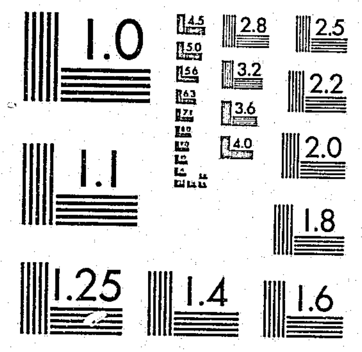

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# THE DESIGN OF ORGANIZATIONAL PERFORMANCE MEASURES FOR HUMAN DECISION MAKING

## PART II: IMPLEMENTATION EXAMPLE *

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## ABSTRACT

The focus of this paper is an application of the approach to designing organizational performance measures described in Part I [1] and is intended to demonstrate how the methodology can be implemented. Each sequence of steps described in Part I is carried out in the context of measuring the performance of inspection personnel for a manufacturing concern. These steps include; construction of the objective matrix, assessment of information preference functions, specification of the parameters of the information volume penalty function, and solving the instrument design problem.

Key Words

Utility, Matrix Representations
Value Function, Cognitive Process
Information Overload

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## I. INTRODUCTION

The methodology for the design of organizational performance measures described in Part I [1] raises five key technological questions. The first concerns how the problem elements (i.e., components and activities) are defined, and how the objective matrix is constructed. In particular, the resolution to which components and activities are enumerated and the extent to which they interrelate must be determined in each application. A second implementation related question concerns how to identify interdependent activities and components for the purpose of forming independent activity and component subgroups. This issue obviously requires us to address the nature of performance interdependencies that characterize a specific problem. Thirdly, value functions defined on subgroups must be assessed, along with the general form and parameters of activity value functions and the characteristic value function. This question requires us to make some conclusions about independence relations between the activity and characteristic subgroups that are formed, and what procedures should be employed to estimate the parameters of the appropriate functional forms. The fourth implementation issue relates to the designation of the critical information volume b, and the parameters of the information volume penalty function. These values must obviously be interpreted with respect to the capabilities and constraints on an individual decision maker. Finally, the approximate procedure for solving the design formulation needs to be operationalized and evaluated.

The purpose of this paper is to demonstrate an application where each of these five key issues is addressed. The approach of the presentation is to first describe the application setting to justify the representation of problem elements that is used and the reasoning behind the objective matrix. The nature of performance interdependencies in the problem is then explored, and procedures for estimating preference models based on these conditions are described. The hypothetical alternatives that the decision maker had to evaluate in order to specify the parameters of activity value functions and the characteristic value function are shown. In addition, conditions in the problem bearing on the specification of the information volume penalty function are illuminated and the associated parameter assessment stage is described. Finally, the problem is solved using the heuristic solution procedure described in Part I.

The next section provides a description of the problem environment in which the implementation takes place. The third section describes the nature of supervisory and performance relationships that result in the independence conditions that determine the form of the preference functions estimated. This includes a summary of model assessment results. The fourth and fifth sections describe the information volume penalty function and summarize the steps of the solution procedure. Finally, the last sections offer some conclusions about the example and the general design methodology.

## II. THE PROBLEM SETTING

This section describes the context of the model implementation. The focus of this implementation is on the quality control function of an industrial firm. Specifically, a manufacturing plant's quality control manager was concerned with evaluating the performance of the night shift inspection force on a bi-weekly basis. The concern was with obtaining sufficient information to make a sound evaluation without having to study the bi-weekly inspection audits (reporting the extent and estimated costs of inspection errors) that were issued for each major product line. Since it required about 30 minutes to read each audit report, the quality control manager did not wish to consider more than six or seven such reports every two weeks. More than three hours spent in performance evaluation of night inspectors was considered unreasonable. However, the quality control manager did not feel comfortable with the idea of spending less than two hours every two weeks monitoring the performance of the night crew and it was generally agreed that the quality audit reports were the only reasonable means for doing so.

Specification of Problem Elements

The night inspection crew had responsibility for inspection of eleven product lines which consisted of three full-time employees and one trainee. Since the only measurable output of the night shift was summarized in the quality audit reports for each of the eleven product lines, an exhaustive summary of the work related activities of this crew could be approximated as simply the inspection of each product line. These activities (inspection for product lines one through eleven) will be described using the notation $\{a_1, a_2, \ldots a_{11}\}$.

The four individuals comprising the night shift will be denoted as $c_1$, $c_2$, $c_3$, and $c_4$. The individual designated as $c_1$ was a full-time employee with inspection responsibility for product lines 1, 2, 3, and 4. The individual designated as $c_2$ was the night shift supervisor with overall responsibility for the night inspection force, and was personally responsible for inspection duties on product lines 6, 7, 9, 10, and 11. The third individual, $c_3$, was a trainee whose only responsibility was for inspection of product line 5, with any additional responsibilities to be assigned by the quality control manager as training progressed. Finally, $c_4$ represented an individual who was a senior technician and whose sole responsibility was inspection for product line 8. This represented the most difficult responsibility from a technical standpoint since the inspection required a high level of skill, and product line 8 accounted for over 30% of the dollar value of the plant's output.

