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SUBJECT: A Value Function Basis for the Comparative Analysis of High-Altitude Photographic Reconnaissance Systems

PREPARED BY: Leslie C. Dirks, Chief, Design and Analysis Division

## I. Introduction

A problem of frequent occurrence is the comparative evaluation of silver halide camera systems from the point of view of strategic intelligence image utility. The primary difficulty which is inevitably encountered in an attempt to undertake such an analysis is in relating a measure of camera system performance which is meaningful in terms of camera design parameters to a quantitative measure of the utility of the resulting imagery as it is used for the broad range or strategic intelligence applications. This paper outlines a technique for dealing with this particular problem which has evolved over a long period of time and has been successfully applied in a major camera system source selection. It should be emphasized that this technique has been developed in the context of silver halide film imaging systems operated at high altitudes against strategic reconnaissance objectives.

In addition to a description of this technique for comparative analysis, this paper also includes summary discussions of the rationale leading to the selection of the technique, along with comments on the application of the technique to specific problems. It should be noted at the outset that the problem of relating image utility to camera performance in the real, operational world is an extremely difficult task. The specific technique discussed below resulted from the review of large quantities of data together with actual operational experience. The technique was subject to extensive review within the Government in the context of a camera source selection proceedings and received a general concurrence from several Government departments and agencies.

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## II. Definition of the Area Value Function

The Area Value Function ($V_A$) provides a means for estimating the total worth of photographic coverage by a given camera system under specified operational conditions over a specified ground area. The Area Value Function is analytically defined as follows . . .

$$V_A = \int_A U(R)\ dA$$

. . . where the integration is to be carried out over the defined ground area. The function U(R) is the Utility Function. The Utility Function serves to associate a quantitative measure of worth with each incremental element of ground area. The Utility Function depends only upon the "minimum ground resolvable length" realized by the camera system for each incremental ground area. The definition of "minimum ground resolvable length" will be treated in a subsequent section of this paper.

Of critical importance in applying the Area Value Function is the selection of an appropriate utility function. In general, it is not sufficient to construct the utility function based only on the level of ground detail that can be extracted from a given image. It is essential in constructing the utility function to take account of the relevance of perceivable detail in the context of the intelligence problems to which the photography is to be applied. In particular, assuming that the utility function is proportional to the total number of resolvable elements in an image is a very poor approximation in the case of strategic intelligence problems. This assumption would lead to a utility function increasing inversely as the square of the minimum resolvable ground length, and as will be seen below, is a very much stronger function than is actually the case.

There are three distinct steps involved in generating a meaningful utility function. First, the specific photointerpretive tasks to be performed with the imagery must be listed. Second, the ability of the

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photointerpreter to perform these tasks must be related in a quantitative fashion to image quality as described by minimum ground resolvable length. It is, of course, critical that the definition of minimum ground resolvable length used in characterizing image quality be relateable to camera system performance. Third, the relative importance of the various tasks must then be established so that the collection of PI performance curves can be weighted and combined to give a single overall relationship between image utility and minimum ground resolvable length. Considerable community-wide effort has been expended on these three tasks. Numerous controlled psycho-physical experiments have been performed with the objective of measuring photointerpreter performance as a function of image quality for various tasks. Based on these experiments and the photointerpreter experience integrated over a long period of time, NPIC has cataloged the level of ground resolved detail (essential elements of information) required to perform the manifold of tasks assigned to the Center. In addition to the various concerned USIB committees, I have attempted to evaluate the relative importance of the various photointerpreter tasks in the context of the national strategic intelligence posture. The discussion which follows draws heavily on these activities.

