Structured procedure for comparison and selection of computer system designs

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Decisions about selecting a configuration for a computer system require an unbiased comparison among alternative designs of the system. Several heterogeneous factors need to be considered and their combined effect must be evaluated. The procedure provides a structure to the selection process activities: developing a selection plan, evaluating each design, and ranking the alternatives. It is based on a cost-effectiveness methodology which characterizes each design by the life-cycle cost through a "system cost index" and by the design effectiveness in reaching the system objectives through a "system utility index." The procedure is applicable to the selection of a system, to tradeoff analysis during the system design, and may constitute the framework for the analysis of the risk associated to a design implementation.

INTRODUCTION

The acquisition of an information system constitutes a painstaking problem for a manager of an organization that makes substantial investments in computer systems [1], [2]. He should identify the needs of the actual and potential users of the system, define the scope of the system, and specify the essential and optional requirements and capabilities for the system. When he has done all his homework his problems are not ended. In fact, he will have to decide which system to implement among several proposals of system designs. He is flooded with a quantity of data representing heterogeneous parameters of system performance and cost from which he has to derive a simple "number" representing the "best" design.

Practically the only method presently existing to help the decision maker is to translate all the data in monetary terms [3]. This method is largely employed and constitutes a teaching topic in many administration courses. The difficulty encountered in several cases is in the definition of a reasonable monetary value for the system parameters when the system objectives are not immediately or conveniently related to economic benefits. Such are the cases of computer systems directly devoted to technical or scientifical analysis or dedicated to information processing for decision analysis. The economical benefits are remote and often the very existence of the computer system is needed to assess its benefits (e.g. information value).

This paper presents a structured procedure for selecting a system configuration among alternative designs based on a cost-effectiveness methodology. The methodology is an extension of E. O. Joslin's concepts [3] through the application of the utility curves concepts introduced by D. Hurta [4] in the risk analysis area.

The procedure has been developed for NASA-GSFC [5], [6], and is applicable to the selection of an entire information system as well as a subsystem, to trade-off analysis during system design, and it is also the framework for the analysis of the risk associated with the decision to implement the selected design.

COST-EFFECTIVENESS METHODOLOGY

The methodology subdivides the items related to the selection of the computer system in two classes: the cost elements which directly affect the life-cycle cost of the system, and the selection factors which are traceable to the system objectives. Accordingly, each system design is represented by two indices: the system cost index that aggregates the time distribution of all cost elements, and the system utility index that expresses the effectiveness of the design in fulfilling the system objectives. The two indices combine through a ranking algorithm in a system rank index which represents the cost-effectiveness of the design.

The definition of the system cost index is directly obtained by discounting to a reference "present time" the costs incurred during the system life cycle (Table I) by means of a specific value (or a range of values) of the interest rate. The basic model to compute the system cost index from expenses distribution and interest rate value is the "present value of expenditures" (PVE) represented by the equation

$$PVE = \sum_{k=0}^{n} \frac{C_{E_k}}{(1 + r)^k}$$

which is easily implemented in a computational algorithm [6]. In the equation, $n$ is the length of the system life-cycle usually in years, $r$ is the interest rate value, and $C_{E_k}$
aggregation of expenditures (and revenues) occurring during the Kth period of the life-cycle.

The system utility index aggregates the heterogeneous selection factors in a measure of system effectiveness through the definition of a utility curve and a weight [5] for each selection parameter (Table II) associated to the selection factors. The utility curve (Figure 1) measures how better (or worse) is any level reachable by the selection parameter with respect to a specific nominal level. The weight measures the relative importance of each parameter with respect to the system objectives.

Several interpretations may be associated to the utility curve concept. If the system objectives have a purely economical nature, the utility curve may represent Joslin's relative monetary worth of each level of a parameter [3]. A probability related meaning is possible when the system life stretches quite into the future. The utility curve translates the probability that each level of a parameter will fulfill the uncertain future objectives. In general, the utility curve is the way to accommodate subjective preferences and judgments within the selection process through a quantitative representation.

The aggregation of the various parameter utilities generates the system utility index. An example of aggregation model is [6]:

\[ U_s = U_d(W_e + W_u U_u) \]

In the model, \( U_d \) is the geometric average of the essential parameter utilities, \( U_u \) is the arithmetic average of the optional parameter utilities, and \( W_e \) and \( W_u \) the respective aggregated weight.

