NUCLEAR CRITERIA AND SYSTEM DESIGN SPECIFICATION

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In order that nuclear hardness criteria might receive proper consideration in system design specifications, it is desirable to have a formalism in which the cost and benefits of nuclear hardness can be examined together with the cost and benefits of alternatives to hardness. This paper presents such a formalism.

Hardness can be thought of as a survival aid for a system. Some alternative survival aids are: decoys, maneuverability, redundancy, camouflage, hard point or area defense, inaccessibility. Therefore, any rationale for selection of a particular hardness criteria should consider not only other levels for the hardness criteria, but also other means of achieving the required system survivability.

In this paper, for survivability we shall require only that a system survive long enough and to an adequate degree such that it can fulfill its assigned role. In this perspective, it can be seen that the system need survive only in terms of its function rather than in terms of its construction. Thus, the level of "functional survivability"

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is an appropriate measure of system effectiveness or output in the operational environment.

Acquiring adequate "functional survivability" for the minimum cost is proposed here as the criterion for selecting nuclear hardness criteria. By "adequate" we assume a subjective choice of what we want the system to do, and what confidence we want that the system will do it.

Factors affecting the adequacy of the "functional survivability" include the threat, which seems to increase with time, and the composite system environment in which the individual system can be considered a subsystem. These factors affect not only the "functional survivability," but also the optimum design criteria. For example, changing threat CEP's can make hard point defense a better design direction than additional nuclear hardening. In this sense it can be seen that the cost may be minimized for a given functional survivability by actually relaxing the hardness criteria in the face of an increased threat.

A graphical representation of the application of the above criterion for selecting nuclear hardness criteria can be observed in Fig. 1. Here is plotted an illustrative "functional survivability" as a function of two survival aids, hardness and redundancy (or number of units deployed). The "surface" of functional survivability has been qualitatively developed for this example by assuming that zero hardness or zero redundancy (no units deployed) results in zero functional survivability. Thus, the hardness and redundancy axes lie in the functional survivability surface. Furthermore, it has been assumed that for a fixed hardness, the functional survivability increases linearly with redundancy. In other words, twice as many units (bombers for example) do twice as much damage. This condition is not expected to apply in nature due to such phenomena as exhaustion of targets for the bombers, exhaustion of defenses, and other non-linearites. Nevertheless, for illustrative purposes we will choose the linear function of redundancy. The hardness dependence for fixed redundancy (see curve a in Fig. 1) was chosen to qualitatively reflect a jump from zero survivability with a little hardness, then not much gained until considerable hardness is incorporated, and finally diminishing returns as the hardness is increased above a reasonable level.

For any functional survivability surface, contours of equal functional survivability can be defined. The contour defined by functional survivability equals the adequate* level (see curve b in Fig. 1) is an interesting contour. The projection of the contour on the hardness-redundancy plane (see curve c in Fig. 1) encloses the region of acceptable system design criteria. In other words, any combination of hardness or redundancy which falls within the projection of the adequate functional survivability contour on the hardness-redundancy plane results in at least an adequate functional survivability.

Returning now to our hardness criteria criterion, we recall that we were interested in acquiring adequate functional survivability at a <u>minimum</u> cost. In order to determine the minimum cost system design "solution" we can now focus on the region of acceptable solutions on

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*The "adequate" level is subjectively chosen by those responsible for sponsoring or approving the system design.

the hardness-redundancy plane (see Fig. 2). Superimposed upon this plane are curves of constant system cost, labeled with costs: C_1, C_2, C_3, C_4. The choice of hardness and redundancy which achieves an adequate level of functional survivability at a minimum cost is represented by the point at which a constant cost curve is tangent to the "region of acceptable solutions."* This "solution" to the system design problem is labeled "optimum solution" in Fig. 2.

The optimum system design solution contains <u>the optimum hardness criteria</u> for the system. This hardness criteria, labeled "optimum hardness" in Fig. 2, has the property that any other hardness criteria will result in a waste of money and/or a system that is not functionally survivable for the assumed threat and system environment. As a bonus we are given the cost or investment that must be made in system acquisition!

By varying the threat, one could use the above technique to observe the sensitivity of the optimum design criteria to changes in the threat. In cases where the threat is uncertain or expected to evolve over the lifetime of the system, one should be inclined to select design parameters (e.g., hardness criteria) that result in adequate functional survivability over the expected range of threats. The optimum design parameters which are <u>guaranteed</u> to yield adequate functional survivability at a minimum cost for the case of an evolving or uncertain threat can be determined by overlaying the "region of acceptable solutions" for each threat expected (see Fig. 3) and considering the intersection,

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*Here it has been assumed that functional survivability and the cost increase monotonically with both hardness and redundancy.

a la set theory, of these regions in the hardness-redundancy plane.

