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Design effectiveness in commercial construction.

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DESIGN EFFECTIVENESS
IN COMMERCIAL CONSTRUCTION

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by

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INTRODUCTION

1.1 Background

One of the major problems facing the construction industry in the coming years is its continual decline in productivity. A recurring problem since the mid 1960s, the extent of the decline continues to elude researchers and industry officials. The inability to determine the extent of the decline has been attributed by the Buisness Roundtable to the diverse and fragmented nature of the industry, as well as the absence of a standard method of measurement and an industry wide data base.[1] In examining the productivity issue it is obvious that all aspects of design, construction and project management must be reviewed.

A general consensus exists that as a project progresses from feasibility studies and preliminary design, to detailed design, procurement, and construction, the amount of control or influence that can be exerted on the project decreases. Decisions made early in the design phase have the largest impact on not only total construction cost, but often on the constructability, maintainability, and operability of the facility. Typically, the cost of the design phase represents less than 10% of the total construction costs. Due to their large impact and relatively small cost, it is essential that the products of the design phase be examined when productivity improvements are desired.

The Construction Industry Institute has identified a matrix evaluation technique known as the Objectives Matrix as a tool for evaluating the effectiveness of design. The matrix format allows the evaluation of many diverse factors that are normally difficult to quantify and produces an index which is used to track and evaluate performance.

1.2 Purpose

The purpose of this study is:

1. to explore the applications of the design evaluation matrix in commercial building and heavy civil construction.
2. to review guidelines for implementing the design evaluation matrix.
3. to make recommendations for additional criteria and sub-criteria.

1.3 Scope

This study is a continuation of a Construction Industry Institute study on the evaluation of design effectiveness. Phase I of the research introduced the Design Evaluation Matrix, a variation of the Objectives Matrix, as a technique for determining design effectiveness.[2] In phase II, the components of the Design Evaluation Matrix were refined through a study of the piping phase of large industrial projects.[3] The evaluation criteria and sub-criteria used in this study are based on those established in phase I of the research. These criteria are: accuracy of the design documents, usability of the design documents, cost of the design, constructability, performance against design schedule, economy of the design, and ease of occupancy / start-up.

1.4 Organization

This report briefly reviews the Design Evaluation Matrix as an evaluation technique for design effectiveness. A review of the matrix theory and matrix construction is presented in Chapter 2. In Chapter 3 the evaluation criteria and sub-criteria are discussed. The feasibility of applying the method to commercial building and heavy civil construction is explored in Chapter 4. A Design Evaluation Matrix example for a commercial building is presented in Chapter 5 using the weights and performance levels collected from the various projects volunteered for the study. Chapter 6 presents the conclusions of the study and recommendations for the report.

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1. Measuring Productivity in Construction, Construction Industry Cost Effectiveness Project Report A-1, The Buisness Roundtable, September, 1982.

2. Scarlett, B. R., Evaluation of Design Effectiveness, M.S. thesis, The University of Texas at Austin, December, 1986.

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Chapter 2

THE DESIGN EVALUATION MATRIX

In an attempt to improve productivity throughout the construction industry many Industrial Engineering techniques used in manufacturing industries such as time and motion studies and time-lapse photography, have been adapted for use by the construction industry. Another method receiving increasing attention is matrix measurement. Matrix measurement does not directly measure productivity. Instead, the factors that affect production time, quality, and cost are measured. One form of matrix measurement known as the Objectives Matrix provides the means to list, categorize, and weight the key indicators of performance that relate to the objectives of a project. A variation of this method, called the Design Evaluation Matrix, is being researched by the Construction Industry Institute for evaluating design effectiveness.

2.1 Introduction

There are four main components of an evaluation matrix, the criteria (sub-criteria), the weights, the performance scale, and the performance index.

The criteria (sub-criteria) define what is to be measured. The weights determine the relative importance of the criteria (sub-criteria) to the operation of interest. The performance scale compares the measured value of a specific criterion on a project to past performance or to future goal for that criterion. From these three

components the performance index is calculated and used to evaluate and track performance.

2.2 Construction of The Matrix

This section is provided a guide on how to construct an evaluation matrix, and to illustrate how the components of the matrix interact. Figure 2.1 should be referred to throughout the explanation of matrix construction.

The first step in constructing a matrix is the selection of the evaluation criteria. In developing the Objectives Matrix, Riggs' proposed three guidelines for selecting evaluation criteria.[1] First, the criteria should pertain only to the activities that contribute directly to the performance goals. Second, all goals should be reasonable, and their attainment dependent only upon the actions of the group being measured. Finally, the criteria should be representative of all of the work responsibilities of the group.

Once the criteria (sub-criteria) have been selected weights are assigned by management in accordance with its perception of how each criterion impacts performance. In the weighting process, 100 points are distributed among the criteria.

Notice that a performance scale of 0 to 10 has been drawn on the right side of the matrix. A score of 10 represents a future goal that is attainable in the foreseeable future with current resources. A score of 3 is designated as average (rather than a score of 5) to allow more room for improvement. A score of 0 represents the minimum acceptable level of performance based on recent experience. These three levels represent the "benchmark" levels for the matrix.

After the values for the benchmark scores are established, values are determined for the levels between benchmarks. These values may be established by

Drawing Revisions	Revised Drawings	Specification Revisions	Revised Specifications	Rework			
35	46	40	9	2.3			PERFORMANCE

The project measureed value of each criterion is recorded under the criterion in the row labeled performance.

							SCORE
5	5	5	5	2			10
8	8	8	8	2.3			9
11	11	11	11	2.6			8
14	14	14	14	3			7
16	16	16	16	3.3			6
19	19	19	19	3.8			5
22	22	22	22	4.4			4
25	25	25	25	5			3
33	33	33	33	7			2
42	42	42	42	10			1
50	50	50	50	15			0

Each criterion's score is multiplied by its weight to obtain its value

1	0	1	8	9			SCORE
15	20	15	15	35			WEIGHT
15	0	15	120	315			VALUE

All values are summed to produce the Performance Index

PERFORMANCE INDEX

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Design Evaluation Sub-Matrix for Accuracy of the Design Documents

FIGURE 2.1

one of three different techniques, numerical increment, percentage increment, or a subjective ratio. The technique used will depend on the nature of the criterion and the workers being evaluated.

In the numerical increment technique each level on the performance scale differs by the same numerical value. For example, the increment between scores one and two is equal to the increment between scores eight and nine. These numerically linear increments result in an increasingly larger percentage of improvement with each upward movement. A formula to determine the numerical increment for values between the benchmark levels is presented in Appendix 1.

The percentage increment technique utilizes a non-linear scale. This technique produces increments in which the percentage difference between any two consecutive levels is the same. A formula to determine the percentage increment scale is also contained in Appendix 1.

After all values have been entered in the appropriate columns and rows of the matrix, the project scores assigned to each criterion are entered in the row under the criteria labeled "performance".

In each column the score closest to the project score that does not exceed it is circled. If a measured score falls between matrix scores it is assigned the lower of the two scores. A score is not assigned until it has been attained.

The circled scores are recorded in the box below each criterion labeled "score". This score is multiplied by the criterion weight, and the product is recorded in the row labeled "value". After all values have been determined they are added together to obtain the "performance index".

2.3 Sub-Matricies

The use of matrix measurement allows each criterion on the master matrix to be individually measured by the use of sub-matricies. A sub-matrix is developed for each criterion on the master matrix in the same manner that the master matrix was developed. Sub-criteria are much more specific than the performance criteria on the master matrix. Once completed, the performance index of a sub-matrix becomes the measured value for the appropriate criterion on the master matrix. This enables the user to track the performance of a specific criterion by tracking the performance index of the corresponding sub-matrix.

