DRSAR/SA/N-67

SYSTEMS ANALYSIS DIRECTORATE

ACTIVITIES SUMMARY

MAY 1977

JUNE 1977

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US ARMY ARMAMENT MATERIEL READINESS COMMAND

SYSTEMS ANALYSIS DIRECTORATE

ROCK ISLAND, ILLINOIS 61201

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Target Acquisition
NATO AC/225
Muzzle Flash Detection

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This monthly publication contains Memoranda for Record (MFR's) and other technical information that summarize the activities of the Systems Analysis Directorate, US Army Materiel Readiness Command, Rock Island, IL. (The most significant MFR's and other data will be published as notes or reports at a later date.)
The subject dealt with is Target Acquisition.

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DRSAR-SA (11 Apr 77) 1st Ind 8 JUN 1977
SUBJECT: Request for Acquisition Data in Support of NATO AC/225 (Panel III S.P.3)

HQ, US Army Armament Materiel Readiness Command, Rock Island, IL 61201

TO: Director, US Army Materiel Systems Analysis Activity, ATTN: DRXSY-GI, Aberdeen Proving Ground, MD 21005

1. Reference is made to the inclosed Memorandum for Record, subject: Response to AMSAA Request for Acquisition Data in Support of NATO AC/225 (Panel III S.P.3).

2. The response to the subject request is contained in the referenced memorandum. For clarification or further details contact Mr. George Schlenker (AUTOVON 793-5075/5930).

FOR THE COMMANDER:

SIGNED

1 Incl
as

M. RHIAN
Director
Systems Analysis Directorate

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Sherm

DEPARTMENT OF THE ARMY

Mr. Clifford/dak/283-4488

U. S. ARMY MATERIEL SYSTEMS ANALYSIS ACTIVITY
Aberdeen Proving Ground, Maryland 21005

S: 22 Apr 77
27 May 77

DRXSY-GI

11 APR 1977

SUBJECT: Request for Acquisition Data in Support of NATO AC/225 (Panel III S.P.3)

SEE DISTRIBUTION

1. Presently, Subpanel 3 of AC/225 (Panel III) is initiating a more concentrated effort on the subject of Target Acquisition. This follows termination of the discussion of a proposal from EASAMS, Ltd., of the United Kingdom for a long-term (and expensive) study of the subject. As a starting point for renewing discussions on this subject and determining a direction for the overall effort, each country has been asked to provide the target acquisition data currently used in their studies. In addition, any studies which give estimates of the importance of detection probability on battle outcomes are to be reported. SHAPE Technical Center made such a presentation at the last meeting of the Subpanel.

2. It is requested that you provide the target acquisition information for armor and antiarmor weapons used in your simulations or other analyses. Actual estimates of detection and recognition probabilities and the associated times as a function of the various conditions simulated (e.g., moving, stationary, fully exposed, hull defilade, detection following firing as opposed to non-firing, etc.) should be provided. A description of the predictive methodology and specification of the values assumed for the pertinent random variables should also be provided. Where possible, the data sources should be indicated. Any studies which have been carried out indicating the overall importance of the acquisition parameters on battle outcomes should also be described.

AMERICAN REVOLUTION BICENTENNIAL 1776-1976

DRXSY-GI APR 1977
SUBJECT: Request for Acquisition Data in Support of NATO AC/225 (Panel III S.P.3)

3. It is requested that this information be provided to AMSAA by 27 May 1977, with designation of a point of contact by 22 April 1977, (ATTN: Walter Clifford, AUTOVON 283-4488).

FOR THE DIRECTOR:

JOHN W. KRAMAR
Acting Chief
Ground Warfare Division

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DRSAR-SAM

2 JUN 1977

MEMORANDUM FOR RECORD

SUBJECT: Response to AMSAA Request for Acquisition Data in Support of NATO AC/225 (Panel III S.P.3)

1. References:

a. Methodology Addendum to the Cannon Launched Guided Projectile (CLGP) Cost and Operational Effectiveness Analysis (COEA), USAFAS, April 1974.

b. MFR, DRSAR-SAM, 7 Jul 76, subject: Algorithm for Estimating Detection Probabilities and Times for Muzzle Flashes at Night. This MFR appears in the Systems Analysis Directorate Activities Summary August 1976, DRSAR/SA/N-54 (AD No. A030892).

