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An Approach to Performance Based Regulation Development

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An Approach to Performance Based Regulation Development**

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ABSTRACT

An approach to the development of performance based regulations (PBR's) is described. Initially, a framework is constructed that consists of a function hierarchy and associated measures. The function at the top of the hierarchy is described in terms of societal objectives. Decomposition of this function into subordinate functions and their subsequent decompositions yield the function hierarchy. "Bottom" functions describe the roles of system components. When measures are identified for the performance of each function and means of aggregating performances to higher levels is established, the framework may be employed for developing PBR's. Consideration of system flexibility and performance uncertainty guide in determining the hierarchical level at which regulations are formulated. Ease of testing compliance is also a factor. To show the viability of the approach, the framework developed by Lawrence Livermore Laboratory for the Nuclear Regulatory Commission for evaluation of material control systems at fixed facilities is presented.

I. Introduction

Performance based regulations (PBR's) impose minimum acceptable performance bounds on system functions which collectively satisfy societal objectives. These PBR's are intended to minimize the overall costs to society by allowing maximum (licensee) design flexibility, while maximizing the effectiveness of the system. The desirability of PBR's is clear. Problems arise in trying to develop a usable framework that will permit their development. This paper defines the basic requirement for PBR's; discusses the basic framework employed in the development of PBR's; describes how the framework is used in the generation of PBR's; and provides an example which demonstrates the framework for material safeguards at licensed nuclear facilities.

II. Definition and Requirements

Regulations impose an acceptance criteria on a system to assure that societal objectives are met. When regulations require the performance of system functions to exceed a specified level, those regulations are called performance based regulations (PBR). As an example, a safeguard PBR may

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dictate a specific minimum access time to all interior points within a facility. A nonperformance based regulation satisfying the same safeguard objective might require a fence of a certain type and height.

The generation of realistic PBR's require

1. identification of all functions contributing to the overall societal objective
2. a set of measures providing quantification of the performance of these functions
3. a means to relate the performances to the overall societal objective
4. a method to evaluate the performance of a complete set of functions

The first requirement allows the regulator to identify functions that require or are amendable to regulatory control. Delaying access to interior points of a facility is an example of a safeguard function. The second requirement provides the regulator with a quantity on which bounds may be imposed. For the function of delaying access, delay time is a measure of performance. The third requirement permits establishing bounds compatible with the overall societal objective. In addition, this requirement allows the regulator to study the trade-offs and sensitivities that may be important in developing effective regulations. The fourth requirement allows the regulator to ascertain whether a given system complies with the regulations.

It is assumed that PBR's have the same general requirements as other regulations. For example, all regulation types must provide the regulator with the means to determine when a function has been achieved, i.e., that the performance is adequate. Additionally, safeguard system regulations must be effective in providing adequate adversary interruption capabilities; assurance data relating to design, capability and operation; data for recovery operations; etc. These general requirements are not discussed herein except as required to demonstrate the requirements specific to PBR's.

When the above four requirements are satisfied, the regulator has the basis for effective PBR's. Lawrence Livermore Laboratory (LLL) has developed a framework which not only satisfies the four basic requirements, but also provides the regulator with the ability to seek the *functional* level at which regulations are best imposed. Although this framework was derived to aid in the development of PBR's for the control of nuclear materials at fixed facilities, the philosophy employed in its derivation is applicable to other regulatory problems.

III. Basic Framework for PBR Development

The prime constituent of the framework for development of PBR's is a function hierarchy as depicted in Figure 1. The top "bubble" of the hierarchy represents the basic function of the PBR's which is to assure that societal objectives are satisfied. The second level of the hierarchy consists of functions which independently or collectively represent the ways to satisfy

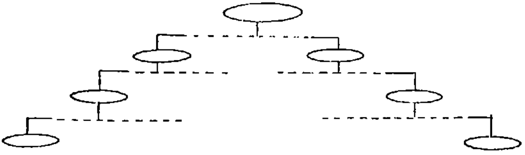

Figure 1. Function Hierarchy

the basic function. The third level of the hierarchy either independently or collectively represent ways to satisfy unctions of the second level and so on. The bottom level contains function, whose performance can be expressed in terms of physical parameters. It is desirable to decompose the hierarchy to this level when possible since physical parameter measures are more easily quantifiable.