In Fig. 3, the regions of acceptable solution, R_1, R_2 and R_3 are enclosed by the projections of adequate functional survivability contours for each of the threats T_1, T_2, and T_3 respectively. The intersection of these regions, $R_1 \cap R_2 \cap R_3$, is a region in "design space" which results in adequate functional survivability over the set of threats (T_1, T_2, T_3). All that remains is to select the point in $R_1 \cap R_2 \cap R_3$ which incurs the minimum cost by plotting cost contours as was done in Fig. 2.

The above graphical illustration of system nuclear hardware criteria selection took advantage of the assumption that the functional survivability of the hypothetical system was a function of only two variables, hardness and redundancy. In a realistic case, the functional survivability is a function of many variables. Some other variables, or survival aids, were identified in the second paragraph of this paper. These were decoys, maneuverability, camouflage, hard point defense, and area defense. The concept of hardness criteria was misrepresented as a one-dimensional quantity itself. More realistically we can imagine having a peak overpressure hardness, an electric field hardness, a neutron fluence hardness, a peak time-rate-of-change of magnetic field hardness and many more.

The fact that functional survivability is a function of many variables complicates the graphical representation of hardness criteria selection, but does not pose any fundamental difficulties. We can conceive of functional survivability existing in hyper-design space or hyper-survival aid space. The objective remains to examine the hyper-volume in which the functional survivability equals or exceeds the adequate level, and find the point in this hyper-volume that corresponds to the lowest cost.

The formalism proposed in this paper represents a technique for manipulating a great many complicated "knowns" and pulling optimal design criteria or specifications out of "hyper-space." It does not in any way generate the "knowns." In particular, application of the formalism requires that functional survivability as a function of system properties be known and that the costs of system acquisition, maintenance, and operation be known. Perhaps the availability of this formalism can serve as a framework for reviewing and organizing the research on these survivability and cost issues.