2. This memorandum is written in response to the subject request from AMSAA for information regarding acquisition of armored targets. Two models have been used by DRSAR-SAM for characterizing the acquisition of armored targets by observers having only binoculars for optical assistance. Both models are of a summary nature, suitable for inclusion in large-scale battlefield simulations.

3. Daylight Acquisition Model.

The first model is applicable to daylight conditions in the presence of an isotropic, scattering aerosol. This model was used during the CLGP COEA (Ref 1a). A special case of Bailey's model (Attachment 1) was used in the ARMCOM Operational Simulation Model (OSM) to describe the acquisition of moving armored targets by artillery forward observers (FO). The scenario treated by OSM was such that detection was tantamount to acquisition, i.e., recognition was unnecessary. As a simulated target moves along a tactical path within OSM, discrete probabilities of acquisition within the next second are calculated (each second) whenever the target enters an FO's field of view. These probabilities are used to determine if the stochastic event of acquisition occurs during the next second. If acquisition does not occur and the target remains intervisible, the updated event calculation is repeated.

4. The probability of acquisition within time t, given target entry into the visual field at time zero, P(t), depends upon the acquisition rate

parameter λ (sec^{-1}). For the OSM scenario,

$$\lambda = (11.6)^{-1} \exp - 3.9 R/R_V,$$

with R the observer-to-target range and R_V the meterological visibility range (same units as R). The constant coefficient in the expression for λ is typically a function of a number of parameters, as explained in Attachment 1. Then,

$$P(t) = 1 - e^{-\lambda t}$$

Given intervisibility and a constant value of R during a target search, the mean search time is λ^{-1}.

5. Graphical results for this model are displayed in Figures 1, 2, and 3. The probability of acquisition within t is shown as a function of range in Figure 1. The mean search time for several values of R_V is shown as a function of range in Figure 2. Figure 3 shows the probability of acquisition at range R as a function of search time.