The system cost index and the system utility index combine in a system rank index by means of a general dominance relation [5]. Also, a ranking algorithm can be defined for a specific class of computer systems. For example, if Grosch's Law [7] can be assumed for large systems, the system rank index is defined by

\[ R_s = (U_s)^{1/2}/C_s \]

and the system design with the largest value of \( R_s \) will be selected.

**THE SELECTION PROCEDURE**

The process of selecting a computer system encompasses several activities such as defining the system's important features, evaluating performance parameters, and ranking system designs with respect to some selection criteria.

The various activities needed to apply the cost-effectiveness methodology are integrated in a procedure that employs, as a starting point, the objectives and requirements...
specified for the system (and also employed by the design activity) and that systematically evaluates each alternative design to identify the best design for the system.

Broadly speaking, the procedure is composed of three major steps: developing a selection plan; evaluating the selection criteria for each alternative configuration design; and determining the order of preference among designs, based upon how closely they satisfy the selection criteria.

Figure 2 presents a scheme of the selection procedure.

Defining the selection plan is the critical step of the procedure because it must provide subsequent activities with the inputs and the controls that will ensure consistency and objectivity within the selection process. Consistency is attained by specifying the methods that will be employed to evaluate each design. Objectivity can be attained by defining in advance topics and criteria related to subjective assessments so that each design will be treated in the same way.

The selection plan must contain an accurate description of the selection process taking into account that the effort dedicated to the selection process should be commensurate with the expected potential saving. The principal functions of the selection plan are: identify the system selection factors and the system life-cycle cost elements; generate the selection parameter utility; and specify models and tools to be employed for evaluating effectiveness and cost and for assessing the alternative design ranking.

Cost elements and selection factors have been already illustrated in Tables I and II respectively.

To each selection parameter identified, correspond a utility curve and a weight generated through: a definition of the acceptable range of the parameter; an assessment of the parameter weight and the utility values for two or more parameter levels; and a calibration of the utility curve model. The first two activities are performed by one or more respondents who have a good knowledge of the system objectives, of the system requirements, and of how a variation in the level of each selection parameter may affect the fulfillment of the system objectives. The last activity will ensure consistency of assessment both among the respondents and among the various utility curves. The choice of the models depends on the specific interpretation of the utility curves. Details may be found in [5] and [6].

For each selection parameter and cost element, the selection plan should define a model and/or an algorithm to evaluate the parameter or cost level and should specify how the model will be employed for any expected system design. For instance, system performance parameters may be estimated by models of the flow of data, controls, and activities within the system such as analytical algorithms based on queueing theory or simulation programs. Examples of simulation programs are the Multi-Purpose System Simulator (MPSS) [8] and the Data System Dynamic Simulation (DSDS) [9]. The selection plan should specify types, volumes, and frequencies of data and information (i.e., the test workload) that enter the system. Other selection parameters, such as flexibility and ease of use, may be estimated through subjective judgments if adequate algorithms are lacking. The selection plan should specify the guidelines, procedures, and methodologies to be used in the subjective assessments in order to ensure a high level of objectivity and consistency.

For the system cost index, the selection plan should specify the following items: time span and present time of the system life cycle; methods and procedures to compute and distribute each cost element; and value of the yearly interest rate or cost of money.

The selection plan should also specify how to handle exceptional cases, such as proposed design options and/or alternative contractual conditions. In general, each alternative should be considered as generating a different system design in order to assess the global and marginal effect of each alternative.

The development of the selection plan should be done with enough care so that the subsequent evaluation and ranking steps may be routinely performed on each alternative design. These last two steps will be performed when each design has been completely defined and will comprehend, in general, the following activities:

- Analyze the documentation of each system design.
- Model the designed system configuration to represent both the selection parameters and the cost elements.
- Estimate the level of each selection parameter, as well as the amount and time distribution of the expenditures relative to each cost element.
- Compute—the system design utility index using the specified utility curves and algorithms
—the system design cost index using the specified models
— the system ranking index using the specified model.

• Order all alternate designs according to the ranking index.

Analysis of the design documentation is the critical activity because it must extract the data and information required to evaluate the design according to the selection plan specifications, and identify all exceptional conditions. The remaining activities should follow the selection plan strictly and will not be discussed further here since they have been analyzed in detail in [5] and [6]. For illustration, the appendix presents a hypothetical example.