In general, the functional relationship between photointerpreter performance on a specific task and minimum ground resolvable length is of the form depicted in Figure I. There will always be a region of minimum ground resolvable length poor image quality (characterized by large minimum ground resolvable length) within which the PI's ability to perform a particular task is unacceptably low or unreliable. In general, there will also be a region where the image quality is sufficiently good so that a particular task can almost always be performed with high dependability. In both of these regions the rate of change in PI performance with minimum ground resolvable length tends to be low. Between these two regions of image quality lies a transition region. This region is characterized by a more rapid rate of change of PI performance with minimum ground resolvable length. It should be emphasized that almost never does this curve of minimum ground resolvable length approximate a step function. There are many reasons for this, but probably the most important ones are variability in individual photointerpreter performance and the fact that any simple engineering definition of minimum ground resolvable length cannot be a complete measure of image quality in the subjective sense of the term. If, for example, the task in question is the identification of wheeled vehicles, the ability of a PI to perform this task will be influenced by the ground scene in which the vehicles are imbedded, the direction in which the vehicle shadow falls, the particular mix of vehicles that must be sorted out, and numerous other parameters which are entirely independent of camera system performance, atmospheric viewing conditions, and scene illumination. Nevertheless, although the slope of the transition region and where it falls on the absolute minimum ground resolvable length scale may vary over broad ranges for the total spectrum of strategic intelligence photointerpretive tasks, the general shape of the PI performance vs. minimum ground resolvable length curve is almost always found to be as depicted in Figure I.

As the image quality increases (the minimum ground resolvable length decreases), the number of photointerpretive tasks that can be performed with the imagery increases. However, in examining the relative importance of the various tasks, it is found that in general the criticality of each individual task tends to decrease as the image quality increases. The utility function is computed at a given image quality by tabulating all the tasks that can be performed at this image quality level as defined by NPIC, weighted by the relative importance of each of these tasks. This computation can be performed for various image qualities as measured by minimum ground resolvable length to generate the curve of utility vs. ground resolvable length given in Figure II. It should be emphasized again that this curve results from the summation over a broad range of strategic intelligence problems.

The utility function computed as described above can be approximated by two analytical functions. For resolvable length less than 10 feet, the dependence of utility on resolvable length is nearly linear of the form

$$U(R) = 1\frac{R}{13.3} \qquad R < 10 \text{ ft.}$$

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For resolvable length greater than 10 feet, a hyperbolic relationship of the following form should be used . . .

$$U(R) = \frac{2.5}{R} \qquad R > 10 \text{ ft.}$$

The data curve in Figure II is a piece-wise approximation to the linear portion of the utility function which has proven to be an adequate representation of the utility function for some application.

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III. Definition of the Target Value Function

Based on the same line of reasoning discussed above, it is possible to define a quantity known as the Target Value Function as follows:

$$V_T = \sum_{i = 1, N} U(R)$$

A target is understood in this sense to designate a specific facility which is sufficiently small in geographic extent so that image quality can be considered as constant over the entire target. The Target Value Function is then simply the summation of the utility function over a defined set of discrete targets. The target value function idea is particularly useful in comparing photographic systems where the primary mission objective is not area coverage but rather the coverage of discrete, small individual targets whose geographic position is known and can be utilized in the execution of the photographic mission. The discussion of the utility function as applied to the area value function applies equally well to the utility function for the target value function.

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## IV. Definition of Minimum Ground Resolvable Length

The key to relating photointerpreter performance and camera system performance is in the selection of an appropriate quantitative performance parameter. The selected performance parameter must be one that is meaningful in camera system engineering terms and also meaningful in context of subjective photographic image quality. The measure which best satisfies both of these conditions is Air Force tri-bar target resolving power as defined in Mil. Spec. 150A. Therefore, the definition of "minimum resolvable length" will be taken as the length of one cycle (the width of a white bar plus the width of a black bar) on the highest frequency Air Force tri-bar target for which the bars can be clearly distinguished.

The next question which must be addressed is how to relate camera system resolution to minimum ground resolvable length (ground resolution). Traditionally, this relationship has been established by constructing an artificial model of the target scene consisting of uniformly distributed tri-bar targets randomly oriented with respect to the ground track of the camera. If such a ground scene were photographed by a given camera system, the tri-bar target resolving power of the system would depend upon the obliquity angle from which a given target scene were viewed, and the orientation of the target bars with respect to the camera system. In general, when viewed at an oblique angle, the bars in the target will tend to appear from the camera aspect to be more closely spaced than they actually are. For the worst case of tri-bar target orientation, a geometric argument leads to the conclusion that camera system resolution and ground resolution are related by the secant squared of the viewing obliquity angle. However, if the bars are oriented perpendicular to this worst case direction, similar arguments lead to a secant to the first power dependence. It has been customary to take the geometric mean of these two extreme cases which leads to the following relationship between camera system resolving power and ground resolving power in the tri-bar target sense.