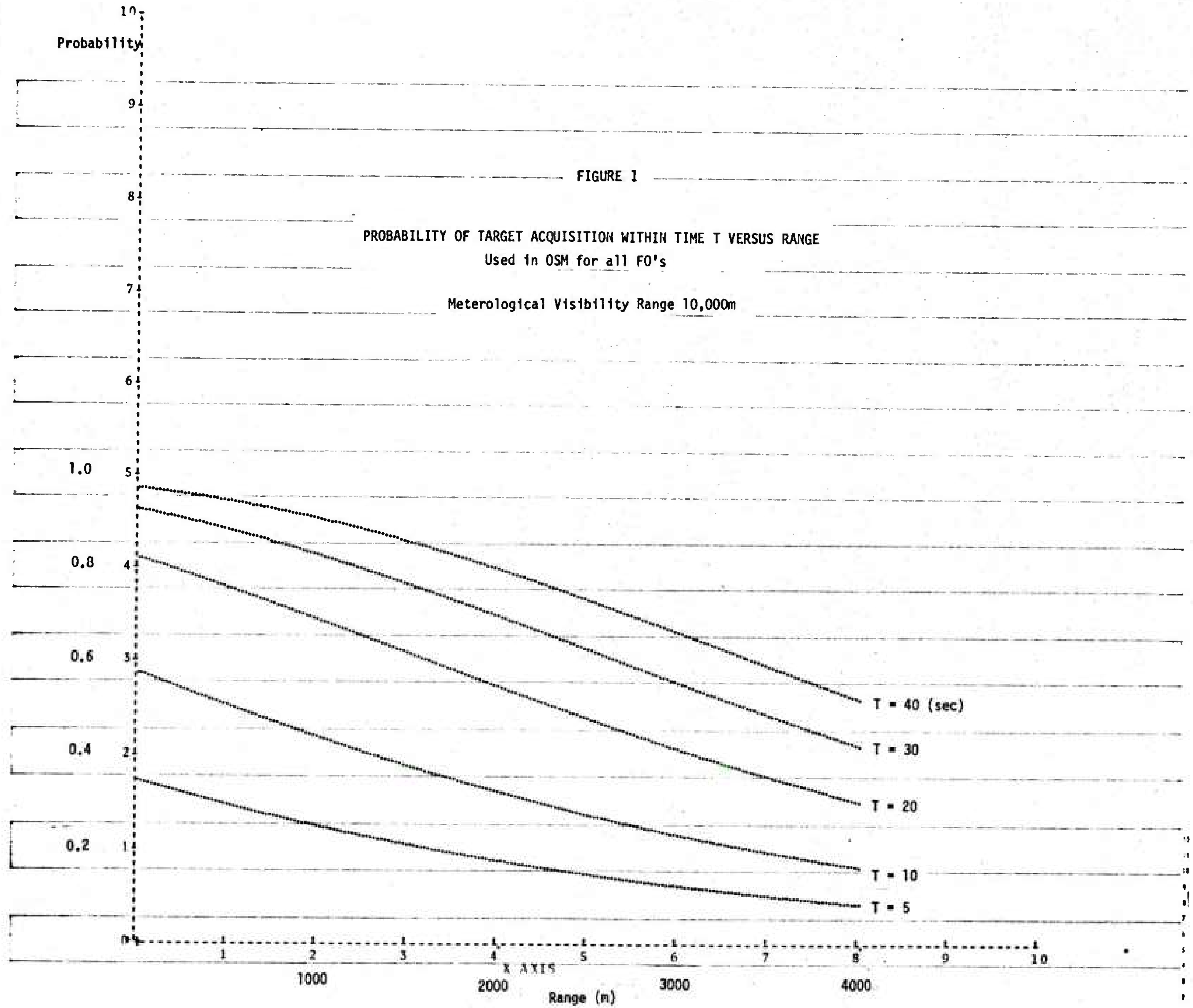


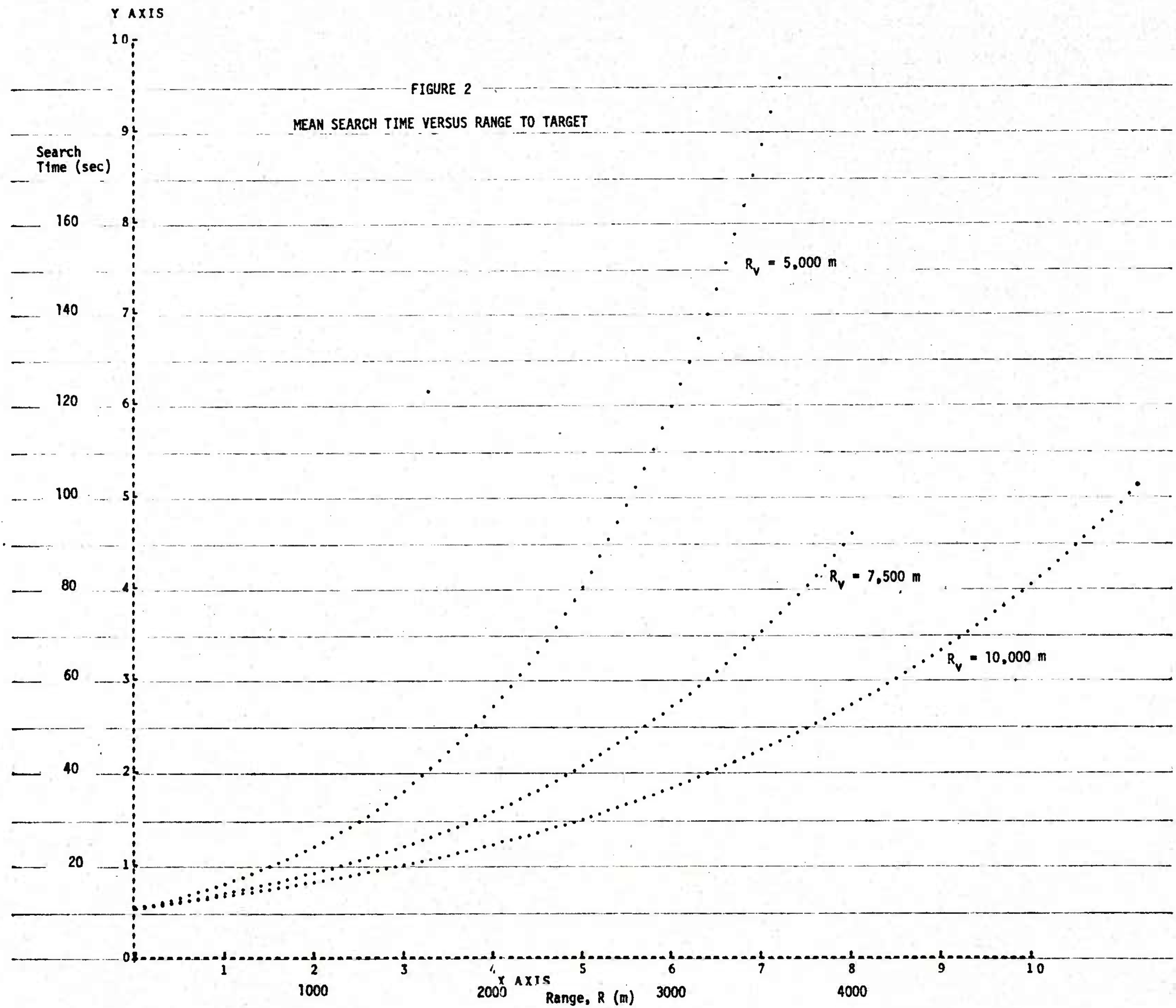
FIGURE 1

PROBABILITY OF TARGET ACQUISITION WITHIN TIME T VERSUS RANGE
Used in OSM for all FO's

Meterological Visibility Range 10,000m

FIGURE 2

MEAN SEARCH TIME VERSUS RANGE TO TARGET



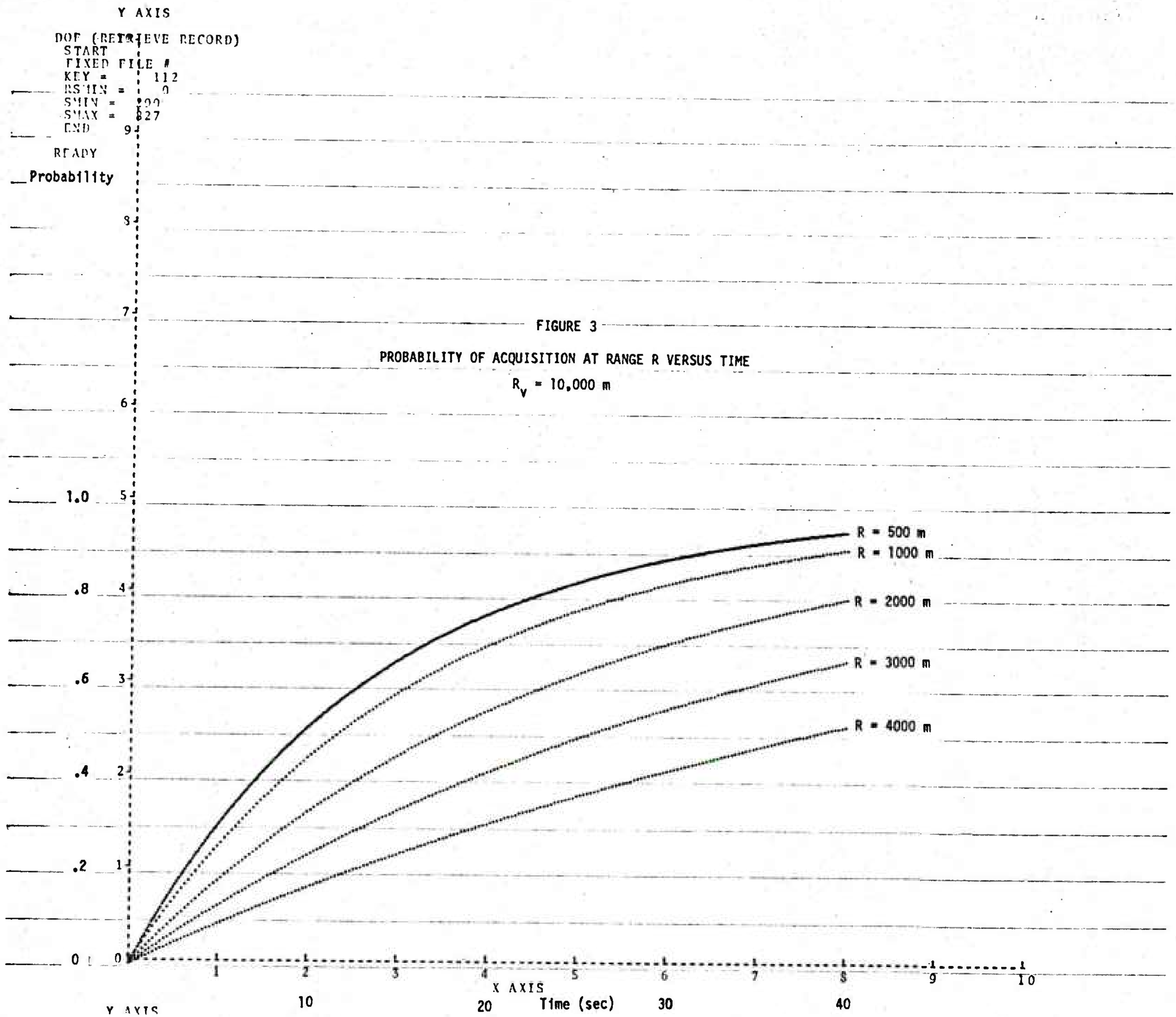


FIGURE 3

PROBABILITY OF ACQUISITION AT RANGE R VERSUS TIME

R_V = 10,000 m

DRSAR-SAM
SUBJECT: Response to AMSAA Request for Acquisition Data in Support of NATO AC/225 (Panel III S.P.3)

6. Night Time Model for Muzzle Flash Detection

The guns associated with most armor and SP artillery exhibit significant visual muzzle flash. This signature permits detecting and locating these targets at night by unaided visual means. Reference b