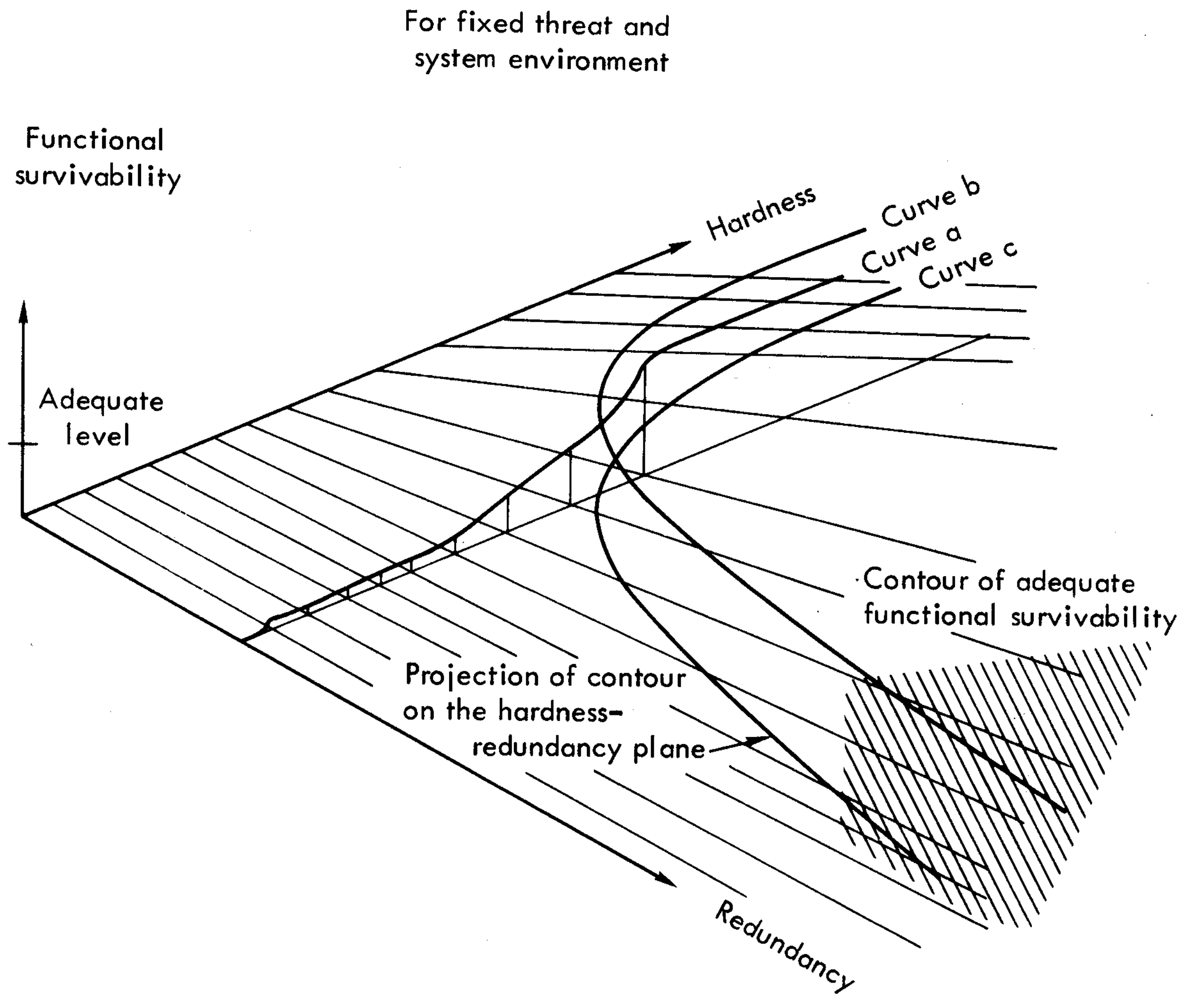

Fig. 1—Functional survivability as a function of system hardness and redundancy.