The Objective and Instrument Matrices

With the set of components $(c_1, c_2, c_3, c_4)$ and activities $(a_1, a_2, \ldots, a_{11})$ enumerated for this problem, construction of the objective matrix lead to the result shown in Table 1. For components $c_1$, $c_3$, and $c_4$ the work related activities that were considered relevant were simply the inspection of product lines assigned to those individuals. The quality control manager felt that this was a reasonable representation of responsibilities since inspectors did not rotate their inspection tasks across products, and each individual had a clear understanding of his responsibilities. Since the supervisor, $c_2$, had overall responsibilities for the crew (e.g. maintaining discipline, filling in for absentees etc.) as well as individual responsibility for product lines 6, 7, 9, 10, and 11, the quality control manager believed that his performance was relevant to all of the shift's designated responsibilities.

Performance measure instruments in this problem consisted of combinations of quality audit reports for various product lines. These computer generated reports were in standard format for each product line and outlined the following items over a two week period; inspection output, inspection errors,

Table 1. The Objective Matrix and Activity Value Function Parameters.

(Objective Matrix)

$$
\begin{array}{c|ccccccccccc}
c_1 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
c_2 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\
c_3 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
c_4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
 & a_1 & a_2 & a_3 & a_4 & a_5 & a_6 & a_7 & a_8 & a_9 & a_{10} & a_{11}
\end{array}
$$

| Component | $c_1$ | | $c_2$ | | | $c_3$ | $c_4$ |
|---|---|---|---|---|---|---|---|
| Scaling Const* | $k_{11}$=0.4 | $k_{12}$=0.6 | $k_{21}$=0.2 | $k_{22}$=0.3 | $k_{23}$=0.25 | $k_{31}$=1 | $k_{41}$=1 |
| Act.Value Subfns | $v_{11}(e_{11})$ | $v_{12}(e_{12})$ | $v_{21}(e_{21})$ | $v_{22}(e_{22})$ | $v_{23}(e_{23})$ | $v_{31}(e_{31})$ | $v_{41}(e_{41})$ |
| | $(a_1)$ 0.1 | $(a_3)$ 1.0 | $(a_1)$ 0.10 | $(a_5)$ 0.15 | $(a_9)$ 0.23 | $(a_5)$ 1.0 | $(a_8)$ 1.0 |
| | $(a_2)$ 0,2 | | $(a_2)$ 0.10 | $(a_6)$ 0.15 | $(a_{10})$ 0.41 | | |
| | $(a_1a_2)$ 0.4 | | $(a_1a_2)$ 0.20 | $(a_5a_6)$ 0.25 | $(a_9a_{10})$ 0.57 | | |
| | $(a_4)$ 0.7 | | $(a_3)$ 0.10 | $(a_7)$ 0.05 | $(a_{11})$ 0.33 | | |
| | $(a_1a_4)$ 0.71 | | $(a_1a_3)$ 0.30 | $(a_5a_7)$ 0.20 | $(a_9a_{11})$ 0.72 | | |
| | $(a_2a_4)$ 0.75 | | $(a_2a_3)$ 0.35 | $(a_6a_7)$ 0.45 | $(a_{10}a_{11})$ 0.83 | | |
| | $(a_1a_2a_4)$ 1.0 | | $(a_1a_2a_3)$ 0.70 | $(a_5a_6a_7)$ ).65 | $(a_9a_{10}a_{11})$ 1.0 | | |
| | | | $(a_4)$ 0.15 | $(a_8)$ 0.20 | | | |
| | | | $(a_1a_4)$ 0.50 | $(a_5a_8)$ 0.70 | | | |
| | | | $(a_2a_4)$ 0,60 | $(a_6a_8)$ 0,50 | | | |
| | | | $(a_1a_2a_4)$ 0,85 | $(a_5a_6a_8)$ 0.70 | | | |
| | | | $(a_3a_4)$ 0.45 | $(a_7a_8)$ 0,80 | | | |
| | | | $(a_1a_3a_4)$ 0,90 | $(a_5a_7a_8)$ 0,90 | | | |
| | | | $(a_2a_3a_4)$ 0,65 | $(a_6a_7a_8)$ 0,78 | | | |
| | | | $(a_1a_2a_3a_4)$ 1.0 | $(a_5a_6a_7a_8)$ 1,0 | | | |

*Other scaling Constants for $c_2$ were; $k_{212}$=0,033, $k_{213}$=0,033, $k_{223}$=0,033 and $k_{2123}$=0.15

inspection costs, material usage in inspection, and reports of internal/external failures. An activity profile for an instrument would consist of an eleven element column of zeros and ones. A one in row i would indicate that the quality audit report for product line i (i.e. activity $a_i$) was generated and provided to the quality control manager, and a zero would indicate that such a report was not provided.

