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LEVEL II

AN INTRODUCTION TO THE LITERATURE OF SEARCH THEORY

Laura H. Nunn

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AN INTRODUCTION TO THE LITERATURE OF SEARCH THEORY

Laura H. Nunn

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INTRODUCTION

The purpose of this paper is to survey the one-sided search problem, starting with Koopman's work in 1946 and continuing to the present. The paper summarizes some basic results for both the optimal allocation of effort problem and the best track problem for stationary and moving targets; but, it is intended as an introduction to the literature of the field rather than an exposition of it.

The paper does not include two-sided searches, i.e., searches in which the target reacts in any intelligent way to the searcher. It does not include surveillance problems or problems involving false contacts or decoys. It includes only repeatable searches.

This survey was aided by earlier surveys, particularly J. M. Dobbie's published in Operations Research in 1968, and Marc Mangle's 1980 OEG publication. The bibliography includes not only those papers actually referenced in the present work, but also other papers of interest in the area of search.

THE SEARCH PROBLEM

Search theory is one of the oldest areas of operations research. Problems involving search arise in such diverse areas as the military looking for enemy submarines, the Coast Guard searching for small boats lost in a storm, prospectors surveying for mineral deposits, the forest service looking for missing backpackers, law enforcement officers searching for lost weapons or escaped criminals, a secretary looking for a missing file, or an analyst scanning a computer printout for a particular piece of data. All of these problems have two elements in common -- a target, in the broad sense of something being searched for, and a searcher.

There are usually two types of cost involved in search problems. The first, the cost of the search itself, may be measured in such terms as dollars, time, manpower expended, or fuel expended. We often want to search in such a way as to maximize the probability of finding the target at a minimum cost, or until our resources run out (fixed cost). A second cost is the cost of not finding the target. This cost may be measured in dollars, in inconvenience, or even in lives lost. The two costs need to be balanced in each search situation. In general, we want to devise a search plan, or "track" which uses the resources most effectively under such

physical limitations as the terrain, the searchers, the instruments used, the resources available, and the nature of the target itself.

The search problem can be loosely described as follows:

- The target is located in an area which is much too large for the searchers to search completely.

- The location of the target is not known exactly, but probabilities can be associated with subregions of the main search area.

- The target may (or may not) move.

- One or more searchers may look for the target, and they may use detection equipment to do so.

In order to solve the problem, we need:

- A model for the location of the target at the start of the search. This model we will call the initial density.

- A model for the motion of the target, which we denote by $q(x,y,t)$.

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● A mathematical goal, or objective function, such as mini-
mizing the time to find the target, or maximizing the prob-
ability of detection by time T.

The search literature breaks the problem down into two main cate-
gories: optimal allocation of effort problems, and best track
problems. The optimal allocation of effort problem is mathematic-
ally the easier of the two problems and hence more work was done in
this area earlier. Optimal allocation of search effort may mean,
for example, optimizing the amount of time spent searching in each
subarea. These problems are nice mathematically since it is often
possible to prove that a plan is optimal. However, it may be that
the optimal plan is not "doable." For example, in the figure
below, the plan may say to put 50 percent of the total effort in
(3,2) and 50 percent in (3,4). Due to physical constraints, this
allocation may be impossible,

	1	2	3	4
1				
2				
3		.50		.50
4				

e.g., the searcher may not be able to get from (3,2) to (3,4)
without expending some effort in (3,3). It would be more useful
for the searcher to have a track to follow. But the best track

problems are difficult to solve. Work has progressed significantly only since the mid-seventies.

We will look first at the best allocation of effort problem and its history.

The earliest developments in search were made by Bernard Koopman and his colleagues in the Anti-Submarine Warfare Operations Research Group (which later became the Operations Evaluation Group) of the U.S. Navy during World War II. Their purpose was to aid the Navy in finding efficient ways to search for enemy submarines. The work done from 1942 to 1945 was published in a book, Search and Screening (Koopman, 1946). Originally classified Confidential, the work was declassified in 1958. A new edition of Search and Screening was published in 1980. Many of the results from the OEG work were published in a series of articles in Operations Research in the mid-fifties (Koopman, 1956 a&b, 1957). Koopman's work is basic to search theory and is a good place to start a survey of this field.

Let us look first at the law of random search[1]. Suppose there is a region, A, over which a search must be made. Assume nothing is known about the location of the target except that it is in A, i.e., we will assume a uniform target distribution and that the target is stationary relative to the searcher. Assume that if we

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[1] See Koopman (1946), p.28 or Koopman (1980), p. 71.

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pass within W/2 distance units from the target, we will detect it
with probability 1. Assume also that the searcher takes a random
piece-wise linear path of total length L, and $\ell = L/n$ is the length
of one of n equal, rather long (in relation to W) segments.
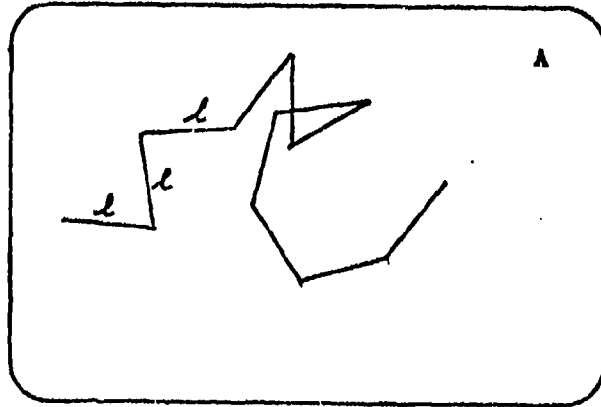
Koopman shows that the probability of finding the target under
these conditions is

$$P = 1 - e^{-(WL/A)}.$$

Since the search path was random, this probability is usually lower
than it would be if we had searched systematically. P is then a
lower bound for the actual probability of detection and is useful
for approximation purposes. If we assume that it is only necessary
to search in a straight line path, P becomes

$$P = WL/A.$$

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This estimate of P assumes "ideal" conditions and thus provides an upper bound for the probability, as indicated in the figure below.
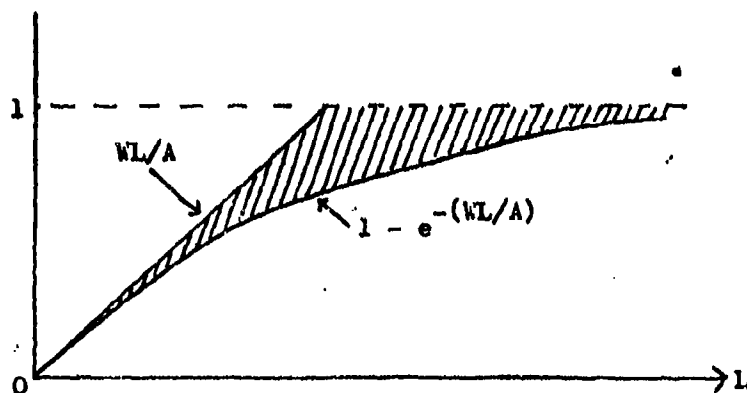
The true probability lies somewhere in the hatched region.

Koopman looked at the optimal allocation of effort problem in both discrete and continuous space. His objective was to optimize allocation of search effort. Suppose that we have a search area divided into two parts A_1 and A_2[1]. Suppose that the probability that the target is in A_1 is p_1, $i = 1,2$, and define ϕ_1, the density of search effort in A_1, by

$$\phi_1 = \frac{\text{Effort in } A_1}{A_1}$$

_____

[1]See Koopman (1946) p. 35, or Koopman (1980) p. 146.