An example of a sub-matrix and its relationship to a criterion on the design evaluation matrix is shown in Figure 2.2.

Criterion in the master matrix	Accuracy of the Design Documents Sub-criterion matrix					
ACCURACY	Drawing Revisions	Revised Drawings	Specification Revisions	Revised Specifications	Rework	
465	35	20	40	9	2	PERFORMANCE

						SCORE
1000	5	5	5	5	2	10
900	8	8	8	8	3	9
800	11	11	11	11	2.3	8
700	14	14	14	14	2.6	7
600	16	16	16	16	3.3	6
500	19	19	19	19	3.8	5
400	22	22	22	22	4.4	4
300	25	25	25	25	5	3
200	33	33	33	33	7	2
100	42	42	42	42	10	1
0	50	50	50	50	15	0

5	1	0	1	8	9	SCORE
20	15	20	15	15	35	WEIGHT
100	15	0	15	120	315	VALUE

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The index for the submatrix becomes the project measured value for the performance criterion on the master matrix.

Relationship Between Design Evaluation Matrix and Sub-Matrix

FIGURE 2.2

ENDNOTES CHAPTER 2

1. Riggs, J. L., "The Objectives Matrix: A Method of Motivating and Monitoring Work Performance for Productivity Improvement in the Construction Industry", Productivity in the Construction Industry, proceedings of the symposium held at The University of Pretoria, June 27, 1982, pp. 154-208.

Chapter 3

DESIGN EVALUATION CRITERIA

In order for the design evaluation matrix to be utilized effectively, evaluation criteria must be identified that relates to the design function and to potential construction and maintenance problems that may result from an improper design. In its effort to develop the design evaluation matrix, the Construction Industry Institute has identified fourteen evaluation criteria that are generally applicable to all types of construction projects. These evaluation criteria were provided to owners, constructors and designers as a starting point for this investigation.

3.1 Criteria Selection

Design is a complex function and will require a variety of performance criteria to effectively evaluate it. Many variables will influence the actual selection of design criteria and sub-criteria. Since each project is unique to a degree, the selection of criteria needs to be tailored to each project. Variables influencing criteria selection include the type of project, type of design contract, type of construction contract, scheduled duration of the design and construction periods, and the project's budget. Additionally, the differing perspectives of the designer, constructor, and owner need to be considered in selecting evaluation criteria and sub-criteria. Some of the designer's principal concerns are a design that meets all owner requirements and regulatory codes, is aesthetically pleasing, and enhances its professional reputation.

The constructor is concerned with the constructability of the design, the accuracy of the design products, and its ability to meet the owner's schedule, as well as the ability to generate a profit. The owner's concerns include the items mentioned above along with the long range aspects of the design, such as life-cycle costs, maintainability, and operability.

3.2 Design Evaluation Criteria

During the initial phase of its study, the Construction Industry Institute identified fourteen design criteria.[1] With only minor modifications these criteria can be utilized on most construction projects. These criteria are presented in Figure 3.1.

Design Evaluation Criteria

Accuracy of the Design Documents
Completeness of the Design Documents
Clarity of the Design Documents
Usability of the Design Documents
Economy of the Design
Timeliness of the Design
Start-up Costs and Time Required
Cost of the Design Effort
Constructability of the Design
Operability of the Design Facility
Maintainability of the Design Facility
Safety of the Design
Plant Operating Efficiency
Plant Performance

Figure 3.1

The process of design evaluation should be an ongoing endeavor and can be divided into three phases. In phase one, efforts are made to track the effectiveness of the design during the design process. The injection of contractor experience and

knowledge can play a significant role in improving the constructability and cost effectiveness of a design.

In the second phase, construction, the design is evaluated for constructability, accuracy, clarity, and information content. Studies have shown a direct relationship between clarity, information content, and overall quality of a design, and the productivity of construction workers.[2]

Immediately after construction is completed an effort should be made to gather information from all members of the project team prior to its dispersion. The cataloging of this information can provide a valuable library of "lessons learned" and prevent the repetition of errors on future projects.

In phase three, a long term evaluation needs to be performed to evaluate the overall effectiveness of the design. Several aspects which should be included in this evaluation are the maintainability of the facility, layout efficiency, and quality.

Based on discussions with industry personnel, those criteria which lend themselves to an initial design evaluation are: Accuracy of the Design Documents, Usability of the Design Documents, Cost of the Design, Constructability of the Design, Economy of the Design, Performance Against Schedule, and Ease of Occupancy. These criteria are discussed in the following paragraphs.

The most obvious products of the design process are the drawings and specifications. The accuracy of the design documents criterion evaluates the effectiveness of the design by monitoring the frequency and impact of errors and omissions in the drawings and specifications. Examples of quantitative measurements for this criterion include the number of drawing revisions, the number of revised drawings, the number of specification revisions, the number of revised

specifications, and the number of rework manhours due to design errors and omissions.

The usability of the design documents measures the completeness, clarity and information content of the plans and specifications. Subjective measurements for this area include the amount of cross referencing, the appropriateness of the drawing size, the completeness of the drawings, and the clarity of the drawings.

The cost of the design effort evaluates the anticipated design cost versus the actual design costs. Caution must be used in monitoring this criterion as many factors may impact on the number of design hours and cost of the design . Owner changes, regulatory (code) changes and schedule compression are some examples of factors that may impact on the design cost and duration. These factors should be accounted for through a revision of the design budget and schedule.

Constructability is defined as the optimum integration of construction knowledge and experience in planning, engineering, procurement and field operations to achieve overall project objectives.[3] General areas indicating the effectiveness of a project's constructability program include the type of construction equipment required, size and skill of the labor force required, special material requirements, and unrealistic tolerances.

The economy of design criterion attempts to evaluate the efficiency of the final design product. Indicators of an efficient design include minimizing the number of overdesigned structural members and overspecified materials, and the efficiency of the building layout.

One of the critical factors in the success of a construction project is the availability of the design. Delays in the release of the design documents can

adversely affect not only the project's overall design and construction schedule, but may increase the cost of bids by contractors, vendors and material suppliers.

The ease of occupancy and start-up criterion addresses the completeness of the design. The efficiency of the design process is judged by comparing the budgeted manhours to the actual manhours required to prepare the facility for occupancy or use.

These seven criteria should be of concern to each of the design users. Additionally, with only limited modifications they can be used for almost any type of construction project. Before their final selection for use in a matrix, each criterion should be thoroughly reviewed not only for its applicability to type of project, but also to determine how it will be measured, subjectively or quantitatively.

3.3 Criteria Weighting

Each of these criteria will vary in the degree of their accuracy as an indicator of design effectiveness. To compensate for this, each criterion is weighted by the design user to reflect the impact of the criterion in relation to the other criteria. The number of points assigned to a criterion is a direct indication of its influence on a design's effectiveness.

In weighting of the criteria consideration must also be given to the uniqueness of the individual project. A project that is schedule driven may require special emphasis on the performance against schedule criterion and constructability. A project that is on an extremely tight budget may place additional emphasis on the cost of the design and economy of the design.

Finally, the objectiveness or subjectiveness of a criterion may influence its weight. Due to a possible lack of confidence in, or controversy surrounding

subjective ratings, a user of the matrix may wish to emphasize those criteria that are measured quantitatively.

ENDNOTES CHAPTER 3

1. Scarlett, B. R., Evaluation of Design Effectiveness, M.S. thesis, The University of Texas at Austin, May, 1986.

2. Borcherding, J.D., Sebastian, S, J., and Samelson, N. M., "Improving Motivation and Productivity on Large Projects", Journal of the Construction Division, Proceedings of the American Society of Civil Engineers, Vol. 106, No. C01, March, 1980, pp. 73-89.