The completed framework has explicit or implicit performance measures associated with each function. Evaluation of a measure provides a quantity (performance) whose value indicates how well the function is performed. At the bottom of the hierarchy performances a e related to physical parameters. Elsewhere, performances are aggregations of lower level performances. In developing PBR's, the regulator establishes bounds on the performances at predetermined hierarchial levels. Upper levels of the hierarchy are used to assure that societal objectives are met. Lower portions are used to establish realism, and check compliance.

Figure 2 is a logic diagram that shows how the framework is developed. The process begins by defining the societal objectives to be gained by the development of PBR's. Defining these objectives identifies the top "bubble" of the hierarchy.

The second step is to determine a complete set of functions each of which contributes to satisfying the objective. There is not a unique set of these functions. It is necessary therefore, to establish a criteria that allows the selection of the set that is most advantageous. For example, it is generally desirable to separate functions over which the regulator has no control from those over which he does have control. There are many such considerations.

The next step in the development of the framework is to establish performance measures. In this step, the performance measure for each function is identified and the rule by which performances can be aggregated to provide the performance of the top function is established. The following steps are dependent on whether the hierarchy is complete. The hierarchy is always complete when all performances are expressible in terms of physical parameters rather than performances of subordinate functions. There are instances when the regulator completes hierarchical development before this point. Such an instance exists when a branch of the hierarchy is one over which he has little influence and he is willing to place worse case bounds on the aggregated performance. When the regulator wishes to continue, the remaining functions are identified as new objectives and the procedure is repeated for each. When complete, the hierarchy is ready to be used in the development of PBR's.

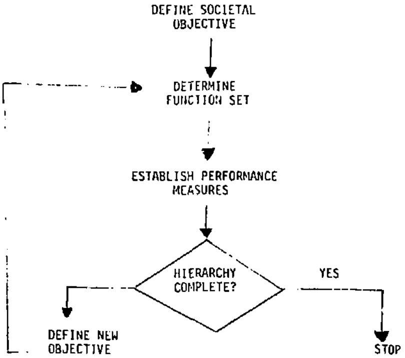

Figure 2. Framework Development

IV. Development of PBR's

PBR's impose bounds on the performances on functions within the function hierarchy. Figure 3 identifies performances at three hierarchical levels and will be used to illustrate considerations that must be made in developmeng PBR's. The performances p_0, p_1, p_2, p_{21} and p_{22} are values of performance measures. The performance p_0 is a function of p_1 and p_2. The performance p_2 is a function of p_{21} and p_{22}.

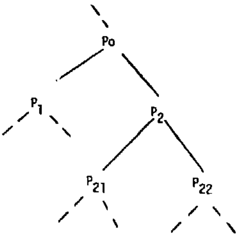

Figure 3. Performance at Hierarchical Levels

To develop PBR's, start at the top of the hierarchy and establish minimum acceptable performance. Then step down the hierarchy placing bounds on performances at each level. The bounds at one level collectively assure that the bounds at the neighboring higher level are satisfied. Some bounds will constitute regulations and other bounds will be used as a criteria for lower level regulations. In some instances, the subjective nature of the functions and the uncertainties associated with them may make precise selection of minimum acceptable bounds meaningless. In these instances, one must assume a worst case bound. Generally, the hierarchy can be constructed to allow for these situations. The example in Section V will illustrate this.

Consider performance bounds placed on p_0 and the desire to place regulations on p_1 and p_2. Let the irregular region[1] of Figure 4 represent that region for which the p_1 and p_2 collectively provide an acceptable p_0.

([1]) Generally when one considers performance, he views greater values to represent better performance. To be completely general however, we have chosen a closed region to represent acceptable operation.

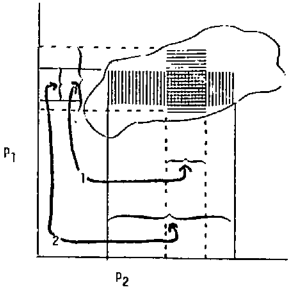

Figure 4. Regulation Options

The regulator has options in placing regulations on p_1 and p_2. Two options are represented respectively by the horizontal and vertical shaded regions. The regulator's selection should be governed by the ease options offer in complying with regulations and by uncertainties existing in methods that test compliance.

The regulator may decide that the vertically shaded area offers the greatest advantage. Assume that he desires to regulate p_1 but that it is desirable to go to the next lower level from p_2. Figure 5 illustrates this condition. Figure 5a represents the acceptance region, the regulation placed on p_1 and the bounds placed on p_2. Figure 5b shows the region containing acceptable values of p_{21} and p_{22} based on the bounds placed on p_2. The shaded region represents regulations on p_{21} and p_{22} considered by the regulator to be best. Regulations for this case are provided on p_1, p_{21} and p_{22}.