Koopman found that, assuming the target is stationary (or more generally, stationary relative to the searcher) and assuming the law of random search, one of three situations arises:

If P_1/A_1 is much larger than P_2/A_2, search only A_1.

If P_2/A_2 is much larger than P_1/A_1, search only A_2.

Otherwise, distribute the total effort $\Phi = A_1\phi_1 + A_2\phi_2$

using $\phi_1 = \log(P_1/A_1) - (1/A)[A_1\log(P_1/A_1) + A_2\log(P_2/A_2)] + \Phi/A$.

For the continuous case, Koopman defined the problem as follows:

● The target is stationary.

● It is contained in a region A. The probability before the search starts that the target is in $(x, x+dx)$ and $(y, y+dy)$ is $p(x,y)dxdy$.

● The total search effort is Φ.

$\phi(\ )$ is the density of search as a function of x. If we integrate $\phi(\ )$ over any subregion B of A, we get the effort expended in B. Koopman shows that the problem reduces to maximizing

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$$P(\phi) = \iint_A p(x,y)(1 - e^{-\phi(x,y)})dxdy$$

where $p(x,y)$ is the probability that the target is around (x,y)

and $1 - e^{-\phi(x,y)}$ is the probability of finding it there assuming

random search. Using Lagrange multiplier and Calculus of Varia-

tions techniques, he finds the unique b such that

$$\log(b) - (1/A_b)\iint_{A_b}\log p(x,y) \, dxdy + \Phi/A_b = 0$$

where A_b is a subset of A which depends on b. Then $\phi(x,y) =$

$\log[p(x,y)/b]$ is the function defined by $\iint_A \phi(x,y)dxdy = WL = \Phi$

and $(x,y) \geq 0$ which gives $P(\phi)$ its largest value. Geometrically,

we can find this value of b by first plotting $z = \log p(x,y)$

over the region A. Cut this surface by the horizontal plane

$z = \log b$ in such a way that the volume of the surfaces above the

plane is equal to Φ. The orthogonal projection on the x,y plane

will be A_b.

For both the discrete and continuous cases, Koopman observed that

for this problem effort allocation has an additive property. That

is, if Φ units of effort are available at the beginning of the

search and Φ' more units become available later, the best search

plan remains the one which would have been chosen at the beginning

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had we known the total effort would be $\Phi + \Phi'$. In other words, says Koopman

> "A well planned search cannot be improved by a
> redistribution of search made at an intermediate
> stage of the operation in an attempt to make use
> of the fact that up to that time the target had
> not yet been observed."[1]

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[1]Koopman (1946), p.38 or Koopman (1980), p.151.

SUBSEQUENT DEVELOPMENTS

Variations on both of Koopman's problems followed quickly after the publication of the unclassified version of his work. The discrete case easily extends to n boxes and to many variations.

Blachman (1959) looked at the problem of finding an object in one of n boxes. He assumed that the probability the object appears in each box is known, and the time of appearance is uniformly distributed over a large interval. Blachman and Proschan (1959) derive an optimum search procedure for a generalization of Blachman's problem. In this case, the object's arrival is in accordance with a Poisson process with arrival rate A. A cost of looking in each box is added. They consider which boxes to scan and how to schedule the scans to minimize the time between the arrival of the object, and finding it. The model is applicable to, say, the appearance of missiles for which early detection is crucial.

Gilbert (1959) added to Koopman's two cell search a cost (perhaps in time) for switching from one cell to another. He treats the problem as a kind of one person game, and applies the method to a search for an odd sized bolt in one of two bins. Gluss (1961) looked at the n-box problem if the boxes are all in a line and Ross

(1968) added a reward R_i for finding the target in box i.
Wegner (1980) find necessary and sufficient conditions for the
existence of admissible search strategies which minimize the
expected cost of "at least surely" finding an object when overlook
probabilities are included. He gives a procedure for computing an
optimal strategy.

Most of the above problems were solved by a dynamic programming
approach. Matula (1964) derived conditions for the existence of an
ultimately periodic search with minimum cost. He finds a closed
form solution to this problem rather than the recursive solution of
dynamic programming. Pollock (1964) introduced a Bayesian approach
to the optimal allocation problem. Decisions are made sequentially
based on what had been observed until that time to minimize the
expected cost of searching and making wrong decisions. In 1970,
Pollock (1970) considered the case when the target is moving
between two regions. The target moves in a Markovian fashion and
with known parameters. He tries to find the expected number of
"looks" required to find the target, and solves the problem in
certain special cases by means of dynamic programming.

The preceeding papers all deal with the problem of effort alloca-
tion when the search space is discrete. The following papers use
continuous search space, or both continuous and discrete space
through the use of the Stieltjes integral. Most of the recent
papers use this latter approach.

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Charnes and Cooper (1958) showed that mathematical programming
could be used in search problems to look at broader classes of
problems. They applied convex-programming along with the Kuhn-
Tucker conditions to obtain the solution. The algorithm they
obtained was an important step in solving search problems by
computer.

In 1961, deGuenin generalized Koopman's models in an algorithm
which made no assumptions on the detection probability function.
He felt that the law of random search (negative exponential) is not
valid for many non-military applications. He used instead func-
tions he terms as "regular" -- that is, the graph is strictly con-
cave downward, passes through the origin with a tangent of positive
slope, and increases monotonically to a horizontal asympotote no
higher than positive one. Many detection functions used by Koopman
have this property, and most subsequent mathematical developments
have been based on deGuenin's regular functions.

Dobbie (1963) started with the additive property mentioned by
Koopman and used this property to derive the optimal search distri-
butions. He was the first to define passive observations -- the
target does not react to the search, the search does not materially
change the target (as covering a lost item with dirt) or the
searcher (as with fatigue) -- as opposed to active observations and
to discuss the mathematical consequences. He pointed out that
often, especially with active observations, the detection function
is not regular (or deGuenin).

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Zahl (1963) derived necessary and sufficient conditions for the existance of solutions to the problem of maximizing the detection probability with a given effort.

Various sequential formulations of the search problem have been applied to several fields. Engel (1957) looked at the search for certain minerals as a two stage process. The first, and least expensive, consists of one or more preliminary searches. The second search is detailed and more expensive, and occurs only where the required "clusters" of signals in the preliminary search indicate the target is likely to be found. Posner (1963) uses a similar preliminary scanning technique to search for a lost satellite by radar. DeGuenin (1963) adds a middle stage, screening the data, when searching for oil wells.

Stone made use of Calculus of Variations, convexity properties, and generalized Lagrange multiplier techniques (which allow for inequality constraints and do not require differentiability assumptions) to formulate a systematic treatment of search theory in his 1975 book Theory of Optimal Search. In this book he deals primarily with stationary targets but extends his methods to false targets and Markovian motion.

Conditionally deterministic target motion -- motion in which the initial position and speed of the target is known but its direction is not -- was considered by Stone (1973) and Pursiheimo (1977).

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Mangle (1980) included an algorithm for Markovian target motion in which the moving target motion is reduced to a sequence of stationary target problems. The observation that a search plan maximizes the overall probability of detecting a moving target if and only if it maximizes the probability of detecting a stationary target at discrete time intervals was made by Brown (1980). When there is random target motion, the number of possible target paths is infinite. Stone (1979) worked on this problem. When the detection function is concave, he gave conditions for optimal search plans which include any "reasonable" target motion.

Stone, et. al. (1978) summarizes the optimal allocation problem and included several algorithms for its solution. They found necessary and sufficient conditions for optimal search for a moving target when time is discrete and an exponential detection function is assumed.

