AD 749696

On the Determination of the "Closeness" to Complete Readiness and of Dynamic Readiness

by

Irwin Greenberg

Technical Report No. 2
September, 1972

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Prepared under Contract N00014-67-A-0467-0028
for the
Office of Naval Research

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UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Department of Industrial Engineering and Operations Research New York University Bronx, New York 10453	2a. REPORT SECURITY CLASSIFICATION 2b. GROUP

3. REPORT TITLE
On the Determination of the "Closeness" to Complete Readiness and of Dynamic Readiness.

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Technical Report

5. AUTHOR(S) (First name, middle initial, last name)
Irwin Greenberg

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
September 30, 1972	8	1

8a. CONTRACT OR GRANT NO. N00014-67-A-0467-0028 b. PROJECT NO. c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) Report No. 2 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT
Distribution of this document is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Office of Naval Research

13. ABSTRACT

Two techniques for the measurement of readiness are discussed: the "closeness" to complete readiness and dynamic readiness. The former is a measurement of the amount of time and effort required to achieve some prespecified level of complete readiness while the latter is a readiness measure which describes the ability of a unit to continue to perform in a satisfactory manner during the entire mission.

DD FORM 1 NOV 65 1473 (PAGE 1)

S/N 0102-014-6600

UNCLASSIFIED
Security Classification

UNCALSSIFIED
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
readiness						
closeness						
dynamic						
long-term						
queuing						

DD FORM 1 NOV 65 1473 (BACK)
(PAGE 2)

UNCLASSIFIED
Security Classification

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Introduction

This report is a follow-up study to Technical Report No. 1, "A Production Function Approach to the Measurement of Short Term Readiness of Navy Units" by S. Kaplan. In that report, several mission examples were introduced to illustrate the measurement procedure. In this study, some of those same examples are used to illustrate two additional measurement techniques: the "closeness" to complete readiness, a long term measurement of the amount of time and effort required to achieve complete readiness, and dynamic readiness, the readiness measure which must be developed to determine the ability of the unit under consideration to continue to perform in a satisfactory manner during the entire mission.

The "Closeness" to Complete Readiness

A readiness measure, useful for both short and long term planning purposes, is the closeness to complete readiness which has been attained. The illustration of this measure is most easily accomplished by use of one of the mission examples discussed in Reference 1. In these examples quantitative "requirements" and "resources" were specified. These are measured in such a way that the larger the value the greater the requirement or resource.

To illustrate more precisely, recall the mission of "maintaining a presence of at least 30 carrier based aircraft daily for the protection of ground troops". This mission, call it mission j, had the following requirement:

a_{1j} = 30 planes

a_{2j} = 30 pilots

a_{3j} = 30,000 gallons of fuel

a_{4j} = 30,000 rounds of ammunition

The amounts of these resources on hand for this mission were:

X_{1j} = 40 planes

X_{2j} = 30 pilots

X_{3j} = 25,000 gallons of fuel

X_{4j} = 200,000 rounds of ammunition

Complete readiness for mission j would be achieved if

$$X_{ij} \geq a_{ij} \quad \text{for all} \quad i .$$

This is not so for mission j: $X_{3j} < a_{3j}$ and hence, complete readiness for mission j has not been achieved.

In general, there will be m missions represented by the set $J = \{1,2,\ldots,m\}$. Some subset J_+ would consist of those missions for which complete readiness has been achieved; i.e.,

$$j \epsilon J_+ \quad \text{iff} \quad X_{ij} \geq a_{ij} \quad \text{for all} \quad i .$$

The resources form a set $I = \{1,2,\ldots,n\}$. For simplicity in the example assume that the only resources are the four items mentioned above, planes, pilots, fuel and ammunition. The quantities

$$q_i = \max \left\{0, \sum_{j=1}^{m} (a_{ij} - X_{ij})\right\} , \; i = 1,2,\ldots,n$$

represent the deficiencies in resource i . Only when all q_i are zero will complete readiness be obtained. The set I can be partitioned into two mutually exclusive and exhaustive subsets:

$$i \in I_+ \text{ iff } q_i = 0$$

$$i \in I_- \text{ iff } q_i > 0 .$$

I_+ is the set of resources which are ample, I_- is the set of resources which are deficient. Complete readiness is achieved when all elements of I_- are "moved" into I_+. The cost involved in this "move" has two components: dollars and time. To illustrate, assume that I_- consists of the items "pilots" and "fuel". More specifically, assume that a specific carrier has a shortage of $q_2 = 5$ pilots and $q_3 = 100,000$ gallons of fuel. In order to achieve complete readiness, it is determined that the logistics system supplying fuel to the carrier will have to be modified, at a cost of d_3 dollars. The time until completion of this system modification is t_3. The deficiency in pilots will be overcome only after new pilots are recruited and trained, at a dollar cost d_2. The pilots would be available after time t_2. Thus the cost of achieving complete readiness for this carrier is

$$D = d_2 + d_3 \quad \text{dollars}$$

and the time required to achieve complete readiness is

$$T = \max(t_2, t_3) .$$

In most cases there will be trade-offs between T and D shorter implementation times might be achieved for more dollars expended. Also, certain of the corrective steps taken might apply to more than one of the deficiencies. In general, inadequate capability to perform a mission is due to one or more of the following factors:

(a) logistic - a shortage of materiel, operable parts, and spares.

(b) technological - the inability of the mechanical, electrical, and/or nuclear systems of the ship to perform as required, either because of inadequate design or insufficient maintenance.

c) crew - a shortage of personnel and/or below standard performance by crew members.