## III. DEVELOPMENT OF INFORMATION PREFERENCE FUNCTIONS

This section describes how an activity value function was generated for each individual on the inspection crew, and how the characteristic value function was generated to describe the quality control manager's information preferences over the component set. Activity value functions for any given component evaluate how well coverage of a subset of activities describes the performance of that component, with respect to the preferences of the quality control manager. Similarly, the characteristic value function evaluates coverage of a subset of activities with respect to the entire inspection crew. Activity value functions must take account of performance interdependencies between the activities of an individual component. The characteristic value function must account for performance interdependencies that exist between individuals.

### Assessment of the Form and Parameters of Activity Value Functions

The process of estimating the form and parameters of activity value functions for each individual on the shift required three basic steps. These were the designation of activity subgroups based on interdependence conditions, specification of the activity value functional forms, and estimation of parameters. This section overviews these three steps for each component.

For component $c_1$, the activity value function describing the value of performance related information was defined over the four activities $a_1$, $a_2$, $a_3$, and $a_4$ (i.e. inspection of product lines one through four). Since products 1, 2, and 4 were materials used within the same subassembly, the quality control manager felt that the inspection of these items was interdependent with respect to the overall performance of component $c_1$. As a result, activities $a_1$, $a_2$, and $a_4$ were placed in a three-activity subgroup designated as $e_{1,1}$ where $e_{1,1} = (a_1, a_2, a_4)$. With inspection of product line 3 (i.e. $a_3$) being basically unrelated to inspection of 1, 2, and 4, the activity $a_3$ was considered as a separate independent activity subgroup designated as $e_{1,2}$ where $e_{1,2} = (a_3)$. At this point the value function on the individual activity subgroups $v_{1,1}(e_{1,1})$ and $v_{1,2}(e_{1,2})$ were assessed. The specific activities that a performance measure instrument covered, determined the values of the $v_{1i}(e_{1i})$ subfunctions. With value subfunctions $v_{1i}(e_{1i})$ scaled between zero (if no activities in $e_{1i}$ are covered) and one (if all activities in $e_{1i}$ are covered), the assessment of the eight possible coverage states of $v_{1,1}(e_{1,1})$ were made by having the quality control manager consider the coverage states summarized for $c_1$ in Table 1. For example, the intermediate coverage state $(a_1, a_4)$ in Table 1 was evaluated by having the quality control manager evaluate this state relative to coverage of the entire $e_{1,1}$ subgroup (i.e. $(a_1, a_2, a_4)$), as a percentage between 0 and 100. His response was 71%. The function $v_{1,2}(e_{1,2})$ was equal to either one or zero depending on whether or not activity $a_3$ was covered.

Since activity subgroups $e_{1,1}$ and $e_{1,2}$ were concluded to be reasonably independent, the form of the overall activity value function for $c_1$, (i.e. $v_1(q_1)$ where $q_1 = (e_{1,1}, e_{1,2})$) was additive. This function was given by;

$$v_1(q_1) = \sum_{i=1}^{2} k_{1i} v_{1i}(e_{1i})$$

where

$k_{1,1}$ and $k_{1,2}$ were scaling constants designating the relative importance of activity subgroups $e_{1,1}$ and $e_{1,2}$ in determining the overall performance of $c_1$. The quality control manager estimated these values to be $k_{1,1} = 0.4$ and $k_{1,2} = 0.6$ as summarized in Table 1. This result implied that inspection performance on product line 3, was felt to be more important

in evaluating $c_3$'s performance than the combined remainder of his other inspection responsibilities, in the opinion of the quality control manager.

For the inspection shift supervisor, $c_2$, the assessment of the activity value function $v_2(q_2)$ proceeded in the same way. Since there was little similarity between the product lines inspected by $c_1$ (i.e. incoming materials) and those done by the remainder of the shift, the quality control manager designated one activity subgroup for which $c_2$ was responsible as $e_{2,1} = (a_1, a_2, a_3, a_4)$. This subgrouping was based on the supervisory role of $c_2$ relative to the inspection responsibilities of $c_1$, and the occasional need for $c_2$ to fill in for $c_1$. Relationships between the way product lines were combined in the plant's production process dictated the quality control manager's justification for grouping the remainder of the shift's activities. Since product lines 5 through 8 represented the output of the plant's parts department (upon which scheduling in the assembly department was dependent), the quality control manager felt that $c_2$'s responsibility for inspection of these products was interrelated. Thus, the second activity subgroup was formed as $e_{2,2} = (a_5, a_6, a_7, a_8)$. Finally, activities $a_9$, $a_{10}$, and $a_{11}$ were grouped together (i.e. $e_{2,3} = (a_9, a_{10}, a_{11})$) since they each represented inspection of outgoing product and were handled personally by $c_2$. The evaluation of the subfunctions $v_{2,1}(e_{2,1})$, $v_{2,2}(e_{2,2})$ and $v_{2,3}(e_{2,3})$ were done using the same approach as applied to those of $c_1$. These results are summarized in Table 1.