$$R_g = \frac{H}{F} R_C (\text{Sec } \theta)^{3/2}$$

In this experssion, H is the altitude of the camera system above the target scene, F is the focal length of the camera system, and ( $\theta$ ) is the obliquity angle at which a given element of the target scene is viewed (this angle is defined as the angle between the vertical at the target element and the line of sight from the target to the camera).

The above relationship between camera resolving power and minimum ground resolvable length is based on an idealized model of the target scene. For a target scene with three-dimensional development, such as is always the case with cultural scenes, the image quality never falls off as rapidly as secant squared and most often is closer to secant to the first power. However, the impact on image quality of atmospheric haze is generally higher at high obliquity angles than at lower obliquity angles which tends to argue in favor of a stronger dependency than secant to the first power. In the final analysis, it has been concluded that the secant to the three-halves power law represents an acceptable approximation to the physical world in the case of this application.

When the value function approach is to be employed in the comparative evaluation of camera systems, it is necessary to define the manner in which camera resolving power ($R_C$) is to be computed. It is important that the camera resolving power be a sufficiently detailed measure of camera performance to reveal the differences between different camera system designs. The definition of camera system resolving power to be used in computing either the area value function or the target value function takes into account the following factors:

a. Optical system performance
b. Image motion compensation
c. Camera focus
d. Target scene illumination and contrast as a function of solar elevation angle
e. Film sensitivity and resolution characteristics.

As the first step in computing camera system resolving power, the modulation transfer function (MTF) for the optical system design as degraded by manufacturing and alignment tolerances is computed. This MTF is then combined with the MTF's for the predicted image smear and the focus error. It is important to treat all of the above degrading factors in a statistically correct manner in that some of the degrading errors vary rapidly in time (throughout a given mission) and others will vary only from one production item to another, while still other errors are inherent in a given camera system design. It is usually best to take a worst set of conditions for comparative evaluation purposes. The image smear will be a function of the scene brightness (which must be specified) and the film sensitivity (which also must be specified). All of the above system MTF's will be a function of the location in the total image format of a particular point being evaluated. The system MTF resulting from the above computations must then be lowered to be representative of the scene contrast of the real world as viewed from high-altitude platforms. The above scene contrast will depend not only on meteorlogical conditions but also on the sun elevation angle. Based on a large sample of scene characteristics, an average scene model has been compiled, as presented in Table I. This table gives both scene contrast and scene illumination as a function of solar elevation angle.

The next step in the process is to intersect the total system MTF as degraded to the appropriate scene contrast with the curve giving the Aerial Image Modulation required for a human observer to resolve a given Air Force tri-bar target. The intersection between the AIM curve and the system MTF will yield the limiting resolving power for the camera system. The AIM curve must be empirically determined for a given film type and film processing conditions.

The computation outlined above can be repeated for all points in the photograph format and converted to minimum ground resolvable length using the expression defined above. On this basis, an area value function can be evaluated over any defined ground area. Similarly, a target value function can be evaluated for any defined target description. Both of these quantities will, of course, depend upon selection of a particular sun angle or variation in sun angle over the defined target or area model.