discusses a summary algorithm for detecting targets which exhibit periodic muzzle flash when the background luminance is 10^{-3} ft-lambert or less. Light scattering by a homogenous isotropic aerosol is also accounted for in this model. This algorithm is based primarily upon the human factors studies of Blackwell relative to foveal detection of transient light sources. The MFR in Ref 1b is included in SA Note 54, available through the DDC.

George Schlenker

GEORGE SCHLENKER
Operations Research Analyst
Methodology Division
Systems Analysis Directorate

ATTACHMENT 1

A MODEL FOR THE DETECTION AND RECOGNITION OF TANK TARGETS BY ARTILLERY GROUND OBSERVERS

This mathematical model is a derivative of one proposed by H. H. Bailey of the Rand Corp. Additional information is provided by Dugas and Peterson of Rand. Although semiempirical in nature, this model has not been thoroughly validated as a whole.

Phenomenological Structure

As respresented by Bailey the task of finding and recognizing a known object in a complex field within a short period of time follows a sequence of three distinct steps. A deliberate and reasonably systematic search is made to place the object within foveal vision. Given superposition by the fovea a detection of contrast must occur. Finally a recognition based on form may follow given the detection of contrast. The process of recognition characterized by this sequence is discrete in time occuring in "glimpses", each lasting 1/3 second. Thus the glimpse rate is 3 per second.