Since $c_2$ had a considerable degree of responsibility for seeing to it that the shift's overall performance was acceptable, the quality control manager believed that there was a moderate degree of interdependence between the activity subgroups $e_{2,1}$, $e_{2,2}$ and $e_{2,3}$. That is, the shift supervisor had to assure that a viable balance was maintained between inspecting raw material, completed parts and subassemblies, and end product. This consideration led to selection of the following form of $v_2(q_2)$;

$$v_2(q_2) = \sum_{i=1}^{3} k_{2i} v_{2i}(e_{2i}) + \sum_{i=1}^{3} \sum_{j>i} k_{2ij} \cdot v_{2i}(e_{2i}) \cdot v_{2j}(e_{2j})$$
$$+ \sum_{i=1} \sum_{j>i} \sum_{\ell>j} k_{2ij\ell} \cdot v_{2i}(e_{2i}) \cdot v_{2j}(e_{2j}) \cdot v_{2\ell}(e_{2\ell}),$$

where; $k_{2,1}$, $k_{2,2}$, $k_{2,3}$ were scaling constants designating the relative importance of subgroups $e_{2,1}$, $e_{2,2}$ and $e_{2,3}$. The two-way scaling constants $k_{2,1,2}$, $k_{2,1,3}$ and $k_{2,2,3}$ estimate the performance interaction of subgroup pairs, and $k_{2,1,2,3}$ is the three-way scaling constant associated with the performance interaction effect of all three activity subgroups. The results obtained by assessments of the quality control manager are summarized in Table 1.

Development of activity value functions for components $c_3$ and $c_4$ was straightforward since these components were each responsible for one activity. For component $c_3$, (the trainee) the applicable activity value function was given by;

$$v_3(q_3) = k_{3,1} v_{3,1}(e_{3,1}), \quad \text{where;}$$

$k_{3,1} = 1$ and $e_{3,1} = (a_5)$. Here, $v_3(q_3)$ was either equal to zero (i.e. and audit report is not generated for product line 5) or one (i.e. such a report was provided). For component $c_4$, (the experienced technician), the activity value function was given by;

$$v_4(q_4) = k_{4,1} v_{4,1}(e_{4,1}) \quad \text{where;}$$

$$e_{4,1} = (a_8),\ k_{4,1}, \quad \text{and} \quad v_4(q_4) = 1 \text{ or } 0.$$

## Assessment of the Form and Parameters of the Characteristic Value Function

After activity value functions were assessed relative to each component, the characteristic value function had to be estimated. In this respect, the quality control manager believed that employees designated $c_1$, and $c_3$, were heavily dependent on supervision to perform adequately. For this reason, the performance of components $c_1$, $c_2$, and $c_3$ were modeled as if they were highly interdependent. On the other hand, the quality control manager did not feel that the senior technician required supervision to perform his duties, and $c_4$ was therefore considered to be in a separate component subgroup. These relationships lead to the following designation of component subgroups; $F_1 = (c_1, c_2, c_3)$ and $F_2 = (c_4)$. However, it would not have been possible to evaluate the supervisor completely without taking account of $c_4$'s performance to some extent. This was due to the fact that product line 8 had a strong influence on the crew's overall output so that it was necessary to allow for some degree of performance interdependence between $c_2$ and $c_4$. These considerations led to the selection of the following characteristic value function model form;

$$f(c_1, c_2, c_3, c_4) = \sum_{i=1}^{2} k_i f_i(F_i) + \sum_{i>j} k_{ij}(f_i(F_i)) \cdot f_j(F_j))$$

where, $F_1 = (c_1, c_2, c_3)$, $F_2 = (c_4)$. The parameters for the characteristic value function were estimated as; $k_1 = 0.37$, $k_2 = 0.24$ and $k_{12} = 0.39$. The $f_i(F_i)$ value subfunctions were estimated by having the decision maker express preferences for hypothetical instruments represented as measurement alternatives giving rise to controlled levels of the activity value function for each component. This required a total of about 45 different assessments of hypothetical alternatives. Figure 1, shows the conditional value curves obtained on $f_1(F_1)$ and $f_2(F_2)$. Evaluation of characteristic value subfunctions was accomplished by interpolating between the points on these curves.

Recall that instrument alternatives were seen as a collection of inspection audit reports pertaining to different product lines. To evaluate the information content of an

alternative, the activity value function was evaluated for each component (based on the product lines included in the reports) and this information was then evaluated using the characteristic value function.

## IV. SPECIFICATION OF PENALTY FUNCTION PARAMETERS

In determining appropriate parameters for the information volume penalty function, two decisions were required. The first concerned an appropriate value for the critical information volume. This immediately raised questions about the units of information volume associated with alternative measure instruments, and the point at which information volume became a decision consideration. The second decision involved the nature of the impact that information volume had on the decision maker. It was necessary to investigate this effect before the empirical parameters of the information volume penalty function could be estimated.