> For a search for a moving target to be optimal, it is
> necessary and sufficient that at each time t it assigns
> an allocation which is optimal for the <u>stationary</u> target
> problem which one obtains at time t by conditioning on
> failure to detection after t as well as before t under
> the plan.[1]

The algorithms first find an optimal allocation of effort for the initial target distribution. Then for times $t = 2,...,T$, they

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[1]Stone, et. al. (1978), abstract.

calculate the posterior distribution for the target location at time t given failure to detect at all previous times and allocate effort for that stationary target problem. The plan resulting from the first pass is called the "myopic" plan. Subsequent passes are made reallocating the effort each time. One can come as close to the optimal plan as desired by performing enough passes. In many situations, the myopic plans are almost as good as the optimal plan.

> The optimal plans typically pay a penalty in probability of detection at the early hours in order to maximize that probability at time t. ...when the myopic plan is close to optimal, the myopic plan is a good one for operational purposes.[1]

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[1]Stone, et. al. (1978), abstract.

KOOPMAN REVISITED

In 1979, Koopman (1979, a&b) published two papers, and in 1980 republished his 1946 work, <u>Search and Screening</u>. In 1979a he generalized his 1946 work. In 1979b his emphasis was on operational feasibility; this subject will be discussed in the last section of this paper. Both of these papers are incorporated in the 1980 edition of <u>Search and Screening</u>.

Koopman rederived his law of random search under slightly more general assumptions. He assumed:

- Search is by passive observations.

- The search is repeatable.

- Short range detectors are used.

- All factors (target, searcher, and environment) are constant.

- $\phi(x,y)$ is the search effort applied at (x,y).

Define $D(x,y,z)$, where $z = \phi(x,y)$, as the probability the target is detected given that it is at (x,y) and with search effort z. Then

$$D(x,y,z) = 1 - e^{-w(x,y)z}, \quad w(x,y) \geq 0$$

In general, the larger $w(x,y)$, the greater the probability of detection; it is a sort of local measure of detectability at (x,y). Under the assumption that everything within a range R of the searcher is detected, w becomes the sweepwidth defined in Koopman's 1946 paper.

The optimal distribution of searching effort problem can be formulated as follows.

Find the search density function $\phi(x,y)$ which maximizes

$$P(\phi) = \iint_A p(x,y)D(x,y,\phi(x,y))\,dxdy$$

$$= \iint_A p(x,y)\left\{1 - \exp[-w(x,y)\phi(x,y)]\right\}\,dxdy$$

subject to $\iint_A \phi(x,y)\,dxdy = \Phi$, and $\phi(x,y) \geq 0$.

Φ is the total available effort.

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He assumed further that the functions p, w, and ϕ are all continuous. He used a method developed by Gibbs in 1928 to solve this Calculus of Variations problem. Koopman shows that there is a unique λ (similar to the "b" in his earlier work) such that the optimal $\phi(x,y)$ is

$$\phi(x,y) = [1/w(x,y)] \log [p(x,y)w(x,y)/\lambda] \quad \text{for } (x,y) \in A(\phi),$$

and

$$\Phi = \iint_{A(\phi)} \left\{ \log[p(x,y)w(x,y)] - \log \lambda \right\} dxdy/w(x,y).$$

The geometric interpretation is the same as in the earlier formulation.

By replacing the exponential detection function $D(x,y,z)$ with a partial detection function $b(x,y,z)$, where

$$b(x,y,z) = 1 - \int_0^\infty e^{-wz} dG(w)$$

(the integral is a Laplace-Stieltjes transform), Koopman finds a larger class than the regular (deGuenin) detection functions for which his results are valid. $G(w)$ usually involves (x,y); as w goes from 0 to ∞, $G(w)$ goes non-decreasingly from 0 to 1. (For other properties of G see Koopman (1979a)). However, Koopman points out that "The practical problem of finding $G(w)$

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has so far only been solved by guesswork, without subsequent verification."[1] The Normal distribution has been suggested. Stone (1975), and Richardson and Belkin (1972), have studied the use of the gamma distribution when the sweep width is uncertain.

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[1]Koopman (1979b), p.538.

BEST TRACK PROBLEMS

Optimal effort allocation problems are relatively easy to solve; however, it is common that the goal is to find the best search track. Mathematically this is a harder problem, and often approximate solutions are all that are available.

In 1946, Koopman developed the method of parallel sweeps for searching for a stationary target or a target whose speed and direction are known. In either case it is assumed that the prior target distribution is uniform in the search area. This search plan calls for the searchers (e.g., airplanes) to move along a series of parallel lines (whose distance apart depends on the search environment) which cover the area. In the case of a moving target, the sweeps are made parallel to the target's motion.

Between the 1940s and 1970 almost no progress was made in solving best track problems. In 1974, Lukka (1974) worked out the theory of optimal track for stationary targets, targets whose motion is known, and targets whose motion is almost known. The methods rely on the theory of optimal control. Mangel and Thomas (1979) wrote a tutorial type paper developing from first principals analytical methods for search for a moving target.

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Mangel (1981), basing his work on Lukka's, derived algorithms for
the optimal control result, one where the detection rate is inde-
pendent of velocity and one where it is not. Mangel defines
$f(x,t,z)$ and $u(x,t,z)$ as

$f(x,t,z)dx$ = Prob[x(t) ϵ (x,x+dx) and search along

z(τ), $0 \leq \tau \leq$ t was not successful]

$u(x,t,z)$ = Prob[non-detection to time $T|$ x(t) = x,

and search along z(τ), t $\leq \tau \leq$ T]

He showed (Mangel and Thomas, 1979) that these quantities must
satisfy

$$\frac{\partial f}{\partial t} = \sum_{i,j} 1/2 \frac{\partial^2}{\partial x_i \partial x_j}(a_{ij}f) - \sum_i \frac{\partial}{\partial x_i}(b_i f) - \psi(x,t,z)f \qquad (1)$$

with $f(x,0,z) = f_0(x)$ plus boundary conditions,

$$\frac{\partial u}{\partial t} = - \sum_{ij} 1/2 a_{ij}\frac{\partial^2 u}{\partial x_i \partial x_j} - \sum_i b_i\frac{\partial u}{\partial x_i} + \psi(x,t,z)u \qquad (2)$$

with $u(x,T,z) = 1$ + boundary conditions,

where a_{ij} is the diffusion matrix and $b_i(x)$ represents the
average velocity of the target (the drift coefficient). $\psi(x,t,z)$
is the instantaneous detection rate, defined by

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$\psi(x,t,z)dt$ = Prob[detection in $(t,t+dt)|$ $X(t)$ = x,

$Z(t)$ = z, no detections before t]

Mangel modified the ray techniques of J.B. Keller (Keller, 1978) to solve equations (1) and (2).

To find the best search track which maximizes $P(t)$, the probability of detection at time T, we must pick $v(t)$, the searcher velocity so that $P(T) = 1 - \int f(x,T,z)dx$ is maximized, $dz/dt = v(t)$, $z(0) = z_0$, and $f(x,T,z)$ satisfies (1). Lukka (1974) derived the maximum principle for this problem, showing that the optimal velocity $v*(t)$ makes $H(t,v,A)$ a maximum over all allowed velocities, where $f(x,t,z)$ satisfies (1), $u(x,t,z)$ satisfies (2), $dz/dt = v(t)$, and

$$H(t,v,A) = \int f(x,t,z)u(x,t,z)\psi(x,t,z)dx + \Sigma A_i(t)v_i(t),$$

$$dA_i/dt = - \int f(x,t,z)u(x,t,z)\frac{\partial \psi}{\partial z_i}(x,t,z) \, dx, \text{ with } A(T) = 0.$$

Mangel points out that when the detection function is independent of velocity, the searcher should move at maximum speed and in the direction of $A(X)$ where

$$A(t) = A(0) - \int\int_0^t f(x,s,z)u(x,s,z)\psi dxds.$$

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$$A(O) = \iint_0^T f(x,t,z)u(x,t,z)\psi\,dxdt.$$

It seems clear that we are a long way from the routine solution of problems of this sort.