A Special Case of Bailey's Model

We consider here a specialized form of Bailey's model in which the search is conducted in an almost linear manner across the visual field (FOV) of the unassisted observer near his horizon. This presumes that the observer is on the ground and that the range of terrain elevations across his FOV is not too large. It is postulated that the observer will generally scan for targets at a range at which under the prevailing atmospheric conditions he has some non-negligible probability of detecting target to background contrast. For tank-sized targets the estimated scan range is about 2400 m under good viewing conditions.

Depending on aspect and degree of terrain masking the presented area of a tank varies from about 10 to 20 m^2. Consider a tank with presented area 16 $m^2 = a_t$. According to Bailey the observer adjusts the area encompassed by his glimpse, A_g to be approximately 100 times the area of the target at the scan range. That is,

$$A_g \cong 100\ a_t.$$

The factor of 100 varies with scene congestion but is the typical value based upon perceptual experiments. The area encompassed by the glimpse is then 1600 m^2. The linear dimension of a square glimpse aperature is then 40 m. At the estimated scan range, the angular subtense of the linear glimpse interval is about 17 milliradians (i.e., 40/2400).

For an observer 2 m above a level earth, the radial range interval covered by this angular glimpse interval extends from about 120 m to the horizon. Thus the observer conducts a systematic, essentially linear scan across the horizon within some prescribed angular FOV ϕ at an angular glimpse interval of about one degree for each third of a second, i.e., at a scan rate of nearly 3 degrees per sec.

Notationally let

π_1 = Prob [observer places foveal vision over the target in one glimpse interval].

Also

$P_1 = P_1(t)$ = Prob [target has been covered by time t].

Assuming a random placement of the target in the field of view ϕ, the probability of covering a target of minimum linear dimension typical of a tank in one glimpse is given approximately by

$$\pi_1 = 17\ 10^{-3}/\phi$$

for $\phi >> 17\ 10^{-3}$ radians.

The rate of successful foveal superpositions implied by this probability is

$$\lambda_1 = 3\ \pi_1 \cong 0.05\ \phi^{-1}. \qquad (1)$$

The time-dependent probability of a successful foveal superposition is then approximately

$$P_1(t) = 1 - e^{-\lambda_1 t}.$$

By comparison with equation (1), the first-order rate constant given by Bailey for this process is

$$\lambda_1' = \frac{700\ a_t}{G\ A_s}$$

for the search area A_s with G depending on the degree of scene congestion.

$$1 \leq G \leq 10.$$

Using the nominal values

$$a_t = 16 \ m^2$$

$$A_s = 40 \ (2400 \ \phi) \text{ and } G = 1$$

$$\lambda_1' = 117 \ 10^{-3} \ /\phi$$

This estimate of λ_1 is 2.3 times the value given (1). The discrepancy between λ_1 and λ_1' is accounted for by noting that Bailey has presumed that the search may not be perfectly random. He argues that a "successful" search rate of 300 a_t per second, compared to the "required" rate of A_s/t, is adjusted to produce a value of $P_1 = 0.9$. Consequently the value of λ_1 is adjusted by the multiplicative constant K so that

$$P_1 = 1 - \exp(-K), \text{ with } P_1 = 0.9.$$

This reasoning is tenuous at best and serves to identify a source of uncertainty in λ_1.

Bailey's Contrast Term

The following definitions and notational conventions are observed.

Let

P_2 = Prob [target will be detected if glimpsed foveally in the absence of noise].

By definition, curves of threshold (50% detection probability) contrast versus size of circular discs under various levels of illumination are called demand contrast functions. The contrast of the target relative to the background is defined as follows.

target contrast =C= | luminance of target -

luminance of background |/luminance of background

Threshold contrast, C_T, is obtained as follows.

Let

$\bar{\alpha}$ = angular subtense of the minimum target dimension in minutes of arc

α = angular subtense in radians

$$\bar{\alpha} = 3438\ \alpha \qquad (2)$$

The demand contrast function can be developed from the approximation

$$(\log_{10} C_T + 2)(\log_{10} \bar{\alpha} + 0.5) = 1 \qquad (3)$$

or

$$C_T = \exp\ [2.302585\ [(\log_{10} \bar{\alpha} + 0.5)^{-1} - 2]].$$

Alternatively

$$C_T = \exp\ [\frac{5.3018976}{\ell n\ \alpha + 9.29393} - 4.60517] \qquad (3a)$$

Then, approximately

$$P_2 = 0.5 \pm 0.5\ [1 - e^{-4.2\ [(C/C_T) - 1]^2}]^{1/2} \qquad (4)$$

with + chosen when $C > C_T$ and - chosen when $C < C_T$.