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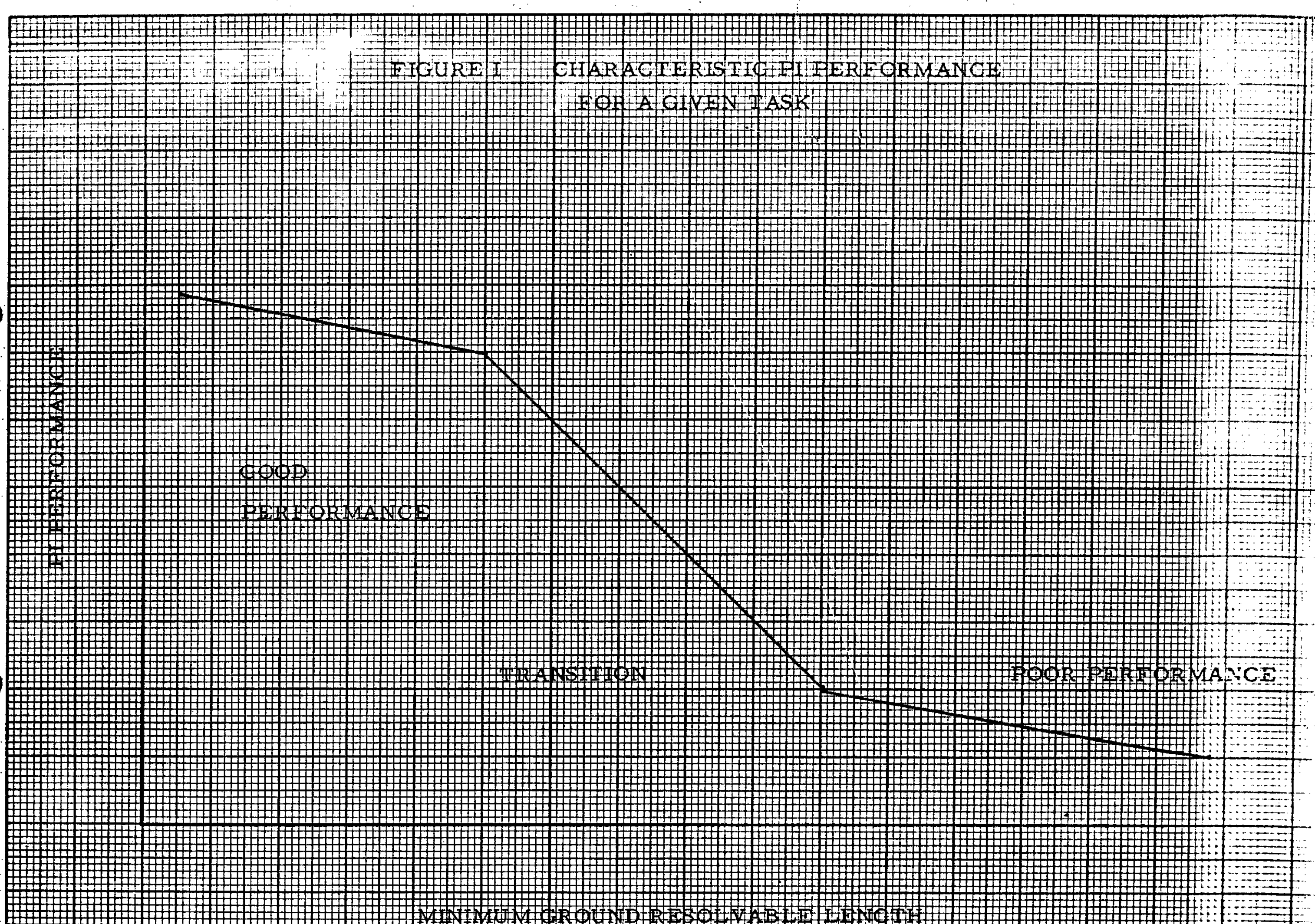
The above scheme for defining camera system resolving power has proven to be adequate when utilized in comparative evaluations of camera systems which have generally similar optical system MTF's. However, it should be noted that serious anomalies can occur in cases where the similarity constraint is not adequately satisfied. These anomalies are not usually of concern, however, in comparing practical, high-performance photograph reconnaissance camera systems.