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In his "Operational Critique of Detection Laws," Koopman asks, "Given a theoretically perfect solution to a problem of optimal search, how accurately can it be implemented by the dispositions of paths of real searchers?"[1] His 1946 work looked at this question for several situations and decided that between 70 and 85 percent of the theoretical optimum is the best which can be expected. Since this is the case, he pointed out that it may be better to spend time finding "good enough" solutions, i.e., finding good "useful first approximations" rather than continuing to find elegant exact solutions.

Many of the techniques discussed in this paper require extensive computer time to implement. A solution which requires an hour on a larger computer is not very useful for searchers operating from an aircraft carrier or from a small law enforcement office. The searchers need to know in real time where to look and how long to look there. In order to make the theory more accessible to those who need it, much work is needed to devise good, simple approximations to optimal plans.

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[1]Koopman (1979a), p.131.

The analyst also needs to let the searcher know how much the plan depends on the search path being followed exactly, since some plans are less flexible in this regard than others. If the probability of detection does not depend strongly on the plan, other operational factors can be considered by the searchers.

Koopman emphasizes the idea that any mathematical model should have a solid basis in reality, be as simple as possible while still describing the problem, and the results should be operationally implementable. He says, "...we may be guided by the following general principle:

> OCCAM's(OR) RAZOR: Complications in models are not to be multiplied beyond the necessity of practical application and insight.[1]

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[1]Koopman (1979a), p.131.

BIBLIOGRAPHY

Belkin, B. (1975), "On the Rate of Expansion of Gamma Search Plans," Daniel H. Wagner, Assoc. Report

Blachman, N. (1959) "Prolegomena to Optimum Discrete Search Procedures," _Naval Res. Log Quart._ 6, 273-281

Blachman, N., Proschan, F. (1959), "Optimum Search for Objects Having Unknown Arrival Times," _Opns. Res._ 7, 625

Black, W. (1965), "Discrete Sequential Search," _Inform. & Control_ 8, 159-162

Braga, M.S.F. (1974), "An Introduction to Search Theory," U.S. Naval Postgrad. Sch. Report (AD 777 878)

Brown, S. (1980), "Optimal Search for a Moving Target in Discrete Time and Space," _Opns. Res._ 28, 1275

Charnes, A. and Cooper, W.W. (1958), "Theory of Search: Optimum Distribution of Search Effort," _Management Science_ 5

Chelst, K.R. (1978), "A Differential Equation Model of Search for Randomly Arriving and Departing Targets," Wayne State U., Col of Eng. report TR-78-3

Chew, M. Jr. (1967), "A Sequential Search Procedure," _Ann. Math. Stat_ 38, 494-501

Ciervo, A.P. (1975a), "A New Equation Governing Search: Theory and Applications," Pacific Sierra Res. Corp Note 68

Ciervo, A.P. (1975b), "A New Development in Search Theory," Pacific-Sierra Res. Corp. Note 79

Coggins, P.B. (1971), "Detection Probability Computation for Random Search of an Expanding Area," Nat. Acad. of Sc. NRC:CUW.0374

Conover, W.J., Bement, T.R., Iman, R.L. (1979), "On a Method for Detecting Clusters of Possible Uranium Deposits," _Technometrics_ 21, 276

Cozzoline, J.M. (1970), "Sequential Search for an Unknown Number of Objects of Non-Uniform Size," _Opns. Res._ 18, 293

BIBLIOGRAPHY (Continued)

Danskin, J.M. (1966), "A Helicopter Versus Submarine Search Game,"
Ctr. for Naval Analyses, CRC 24

Danskin, J.M. (1962), "A Theory of Reconnaissance I," _Opns. Res._
10, 285-299

deGuenin, J. (1961), "Optimum Distribution of Effort: An Extension
of the Koopman Basic Theory," _Opns. Res._ 9, 1-7

Dobbie, J.M. (1945), "Search for Stationary and for Moving Targets
About Point of Fix," Opns. Res. Gp. No. 23, Ctr. for Naval
Analyses CRC 45

Dobbie, J.M. (1963), "Search Theory: A Sequential Approach," _Naval
Res. Log. Quart._ 10,323-334

Dobbie, J.M. (1964), "Surveillance of a Region by Detection and
Tracking Operations," _Opns. Res._ 12, 379-394

Dobbie, J.M. (1968), "A Survey of Search Theory," _Opns Res._
16,525-537

Engel, J. H. (1957), "Use of Clustering in Minerological and Other
Surveys," Proceedings of the First Int'l Conf. on O.R., _ORSA
Bull._, 176

Engler, B.D. (1970), "A Survey of Allocation Models in Search
Theory," U.S. Naval Postgrad. Sch. Thesis

Forrest, R.N. (1975), "Some Notes on Search, Detection, and
Localization Modeling," U.S. Naval Postgrad. Sch. Tech. Report

Gilbert, E.N. (1959), "Optimal Search Strategies," _Indust. Appl.
Math._ 7

Gluss, B. (1961), "Approximately Optimal One-Dimensional Search
Policies in Which Search Costs Vary with Time," Opns. Res. 9

Kadane, J. (1968), "Discrete Search and the Neyman-Pearson Lemma,"
J. Math. Anal. and Appl. 22 156-171

Kan, Y.C. (1977), "Optimal Search of a Moving Target," _Opns Res._
25, 864

BIBLIOGRAPHY (Continued)

Kaufman, A. (1976), "An Analysis of the Search and Detection
Problem," Ctr For Naval Analyses CRC 292

Keller, J.B. (1978), Bull. Amer. Math. Soc. 84, 727

King, L. J. (1969), "Applications of Probability Models in
Geographic Problems: One-Dimensional Situations," Statistical
Analysis in Geography, Prentice-Hall

Klein, M. (1968), "A Note on Sequential Search," Nav. Res. Log.
Quart. 15, 469-474

Koopman, B.O. (1946), "Search & Screening," OEG Report No. 56

Koopman, B.O. (1956a), "The Theory of Search I: Kinematic Bases,"
Opns. Res. 4, 324

Koopman, B.O. (1956b), "The Theory of Search II: Target
Detection," Opns Res. 4, 502

Koopman, B.O. (1957), "The Theory of Search III: The Optimum
Distribution of Searching Effort," Opns. Res. 5, 612

Koopman, B.O. (1979a), "An Operational Critique of Detection Laws,"
Opns Res. 27, 114

Koopman, B.O. (1979b), "Search and its Optimization," Amer. Math.
Monthly 86, 527-540

Koopman, B.O. (1980), Search and Screening, Perganon Press,
New York

Lukka, M. (1974), "On the Optimal Searching Tracks for a Stationary
Target," Inst. for Appl. Math., Univ. of Turku, Pub. No. 4

Mangel, M. (1980), "Optimal Search: Old Problems and New Answers,"
Unpublished CNA Report

Mangel, M. (1981), "Search for a Randomly Moving Object," to appear
SIAM J. on Appl. Math.