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Chapter 4

APPLICATION OF THE DESIGN EVALUATION MATRIX TO COMMERCIAL BUILDING AND HEAVY CIVIL PROJECTS

To explore the application of the Design Evaluation Matrix on commercial buildings and heavy civil construction projects, it was necessary to obtain data from actual projects and solicit the views of construction industry professionals.

Since the application of the Evaluation Matrix is relatively new, the seven initial criteria for measurement of design effectiveness were used. Industry personnel were encouraged to suggest additional criteria and sub-criteria for use in the evaluation matrix.

4.1 Methodology

The first step in testing the feasibility of the evaluation matrix was the collection of project data. Questionnaires were mailed out to CII member companies / firms requesting projects for the study.

An interview guide was included with each project request letter to aquaint personnel designated as "points of contact" with the purpose of the study prior to interviews. The design evaluation matrix was presented with a description of the criteria and sub-criteria. Efforts were made to contact owners, designers, and constructors of commercial buildings and heavy civil construction projects. However, no responses received from design firms.

Telephone interviews were conducted with personnel from those companies responding to the request for projects. The projects volunteered for the study ranged from a 430,000 SF office complex to a power plant facility including 1500 feet of tunnels connecting the major buildings. All project personnel interviewed were degreed engineers.

The interview guide was divided into four sections. The first section provided a summary of the research project, its scope, and requested a point of contact. An explanation of the design evaluation matrix was presented, criteria and sub-criteria discussed, and definitions provided.

Section two contained a project description sheet requesting general information about the project. Also included in this section was an interview guide addressing each of the seven design criteria, and requesting the information required for determining the sub-criteria ratios.

In section three the interviewees were asked to rank the criteria and sub-criteria in order of their importance, and to assign weights to the individual criteria and sub-criteria.

In section four the interviewees were asked to estimate the industry averages for the benchmark performance levels of ten, three, and zero for each of the sub-criteria. These are subjective estimates based on the cumulative experience and knowledge of the interviewees.

4.2 Sources of Data

Letters requesting projects for the study were sent to representatives of owners, designers, and constructors belonging to the Construction Industry Institute. Projects were requested in the categories of commercial buildings (office buildings,

corporate headquarters etc.) and heavy civil projects (highway, bridge, and the heavy civil phase of industrial projects, etc.).

Responses were received from five firms, representing owners (3) and constructors (2). No response was received from a design firm. One constructor, who was also the facilitiy's owner, is classified as an owner. The projects reviewed included three commercial buildings and two heavy civil projects. Additionally, one constructor provided assistance in the determination of benchmark values, industry weights, and recommendations for additional criteria and sub-criteria in the commercial building sector. Figure 4.1 provides a brief description of each project volunteered.

Project Summary

Commercial Buildings

Classification	Project Description
Owner	Regional headquarters (300,000SF), offices, conference facilities, and cafeteria.
Owner	Regional headquarters (430,000 SF), conference facilities, computer center, and cafeteria.
Owner (Constructor)	Corporate office and laboratory expansion.
Constructor	* * * *

Figure 4.1

Project Summary (Continued)

Heavy Civil

Classification	Project Description
Constructor	Office building, refinery power plant, facilities building, 1500 feet of interconnecting tunnels.
Constructor	Nuclear waste processing plant (new technology)

Figure 4.1

4.3 Design Criteria

The initial step in evaluating design effectiveness is the identification of sub-criteria for each of the design criteria. The sub-criteria should be much more specific that the criteria on the master matrix.

In an effort to increase the acceptance of the evaluation matrix sub-criterion should be quantitatively measured. Subjective measurements should be used only when absolutely necessary.

The sub-criterion for each of the seven criteria are shown in Figure 4.2: Criteria and Sub-Criteria. The abbreviated criteria and sub-criteria titles utilized in the matricies are contained in parentheses.

Criteria and Sub-Criteria

ACCURACY OF THE DESIGN DOCUMENTS (ACCURACY)
- Drawing revisions / total number of drawings (Drawing Revisions)
- Revised drawings / total number of drawings (Revised Drawings)
- Specification revisions / total number of specifications (Specification Revisions)
- Revised Specifications / total number of specifications (Revised Specifications)
- Manhours of rework / total number of manhours (Rework)

USABILITY OF THE DESIGN DOCUMENTS (USABILITY)
- Subjective rating for drawing size (Drawing Size)
- Subjective rating for number of drawings (Number of Drawings)
- Subjective rating for number of cross references (Cross References)
- Field engineering manhours / total engineering manhours (Field Engineering)
- Subjective rating for clarity of drawings (Clarity)
- Subjective Rating for completeness of drawings (Completeness)

COST OF DESIGN EFFORT (COST)
- Design cost / construction cost (Design Cost)
- Design manhours expended / design manhours budgeted (Design Manhours)

CONSTRUCTABILITY (CONSTRUCTABILITY)
- Subjective rating for the number of unrealistic tolerances vs. quality expectations (Tolerances)
- Subjective rating for the number of crafts (Different Crafts)
- Subjective rating for compatibility with current materials and technology (Compatibility)

ECONOMY OF DESIGN (ECONOMY)
- Building layout efficiency (Layout)
- Amount of overdesigned members (Overdesign)
- Amount of overspecified materials (Overspecified)

PERFORMANCE AGAINST SCHEDULE (SCHEDULE)
- Percent of construction document release dates attained (Document Release)
- Percent of intermediate release dates attained (Intermediate Release)

EASE OF OCCUPANCY (OCCUPANCY)
- Occupancy preparation days required / days budgeted (Occupancy Days)
- Number of maintenance personnel required / number budgeted (Personnel)

Figure 4.2

The accuracy of the design documents criterion concerns the number of errors and omissions in the plans and specifications. For commercial buildings and heavy civil projects, as with most construction projects, accuracy is best reflected by the number of revisions in the design documents, and the number of rework manhours due to these errors and omissions. In evaluating the accuracy of the design documents only those drawings issued for construction are reviewed. Prior to issuance, a drawing is not considered to be complete. Sub-criteria utilized in evaluating the accuracy criteria include distinctions between the number of drawing revisions and the number of revised drawings, and the number of specification revisions and the number of revised specifications. This was necessary since the impact of numerous revisions to a single drawing or specification may result in a different impact when compared to a larger number of drawings or specifications being revised.

Usability of the design documents is primarily a subjective criterion that reflects the information content and format of the drawings and specifications. The use of subjective ratings in this and other criteria must be approached with caution due to the different education, experiences, and standards of each evaluator. The only quantitative sub-criteria included in this evaluation is the number of field engineering manhours versus the total number of design manhours.

The cost of the design can be subdivided for the various phases (electrical, mechanical, HVAC, etc.) of a project to determine the overall cost effectiveness of the project. The actual cost versus the budgeted costs is one measure of the effectiveness of the design effort. Due to the preliminary nature of this study no subdivisions were made. Allowances should also be made for owner initiated changes affecting scope, installed equipment, materials, and methods.

The constructability criterion is subjectively rated and difficult to measure due to the unique aspects of each project's program. Some factors that impact on constructability include unrealistic tolerances which can increase costs and slow production, and the type of equipment to be installed which when coupled with the number of different crafts required may increase the probability of jurisdictional disputes on union projects. Other important items to be reviewed include the use of prefabrication yards, models, taking advantage of repetitive operations to obtain the maximum benefits from learning curves, and the necessity of specialized equipment and skills.

The economy of design criterion is indicative of a design's waste and inefficiency. Material waste adds directly to the cost of a project and operational inefficiencies may create scheduling and access problems. Additionally, the presence of overdesigned members and overspecified materials can increase the cost of a project.