Declassified and Approved For Release 2014/06/09 : CIA-RDP78B05167A001800170003-5

FIGURE II STRATEGIC UTILITY FUNCTION

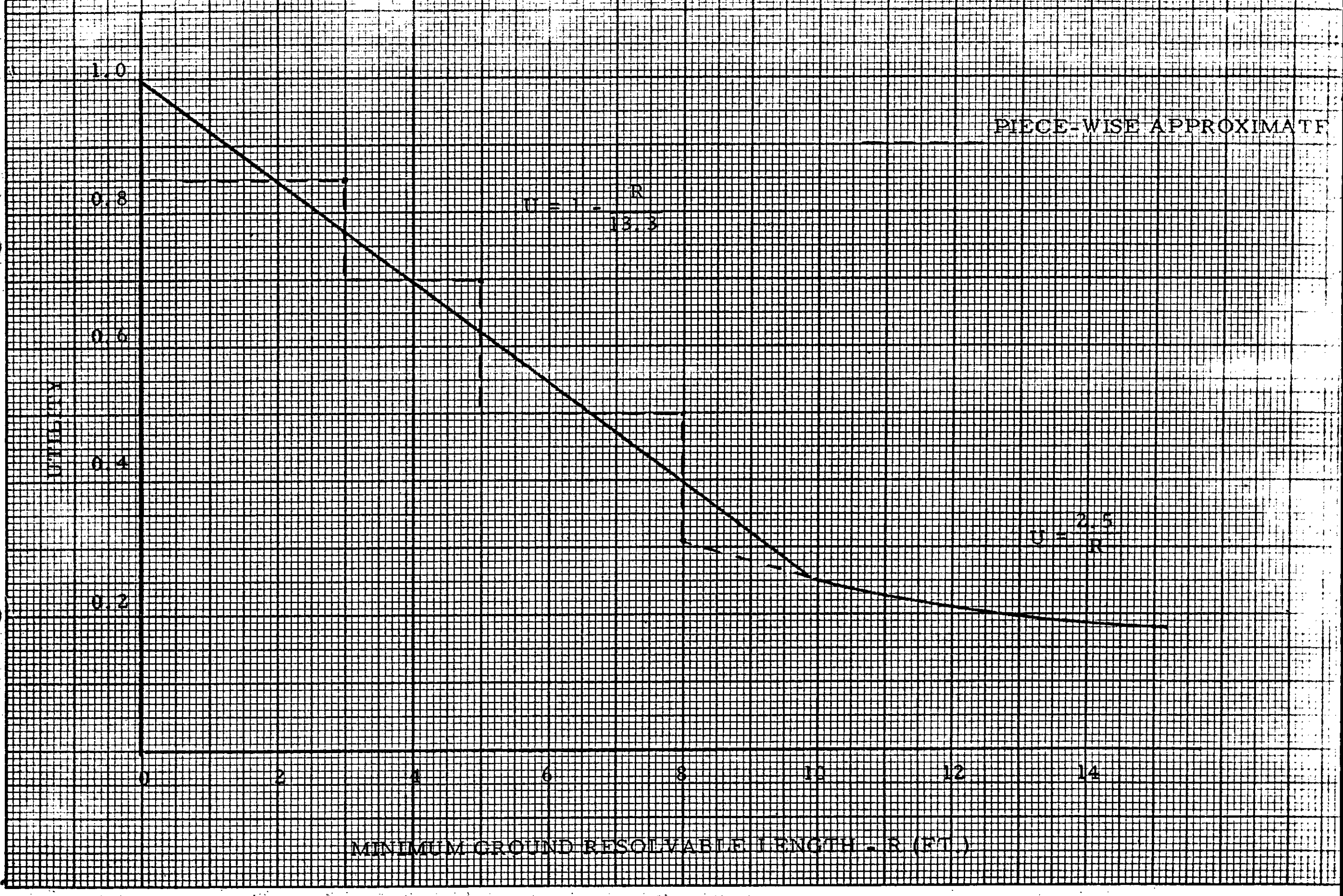


TABLE I

## SCENE BRIGHTNESS AND TARGET CONTRAST

| Sun Angle | Min Scene Brightness in Foot Lanberts | Target Contrast at Entrance Pupil |
|---|---|---|
| 0 | 200 | 1.1 |
| 5° | 240 | 1.3 |
| 10° | 300 | 1.5 |
| 20° | 450 | 1.8 |
| 30° | 600 | 2.0 |
| 40° | 650 | 2.1 |
| 50° | 700 | 2.2 |
| 60° | 720 | 2.1 |
| 70° | 750 | 2.0 |
| 80° | 750 | 1.9 |
| 90° | 750 | 1.8 |