Mangel, M., Thomas, S. (1979), "Analytical Methods in Search
Theory," CNA Professional Paper 258

30

BIBLIOGRAPHY (Continued)

Mattson, R.J. (1980), "Overland Search for Missing Aircraft and
    Missing Persons," Presented TIMS/ORSA Conference, Washington,
    D.C.

Matula, D. (1964), "A Periodic Optimal Search," Amer. Math Monthly
    71, 15-21

Mela D.F. (1961), "Information Theory and Search Theory as Special
    Cases of Decision Theory," Opns. Res. 9, 907

Moore, M.L. (1970), "A Review of Search and Reconnaissance Theory
    Literature," U. of Mich. Systems Res. Lab. Report TR 70-1

Persinger, C.A. (1973), "Optimal Search Using Two Nonconcurrent
    Sensors," Nav. Res. Log. Quart. 20, 277-288

Pierce, J.G. (1978), "A New Look at the Relation Between
    Information Theory and Search Theory," Ctr. for Naval Analyses
    CRC 357

Pollock S. (1964), "Sequential Search and Detection," Opns. Res.
    Ctr, MIT, Cambridge, Mass., Tech Report No. 5

Pollock, S. (1970), "A Simple Model of Search for a Moving Target,"
    Opns. Res. 18, 883

Posner, E. (1963), "Optimal Search Procedures," IEEE Trans. on
    Information Theory, IT-9, 157-160

Perisiheimo, U. (1977), "On the Optimal Search for a Target Whose
    Motion is Conditionally Deterministic with Stochastic Initial
    Conditions on Location and Parameters," SIAM, J. of App. Math.,
    32-105

Richardson, H.R. and Belkin B. (1972), "Optimal Search with
    Uncertain Sweep Width," Opns. Res. 20, 764-784

Richardson, H.R. and Stone, L.D. (1971), "Operations Analysis
    During the Underwater Search for Scorpion," Nav. Res. Log. Quart.
    18, 141-157

Ross, S.M. (1968), "A Problem in Optimal Search and Stop," Opns.
    Res. 17, 984

Shubert, B.O. (1975), "Modeling a Random Search," U.S. Naval
Postgrad. Sch. Thesis

Stone, L.D. and Stanshine, J.A. (1971), "Optimal Search Using
Uninterrupted Contact Investigation," SIAM J. Appl. Math 20

Stone, L.D. (1972), "Incremental Approximation of Optimal
Allocations," Nav. Res. Log. Quart. 19

Stone, L.D. (1973), "Total Optimality of Incremental Optimal
Allocations," Nav. Res. Log. Quart. 20

Stone, L.D. (1975), Theory of Optimal Search, Academic Press,
New York

Stone, L.D. and Richardson, "H.R. (1974) "Search for Targets with
Conditionally Deterministic Motion," SIAM J. Appl. Math 27

Stone, L.D., Brown, S.S. and, Buemi, R.P., Hopkins, C.R. (1978),
"Numerical Optimization of Search for a Moving Target," Daniel H.
Wagner Assoc. Report to the Off. of Naval Res.

Stone, L.D. and Kadane, J.B. (1979), "Optimal Whereabouts Search
for a Moving Target," Daniel H. Wagner, Assoc. Report

Stone, L.D. (1979), "Necessary and Sufficient Conditions for
Optimal Search Plans for Moving Targets," Math. of O.R. 4

Washburn, A. (1969), "A Probability Density of a Moving Particle,"
Opns. Res. 17

Wegner, Ingo (1980), "The Discrete Sequential Search Problem with
Non-Random Cost and Overlook Probabilities," Math. of O.R. 5,
373

Zahl, S. (1963), "An Allocation Problem with Applications to
Operations Research and Statistics," Opns. Res. 11 426-441

CNA Professional Papers — 1976 to Present[†]

PP 141
Mizrahi, Maurice M., "Generalized Hermite Polynomials,"* 5 pp., Feb 1976 (Reprinted from Journal of Computational and Applied Mathematics, Vol. 1, No. 4 (1975), 273-271).
*Research supported by the National Science Foundation

PP 143
Horowitz, Stanley and Sherman, Allan (LCdr., USN), "Maintenance Personnel Effectiveness in the Navy," 33 pp., Jan 1976 (Presented at the RAND Conference on Defense Manpower, Feb 1976) AD A021 581

PP 144
Durch, William J., "The Navy of the Republic of China — History, Problems, and Prospects," 66 pp., Aug 1976 (Published in "A Guide to Asiatic Fleets," ed. by Barry M. Blechman and Robert Berman, Naval Institute Press) AD A030 460

PP 145
Kelly, Anne M., "Port Visits and the "International Mission" of the Soviet Navy," 36 pp., Apr 1976, AD A023 436

PP 147
Kessler, J. Christian, "Legal Issues in Protecting Offshore Structures," 33 pp., Jun 1976 (Prepared under task order N00014-68-A-0091-0023 for ONR) AD A028 388

PP 148
Squires, Michael L., "Counterforce Effectiveness: A Comparison of the Triple "K" Measure and a Computer Simulation," 24 pp., Mar 1976 (Presented at the International Study Association Meetings, 27 Feb 1976) AD A022 591

PP 150
Kelly, Anne M. and Petersen, Charles, "Recent Changes in Soviet Naval Policy: Prospects for Arms Limitations in the Mediterranean and Indian Ocean," 28 pp., Apr 1976, AD A 023 723

PP 151
Horowitz, Stanley A., "The Economic Consequences of Political Philosophy," 8 pp., Apr 1976 (Reprinted from Economic Inquiry, Vol. XIV, No. 1, Mar 1976)

PP 152
Mizrahi, Maurice M., "On Path Integral Solutions of the Schrödinger Equation, Without Limiting Procedure,"* 10 pp., Apr 1976 (Reprinted from Journal of Mathematical Physics, Vol. 17, No. 4 (Apr 1976), 566-575).
*Research supported by the National Science Foundation

PP 153
Mizrahi, Maurice M., "WKB Expansions by Path Integrals, With Applications to the Anharmonic Oscillator,"* 137 pp., May 1976, AD A025 440
*Research supported by the National Science Foundation

PP 154
Mizrahi, Maurice M., "On the Semi-Classical Expansion in Quantum Mechanics for Arbitrary Hamiltonians," 19 pp., May 1976 (Published in Journal of Mathematical Physics, Vol. 18, No. 4, pp. 786-790, Apr 1977), AD A025 641

PP 155
Squires, Michael L., "Soviet Foreign Policy and Third World Nations," 26 pp., Jun 1976 (Prepared for presentation at the Midwest Political Science Association meetings, Apr 30, 1976) AD A029 368

PP 156
Stallings, William, "Approaches to Chinese Character Recognition," 12 pp., Jun 1976 (Reprinted from Pattern Recognition (Pergamon Press), Vol. 8, pp. 97-98, 1976) AD A026 882

PP 157
Morgan, William F., "Unemployment and the Pentagon Budget: Is There Anything in the Empty Pork Barrel?" 20 pp., Aug 1976 AD A030 455

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Haskell, LCdr. Richard D. (USN), "Experimental Validation of Probability Predictions," 25 pp., Aug 1976 (Presented at the Military Operations Research Society Meeting, Fall 1976) AD A030 458

PP 159
McConnell, James M., "The Gorshkov Articles, The New Gorshkov Book and Their Relation to Policy," 93 pp., Jul 1976 (Published in Soviet Naval Influence: Domestic and Foreign Dimensions, ed. by M. MccGwire and J. McDonnell; New York: Praeger, 1977) AD A029 227