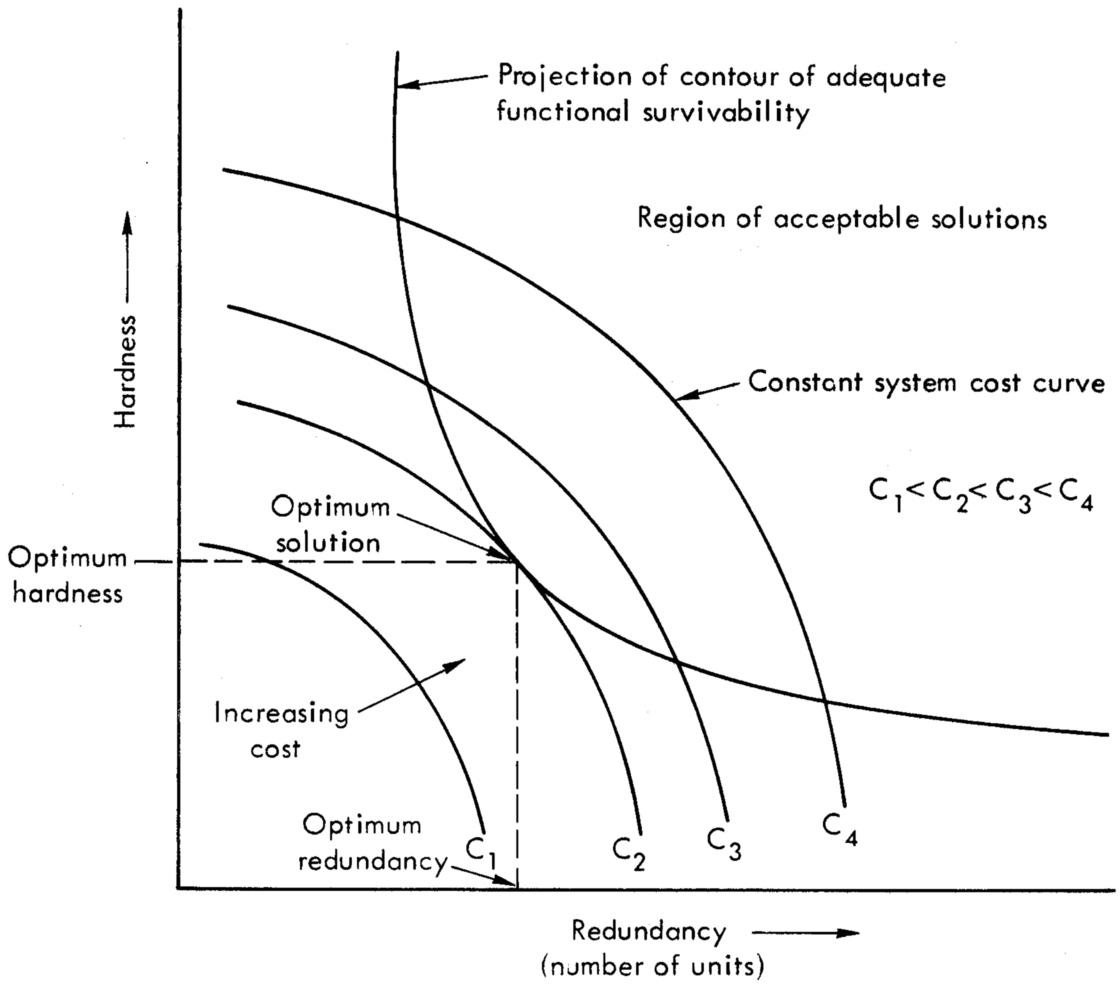

Fig. 2—The optimum system design solution in the hardness- redundancy plane

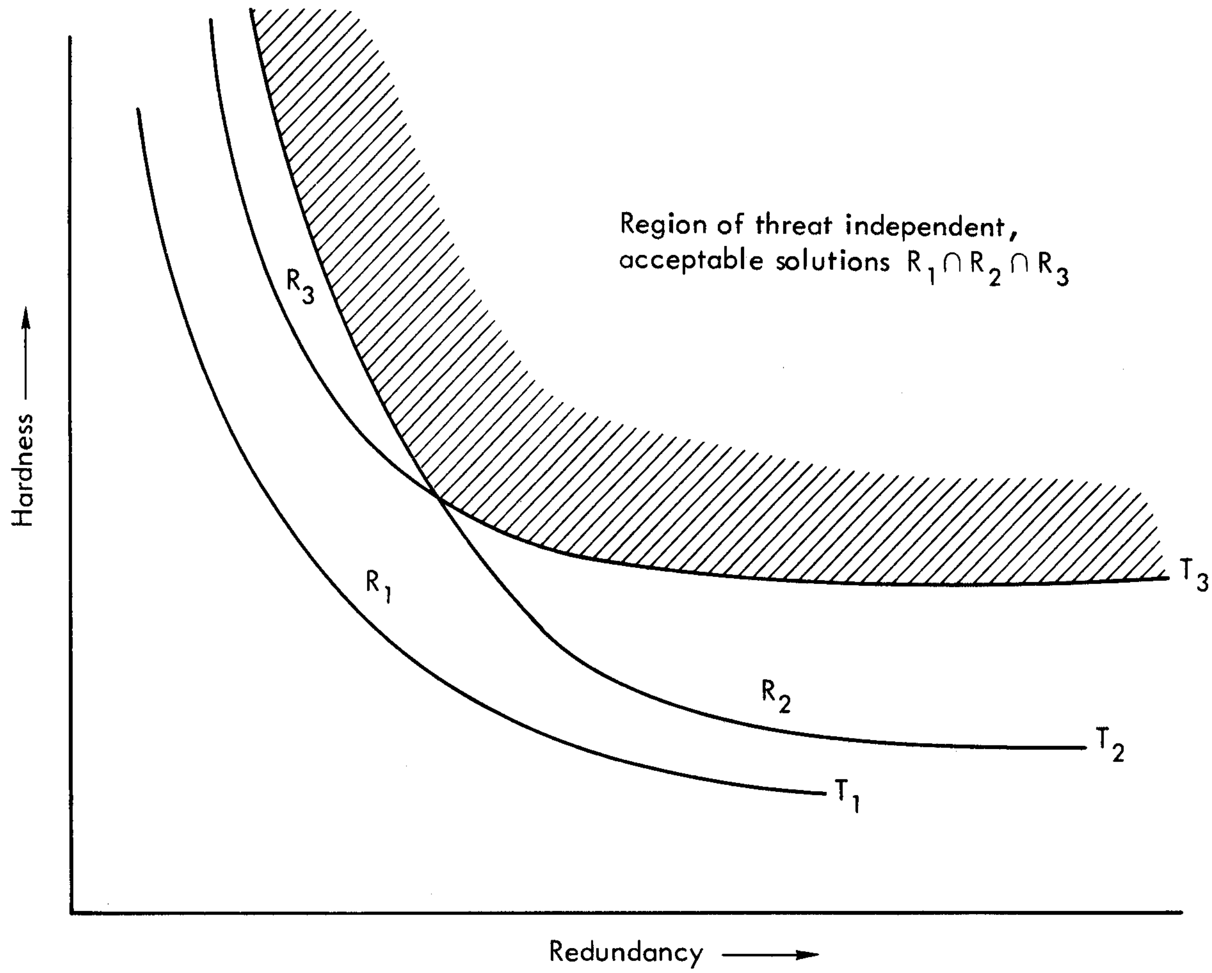

Fig.3—Optimum system design for an evolving threat