CONCLUSION

The selection of a computer system design among several alternative configurations requires the analysis of heterogeneous items, both technical and economic, that need to be combined in a consistent and rational ordering of the alternatives.

The selection procedure presented in this paper is based upon a cost-effectiveness methodology that subdivides those items in two classes: selection parameters representing the ability to fulfill the system objectives; and cost elements affecting the life cycle cost of the system. The impact of each class on the selection is combined in a selection criterion: the system utility index as a measure of the system design effectiveness; and the system cost index as a measure of the distribution of costs over the system life. The two system indices are evaluated for each alternative system design which is thus characterized by a pair of utility costs. The application of a ranking algorithm provides a rational ordering of the designs from which the “best” system can be selected.

The various activities of the selection process are structured in a systematic procedure that clearly identifies the functions, the inputs and the results of each step. Furthermore, the procedure can ensure a maximum degree of consistency and objectivity through the development of a selection plan which specifies in advance any controlling topic and subjective assessment needed for the evaluation of the alternatives. The selection procedure has been experimentally applied with success to a real case study [6].

REFERENCES


APPENDIX—HYPOTHETICAL EXAMPLE OF THE SELECTION PROCEDURE

In order to furnish a complete description of the procedure, this Appendix describes a hypothetical example of system selection taken from a presentation of the procedure to NASA-GSFC. The case study is oversimplified, to cover completely the selection procedure in a short space.

The example is the selection on an hypothetical entry system to support program coding and debugging for a software development facility.

A series of tables and figures describe the example with the following types of information:

• Definition of the system (Table A-I)
• Selection plan (Table A-I) and utility curves (Figures A-I through A-3)
• Description of the alternative configuration designs (Table A-III)
• Alternative design evaluation and ranking:
  — selection parameter evaluation (Table A-IV)
  — system utility index determination (Table A-V)
  — life-cycle cost and system cost index evaluation (Table A-VI)
  — utility index-cost index diagram (Figure A-4)
  — system rank index evaluation and identification of the best design (Table A-VII)

Although the tables and figures are self-explanatory, some discussion of the content will aid in following the example. The system is defined by specifying its principal characteristics (Table A-I): system objectives, functions, and nominal requirements specifications. Obviously these are only a

<table>
<thead>
<tr>
<th>TABLE A-I.—Definition of System</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SYSTEM DEFINITION</strong></td>
</tr>
<tr>
<td>• OBJECTIVES: PROVIDE COMPUTER SUPPORT TO PROGRAM CODING</td>
</tr>
<tr>
<td>• FUNCTIONS: GENERATE SOURCE CODE</td>
</tr>
<tr>
<td>• SPECIFICATIONS: NUMBER OF PROGRAMMER POSITIONS SUPPORTED (NOMINAL) 10</td>
</tr>
<tr>
<td>(CRT TERMINAL)</td>
</tr>
</tbody>
</table>

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small subset of what should have been needed to define an actual system. The nominal requirement levels are assumed to derive from a compromise between user need to optimize programmers' performance and constraints due to the hypothetical operational environment.

The selection procedure follows the steps discussed in the previous sections.

First, the selection plan is developed (Table A-II) using the system definition. The major topic is represented by the generation of the selection parameters' utility curves and weights (see Figures A-1 through A-3). These have been assessed by the writer through an arbitrary judgment. The rationale behind the assessment of parameter ranges and utility values derives from a hypothetical analysis of the programmers' productivity.

The system's hypothetical design, which does not belong to the selection procedure, resulted in several alternative system designs. These are grouped (Table A-III) in two basic configurations. The first one relies upon the host central computer for the editing capability; the second configuration distributes the editing capability. Each of the two configurations is associated with three alternative communication solutions. Therefore, six designs need to be evaluated.

The evaluation activities for the selection procedure are described next. First, each selection parameter is evaluated for each of the six designs (Table A-IV). Response time and turnaround time, hypothetically derived from the modeling and simulation of each design, have been assessed in actuality by a subjective judgment of the writer. Combining parameter levels and utility curves by means of the system utility model provides the value of the system utility index for each system design (Table A-V). This value represents the capability of each design to meet the system objectives. Note that only design D is above the nominal level. However, the other designs are also technically acceptable and constitute a trade-off among requirement specifications.