### Finding the Value of b

The fact that quality audit reports were generated using a standardized format for each product line simplified the problem of measuring the information volume of alternatives. This was due to the fact that it required the quality control manager about the same amount of time to review a quality audit report regardless of the product line in question. Therefore, we could conclude that $d_i = d_j$ for $\forall_{i \neq j}$. Furthermore, since the quality control manager's complaints regarding the cumbersome reports were based on the amount of time it required to pour over them, time per report seemed to be an appropriate unit of information volume. The quality control manager estimated that it required roughly 30 minutes to review each report so $d_i$ was set equal to 1/2 hour. In addition, since the quality control manager favored spending as little time as possible reviewing night shift performance, but was distinctly uncomfortable with the idea of spending less than two hours every two weeks, the value of b was considered to be two hours.

Although the two hour constraint does not precisely represent the impact of information volume on a cognitive process, it did indicate that the optimal instrument alternative would require at least two hours to review. In light of this, the quality control manager was asked to state the maximum amount of time he could allocate to night shift performance. The response to this question was a confident statement of three hours every two weeks. This value in turn was considered analogous to b´ as defined in Part I. Again, this value of b´ did not precisely reflect the impact of information volume on a cognitive decision process, but it allowed us to express the range of an optimal solution in terms of information volume. To do this, recall that each report required about 30 minutes. With b = 2 hours and b´ = 3 hours, we know that the optimal

instrument solution will consist of a collection of audit reports on 4, 5, or 6 product lines. That is;

$$b \leq \sum_{i=1}^{11} d_i x_i^* \leq b' \quad \text{implies} \quad 2 \leq .5 \sum_{i=1}^{11} x_i^* \leq 3 \quad \text{or}$$

$$4 \leq \sum_{i=1}^{11} x_i^* \leq 6.$$

### Finding the Value of γ and β

At this point, the empirical parameters of the information volume penalty function had to be evaluated. Increases in information volume beyond that associated with four reports was undesirable. However, increases in information volume associated with providing additional audit reports resulted in an alternative with a greater (more desirable) information content. The deleterious impact of volume relative to the beneficial impact of content had to be approximated. To do this, it was first necessary to determine whether or not the impact of volume was independent of the level of information content. If not, the information volume penalty function would have to be conditional on the information content associated with a solution.

To investigate volume/content interdependence and the specific impact of volume on the desirability of a solution, the quality control manager was asked about the impact of volume at different levels of information content. Specifically, he was asked to evaluate the relative desirability of a solution that required three hours to review relative to one requiring two hours to review, if they had comparable information content. Similarly, he was asked to state the relative desirability of a solution requiring 2 1/2 hours to review, if it had comparable information content. After repeating this line of questioning for different content levels expressed as percentages of complete coverage of all product lines, it was determined that the impact of volume was not appreciably affected by the level of information content. Furthermore, alternatives requiring 3 and 2 1/2 hours to review were respectively about 80% and 92-93% as desirable as an alternative requiring only two hours to review (for a given content of information). Therefore, adding one additional audit report to a solution comprised of four reports led to a 7-8% reduction in the desirability of that solution while adding a second additional report led to a 20% reduction is desirability (apart from the beneficial impact on information content).

These conditions suggested the parameters $\beta = 0.135$ and $\gamma = 0.55$, since such values would cause the $\lambda$ penalty function to approximate the curve implied in the previous assessments between b and b'.

This yielded the penalty function;

$$\lambda\left(\sum x_i d_i\right) = 0.135\left(\sum_{i=1}^{11} d_i x_i - 2\right) \frac{\exp\left[.55\left(\sum_{i=1}^{11} d_i x_i - 2\right)\right]}{1+\exp\left[.55\left(\sum_{i=1}^{11} d_i x_i - 2\right)\right]} \cdot f(c_1^*, c_2^*, c_3^*, c_4^*).$$

where the units of b and $d_i$ $(i = 1,\ldots 11)$ are expressed as hours. This function simplifies to;

$$0.135\left(\sum_{i=1}^{11} x_i - 4\right) \frac{\exp\left[.55\left(\sum_{i=1}^{11} x_i - 4\right)\right]}{1+\exp\left[.55\left(\sum_{i=1}^{11} x_i - 4\right)\right]}$$

since $d_i = d_j = 0.5\ \forall_{ij}$ and the characteristic value function is scaled so that $f(c_1^*,\ldots c_4^*) = 1$.

## V. SOLVING THE DESIGN PROBLEM

At this point, preference functions measuring the value of different information sources were assessed, and the parameters of the information volume penalty function have been estimated. Also, it has been determined that the optimal solution is to provide quality audit reports for six, five or four product lines. It remains to determine if six, five or four is preferable, and which product lines should be involved. Toward this end, the solution procedure described in Part I was implemented.