Measures taken to correct a logistic deficiency of, say, fuel, might also help correct deficiencies in other areas. Also, correcting the deficiencies facing one ship will probably assist others in the fleet. Hence, the move toward complete readiness will involve a dollar cost which may differ significantly from the sum of the dollar costs of the individual modifications. The achievement of complete readiness might require a PERT-type network analysis to determine the most expeditious route.

In discussing the various missions, it should be kept in mind that certain requirements exist for the everyday operation of the ship. Using an analogy from cost accounting, there are certain "overhead" functions of the ship which cannot be directly "charged" to a particular mission. Deficiencies in some of them (e.g., deck crews on a carrier) can hinder a number of missions and hence, the maintaining of adequate resources in some of these "overhead" areas can be more important than simply meeting mission requirements.

The "closeness to complete readiness" measures discussed above would probably be most useful when used in conjunction with some of the measures developed in Reference 1. These latter measures define a point at which the ship (or fleet, or Navy) finds itself at some time. The "closeness" measures, D and T, define the effort in money and time required to move from this point to a desired goal. If the determination of D and T indicate that these costs are prohibitive, the Navy might want to re-examine some of its goals in light of the realization that their attainment is difficult.

While the term "complete readiness" has been used here as an absolute, it is recognized that it may, in fact, be more meaningful to specify several levels of readiness (and hence, several levels of requirements a_{ij}) such as "barely adequate", "adequate", and "desirable", perhaps associated with different threat levels. The "closeness" to each can be ascertained and planning can be done accordingly.

Dynamic Readiness Measurement

One of the more difficult aspects of measuring readiness is the determination of the mission requirements in the dynamic environment of mission performance. In the examples cited in Reference 1 missions were specified in such a way that the requirements could be expressed as initial stocks of men, materiel, aircraft, etc. To be "ready" to perform a mission, however, implies not only an initial capability but a continuing capability to accomplish what is required. This capability involves an interplay between the three factors mentioned earlier (logistic, technological, and crew) and is dependent not only on the individual missions that the ship is called upon to perform but on the mix of missions that a ship will have to perform at any instant.

To illustrate, consider an aircraft carrier supplying planes for two of the missions mentioned in Reference 1: protection of ground troops and dropping mines. The logistic requirements which were developed in Reference 1 are necessary but not sufficient requirements for successful mission completion. During the course of the missions logistic problems may arise due to attrition or unreliability, technological problems may arise as equipment is utilized under conditions of heavy stress, and crew problems can arise, both from attrition and from the need for high skill levels to continually perform the exacting tasks that the missions call for. More precisely, consider the communications center of the carrier. Although not mentioned in Reference 1, each mission will carry with it some requirement for communication between the carrier and the planes. These a_{ij} will be in terms of speed and reliability of message completion, expected message loads, and perhaps, security. During the execution of the missions the communications requirements might not be met because of logistic factors, (e.g., a shortage of spare parts to replace those which fail), technological factors (e.g., the inability of the communications equipment to handle the message load), or crew factors (e.g., a shortage of adequately trained communications specialists). Even if the requirements for either mission might be met individually, the combined requirements for the two missions might be too much for the communications center to handle at once. Still another possibility is that while the expected communications loads of the two missions could be handled simultaneously, statistical variations could create a period of time during which the communications center is overwhelmed and incapable of performing properly. One could postulate situations where this overloading leads to the failure of the missions with disasterous results.

It is clear, then, that operational readiness cannot be expressed only in a set of initial requirements but must take into account the requirements which arise during the performance of the mission. Further, expected or average levels are not in themselves meaningful. The success or failure of a mission is often times determined by stochastic variations from the mean rather than the mean itself. Thus, it is necessary to incorporate stochastic models into the determination of the resources required.

One class of stochastic models particularly well suited for this type of determination comes from some considerations of queuing theory. In the communications illustration discussed above, queuing theory would be the obvious means for analyzing the problems of facilities overload, the queuing of messages waiting to be serviced or which are lost. The technological and crew trade-offs can be studied in this manner· if it is necessary to increase the capacity of the system by some amount, is this best done by new equipment design, improved skill levels among the crew brought about by increased training (both of these increase the mean service rate), or should more equipment and operators be utilized (which increases the number of servers)? This sort of optimization problem has been treated extensively in the operations research literature dealing with the optimization of queuing systems. It has substantial application to performance of tasks on ship where "tasks" arrive to be "performed" and either wait, if they cannot be handled immediately (e.g., aircraft arriving to land on a carrier) or are "lost" (e.g., enemy aircraft which could be attacked by ship-to-air missiles, but will be in range only a limited amount of time).

In addition to this type of problem, many aspects of reliability and logistics operations can be treated by queuing analysis. Spare parts are "customers" who arrive (possibly in bulk) to be "served", i.e., installed for use. If they are not used immediately they "wait" until required. The service time distribution of these "customers" is the lifetime distribution of the components. The "waiting time" distribution of the parts is the shelf-time distribution which might effect their capability to function properly when installed. The probability of an empty queue corresponds to the probability of a stockout and the distribution of the length of the idle period corresponds to the distribution of the length of the shortage.

This is not to suggest that all stochastic models of warfare, reliability and logistics can be cast in the queuing mold. While it would be desirable to have a single framework to encompass all of the probabilistic aspects of ship performance which constitute operational readiness, the price which would have to be paid in terms of model realism would probably be too high to be worthwhile. Nevertheless, the queuing models can go a long way in unifying the approach to the measurement of operational readiness in the dynamic mission environment.

Reference

1. Kaplan, S. A Production Function Approach to the Measurement of Short Term Readiness of Navy Units, Technical Report No. 1.