For a project to remain on schedule the design documents must be issued on their scheduled release dates. Poor performance in the release of plans and specifications can impact on areas such as procurement, quality, and schedule.

The ease of occupancy and start-up criterion attempts to evaluate the completeness of the design and identify unexpected problem areas. An increase in the maintenance manhours required prior to occupancy or use may be indicative of a design omission.

During the interviews industry personnel were asked to suggest additional criteria and sub-criteria to add to the matrix. Suggested additions to the seven criteria for the master matrix are:

1. Aesthetics

2. Maintainability
3. Installed systems reliability.
4. Expandability
5. Quality
6. Durability of finishes
7. Safety

Recommendations for additional sub-criteria included:

Accuracy of the Design Documents

1. The number of drawing clarification memos sent to the designer by the contractor / the total number drawings.
2. Number of changes due to misunderstanding of the building code requirements.
3. Number of changes due to errors and omissions and their associated costs.

Usability of the Design Documents

1. The number of requests for information sent to the designer by the contractor.
2. Number of changes due to shop drawing review comments.

Cost of the Design Effort

1. Duration of the design.

Constructability

1. Engagement of the contractor.

Maintainability

1. Accessibility of building utilities / services (e.g. plumbing, HVAC, piping, ducts, controls, etc.) for maintenance and repair.
2. Maintenance manhours budgeted vs. maintenance manhours expended.
3. Actual cost of maintenance vs. budgeted costs.
4. Quality of documentation (as-built drawings).
5. Durability of materials chosen for high traffic areas.

4.4 Weights

The evaluation criteria used in the Design Evaluation Matrix were assigned weights to reflect their impact on the effectiveness of design. These weights, based on the averages of the weights assigned by industry personnel, are shown in Figure 4.3: Criteria Weights.

Criteria Weights

Criteria	Commercial Building	Heavy Civil
Accuracy	20	20
Usability	20	20
Cost	10	10
Constructability	20	25
Economy	10	10
Schedule	15	10
Occupancy	5	5

Figure 4.3

For commercial buildings and heavy civil projects, the criteria accuracy of the design documents, usability of the design documents, and constructability, were ranked as the most important indicators of design effectiveness. A slightly higher weight was assigned to constructability by the heavy civil evaluators than by those evaluating commercial buildings. While assigned equal weights, the top three evaluation criteria for commercial buildings in rank order, were, constructability, accuracy of the design documents, and usability of the design documents.

The sub-criteria for each criterion were also assigned weights to reflect their relationship to the evaluation criterion on the master matrix. These assignments are presented in Figures 4.4 through 4.10.

On both commercial building and heavy civil projects, the amount of rework was considered to be the most important indicator of design document accuracy. This was expected due to the relationships between rework, cost, productivity, schedule, and worker morale. The number of revised specifications was rated the least important sub-criteria for heavy civil projects.

Accuracy Sub-Criteria Weights

Criteria	Commercial Building	Heavy Civil
Drawing Revisions	15	15
Revised Drawings	20	15
Specification Revisions	15	20
Revised Specifications	15	10
Rework	35	40

Figure 4.4

The usability of the design documents was ranked as the third most important evaluation criteria on both commercial building and heavy civil projects. The sub-criteria, completeness, and clarity, were judged the most important indicators of design document usability for both types of construction.

Usability Sub-Criteria Weights

Criteria	Commercial Building	Heavy Civil
Drawing Size	5	5
Number of Drawings	10	5
Cross References	15	10
Field Engineering	15	10
Clarity	25	35
Completeness	30	35

Figure 4.5

The cost of the design criterion was generally ranked low in importance. Of the sub-criteria, personnel involved with heavy civil projects favored design manhours over design cost. One interesting response was the assignment of an extremely high weight to a write-in criteria, duration of the design process, by one of the evaluators for commercial buildings.

Cost Sub-Criteria Weights

Criteria	Commercial Building	Heavy Civil
Design Cost	75	40
Design Manhours	25	60

Figure 4.6

Overall, the constructability criterion was rated as the most important indicator of design effectiveness. In evaluating the constructability sub-criteria, both industry segments rated the amount of unrealistic tolerances as the most important factor. Compatibility of the design with current materials and technology was ranked second by both groups.

Constructability Sub-Criteria Weights

Criteria	Commercial Building	Heavy Civil
Tolerances	50	60
Different Crafts	10	10
Compatibility	40	30

Figure 4.7

Economy Sub-Criteria Weights

Criteria	Commercial Building	Heavy Civil
Layout	55	15
Overdesign	25	45
Overspecified	20	40

Figure 4.8

For commercial building projects the sub-criteria layout was favored by a wide margin. It is interesting to note that both overdesigned members and overspecified materials were weighted very close together for heavy civil projects, while layout received relatively little attention.

Schedule Sub-Criteria Weights

Criteria	Commercial Building	Heavy Civil
Document Release	55	45
Intermediate Release	45	55

Figure 4.9

For the performance against schedule criterion, both sub-criteria were regarded as relatively equal. Those personnel evaluating commercial buildings favored document release dates met, while the heavy civil evaluators favored intermediate document release dates.

Occupancy Sub-Criteria Weights

Criteria	Commercial Building	Heavy Civil
Occupancy	55	55
Personnel	45	45

Figure 4.10

The occupancy / start-up criterion was ranked the least important on both commercial and heavy civil projects. Weight assignments for the sub-criteria were identical with the number of days required to prepare for occupancy / put the facility into use favored over the number of manhours required to prepare the building / facility.

4.5 Performance Scale Assignments

The assignment of benchmark values by industry personnel are shown in Figures 4.11 and 4.12, Estimated Benchmark Values. These are the values that would be entered into the master and sub-matricies at the performance levels of ten, three, and zero. The increments between these scores would be determined by utilizing the percentage increment technique, numerical increment technique, or the subjective ratio technique. Caution must be used in applying these values to actual projects due to the limited number of projects studied during this investigation.

Figure 4.11 presents the estimated benchmark values for commercial buildings based on the projects volunteered for the study. The "Measured Value" represents the average of the values assigned to a particular sub-criteria by industry

Estimated Benchmark Values

Commercial Buildings

Sub-Criteria	Percentage Values: Ten	Three	Zero	Measured Value
ACCURACY				
Drawings Revisions	5	25	50	35
Revised Drawings	5	25	50	46
Specification Revisions	5	25	50	40
Revised Specifications	5	25	50	9
Rework	2	5	15	2.3
USABILITY				
Field Engineering	5	30	55	35
COST				
Design Cost	4	7	9	9
Design Manhours	100	120	140	116
SCHEDULE				
Document Release	100	80	65	68
Intermediate Release	100	80	70	64
OCCUPANCY / START-UP				
Occupancy	90	110	130	92
Personnel	90	115	130	127

Figure 4.11

personnel for the projects volunteered for the study. All values are expressed as percentages. A comparison of the measured values with the estimated values indicates that the average project is generally between the level three and level zero benchmarks. This is even more apparent when the measured values are placed in the example evaluation matrix in the next chapter.

Figure 4.12 presents the estimated benchmark values for heavy civil projects based on the projects studied. A comparison of project measured values with the estimated benchmark values indicates that the average heavy civil project falls between the level three and level zero benchmarks. The measured values for two of the sub-

Estimated Benchmark Values

Heavy Civil

	Percentage Values			Measured Values
Sub-Criteria	Ten	Three	Zero	
ACCURACY				
Drawings Revisions	20	225	400	350
Revised Drawings	10	50	85	75
Specification Revisions	10	50	85	340
Revised Specifications	2	10	25	60
Rework	2	10	25	6
USABILITY				
Field Engineering	3	12	25	23
COST				
Design Cost	10	20	30	24
Design Manhours	100	120	130	125
SCHEDULE				
Document Release	100	75	60	50
Intermediate Release	100	70	60	55
OCCUPANCY / START-UP				
Occupancy	100	110	120	100
Personnel	100	110	120	100

Figure 4.12

criteria, specification revisions and revised specifications score substantially above the zero level of performance. These values are heavily influenced by the new, unproven technology associated with one of the heavy civil projects studied. Sufficient data is not currently available to determine the actual values that should be used for the benchmark scores. These values are provided for illustrative purposes only.