The apparent contrast of the target will vary with slant range, d, to the target in approximately the following manner.

$$C = C_o\ e^{-cd} \qquad (5)$$

with

$$c = 3.912\ /\ VR$$

where VR is the visibility range and d the slant range in kilometers. The intrinsic contrast is C_o.

Example

Suppose a tank of minimum linear dimension 4 meters is located at 2 km from the observer

Then $\alpha = 2\ 10^{-3}$ radians

or $\bar{\alpha} = 6.876$ minutes

From (3) or (3a)

$$C_T = 0.056$$

If $C_O = 0.2$ and $VR = 10$ km,

$$C = 0.0914 \qquad \text{(from (5))}$$

And $C/C_T = 1.632$

Then $P_2 = 0.9509$.

Bailey's Resolution Term

Let

P_3 = Prob [target is recognized correctly, given detection]

Then, in the absence of prior information concerning the identity of the object detected

$$P_3 = 1 - \exp\left[-\left(\frac{N_r}{2} - 1\right)^2\right], \quad N_r \geq 2$$
$$= 0 \qquad\qquad , \quad N_r < 2 \qquad (6)$$

with N_r the number of resolution cells in the scene (or display) contained in the minimum dimension of the projected image of the target. A "resolution cell" as used here is the size of an independently detectable spot, with detection probability 0.90, at the contrast level with which the spot is presented to the observer.

The value of N_r can be computed by finding the image subtense α' which yields a demand contrast C_T'.

$$C_T' = C'/1.5 \qquad (7)$$

where C' is the presented (observed) contrast of an image with subtense α'. For unassisted vision, the observed contrast of the image of subtense α is identical to that of an image of subtense α'. Note that $C'/C_T' = 1.5$ when $P_2 = 0.9$.

$$\text{Then } N_r = \alpha/\alpha' \qquad (8)$$

Example

Suppose that the apparent size of the target is 2 10^{-3} radians or 6.876 minutes, equivalent to a 4 meter target at 2 km. Then the demand contrast is

$$C_T = 0.056$$

Also suppose that the apparent contrast of the target relative to the background is 0.1 (C'). Then from (7)

$$C_T' = 0.1/1.5 = 0.06667.$$

For the last value of demand contrast, the associated value of target size as given by (3) is

$$\bar{\alpha}' = 5.173 \text{ minutes}$$

$$\text{or} \quad \alpha' = 1.505\ 10^{-3} \text{ radians.}$$

Then α' is the size of the resolution element and

$$N_r = 2/1.505 = 1.329.$$

For this value equation (6) yields $P_3 = 0$.

However when the observer has prior information indicating that any foreign presence in the scene is a target, detection is tantamount to recognition and P_3 should be set to unity.

Modifications of Bailey's Recognition Model

As Bailey formulated his model the human observer is postulated to perform a series of glimpses or Bernouilli trails, each lasting 1/3 second in duration. On each trial there is a finite probability of foveal superposition, of detection of contrast given superposition, and of recognition of form given detection. Each of these events leading to recognition is regarded as independent. Consequently the probability of recognition on a single glimpse is

$$\pi_1 P_2 P_3$$

If this quantity is very small relative to unity, the binomial expression for the probability of recognition after n trials in time t can be replaced with the Poisson approximation

$$P_r = 1-e^{-Bt} \tag{9}$$

with rate parameter $B = 3\ \pi_1\ P_2\ P_3$

$$B = \lambda_1\ P_2\ P_3$$

since each trial occupies 1/3 second. This expression differs from that used by Bailey who writes

$$P_r = P_1\ P_2\ P_3$$

with $P_1 = 1 - e^{-\bar{\lambda}_1 t}$.