### Finding an Initial Solution

Recall that the designated activity subgroups were; $e_{11} = (a_1, a_2, a_4)$, $e_{12} = (a_3)$, $e_{21} = (a_1, a_2, a_3, a_4)$, $e_{22} = (a_5, a_6, a_7, a_8)$, $e_{23} = (a_9, a_{10}, a_{11})$, $e_{31} = (a_5)$, and $e_{41} = (a_8)$. The $P_j$ characteristic weight was then calculated for each subgroup. For example, for $e_{21}$, $P_{21}$ was calculated by subtracting the value of a solution covering $(a_5, a_6, a_7, a_8, a_9, a_{10}, a_{11})$, (i.e. the activity complement of $e_{21}$), from the maximum value of the characteristic value function (i.e. 1). Table 2 summarizes the seven $P_j/B_j$ ratios obtained by this first step. Based on these ratios, the activities within subgroups were included in the initial solution in the following order; $e_{41}$, $e_{31}$, $e_{12}$, $e_{22}$, $e_{23}$. Upon adding $e_{23}$, the volume of the initial solution exceeds $b'$ so the sequential building phase is completed. The initial solution provides for covering $(a_3, a_5, a_6, a_7, a_8, a_9, a_{10}, a_{11})$.

### The Improvement Phase

At this point, the improvement phase of the solution procedure was initialized. This phase took four iterations that are summarized in Table 3. The final solution was to provide quality audit reports on product lines 3, 7, 8, 10 and 11. To arrive at this result, it was necessary to re-evaluate the characteristic value function a total of 33 times. With eleven binary variables, 2048 different solutions

Table 2. Summary of Building Phase of the Solution Procedure.

Sequential Building Phase:

$P_j/B_j$ Ratios for Activity Subgroups:

$e_{11} = (a_1, a_2, a_4) : \frac{P_{11}}{B_{11}} = \frac{.311}{3} = 0.104$

$e_{12} = (a_3) : \frac{P_{12}}{B_{12}} = \frac{.228}{1} = 0.228$

$e_{21} = (a_1, a_2, a_3, a_4) : \frac{P_{21}}{B_{21}} = \frac{.392}{4} = 0.098$

$e_{22} = (a_5, a_6, a_7, a_8) : \frac{P_{22}}{B_{22}} = \frac{.772}{4} = 0.193$

$e_{23} = (a_9, a_{10}, a_{11}) : \frac{P_{23}}{B_{23}} = \frac{.379}{3} = 0.126$

$e_{31} = (a_5) : \frac{P_{31}}{B_{31}} = \frac{.234}{1} = 0.234$

$e_{41} = (a_8) : \frac{P_{41}}{B_{41}} = \frac{.733}{1} = 0.733$

Initial Solution: $(e_{41}, e_{31}, e_{12}, e_{22}, e_{23}) = (a_3, a_5, a_6,$
$a_7, a_8, a_9, a_{10}, a_{11})$

Table 3. Summary of the Improvement Phase

| Subgroup | $P_j - P_j'$ |
|---|---|
| $e_{41} = (a_8)$ | .491 |
| $e_{31} = (a_5)$ | .076 |
| $e_{12} = (a_3)$ | .081 |
| $e_{22} = (a_5a_6a_7a_8)$ | .015* $= \min_j(P_j - P_j')$ |
| $e_{23} = (a_9a_{10}a_{11})$ | .021 |

$\Rightarrow$leaving variable $x_6$ (i.e. $a_6$)

Revised Solution: $(a_3a_5a_7a_8a_9a_{10}a_{11})$

Penalty Fn. Value: $\infty$ (by definition)

Objective Value: $-\infty$

| Subgroup | $P_j - P_j'$ |
|---|---|
| $e_{41} = (a_8)$ | .562 |
| $e_{31} = (a_5)$ | .059 |
| $e_{12} = (a_3)$ | .093 |
| $e_{22} = (a_5a_6a_7a_8)$ | .023 |
| $e_{23} = (a_9a_{10}a_{11})$ | .018* $= \min_j(P_j - P_j')$ |

$\Rightarrow$leaving variable $x_9$ (i.e. $a_9$)

Revised Solution: $(a_3a_5a_7a_8a_{10}a_{11})$

Penalty Fn. Value: .2026

Objective Value: .656 - .2026 = .4534

Iteration 3:

| Subgroup | $P_j - P_j'$ |
|---|---|
| $e_{41} = (a_8)$ | .546 |
| $e_{31} = (a_5)$ | .053* $= \min_j(P_j - P_j')$ |
| $e_{12} = (a_3)$ | .137 |
| $e_{22} = (a_5a_6a_7a_8)$ | .053* $= \min_j(P_j - P_j')$ |
| $e_{23} = (a_9a_{10}a_{11})$ | .172 |

$\Rightarrow$leaving variable $x_5$ (i.e. $a_5$)

Revised Solution: $(a_3a_7a_8a_{10}a_{11})$

Penalty Fn. Value: .0856

Objective Value: .603 - .0856 = .5174

Iteration 4:

| Subgroup | $P_j - P_j'$ |
|---|---|
| $e_{41} = (a_8)$ | .498 |
| $e_{31} = (a_5)$ | -- |
| $e_{12} = (a_3)$ | .259 |
| $e_{22} = (a_5a_6a_7a_8)$ | .139 |
| $e_{23} = (a_9a_{10}a_{11})$ | .128* $= \min_j(P_j - P_j')$ |

$\Rightarrow$leaving variable $x_{11}$ (i.e. $a_{11}$)

Revised Solution: $(a_3a_7a_8a_{10})$

Penalty Fn. Value: 0

Objective Value: .475 - 0 = .475 < .5172 $\therefore$ STOP at Iteration 3.

were possible. Specifying that the optimal solution had 6, 5 or 4 positive variables reduced this number to 1254 possible solutions. Since the solution obtained was within 20% of the optimal, it is reasonable to conclude that the sequential building heuristic has good potential for providing quality solutions for a manageable computational effort in this example.