4.6 Conclusions

The Design Evaluation Matrix is extremely flexible and holds a great deal of promise for use throughout the construction industry. The information required to construct the matricies is readily available on current construction projects. Due to the limited number of projects investigated during this study, the values presented in this paper should be considered for illustrative purposes only. As the evaluation matrix receives more attention from industry the database for criteria and sub-criteria weights and benchmark levels should expand and become more refined.

Chapter 5

DESIGN EVALUATION MATRIX EXAMPLE

The next step in exploring the application of the Design Evaluation Matrix to the areas of commercial buildings and heavy civil construction is the construction of an example matrix. In this chapter, an evaluation matrix for a commercial building will be constructed and discussed.

5.1 Construction of the Matricies

The first step in the construction of the master matrix and sub-matricies is entering the criteria and sub-criteria column headings, the weight assignments, and the level zero, three, and ten benchmark estimates in the matrix forms. For each criterion in the master matrix and sub-criterion in the sub-matricies, the benchmark values collected during the interviews will be used.

After all the interview data has been entered in the matricies scores must be assigned to the increments between the benchmark levels of zero, three, and ten. In this example, the percentage increment technique will be utilized to determine the scores for the sub-criteria rework, design cost, design manhours, document release, intermediate release, and occupancy. The sub-criteria scores for drawing revisions, revised drawings, specification revisions, field engineering, and maintenance manhours will be determined using the numerical increment method. Subjectively rated sub-criteria scales are equal to their scores.

In order to determine the performance index for each of the evaluation criteria on the master matrix the sub-matricies must first be completed. The performance scores, representing the averages of the data collected during the study, are entered in the row labeled performance immediately below the sub-criteria headings. The score closest to these values in the sub-matrix body are circled and recorded in the row marked "score" at the bottom of the matrix form. Scores are multiplied by their corresponding weights, and the results entered in the row labeled "value". The values for each sub-criteria are added to yield the "performance index".

The sub-criteria performance indicies are transferred to the master matrix form and recorded under the appropriate criteria heading in the row marked "performance".

The score that is equal to or less than the performance score is circled in the body of the matrix and entered at the bottom of the matrix in the row labeled "score". These scores are multiplied by their corresponding weights and the results are recorded in the "value" row. The values are added together to produce the overall "performance index".

5.2 Matricies Analysis

The completed sub-criteria evaluation matricies and the master matrix for the example are presented in Figures 5.1 through 5.8. Each will be discussed in the following paragraphs.

The sub-matrix for Accuracy of the Design Documents is shown in Figure 5.1. Accuracy of the Design Documents was ranked as the second most important criterion. Based on the data utilized for this example, the sub-matrix has a performance index of 465. While this index is above average, the majority of its value comes from two sub-criteria, rework, and revised specifications. Thus,

attention should be directed to the sub-criteria revised drawings, drawing revisions, and specification revisions. Each of these sub-criteria have extremely low scores, with the sub-criteria, revised drawings, contributing zero points to the index.

Figure 5.2 is the Usability of the Design Documents Sub-Matrix. With a performance index of 240, this sub-matrix is considered below average (300). Two of the six sub-criteria were rated average, and one, number of drawings, was rated above average. However, the most important sub-criterion, completeness of the design documents, received the lowest actual score. This tends to reemphasize the problems identified in the Accuracy of the Design Documents Sub-Matrix concerning the number of drawings and specification revisions, and the number of revised drawings. Another interesting observation in this sub-matrix concerns the scores associated with those sub-criteria which were rated subjectively. In previous research, subjectively rated criteria consistently received scores higher than quantitatively rated sub-criteria. This trend was not encountered during this investigation.

The Cost of the Design Effort Sub-Matrix is shown in Figure 5.3. The cost of the design effort was given the second lowest priority by industry personnel. With a combined score of 100, it has the second lowest performance index.

Constructability was ranked as the most important design evaluation criterion. The Constructability Sub-Matrix is presented in Figure 5.4. As the most important criterion, the sub-matrix's performance index of 180, well below average, should be of major concern. The most important sub-criteria, unrealistic tolerances versus quality expectations, has tied for the lowest score. Though this study was limited in the number of projects investigated, this particular sub-matrix illustrates the importance and potential of constructability programs.

Figure 5.5 is the Economy of Design Sub-Matrix. One interesting aspect of this sub-matrix is the low score of the layout sub-criteria. As mentioned earlier, no responses were received from design firms. The performance index of 345 is slightly above average.

Figure 5.6 presents the Performance Against Schedule Sub-Matrix. All contributors to the study were unhappy with the schedule performance of the design documents. Comments form one constructor indicated that each time a scheduled release or intermediate release date was missed, it was simply rescheduled as if nothing had happened. The performance index of 0 is the lowest of any sub-matrix.

The Ease of Occupancy / Start-up Sub-Matrix is presented in Figure 5.7. This criterion was assigned the lowest weight by industry evaluators. The performance index for this sub-matrix was 495, slightly above average. Owners generally were able to occupy their projects on or slightly ahead of schedule, but required extra personnel to prepare the facilities.

Figure 5.8, The Design Evaluation Matrix, presents a completed master matrix based on the values (performance indicies) obtained from the sub-matricies. The overall performance index for this example is 200, below average. While a below average index is disappointing, the example illustrates the usefulness of the method in identifying problem areas. Attention should be directed to those criteria which scored below in their respective sub-matricies, usability of the design documents, cost of the design effort, constructability, and performance against schedule. Additionally, due to the influence of the accuracy of the design documents on these criteria, efforts should be made to improve the performance of this criterion.

Drawing Revisions	Revised Drawings	Specification Revisions	Revised Specifications	Rework			
35	46	40	9	2.3			PERFORMANCE

							SCORE
5	5	5	5	2			10
8	8	8	7.8	2.3			9
11	11	11	11	2.6			8
14	14	14	14	3			7
16	16	16	16	3.3			6
19	19	19	19	3.8			5
22	22	22	22	4.4			4
25	25	25	25	5			3
33	33	33	33	7			2
42	42	42	42	10			1
50	50	50	50	15			0

1	0	1	8	9			SCORE
15	20	15	15	35			WEIGHT
15	0	15	120	315			VALUE

PERFORMANCE INDEX

465

Accuracy of the Design Documents Sub-Matrix

FIGURE 5.1

Number of Drawings	Drawing Size	Cross References	Field Engineering	Clarity	Completeness		
8	2	3	35	3	1		PERFORMANCE

							SCORE
10	10	10	5	10	10		10
9	9	9	9	9	9		9
(8)	8	8	12	8	8		8
7	7	7	16	7	7		7
6	6	6	19	6	6		6
5	5	5	23	5	5		5
4	4	4	26	4	4		4
3	3	(3)	30	(3)	3		3
2	(2)	2	(38)	2	2		2
1	1	1	47	1	(1)		1
0	0	0	55	0	0		0

8	2	3	2	3	1		SCORE
5	10	15	15	25	30		WEIGHT
40	20	45	30	75	30		VALUE

PERFORMANCE INDEX

(240)