PP 160
Wilson, Desmond P., Jr., "The U.S. Sixth Fleet and the Conventional Defense of Europe," 50 pp., Sep 1976, AD A030 457

PP 161
Melich, Michael E. and Peet, Vice Adm. Ray (USN, Retired), "Fleet Commanders: Afloat or Ashore?" 9 pp., Aug 1976 (Reprinted from U.S. Naval Institute Proceedings, Jun 1976) AD A030 456

PP 162
Friedheim, Robert L., "Parliamentary Diplomacy," 106 pp. Sep 1976 AD A033 306

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Lockman, Robert F., "A Model for Predicting Recruit Losses," 9 pp., Sep 1976 (Presented at the 84th annual convention of the American Psychological Association, Washington, D.C., 4 Sep 1976) (Published in Defense Manpower Policy (Richard V. L. Cooper, ed.), The Rand Corporation, 1979), AD A030 459

PP 164
Mahoney, Robert B., Jr., "An Assessment of Public and Elite Perceptions in France, The United Kingdom, and the Federal Republic of Germany," 31 pp., Feb 1977 (Presented at Conference "Perception of the U.S. — Soviet Balance and the Political Uses of Military Power" sponsored by Director, Advanced Research Projects Agency, April 1976) AD A036 599

PP 165
Jondrow, James M. "Effects of Trade Restrictions on Imports of Steel," 67 pp., November 1976, (Delivered at ILAB Conference in Dec 1976) AD A084 798

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Feldman, Paul, "Why It's Difficult to Change Regulation," Oct 1976, AD A037 662

PP 167
Kleinman, Samuel, "ROTC Service Commitments: a Comment," 4 pp., Nov 1976, (Published in Public Choice, Vol. XXIV, Fall 1976) AD A033 305

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Lockman, Robert F., "Revalidation of CNA Support Personnel Selection Measures," 36 pp., Nov 1976

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Jacobson, Louis S., "Earnings Losses of Workers Displaced from Manufacturing Industries," 38 pp., Nov 1976, (Delivered at ILAB Conference in Dec 1976), AD A039 809

PP 170
Brechling, Frank P., "A Time Series Analysis of Labor Turnover," Nov 1976, (Delivered at ILAB Conference in Dec 1976), AD A096 630

PP 171
Jordan, A. S.* and Ralston, J. M., "A Diffusion Model for GaP Red LED Degradation," 10 pp., Nov 1976, (Published in Journal of Applied Physics, Vol. 47, pp. 4518-4527, Oct 1976)
*Bell Laboratories

PP 172
Classen, Kathleen P., "Unemployment Insurance and the Length of Unemployment," Dec 1976, (Presented at the University of Rochester Labor Workshop on 16 Nov 1976)

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Kleinman, Samuel D., "A Note on Racial Differences in the Added-Worker/Discouraged-Worker Controversy," 2 pp., Dec 1976, (Published in the American Economist, Vol. XX, No. 1, Spring 1976)

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Mahoney, Robert B., Jr., "A Comparison of the Brookings and International Incidents Projects," 12 pp. Feb 1977 AD A037 205

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Levine, Daniel; Stoloff, Peter and Spruill, Nancy, "Public Drug Treatment and Addict Crime," June 1976, (Published in Journal of Legal Studies, Vol. 8, No. 2)

PP 176
Felix, Wendi, "Correlates of Retention and Promotion for USNA Graduates," 38 pp., Mar 1977, AD A039 040

PP 177
Lockman, Robert F. and Warner, John T., "Predicting Attrition: A Test of Alternative Approaches," 33 pp. Mar 1977, (Presented at the OSD/ONR Conference on Enlisted Attrition, Xerox International Training Center, Leesburg, Virginia, 4-7 April 1977), AD A039 047

PP 178
Kleinman, Samuel D., "An Evaluation of Navy Unrestricted Line Officer Accession Programs," 23 pp. April 1977, (Presented at the NATO Conference on Manpower Planning and Organization Design, Stress, Italy, 20 June 1977), AD A039 048

PP 179
Stoloff, Peter H. and Balut, Stephen J., "Vacate: A Model for Personnel Inventory Planning Under Changing Management Policy," 14 pp. April 1977, (Presented at the NATO Conference on Manpower Planning and Organization Design, Stress, Italy, 20 June 1977), AD A039 046

PP 180
Horowitz, Stanley A. and Sherman, Allan, "The Characteristics of Naval Personnel and Personnel Performance," 18 pp. April 1977, (Presented at the NATO Conference on Manpower Planning and Organization Design, Stress, Italy, 20 June 1977), AD A039 060

PP 181
Balut, Stephen J. and Stoloff, Peter, "An Inventory Planning Model for Navy Enlisted Personnel," 35 pp., May 1977 (Prepared for presentation at the Joint National Meeting of the Operations Research Society of America and The Institute for Management Science, 9 May 1977, San Francisco, California), AD A042 221

PP 182
Murray, Russell, 2nd, "The Quest for the Perfect Study or My First 1138 Days at CNA," 57 pp., April 1977

PP 183
Kassing, David, "Changes in Soviet Naval Forces," 33 pp., November, 1976, (Published as part of Chapter 3, "General Purpose Forces: Navy and Marine Corps," in Arms, Men, and Military Budgets, Francis P. Hoeber and William Schneider, Jr. (eds.), (Crane, Russak & Company, Inc.: New York), 1977), AD A040 106

PP 184
Lockman, Robert F., "An Overview of the OSD/ONR Conference on First Term Enlisted Attrition," 22 pp., June 1977, (Presented to the 39th MORS Working Group on Manpower and Personnel Planning, Annapolis, Md., 28-30 Jun 1977), AD A043 618

PP 185
Kassing, David, "New Technology and Naval Forces in the South Atlantic," 22 pp. (This paper was the basis for a presentation made at the Institute for Foreign Policy Analyses, Cambridge, Mass., 28 April 1977), AD A043 619

PP 186
Mizrahi, Maurice M., "Phase Space Integrals, Without Limiting Procedure," 31 pp., May 1977, (Invited paper presented at the 1977 NATO Institute on Path Integrals and Their Application in Quantum Statistical, and Solid State Physics, Antwerp, Belgium, July 17-30, 1977) (Published in Journal of Mathematical Physics 19(1), pp. 298-307, Jan 1978, with Erratum in same journal 21 (1980), p. 1965) AD A040 107

PP 187
Coile, Russell C., "Nomography for Operations Research," 35 pp., April 1977 (Presented at the Joint National Meeting of the Operations Research Society of America and The Institute for Management Science, San Francisco, California, 9 May 1977), AD A043 620

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Durch, William J., "Information Processing and Outcome Forecasting for Multilateral Negotiations: Testing One Approach," 53 pp., May 1977 (Prepared for presentation to the 18th Annual Convention of the International Studies Association, Chase-Park Plaza Hotel, St. Louis, Missouri, March 16-20, 1977), AD A042 222

PP 189
Coile, Russell C., "Error Detection in Computerized Information Retrieval Data Bases," July, 1977, 13 pp. (Presented at the Sixth Cranfield International Conference on Mechanized Information Storage and Retrieval Systems, Cranfield Institute of Technology, Cranfield, Bedford, England, 26-29 July 1977), AD A043 580

PP 190
Mahoney, Robert B., Jr., "European Perceptions and East-West Competition," 96 pp., July 1977 (Prepared for presentation at the annual meeting of the International Studies Association, St. Louis, Mo., March, 1977), AD A043 661

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Sawyer, Ronald, "The Independent Field Assignment: One Man's View," August 1977, 25 pp.

