the activities go on anyway in the absence of the program under analysis? Effectiveness is hard enough to measure for one weapon system with a single role, worse if there are several roles. But the real dilemmas come when different systems that do different things have to be compared with one another on the same scale of effectiveness.

The type of problem which I have been discussing during the last few minutes is generally described as systems analysis rather than operational research. In addition, the Canadian Government is facing other problems in the areas of external affairs and national defence which require research and analysis even more remote from the original type of operational research, which was confined to specific equipments for specific purposes.

Good examples of this latter type of problem arise in the various areas of arms control. Several proposals, such as limitations of weapons of mass destruction from the seabed, banning of chemical and biological weapons, and a comprehensive ban on the testing of nuclear weapons, are under active discussion at the United Nations. Canada takes a prominent part in the negotiations, and must assess each proposal not only in terms of its probable affect on world stability, but also in terms of her own national interests. For example, the waters adjacent to Canada are fished by many nations, and include one of the largest areas in the world of the shallow Continental Shelf, which may soon become the site of lucrative commercial exploitation. Problems of sovereignty and control could well arise from commercial as well as military activities. The national interest goes well beyond defence, but defence is concerned with any agreements regarding prohibition of activities or inspection of installations.

Perhaps this is enough on the general types of defence analysis engaging our interests today. Let us turn to a few examples of studies concerned with communications and electronics.

3. Analysis of the Survivability of a Communications Network

Recently a requirement arose to estimate the vulnerability of the Canadian Forces communications network in the event of attack on North America by nuclear weapons. One of the objectives was to select a routing and design that would reduce the vulnerability.

In order to carry out the analysis, four assumptions had to be specified:

1. The characteristics of the attack.
2. The vulnerability of the components.
3. The layout of the system.
4. Measures of effectiveness after attack.

It was assumed that nuclear weapons, of a certain energy yield, were directed against certain cities and military installations, with certain accuracy, but that some additional weapons fell at random points (due, for example, to destruction of bombers by defences).

For each component of the communications system (e.g. switching centres, land lines, microwave relays) and for each subscriber (e.g. a military HQ or operations centre) it was necessary to assign a "vulnerable distance", such that it would be destroyed if a weapon burst at a point closer than this distance.

The communications system was regarded as a basic message switching network, composed of a few trunk nodes and a number of trunk circuits, and a large number of subscribers, each connected to one or more nodes by one or more access circuits.

As is very often the case, no-one was successful in devising a single measure of effectiveness for the system after damage was sustained. In the end, three were used:

1. The proportion of attacks for which all surviving trunk nodes maintained a connection with all other surviving trunk nodes.
2. The proportion of surviving subscribers that were still connected to the surviving proportion of the basic switching network.
3. The proportion of traffic from surviving subscribers that could be handled by the surviving components of the basic switching network.

The calculations were performed by what is known as a Monte Carlo simulation. For one sample attack, the points of burst of nuclear weapons were calculated by random sampling, using the assumed distributions of aiming error about the intended point of impact. Then, using a large scale map of the communications system, the burst points were plotted, and the resulting destruction of components and of subscribers determined. Then, using the surviving components and subscribers, the numbers representing the three measures of effectiveness were calculated.

The Monte Carlo method consists of repeating this process many times, always starting with a new randomly selected set of burst points. The measure of effectiveness numbers were averaged over the series of repetitions.

Various alterations were made in the facilities assumed to be available: e.g.

1. only normal peacetime trunk routes and access routes;
2. add pre-engineered call-up routes;
3. use in addition any other surviving communications circuits.

Early results showed that survivability could be considerably improved by dispersing circuits and routing them away from likely targets, and by duplicating long access routes.

A computer was used to select the weapon detonation points for each random attack, but the determination of destruction and of the residual capability of the surviving system was done by hand. At present a computer program is being prepared to carry out these last two processes as well. However, it will still employ the Monte Carlo method.

4. Sensors for Surveillance and Reconnaissance Aircraft

Airborne surveillance and reconnaissance needs to be studied in connection with several activities of the Canadian Armed Forces. The Air Division has the role of strike and reconnaissance. Close air support of ground troops will require reconnaissance. Maritime recce is a main role for the Argus. The USAF have plans to transfer some of the warning and control that is now carried out for continental air defence, in large ground stations equipped with heavy radars and computers, into large Airborne Warning and Control System aircraft. The logical place for many of these AWACS aircraft to operate would be over Canada.

In order to be able to assess a wide variety of surveillance and reconnaissance sensors for various types of aircraft, a computer program has been assembled which takes account of:

1. Availability of total recce system, as a function of mean time between failures, and mean time to repair.
2. Navigation accuracy.
3. Target/background relationship.
4. Atmospheric conditions.
5. The recce sensors, including
   a. visual
   b. radar (forward-looking, side-looking, all-around)
   c. camera (vertical, oblique, panoramic)
   d. low light level television
   e. Laser line scan
   f. infrared (line scan and forward-looking)

The program can be used to evaluate probabilities of detection, recognition, and identification for any of these sensors, either singly or in combination.

Because of the very high unit cost of aircraft, and because each new type creates an expensive requirement for additional maintenance stores and training, there is a real premium for multi-role aircraft in the Canadian Forces.

An AWACS aircraft must have long endurance, a very good radar, and a computer. If it is flying long missions in the North for air defence, it might be able to conduct effective ground surveillance as well, perhaps with the addition of certain reconnaissance sensors.

An ASW maritime patrol aircraft must have long endurance, a good radar, cameras, and a number of other sensors. It should be able to conduct surveillance and reconnaissance over land, snow, and ice, as well as over the sea.

A smaller aircraft, such as the CX-84 VSTOL might be a very effective platform for tactical reconnaissance, in addition to several other functions.

It is important to exploit any opportunities to use aircraft in several roles, and there is hope that useful capabilities for surveillance and reconnaissance may be obtained by adding equipment to aircraft originally designed for another purpose.

5. Land Forces Combat Intelligence System

A computer simulation of land combat has been designed to emphasize the various components of the combat intelligence system of a brigade: sensing devices, communications, and information processing.

A generalized method allows simulation of most sorts of sensing devices, including airborne or ground-based radars, infrared, image intensifiers, and so on. The model simulates transmission of individual messages (e.g. contact reports from sensors) through the tactical communications network. At each level of headquarters, the incoming messages are collated with information already known and possibly passed up the chain of command.

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Using the model, we can examine how the various components of the intelligence system affect the information which is presented to the brigade commander. For example, the relative contributions of the various types of sensing devices can be measured. The effect of longer range radios could be examined in terms of the timeliness of the information provided, by comparing the results of two simulations runs; one with the old radios, the other with the new. In a similar fashion, the benefits of improved information handling techniques or of the introduction of Automatic Data Processing Systems can be examined.

It is intended to use this computerized model to examine the combat intelligence system of the proposed new Canadian battle group for NATO, and also to develop the model itself into a real-time war game, to allow examination of the way in which a commander uses information and makes his decision.

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