This latter expression implies that there is a finite probability that recognition will never occur even when the probability of recognition on a single glimpse is finite.

Another change is required in Bailey's model to account for target motion. Experiments by Dugas and Peterson at Rand Corp. have shown that the effect of target motion is to increase the rate parameter B by a factor of

$$1 + 1477\ \omega^2$$

with ω the presented angular rate of the target in radians/sec. Then a complete expression for the detection rate in the absence of noise in the display is

$$B = \lambda_1\ P_2\ P_3\ (1 + 1477\ \omega^2). \tag{10}$$

The time dependence of parameters involved in B has been suppressed in Bailey's formulation. In cases where relative position of observer and target changes substantially during an observation period and thus may change apparent target size and contrast, it is necessary to compute recognition probability incrementally (or differentially) for time intervals over which the parameters are essentially constant. Thus the probability of recognition within a time interval (o, t_n) can be written using the recurrence relation

$$P_r(t_n) = P_r(t_{n-1}) + p_r(u_n)(1-P_r(t_{n-1})),\ n \geq 1$$

with

$$t_n = \sum_{i=1}^{n} u_i$$

$$p_r(u_n) = 1 - e^{-B_n u_n} \qquad (11)$$

and $P_r(t_o) = 0,\ t_o = 0.$

The values of the parameters prevailing over the interval $u_n = t_n - t_{n-1}$ are used in computing B_n.

In digital simulations involving a recognition process, the time at which recognition occurs is that time for which P_r exceeds a previously drawn uniform random number U. The recognition algorithm is regularly called at intervals of length u in order to update P_r. The value of u chosen should be such as to result in little change in the parameters over u, but in no case should u be less than 1/3 second because of the discrete nature of the recognition process.

If the parameters describing the scene are reasonably constant for an extended period of observation, the mean time to recognize is just B^{-1}.

Example

Assume that an observer is searching a 57.3 degree sector for a tank whose presented dimensions are 3 X 4 meters. Assume the tank going 5 m/sec is at 2 km with intrinsic contrast of 20% and that atmospheric visibility is 10 km. The observer is assumed to conduct his search with unaided vision but at detection recognition is facilitated by use of binoculars so that $P_3 = 1$.

Using the minimum tank dimensions the minimum angular subtense is

$$\alpha = 3/2000 = 1.5\ 10^{-3} \text{ radians}$$

$$\bar{\alpha} = (3438)(1.5\ 10^{-3}) = 5.157 \text{ minutes}$$

$$\log_{10} \bar{\alpha} = 0.71240$$

From (3),

$$\log_{10} C_1 = (1/1.2124) - 2 = -1.17519$$

$$= 0.8248 - 2$$

(demand contrast) $C_T = 6.676\ 10^{-2}$

From (5) the actual contrast is given by

$$C = 0.2\ e^{-(0.3912)2}$$

$$C = 0.0914$$

and $C/C_T = 1.369$.

From (4),

$$P_2 = 0.83$$

From (1),

$$\lambda_1 = 0.05/1$$

Then

$$B = \lambda_1\ P_1\ (1 + .009) = 0.04187\ \text{sec}^{-1}$$

and $B^{-1} \cong 24$ sec.

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LIST OF SYMBOLS FOR TARGET DETECTION/RECOGNITION SUBROUTINE

inputs

1. time k th target entered FOV of i th FO, TENT(i,k)
2. field of view boundaries and holes
3. time FO search begins
4. observers position
5. target position and velocity
6. target identity code
7. intrinsic contrast of the target
8. visibility range
9. scene clutter factor
10. optical magnification

endogenous variables

1. scan limits of FOV
2. probability of foveal superposition, π_1
3. probability of detection of contrast, P_2
4. probability of recognition by form identification, P_3
5. detection rate parameter for the n th time interval u_n, B_n
6. recognition probability, $P_r(t_n)$

outputs

1. time at which detection occurs, if it occurs at all
2. indication of failure to detect while target is within the i th FOV

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