PP 192
Holen, Arlene, "Effects of Unemployment Insurance Entitlement on Duration and Job Search Outcome," August 1977, 6 pp., (Reprinted from Industrial and Labor Relations Review, Vol., 30, No. 4, Jul 1977)

PP 193
Horowitz, Stanley A., "A Model of Unemployment Insurance and the Work Test," August 1977, 7 pp. (Reprinted from Industrial and Labor Relations Review, Vol. 30, No. 40, Jul 1977)

PP 194
Classen, Kathleen P., "The Effects of Unemployment Insurance on the Duration of Unemployment and Subsequent Earnings," August 1977, 7 pp. (Reprinted from Industrial and Labor Relations Review, Vol. 30, No. 40, Jul 1977)

PP 195
Brechling, Frank, "Unemployment Insurance Taxes and Labor Turnover: Summary of Theoretical Findings," 12 pp. (Reprinted from Industrial and Labor Relations Review, Vol. 30, No. 40, Jul 1977)

PP 196
Ralston, J. M. and Lorimor, O. G., "Degradation of Bulk Electroluminescent Efficiency in Zn, O-Doped GaP LED's," July 1977, 3 pp. (Reprinted from IEEE Transactions on Electron Devices, Vol. ED-24, No. 7, July 1977)

PP 197
Wells, Anthony R., "The Centre for Naval Analyses," 14 pp., Dec 1977, AD A049 107

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Classen, Kathleen P., "The Distributional Effects of Unemployment Insurance," 25 pp., Sept. 1977 (Presented at a Hoover Institution Conference on Income Distribution, Oct 7-8, 1977), AD A054 423

PP 199
Durch, William J., "Revolution From A F.A.R. — The Cuban Armed Forces in Africa and the Middle East," Sep 1977, 16 pp., AD A049 268

PP 200
Powers, Bruce F., "The United States Navy," 40 pp. Dec 1977 (Published as a chapter in The U.S. War Machine by Salamander Books, England,1978), AD A049 108

PP 201
Durch, William J., "The Cuban Military in Africa and The Middle East: From Algeria to Angola," Sep 1977, 67 pp., AD A049 675

PP 202
Feldman, Paul, "Why Regulation Doesn't Work," (Reprinted from Technological Change and Welfare in the Regulated Industries, Brookings Reprint 219, 1971, and Review of Social Economy, Vol. XXIX, March, 1971, No. 1.) Sep 1977, 8 pp.

PP 203
Feldman, Paul, "Efficiency, Distribution, and the Role of Government in a Market Economy," (Reprinted from The Journal of Political Economy, Vol. 78, No. 3, May/June 1971.) Sep 1977, 19 pp., AD A045 675

PP 204
Wells, Anthony R., "The 1967 June War: Soviet Naval Diplomacy and The Sixth Fleet — A Reappraisal," Oct 1977, 36 pp., AD A047 236

PP 205
Coile, Russell C., "A Bibliometric Examination of the Square Root Theory of Scientific Publication Productivity," (Presented at the annual meeting of the American Society for Information Science, Chicago, Illinois, 29 September 1977.) Oct 1977, 6 pp., AD A047 237

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McConnell, James M., "Strategy and Missions of the Soviet Navy in the Year 2000," 48 pp., Nov 1977 (Presented at a Conference on Problems of Sea Power as we Approach the 21st Century, sponsored by the American Enterprise Institute for Public Policy Research, 6 October 1977, and subsequently published in a collection of papers by the Institute), AD A047 244

PP 207
Goldberg, Lawrence, "Cost-Effectiveness of Potential Federal Policies Affecting Research & Development Expenditures in the Auto, Steel and Food Industries," 36 pp., Oct 1977, (Presented at Southern Economic Association Meetings beginning 2 November 1977), AD A049 299

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Roberts, Stephen S., "The Decline of the Overseas Station Fleets: The United States Asiatic Fleet and the Shanghai Crisis, 1932," 18 pp., Nov 1977 (Reprinted from The American Neptune, Vol. XXXVII, No. 3, July 1977), AD A047 245

PP 209 — Classified.

PP 210
Kassing, David, "Protecting The Fleet," 40 pp., Dec 1977 (Prepared for the American Enterprise Institute Conference on Problems of Sea Power as We Approach the 21st Century, October 6-7, 1977), AD A049 109

PP 211
Mizrahi, Maurice M., "On Approximating the Circular Coverage Function," 14 pp., Feb 1978, AD A054 429

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Mangel, Marc, "On Singular Characteristic Initial Value Problems with Unique Solutions," 20 pp., Jun 1978, AD A058 535

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Mangel, Marc, "Fluctuations in Systems with Multiple Steady States. Application to Lanchester Equations," 12 pp., Feb 78, (Presented at the First Annual Workshop on the Information Linkage Between Applied Mathematics and Industry, Naval PG School, Feb 23-25, 1978), AD A071 472

PP 214
Weinland, Robert G., "A Somewhat Different View of The Optimal Naval Posture," 37 pp., Jun 1978 (Presented at the 1978 Convention of the American Political Science Association (APSA/IUS Panel on "Changing Strategic Requirements and Military Posture"), Chicago, Ill., September 2, 1976), AD A056 228

PP 215
Colle, Russell C., "Comments on: Principles of Information Retrieval by Manfred Kochen," 10 pp., Mar 78, (Published as a Letter to the Editor, Journal of Documentation, Vol. 31, No. 4, pages 298-301, December 1975), AD A054 426

PP 216
Colle, Russell C., "Lotka's Frequency Distribution of Scientific Productivity," 18 pp., Feb 1978, (Published in the Journal of the American Society for Information Science, Vol. 28, No. 6, pp. 366-370, November 1977), AD A054 425

PP 217
Colle, Russell C., "Bibliometric Studies of Scientific Productivity," 17 pp., Mar 78, (Presented at the Annual meeting of the American Society for Information Science held in San Francisco, California, October 1976), AD A054 442

PP 218 — Classified.

PP 219
Huntzinger, R. LaVar, "Market Analysis with Rational Expectations: Theory and Estimation," 60 pp., Apr 78, AD A054 422

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Maurer, Donald E., "Diagonalization by Group Matrices," 26 pp., Apr 78, AD A054 443

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Weinland, Robert G., "Superpower Naval Diplomacy in the October 1973 Arab-Israeli War," 76 pp., Jun 1978 (Published in Seapower in the Mediterranean: Political Utility and Military Constraints, The Washington Papers No. 61, Beverly Hills and London: Sage Publications, 1979) AD A055 564

PP 222
Mizrahi, Maurice M., "Correspondence Rules and Path Integrals," 30 pp., Jun 1978 (Invited paper presented at the CNRS meeting on "Mathematical Problems in Feynman's Path Integrals," Marseille, France, May 22-26, 1978) (Published in Springer Verlag Lecture Notes in Physics, 106, (1979), 234-253) AD A055 536

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Mangel, Marc, "Stochastic Mechanics of Molecule-ion Molecule Reactions," 21 pp., Jun 1978, AD A056 227

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Mangel, Marc, "Aggregation, Bifurcation, and Extinction in Exploited Animal Populations*," 48 pp., Mar 1978, AD A058 536
*Portions of this work were started at the Institute of Applied Mathematics and Statistics, University of British Columbia, Vancouver, B.C., Canada

PP 225
Mangel, Marc, "Oscillations, Fluctuations, and the Hopf Bifurcation*," 43 pp., Jun 1978, AD A058 537
*Portions of this work were completed at the Institute of Applied Mathematics and Statistics, University of British Columbia, Vancouver, Canada.