The impact of making regulations at lower levels is loss of flexibility. For example, placing bounds on p_1 and p_2 has constrained values of the performances to be within the shaded area of Figure 5a. If regulations would have been placed on p_0, then any p_1, p_2 combination that lies within the acceptance region would have been acceptable. Flexibility, therefore, is lost because some acceptable p_1, p_2 combinations are prohibited. When the regulations are placed on p_{21} and p_{22}, more flexibility is lost because some values of p_{21} and p_{22} which provide an acceptable p_2 are considered unacceptable. The conclusion is that greater flexibility exists in meeting regulations when such PBR's are made at higher levels on the function hierarchy. Figure 6 illustrates that trend. To the person or organization being regulated, a greater flexibility implies a greater trade-off potential.

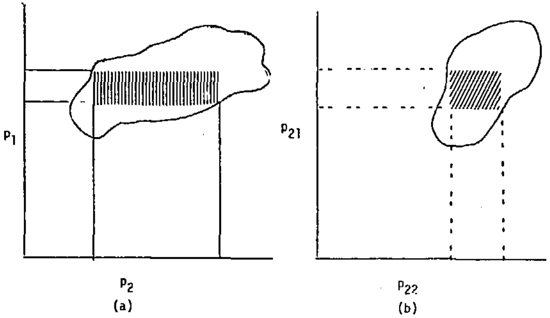

Figure 5. Regulations at a Lower Level

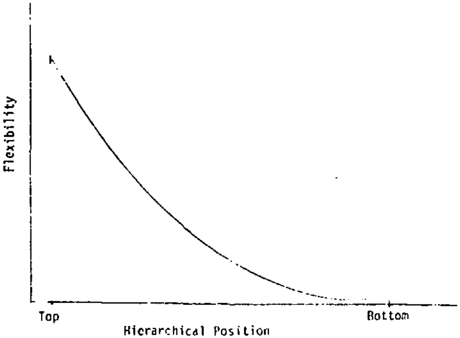

Figure 6. Flexibility Offered by PBR's

Based on the above discussion, it appears as though the best PBR's are those made at the top of the function hierarchy since those PBR's offer the greatest flexibility. This is frequently not the case. At the top of the hierarchy, functions may exist over which the regulator has little or no control. In addition, inherent in performance measures at the upper levels are uncertainties. Bounds formulated that employ today's probability assessments may not be valid in tomorrow's world. The sensitivity of upper level variables to performance bounds at lower levels should be examined by the regulator and considered in PBR development. PBR's formulated in this manner would remain valid through uncontrolled variation in variables influencing upper level functions. Another factor that tends to force PBR's to a lower hierarchical level is the method to test compliance. Compliance at a lower level will be easier to test and with less uncertainty than at a higher level since at lower levels functions are less abstract and influenced by few variables.

Figure 7 combines the factors discussed in this preceding paragraph into a single variable identified as "uncertainty" and shows it as a function of hierarchical level. Selecting a "best level" at which to establish regulations involves a trade-off between "uncertainty" and "flexibility." The regulator has a preference function, P(U,F), which defines his willingness to trade-off these variables. That function is sketched in Figure 8. The best regulations are made at the hierarchical level where the P(U,F) peak is found. Different branches of the hierarchy may suggest PBR's at different levels.

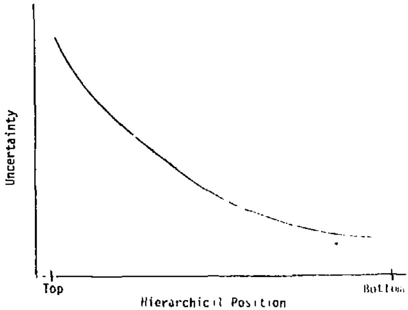

Figure 7. Uncertainty at Hierarchical Levels

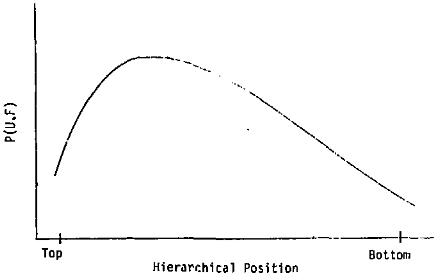

Figure 8. PBR Preference Function

PBR's are developed by constructing a function hierarchy, associating measures with each function and employing a rationale similar to that discussed. Since the framework consisting of the function hierarchy and associated measures is the "backbone" of this approach, an example will be used to add to its understanding.