Usability of the Design Documents Sub-Matrix

FIGURE 5.2

Design Cost	Design Manhours						
9	116						PERFORMANCE

							SCORE
4	100						10
4.3	103						9
4.7	105						8
5.1	108						7
5.5	111						6
6	114						5
6.5	(117)						4
7	120						3
7.6	126						2
8.3	133						1
(9)	140						0

0	4						SCORE
75	25						WEIGHT
0	100						VALUE

PERFORMANCE INDEX

(100)

Cost of Design Effort Sub-Matrix

FIGURE 5.3

Tolerances	Different Crafts	Compatibility					
1	1	3					PERFORMANCE

10	10	10					10	SCORE
9	9	9					9	
8	8	8					8	
7	7	7					7	
6	6	6					6	
5	5	5					5	
4	4	4					4	
3	3	3					3	
2	2	2					2	
1	1	1					1	
0	0	0					0	

1	1	3					SCORE
50	10	40					WEIGHT
50	10	120					VALUE

PERFORMANCE INDEX

180

Constructability Sub-Matrix

FIGURE 5.4

Layout	Overdesign	Overspecified					
2	3	8					PERFORMANCE

10	10	10					10
9	9	9					9
8	8	(8)					8
7	7	7					7
6	6	6					6
5	5	5					5 SCORE
4	4	4					4
3	(3)	3					3
(2)	2	2					2
1	1	1					1
0	0	0					0

2	3	8					SCORE
55	25	20					WEIGHT
110	75	160					VALUE

PERFORMANCE INDEX
(345)

Economy of Design Sub-Matrix

FIGURE 5.5

Document Release	Intermediate Release						
68	64						PERFORMANCE

							SCORE
100	100						10
97	95						9
94	90						8
91	86						7
88	82						6
85	78						5
83	74						4
80	80						3
75	77						2
70	73						1
65	70						0

0	0						SCORE
55	45						WEIGHT
0	0						VALUE

PERFORMANCE INDEX

0

Performance Against Schedule Sub-Matrix

FIGURE 5.6

Occupancy	Personnel						
92	127						PERFORMANCE

							SCORE
90	90						10
93	93						9
95	97						8
98	100						7
101	104						6
104	107						5
107	111						4
110	115						3
116	118						2
123	125						1
130	130						0

9	0						SCORE
55	45						WEIGHT
495	0						VALUE

PERFORMANCE INDEX

495

Ease of Occupancy / Start-up Sub-Matrix

FIGURE 5.7

ACCURACY	USABILITY	COST	CONSTRUCTABILITY	ECONOMY	SCHEDULE	OCCUPANCY	
465	240	100	180	345	0	495	PERFORMANCE

							SCORE
1000	1000	1000	1000	1000	1000	1000	10
900	900	900	900	900	900	900	9
800	800	800	800	800	800	800	8
700	700	700	700	700	700	700	7
600	600	600	600	600	600	600	6
500	500	500	500	500	500	500	5
400	400	400	400	400	400	400	4
300	300	300	300	300	300	300	3
200	200	200	200	200	200	200	2
100	100	100	100	100	100	100	1
0	0	0	0	0	0	0	0

4	2	1	1	3	0	4	SCORE
20	20	10	20	10	15	5	WEIGHT
80	40	10	20	30	0	20	VALUE

PERFORMANCE INDEX

200

Design Evaluation Matrix

FIGURE 5.8

5.3 Conclusions

Based on this example matrix evaluation, several conclusions can be reached. The data required to evaluate design effectiveness on both commercial building and heavy civil construction projects is readily available. While most people interviewed felt more comfortable with quantitative measurements, no identifiable score inflation occurred due to the use of subjective ratings. The application of the matrix to an entire project is rather simplistic. A more extensive study will be required to determine the actual weights and benchmark values that should be assigned to the various criteria and sub-criteria. Each project should be sub-divided into the major design divisions for a detailed analysis. All users of the design, owners, designers, and constructors need to be included in the collection of data for a realistic database.

Chapter 6

CONCLUSIONS AND RECOMMENDATIONS

This report investigates the feasibility of utilizing a matrix evaluation technique known as the Design Evaluation Matrix, as a method to evaluate the design effectiveness in commercial building and heavy civil construction. The Design Evaluation Matrix, a variation of the Objectives Matrix, has proven to be a flexible and effective method to categorize and weight those factors that have a significant impact on a construction project. This final chapter presents the conclusions of the study and recommendations for future research.

6.1 Conclusions

1. The seven design evaluation criteria identified in the initial phase of the research are applicable to all construction projects regardless of industry segment.

2. The Design Evaluation Matrix can be used during the individual design, construction, and operation phases of a project, or combined for a more simplistic evaluation of an entire project.

3. The list of evaluation criteria should be expanded. This will occur as a by-product of the method's utilization by industry, and feedback being provided to researchers.

4. The data collected for this study was inconclusive (due to the limited data available) for determining the values that should be used by industry for weighting the criteria (sub-criteria) and establishing benchmark values.

6.2 Recommendations

1. An extensive database should be established for each segment of the construction industry, reflecting the views of owners, designers, and constructors.

2. Data collections should be undertaken to establish benchmark values for each major design function (electrical, mechanical, HVAC, et c.).

3. As the method is adopted for use by industry, feedback should be collected to further refine the database.

4. The experiences of companies utilizing the method need to be cataloged in a "lessons learned" format in order to periodically review the guidelines for applying the method.

5. The additional design evaluation criteria and sub-criteria summarized in Figure 6.1 should be considered for future evaluations of commercial building and heavy civil projects.

Additional Criteria and Sub-Criteria

Evaluation Criteria

1. Aesthetics
2. Maintainability
3. Installed systems reliability.
4. Expandability
5. Quality
6. Durability of finishes
7. Safety

Sub-Criteria

Accuracy of the Design Documents

1. The number of drawing clarification memos sent to the designer by the contractor the total number drawings.
2. Number of changes due to misunderstanding of the building code requirements.
3. Number of changes due to errors and omissions and their associated costs.

Usability of the Design Documents

1. The number of requests for information sent to the designer by the contractor.
2. Number of changes due to shop drawing review comments.

Cost of the Design Effort

1. Duration of the design.

Constructability

1. Engagement of the contractor.

Maintainability

1. Accessibility of building utilities / services (e.g. plumbing, HVAC, piping, ducts, controls, etc.) for maintenance and repair.
2. Maintenance manhours budgeted vs. maintenance manhours expended.
3. Actual cost of maintenance vs. budgeted costs.
4. Quality of documentation (as-built drawings).
5. Durability of materials chosen for high traffic areas.

Figure 6.1

APPENDIX 1

INCREMENT FORMULA TECHNIQUE

PERCENT FORMULA TECHNIQUE

SUBJECTIVE RATIO TECHNIQUE

A1.1 Numerical Increment Technique

The following formula can be utilized to determine the numerical increment between benchmark levels:

Numerical Increment Formula

$(X - Y) / Z = I$

X - represents the larger benchmark score ratio

Y - represents the smaller benchmark score ratio

Z - represents the number of increments between the benchmark scores, either 7 (between levels three and ten) or 3 (between levels zero and three).

I - represents the numerical ratio increment between two consecutive levels going from Y to X.

A1.2 Percentage Increment Technique

The following formula can be utilized to determine the percentage increment between benchmark levels:

Percentage Increment Formula

$(Y / X)^{1/z} = K$

X - represents the larger benchmark score ratio

Y - represents the smaller benchmark score ratio

Z - represents the number of increments between the benchmark scores, either 7 (between benchmark levels three and ten) or 3 (between benchmark levels zero and three).

K - represents the percentage decrease of ratios between consecutive levels going from X to Y.