The second evaluation concerns the system life-cycle cost of each design (Table A-VI). Each cost element specified by the selection plan is evaluated from a hypothetical vendor price list or, for maintenance and personnel support, from the corresponding models also specified by the selection
TABLE A-III.—Description of Alternative Configuration Designs

<table>
<thead>
<tr>
<th>ALTERNATIVE CONFIGURATION DESIGNS</th>
<th>SYSTEM DESIGN</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. PASSIVE CRT TERMINALS</td>
<td>A</td>
</tr>
<tr>
<td>1.1 DIRECT CONNECTION</td>
<td>10 TERMINALS</td>
</tr>
<tr>
<td>1.2 USE OF REMOTE CONCENTRATORS</td>
<td>B</td>
</tr>
<tr>
<td>1.2.1 1 CONCENTRATOR</td>
<td>6 TERMINALS</td>
</tr>
<tr>
<td>1.2.2 2 CONCENTRATORS</td>
<td>12 TERMINALS</td>
</tr>
<tr>
<td>2. DISTRIBUTED EDITING CAPABILITY</td>
<td>D</td>
</tr>
<tr>
<td>2.1 USE OF FRONT-END MINIS</td>
<td>6 TERMINALS</td>
</tr>
<tr>
<td>2.1.1 1 MINI</td>
<td>15 TERMINALS</td>
</tr>
<tr>
<td>2.2 USE OF PROXIMENT MINIS</td>
<td>12 TERMINALS</td>
</tr>
<tr>
<td>2.2.1 2 MINIS</td>
<td>30 TERMINALS</td>
</tr>
</tbody>
</table>

TABLE A-IV.—Selection Parameter Evaluation

<table>
<thead>
<tr>
<th>NUMBER OF TERMINALS</th>
<th>COMPILATION TURNAROUND (MIN)</th>
<th>EDITION RESPONSE TIME (SEC)</th>
<th>SYSTEM UTILITY INDEX</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>10</td>
<td>0.25</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
<td>20</td>
<td>0.50</td>
</tr>
</tbody>
</table>

TABLE A-V.—System Utility Index Determination

<table>
<thead>
<tr>
<th>SYSTEM UTILITY INDEX</th>
<th>SYSTEM DESIGN</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25</td>
<td>A</td>
</tr>
<tr>
<td>0.50</td>
<td>B</td>
</tr>
</tbody>
</table>

TABLE A-VI.—Life-Cycle Cost and System Cost Index Evaluation

<table>
<thead>
<tr>
<th>SYSTEM DESIGN</th>
<th>US</th>
<th>CS</th>
<th>RS</th>
<th>RANK</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.2.1 (A)</td>
<td>46</td>
<td>65.8</td>
<td>1.43</td>
<td>3</td>
</tr>
<tr>
<td>1.1 (A)</td>
<td>89</td>
<td>105.1</td>
<td>1.18</td>
<td>1*</td>
</tr>
<tr>
<td>2.2.1 (B)</td>
<td>99</td>
<td>125.5</td>
<td>1.27</td>
<td>2</td>
</tr>
<tr>
<td>2.1 (C)</td>
<td>105</td>
<td>192.0</td>
<td>1.83</td>
<td>4</td>
</tr>
</tbody>
</table>

The system utility index is computed as a weighted geometric average of the selection parameters utility values:

\[ U_S = w_1U_{11} + w_2U_{12} + w_3U_{13} \]

The system cost index is computed as a weighted geometric average of the life-cycle cost elements:

\[ C_S = w_1C_{11} + w_2C_{12} + w_3C_{13} \]

plan. The computation of the system cost index is a direct application of the formula relative to the PVE.

The last evaluation concerns the system ranking index for each design. The first step consists of plotting the system utility index \((U_S)\) versus the system cost index \((PVE)\) for each design (Figure A-4). This step identifies the designs (namely C and F) to exclude immediately because of inferior cost-effectiveness. With the second step, the remaining designs are then ordered according to the system ranking index computed by means of the model specified by the selection plans (Table A-VII). The best design (namely A) results in being the most cost-effective. Although it has a performance below the nominal requirements, it will support the number of terminals nominally required. The selected design is a trade-off among technical and economical characteristics, a trade-off which is best in relation to the selection plan specifications.

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