PP 226
Ralston, J. M. and J. W. Mann*, "Temperature and Current Dependence of Degradation in Red-Emitting GaP LEDs," 34 pp., Jun 1978 (Published in Journal of Applied Physics, 50, 3630, May 1979) AD A058 538
*Bell Telephone Laboratories, Inc.

PP 227
Mangel, Marc, "Uniform Treatment of Fluctuations at Critical Points," 50 pp., May 1978, AD A058 539

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PP 230
Mangel, Marc, "Diffusion Theory of Reaction Rates, II Ornstein-Uhlenbeck Approximation," 34 pp., Feb 1978, AD A058 542

PP 231
Wilson, Desmond P., Jr., "Naval Projection Forces: The Case for a Responsive MAF," Aug 1978, AD A058 543

PP 232
Jacobson, Louis, "Can Policy Changes Be Made Acceptable to Labor?" Aug 1978 (Submitted for publication in Industrial and Labor Relations Review], AD A061 528

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Jacobson, Louis, "An Alternative Explanation of the Cyclical Pattern of Quits," 23 pp., Sep 1978

PP 234 — Revised
Jondrow, James and Levy, Robert A., "Does Federal Expenditure Displace State and Local Expenditure: The Case of Construction Grants," 25 pp., Oct 1978, AD A061 529

PP 235
Mizrahi, Maurice M., "The Semiclassical Expansion of the Anharmonic-Oscillator Propagator," 41 pp., Oct 1978 (Published in Journal of Mathematical Physics 20 (1979), pp. 844-855), AD A061 538

PP 237
Maurer, Donald, "A Matrix Criterion for Normal Integral Bases," 10 pp., Jan 1979 (Published in the Illinois Journal of Mathematics, Vol. 22 (1978), pp. 672-691)

PP 238
Utgoff, Kathleen Classen, "Unemployment Insurance and The Employment Rate," 20 pp., Oct 1978 (Presented at the Conference on Economic Indicators and Performance: The Current Dilemma Facing Government and Business Leaders, presented by Indiana University Graduate School of Business), AD A061 527

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Trost, R. P. and Warner, J. T., "The Effects of Military Occupational Training on Civilian Earnings: An Income Selectivity Approach," 38 pp., Nov 1979, AD A077 831

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Powers, Bruce, "Goals of the Center for Naval Analyses," 13 pp., Dec 1978, AD A063 759

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Mangel, Marc, "Fluctuations at Chemical Instabilities," 24 pp., Dec 1978 (Published in Journal of Chemical Physics, Vol. 69, No. 8, Oct 15, 1978), AD A063 787

PP 242
Simpson, William R., "The Analysis of Dynamically Interactive Systems (Air Combat by the Numbers)," 160 pp., Dec 1978, AD A063 760

PP 243
Simpson, William R., "A Probabilistic Formulation of Murphy Dynamics as Applied to the Analysis of Operational Research Problems," 18 pp., Dec 1978, AD A063 761

PP 244
Sherman, Allan and Horowitz, Stanley A., "Maintenance Costs of Complex Equipment," 20 pp., Dec 1978 (Published By The American Society of Naval Engineers, Naval Engineers Journal, Vol. 91, No. 6, Dec 1979) AD A071 473

PP 245
Simpson, William R., "The Acceleration Methods of Obtaining Aircraft Performance from Flight Test Data (Dynamic Performance Testing)," 403 pp., Jun 1979, AD A075 226

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Breckling, Frank, "Layoffs and Unemployment Insurance," 35 pp., Feb 1979 (Presented at the NBER Conference on "Low Income Labor Markets," Chicago, Jun 1978), AD A096 629

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Thomas, James A., Jr., "The Transport Properties of Dilute Gases in Applied Fields," 183 pp., Mar 1979, AD A096 464

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Glasser, Kenneth S., "A Secretary Problem with a Random Number of Choices," 23 pp., Mar 1979

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Mangel, Marc, "Modeling Fluctuations in Macroscopic Systems," 26 pp., Jun 1979

PP 251
Trost, Robert P., "The Estimation and Interpretation of Several Selectivity Models," 37 pp., Jun 1979, AD A075 941

PP 252
Nunn, Walter R., "Position Finding with Prior Knowledge of Covariance Parameters," 5 pp., Jun 1979 (Published in IEEE Transactions on Aerospace & Electronic Systems, Vol. AES-15, No. 3, March 1979

PP 253
Glasser, Kenneth S., "The d-Choice Secretary Problem," 32 pp., Jun 1979, AD A075 225

PP 254
Mangel, Marc and Quanbeck, David B., "Integration of a Bivariate Normal Over an Offset Circle," 14 pp., Jun 1979, AD A096 471

PP 255 — Classified, AD B051 441L

PP 256
Maurer, Donald E., "Using Personnel Distribution Models," 27 pp., Feb 1980, AD A082 218

PP 257
Thaler, R., "Discounting and Fiscal Constraints: Why Discounting is Always Right," 10 pp., Aug 1979, AD A075 224

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Mangel, Marc S. and Thomas, James A., Jr. "Analytical Methods in Search Theory," 86 pp., Nov 1979, AD A077 832

PP 259
Glass, David V.; Hsu, Ih-Ching; Nunn, Walter R. and Perin, David A., "A Class of Commutative Markov Matrices," 17 pp., Nov 1979, AD A077 833

PP 260
Mangel, Marc S. and Cope, Davis K., "Detection Rate and Sweep Width in Visual Search," 14 pp., Nov 1979, AD A077 834

PP 261
Vila, Carlos L.; Zvijac, David J. and Ross, John, "Franck-Condon Theory of Chemical Dynamics. VI. Angular Distributions of Reaction Products," 14 pp., Nov 1979 (Reprinted from Journal Chem. Phys. 70(12), 15 Jun 1979), AD A076 287

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Petersen, Charles C., "Third World Military Elites in Soviet Perspective," 50 pp., Nov 1979, AD A077 835

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Robinson, Kathy I., "Using Commercial Tankers and Containerships for Navy Underway Replenishment," 25 pp., Nov 1979, AD A077 836

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Weinland, Robert G., "The U.S. Navy in the Pacific: Past, Present, and Glimpses of the Future," 31 pp., Nov 1979 (Delivered at the International Symposium on the Sea, sponsored by the International Institute for Strategic Studies, The Brookings Institution and the Yomiuri Shimbun, Tokyo, 16-20 Oct 1979) AD A066 837

PP 265
Weinland, Robert G., "War and Peace in the North: Some Political Implications of the Changing Military Situation in Northern Europe," 18 pp., Nov 1979 (Prepared for presentation to the "Conference of the Nordic Balance in Perspective: The Changing Military and Political Situation," Center for Strategic and International Studies, Georgetown University, Jun 15-16, 1979) AD A077 838

PP 266
Utgoff, Kathy Classen, and Brechling, Frank, "Taxes and Inflation," 25 pp., Nov 1979, AD A081 194

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Trost, Robert P., and Vogel, Robert C., "The Response of State Government Receipts to Economic Fluctuations and the Allocation of Counter-Cyclical Revenue Sharing Grants," 12 pp., Dec 1979 (Reprinted from the Review of Economics and Statistics, Vol. LXI, No. 3, August 1979)

PP 268
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