A1.3 Subjective Ratio Technique

This technique involves the use of subjective ratios to assign values to the levels between the benchmark levels. This type of ratio assignment requires personnel knowledgeable with the criteria, objectives, and workers. Concurrence by those being evaluated is desired to ensure the maximum cooperation and understanding of the workforce.

APPENDIX 2

PROJECT REQUEST LETTER

INTERVIEW GUIDE

Project Request Letter

*
*
*
*

Dear :

Enclosed is an explanation of how the Construction Industry Institute is continuing its research on design effectiveness. Phase I of the research developed an evaluation method and established several design performance criteria. Industrial projects were investigated during phase II. In phase III, the researchers wish to explore the applications of the method to commercial building and heavy civil construction. Included with the general explanation of the evaluation method is a copy of the interview guide the researchers will use to gather information from individuals on selected projects.

Please do not let the size of this package trouble you. We are only asking that you fill out a point of contact form at this time.

Your company is being asked to volunteer commercial building and/or heavy civil projects which would provide useful information on the design evaluation criteria and sub-criteria listed below. Optimally, the projects volunteered would allow the researchers to obtain input from the project's owner, designer, and constructor. If your company has already implemented the objectives matrix on a project(s) a point of contact is requested so the researchers can collect information concerning the strengths and weaknesses of the method. For this portion of the research all types of projects are welcome.

Criteria and Sub-Criteria include:

ACCURACY OF THE DESIGN DOCUMENTS
-- Drawing revisions / total number of drawings
-- Revised drawings / total number of drawings
-- Specification revisions / total number of specifications
-- Revised specifications / total number of specifications
-- Manhours of rework / total number of manhours

USABILITY OF THE DESIGN DOCUMENTS
-- Drawing size
-- Number of drawings
-- Number of cross references
-- Field engineering manhours / total engineering manhours
-- Clarity of drawings
-- Completeness of drawings

COST OF DESIGN EFFORT
-- Design cost / construction cost
-- Design manhours expended / design manhours budgeted

CONSTRUCTABILITY
-- Unrealistic tolerances vs. quality expectations
-- Number of crafts
-- Compatibility with current materials and technology

ECONOMY OF DESIGN
-- Building layout efficiency
-- Amount of overdesigned members
-- Amount of overspecified materials

PERFORMANCE AGAINST SCHEDULE
-- Percent of construction document release dates attained
-- Percent of intermediate document release dates attained

EASE OF OCCUPANCY / START-UP
-- Occupancy preparation days required / days budgeted
-- Number of maintenance personnel required / number budgeted

The graduate student conducting the interviews is Michael Peek. If you could pass this package to an appropriate individual on a suitable project, and return the "point of contact" form, Mike will make the next contact.

RESEARCH OFFICE ADDRESS
(512) 471-4648
Michael Peek
Construction Industry Institute
The University of Texas at Austin
3208 Red River Street, Suite 300
Austin, Texas 78705-2650

Home Phone Number
(512) 345-2640

Again we want to emphasize that this package is purely informative, and intended only to give you some insight into what information the research requires. Thank you for your time and assistance.

Sincerely,

DESIGN RESEARCH PROJECT III - OUTPUTS

POINT OF CONTACT FORM

Please provide the following information regarding the project. All data provided, including company identification, will be kept confidential.

Company name: ______________________________

Point of contact: ______________________________

Phone number: ______________________________

Project title & description: ______________________________

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____

____

____

Contact's address: ______________________________

____

____

____

Please return the completed form to:

Michael Peek
Construction Industry Institute
The University of Texas at Austin
3208 Red River Street, Suite 300
Austin, Texas 78705-2650

EVALUATION OF DESIGN EFFECTIVENESS
(DESIGN RESEARCH PROJECT - III)

Purpose of the Study

Problem description

Phases I and II of the "Outputs" research effort have a) adapted the objectives matrix technique as a method for evaluating design effectiveness and b) established guidelines for utilizing the method. Unless this method is implemented on actual construction projects, no benefits will be realized.

Problem scope

The purpose of this research effort is two-fold: (1) to encourage and assist CII member companies in implementing the objectives matrix for evaluating design effectiveness, and (2) to apply the method to additional areas of construction, such as commercial building and heavy civil projects.

Expected product

The expected product of this research effort will include reports to the CII membership on the results of implementing the objectives matrix on actual projects. Included will be an evaluation of the method's strengths and weaknesses, and recommended changes for implementing and using the objectives matrix. Additionally, a report will be prepared on the application of the objectives matrix to other areas of construction, (only piping was studied in phases I & II of the "outputs" research).

THE OBJECTIVES MATRIX

Explanation of the Objectives Matrix

The following is a brief explanation of the Objectives Matrix.

Select the performance criteria

The first step in constructing the matrix is to select the criteria which pertain to the performance goals. This requires the identification of key indicators of performance. These indicators should relate to such factors as quality, production time, ability to meet deadlines, waste, etc. Each of these criterion and how it will be measured should be well defined.

Select performance scores

Each column in the matrix represents one performance criterion. Each row represents a specific level of performance. Performance levels range from a low score of zero, to a high score of ten. A score of three is assumed to be the average in order to provide more room for improvement. Each score corresponds to a value under the criteria, and it is these values which form the performance scale for the criteria. Benchmark scores are designated for performance levels zero, three, and ten.

Level 0 - The lowest level of acceptable performance over a recent period, say of two years, under normal operating conditions.
Level 3 - The current level of performance.
Level 10 - The desired level of performance. This should represent a level of performance that can be realistically obtained in the forseeable future with essentially the same resources available at the present time.

Once these benchmark scores are established, the increments between them are assigned values.

Assignment of weights

Weighting of the performance criteria provides a means of directing management's attention toward those criteria which have the most impact on performance. All the criteria selected do not have an equal impact on overall performance. A total of one hundred points should be distributed among the performance criteria to reflect the contribution of each criterion to the overall performance. One aspect of this study is to consult with industry personnel to determine what weights should be assigned to the chosen criteria.

Calculate the performance index

The final phase ties together the criteria scores and weights to determine the overall performance index. The performance index is calculated by multiplying the score (from zero to ten) corresponding to the measured performance level for each criterion

by its weight, and adding the products. The figure obtained is entered in the box at the bottom right of the matrix, and represents the performance index for a particular evaluation period.

Objectives Matrix example

An example of an objectives matrix is attached as an exhibit.

Evaluation criteria and sub-criteria

In addition to adapting the objectives matrix for use in the construction industry, phase I established seven performance criteria applicable to all types of construction projects. Sub-criteria were then developed for each criterion.

Accuracy of the Design Documents (Accuracy)
-- Drawing revisions / total number of drawings (Drawing Revisions)
-- Revised drawings / total number of drawings (Revised Drawings)
-- Specification revisions / total number of specifications (Specification Revisions)
-- Revised specifications / total number of specifications (Revised Specifications)
-- Manhours of rework / total number of manhours (Rework)

Usability of the Design Documents (Usability)
-- Drawing size (Drawing Size)
-- Number of drawings (Number of Drawings)
-- Number of cross references between drawings and specifications (Cross References)
-- Field engineering manhours / total engineering manhours (Field Engineering)
-- Clarity of drawings (Clarity)
-- Completeness of drawings (Completeness)

Cost of the Design Effort (Cost)
-- Design cost / construction cost (Design Cost)
-- Design manhours expended / design manhours budgeted (Design Manhours)

Constructability (Constructability)
-- Unrealistic tolerances vs. quality expectations (Tolerances)
-- Number of crafts (Different Crafts)
-- Compatibility with current materials and technology (Materials and Technology)

Economy of Design (Economy)
-- Building layout efficiency (Layout)
-- Amount of overdesigned members (Oversized Members)
-- Amount of overspecified materials (Overspecified Materials)

Performance Against Schedule (Schedule)
-- Percent of construction document release dates attained (Document Release)
-- Percent of intermediate release dates attained (Intermediate release)

Ease of Occupancy / Start-up (Occupancy)
-- Occupancy preparation days required / days budgeted (Occupancy Days)
-- Number of maintenance personnel required / number budgeted (Maintenance Personnel)

Sub-Criteria Definitions

Accuracy: Relates to the two most common design documents, drawings and specifications.