V. Framework Example

Lawrence Livermore Laboratory has developed for the Nuclear Regulatory Commission a framework that can assist in developing PBR's for material control systems at fixed facilities. A material control system is part of the Safeguard system at a facility and is intended to prevent the unauthorized diversion of SNM. It consists of components and decision logic. Components may delay or prevent access to material, sense abnormal situations that may be induced by an adversary attempting to divert material, or react to abnormal situations. Functions at the bottom level of the functional hierarchy developed for the material control system represent the functions of these components. Component performances are expressed in terms of the physical parameters of the system, the facility and/or the environment.

A material control system interacts with the physical security system at a facility to provide the safeguarding of SNM. Trade-offs can be made between these two systems. Therefore, in order to formulate regulations or evaluate the effectiveness for either system, it is necessary to consider the influence of the other. For this reason, the top function of the hierarchy is that of the entire safeguard system thereby allowing NRC the flexibility of "trading off" material control and physical security performances. From the top function, the hierarchy continues through levels of intermediate functions to the functions of individual components.

Figure 9 is the framework that has been developed. The top function is to "protect the public against the consequences of theft." There are two ways in which protection can be provided. One is to minimize the consequences resulting from thefts and the other is to protect against thefts. NRC has very little control, if any, over the first function and must, therefore, concentrate on the second. This was the reason for the first decomposition.

With x defined as an attempt to accomplish a specific theft objective and y defined as the outcome resulting from such attempts, the performance measures for the two subordinate functions are respectively $C(x,y)$ and $p(x,y)$. The consequence $C(x,y)$ is expressed in quantities such as loss of lives, revenue, etc., and has an expected value for each x,y pair. $p(x,y)$ is the joint probability of the attempt x and a specified outcome, y. It provides an estimate of the anticipated frequency of occurrence of theft acts and resulting outcomes and, therefore, is a measure of how well the system protects against thefts. Aggregation to provide top level performance is judgemental and derived through a decision theoretic approach.

Protection against theft of material can be accomplished by reducing the adversary incentive and by reducing the adversary's probability of success. This step separated functions concerning factors that motivate the adversary from those that are safeguard system dependent. The measures associated with these functions are respectively probability of attempt, $p(x)$, and the probability of an outcome given an attempt, $p(y/x)$. The product of these two measures is the rule for aggregation.

As discussed in Section IV, the hierarchy can be constructed to minimize the regulators problems in assigning bounds to subjective functions. This decomposition addresses such a problem where the highly subjective probability $p(x)$, is separated from the more system specific and less subjective probability, $p(y/x)$. The regulator can thus assume a large value for $p(x)$ and still determine the effectiveness of various safeguard systems or system strategies. Nevertheless, it is still desirable to decompose $p(x)$.

The function "reduce adversary's incentive" was decomposed further. Two functions resulted. They are "phychologically deter the adversary" and "limit target attractiveness." This decomposition was provided because one of these functions relates primarily to the chemical specie within the facility while the other is related more to the safeguard system and environment. Measures for these functions are referred to as the "deterrence factor," $D(x)$, and "attractiveness factor," $A(x)$. Both are subjective. The aggregation rule is multiplicative. Further decomposition on this branch is shown on the diagram but measures have not been associated with these functions.

Safeguard systems are designed to defend against a set of postulated sequences of actions, s, that an adversary might employ. The function "reduce adversary's probability of success" was subdivided into two functions. One of which is "affect adversary's choice of actions" and the other is "guard against adversary actions." This decomposition further separates adversary characteristics from safeguard system performance. The measure associated with the first function is the probability that sequence, s, will be chosen