## IV. CONCLUSIONS

In this paper, an application of the performance measurement design methodology was described. Specific values were obtained for each of the elements in the design formulation described in Part I.

It was shown that the approach for modeling performance interdependencies must be based on conditions surrounding specific problems. This rule applies to the formation of independent activity and component subgroups, and the form of models for aggregating performance information preferences over these subgroups. Based on results for a problem with 11 activities and four components, the estimation of the performance measurement preference function does not pose a prohibitive assessment task. In addition, it was shown that an additional assessment phase was required to estimate the behavioral and empirical parameters of the volume penalty functions. This phase is apt to be somewhat more involved in situations where the $d_i$ volume coefficients are unequal, and the ranges of critical information volume are less certain.

Finally, the simple heuristic procedure was applied to find a solution to the design problem. The procedure was based on obtaining an initial solution using a heuristic sequential building rule and then applying an improvement phase. The procedure found a solution within 20% of optimal using only 33 re-evaluations of the objective function for a problem with 11 binary variables. General conclusions about the effectiveness of the procedure should be reserved until additional examples can be tested.

## VII. ACKNOWLEDGEMENT

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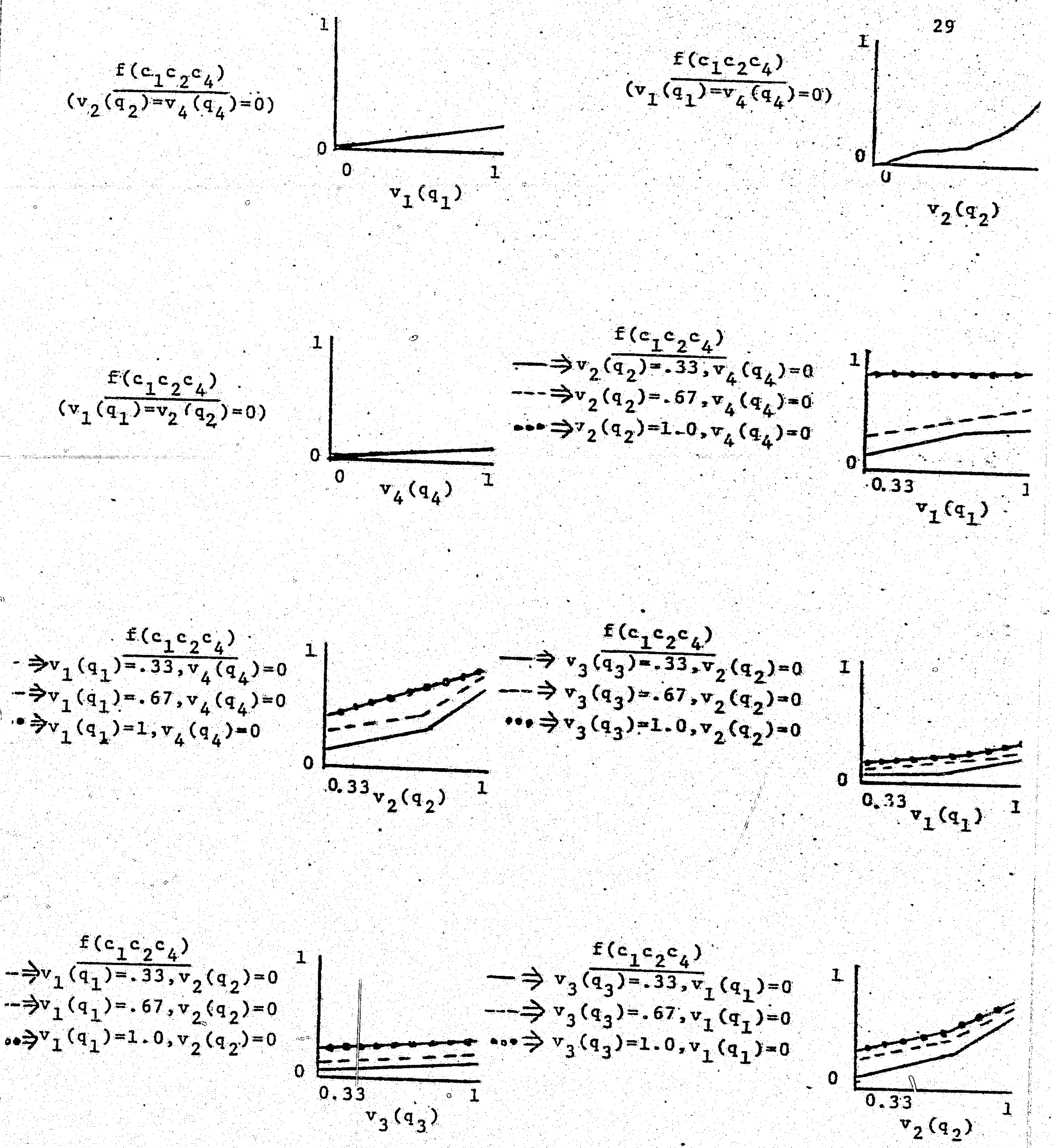
## REFERENCES