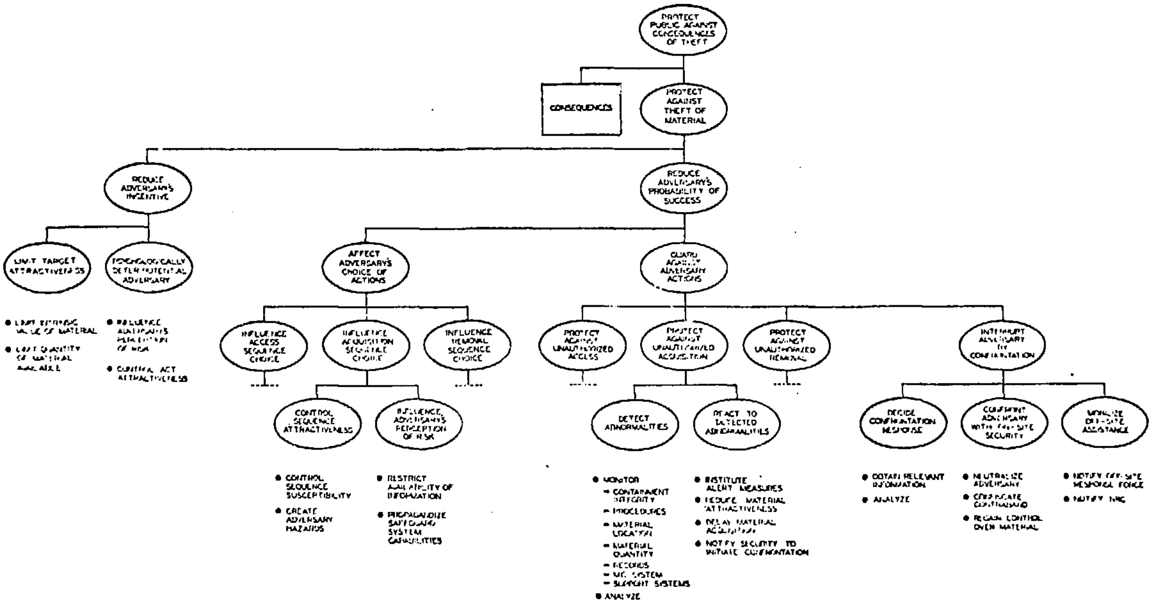

Figure 9. Safeguard Function Hierarchy for Theft at Nuclear Facility

for a given attempt x,p(s/x). The second is the probability tht outcome y will result when sequence s is employed, p(y/s,x). The p(y/x) value is obtained through multiplication and integration over all sequences.

Since the material control system protects against the unauthorized acquisition of material, the sequence s has been divided into three subsequences where s_1 is employed in the gaining access, s_2 in acquiring material and s_3 in removing material. Further decomposition of the function, "affect adversary's choice of actions", reflects this partitioning of the sequence. Conditional probabilities are the measures associated with the resulting functions and aggregation is obtained by combining probabilities. Further functional decomposition is shown but measures have not been associated with resulting functions.

"Guard against adversary actions" is decomposed into four subordinate functions where three of the four are the responsibility of the physical security system. Measures for these three functions and those of subordinate functions have been developed. Aggregation for these measures obey probability rules for conditional probabilities.

The material control system plays two roles in protecting against unauthorized acquisition. It must detect abnormalities and it must react to detected abnormalities. Measures quantifying the performance of these functions are conditional probabilities providing the probability of detection for given sequences and the probability of reaction given detection. Rules for conditional probabilities allow aggregation.

The bottom level of the function hierarchy is reached through the next decomposition. The ability of the material control system to detect abnormalities and react to abnormalities is directly dependent on the performances of the components. The functions of the various types of components are shown in Figure 9. Upon sensing a stimulus resulting from adversary actions, a monitor type component will generate a signal to be operated on by the decision logic within the material control system. The performance measure of monitor components relates the probability of the decision signal to characteristics of the stimulus and physical parameters of component, facility and environment. Performance of components to delay or prevent access to material and to react to detected abnormalities are also required at this bottom level. Aggregation is obtained through the decision logic and command structure employed by the material control system.

The physical parameters describing the performance of components of the material control system and those of physical security can be successively aggregated to test compliance to PBR's developed from the function hierarchy of Figure 9. In addition, PBR's can be established by a top-down analysis which investigates possible changes in factors at the upper levels and notices their influence on performance criteria that may be established at lower levels. Not only is this framework feasible, but portions of it are being implimented by LLL to provide NRC with the capability of evaluating material control systems. The evaluation method is the topic of a companion paper.

VI. Conclusions

Performance based regulations allow maximum design flexibility while maintaining a prescribed societal standard. Such regulations may be devised from the framework described. Considerations of flexibility versus uncertainty allow optimization of the functional level at which regulations should exist. In addition, the framework assists in determining methods to test compliance. Not only is such an approach beneficial, it is practical as shown by the example.