[1] S. J. Deutsch and C. J. Malmborg, "The Design of Organizational Performance Measures for Human Decision Making: Part I; Description of the Design Methodology", <u>ISyE Report Series</u>, J-81, Georgia Institute of Technology, Atlanta, Ga., 1981.

Figure 1. Conditional Preference Curves for Characteristic Value Subfunctions $f(c_1c_2c_4)$ and $f(c_3)$.



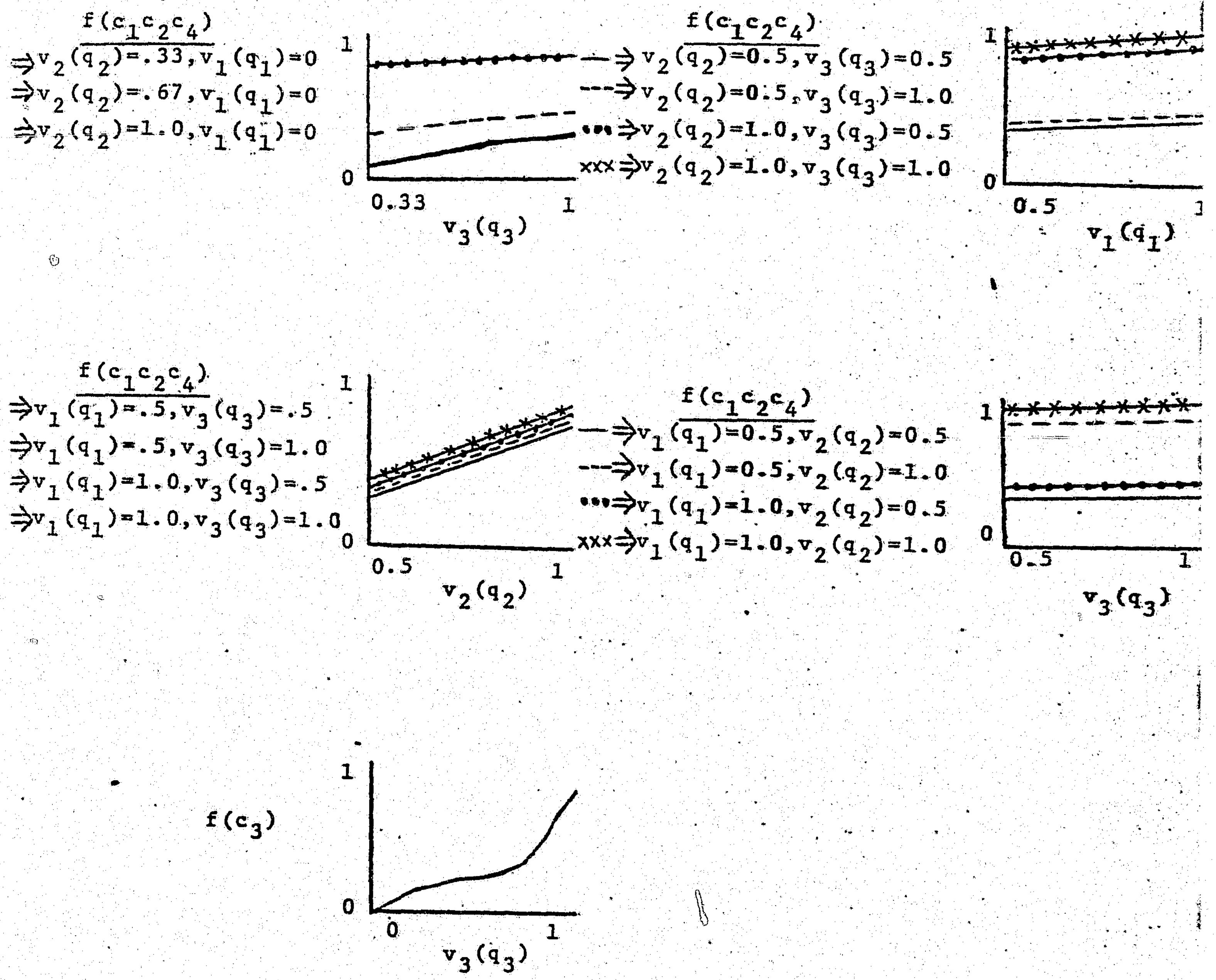


Figure 1. (continued)

END

END