Drawings and Specifications: Refers to all drawings and specifications that are necessary to construct the project.

Revision: Is defined as a change in a drawing or specification that occurs after construction of the project has begun. Revisions that occur during the design phase or bid phase will not be counted.

Manhours: Refers to all manhours required for the construction phase of the project.

Rework: Is defined as a change made to a finished piece, or a portion a finished piece of construction. It can also be any additional work performed, but not stipulated on the design documents. Rework may be repeated on the same item on more than one occasion. Rework occurring only because of design document changes, errors or omissions will be counted here. Rework due to an error in a drawing, a change to a drawing or a late drawing will be included here. Rework due to a misinterpretation of, or conflict with, the design documents will be counted. Rework due to worker error will not be counted.

Usability: Is best reflected by the content and format of the design documents and the engineering work required at the construction site.

Drawing Size: This element is rated on a scale of zero to ten, and should be given a high rating when the physical size, scale, and clarity of the drawings were right for the work being performed. A low score should be given if the drawing size and scale makes them difficult to read.

Cross References: This item is rated on a scale of zero to ten. If the design documents contain an appropriate amount of cross references, that is if all necessary referencing between drawings, specifications, and drawings and specifications are included, then a high score should be awarded.

Clarity: Is rated on a scale of zero to ten. This item deals with how well the drawing explains what is to be done. If what is to be done is unclear, then a low score should be awarded. A drawing that leaves no room for misinterpretation should be given a ten. A drawing that could easily mean several different things should be given a zero.

Completeness: This item measures on a scale of zero to ten, how well the drawings address what is to be done. If the drawing omits several important details, it should be given a zero. A drawing that contains all the information necessary to perform the work should be given a rating of ten.

Cost: Cost refers only to those costs necessary to perform the construction phase of the project. The total cost of the construction phase includes the cost of the design, equipment rental, installation, materials, and labor.

Engineering Manhours: Manhours spent on actual design.

Constructability: Is defined as the optimum use of construction knowledge and experience in the planning, engineering, procurement, and field operations to achieve the overall project objectives.

Unrealistic Tolerances: This item is rated on a scale of zero to ten, and relates to any tolerance that is either unachievable or much too strict for the purpose. Tolerances are given a low rating if they are not strict enough to meet the level of quality expected for the type of work.

Crafts: Is rated on a scale of zero to ten, and refers to the number of different crafts required for the construction of the project.

Current Materials and Technology: Is rated on a scale of zero to ten, and includes the use of items or methods that are out of date or inefficient.

Building Layout Efficiency: This item is rated on a scale of zero to ten, and refers to how well the building layout is in relation to its function. It takes into account such items as placement of stairways, elevators, mechanical rooms etc.

Overspecified Materials: Is rated on a scale of zero to ten, and includes those materials whose properties are more than adequate for their intended use.

Overdesigned Members: Is rated on a scale of zero to ten, and refers to the number of structural members that are much larger than their intended load requires.

Design Document Release Deadlines: These dates are stipulated in the original schedule and include dates on which information, drawings, and specifications are to be made available to the constructor.

Intermediate Release Dates: These dates area deadlines for which drawings and specifications must be available for procurement, permits, or other owner or designer provided items that pertain to the project.

INTERVIEW GUIDE
FOR
DESIGN EFFECTIVENESS
DESIGN RESEARCH PROJECT III - OUTPUTS

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PROJECT DESCRIPTION SHEET

1. What type of project is this?

2. How long were the durations of the design and construction phases of this project?
DESIGN _______________ CONSTRUCTION _______________

3. What type of contracts were used for the design and construction phases of this project?
DESIGN _______________ CONSTRUCTION _______________

4. In what locations were the construction and design phases of this project performed?
DESIGN _______________ CONSTRUCTION _______________

5. What company did the design phase of this project?
DESIGNER ___________________________________

6. What company did the construction phase of this project?
CONSTRUCTOR _______________________________

7. What company was the owner of the finished product? How would you rate the communications between the owner, the designer, and the construction companies?
OWNER ____
Communications __________ OK __________ Problem

8. Were union or non-union workers involved in the construction of the project?

9. Was there any overlap between the design and construction of the project? If so, how long?
Overlap __________ Yes __________ No
Duration ___________ (months)

10. On a scale of one to ten, how would you arbitrarily rate the drawings and specifications used on the project?

11. What was the total cost of this project?
$ ______________________

12. What other criteria or sub-criteria would you add to the list of criteria and sub-criteria discussed in the explanation of the objectives matrix, (as a measurement of the design outputs)? What weight would you assign these criteria?

13. What existing information does your company track that could be incorporated into a matrix of this type?

ACCURACY OF THE DESIGN DOCUMENTS

1. Total number of drawings on this project.
   ____________ drawings

2. Total number of revisions to the drawings on this project.
   ____________ drawing revisions

3. Total number of revised drawings on this project.
   ____________ revised drawings

4. Total number of specifications on this project.
   ____________ specifications

5. Total number of revisions to the specifications on this project.
   ____________ specification revisions

6. Total number of revised specifications on this project.
   ____________ revised specifications

7. Total number of construction manhours on this project.
   ____________ manhours

8. Total number of construction manhours due to rework on this project.
   ____________ manhours

USABILITY OF DESIGN DOCUMENTS

1. Rating for drawing size for this project (use a scale of zero to ten, three is average).

2. Rating of the number of drawings on this project necessary for crew use (use a scale of zero to ten, three is average).

3. Rating of number of cross references between design documents on this project (use a scale of zero to ten, three is average).

4. Number of field engineering manhours required for this project.
   ____________ manhours

5. Total number of design and field engineering manhours required for this project.
   ____________ manhours

6. Rating of clarity of design documents for this project (use a scale of zero to ten, three is average).

7. Rating of completeness of drawings for this project (use a scale of zero to ten, three is average).

COST OF DESIGN EFFORT

1. Total budgeted manhours for the design of this project.
   ___________ manhours

2. Total expended manhours for the design of this project.
   ___________ manhours

3. Total design cost for this project.
   $ ___________________

4. Total construction cost for this project.
   $ ___________________

CONSTRUCTABILITY

1. Rating for number of different crafts required to complete this project (use a scale of zero to ten, three is average).

2. Rating for the number of unrealistic tolerances versus the quality expectations in the design documents for this project (use a scale of zero to ten, three is average).

3. Rating for level of compatibility of the design of this project with current materials and technology (use a scale of zero to ten, three is average).

ECONOMY OF DESIGN

1. Rating for the amount of overdesigned members in this project (use a scale of zero to ten, three is average).

2. Rating for the amount of overspecified materials in this project (use a scale of zero to ten, three is average).

3. Rating for the level of efficiency in building layout (or project layout for heavy civil projects) for this project (use a scale of zero to ten, three is average).

PERFORMANCE AGAINST SCHEDULE

1. Total number of scheduled release dates for the design documents of this project.
   ____________ scheduled release dates

2. Total number of the design documents released on the scheduled release dates.
   ____________ release dates met

3. Total number of intermediate scheduled release dates for the design documents of this project.
   ____________ intermediate release dates

4. Total number of intermediate scheduled release dates met as per the scheduled dates.
   ____________ release dates met

EASE OF OCCUPANCY / START-UP

1. Total number of days required to prepare for occupancy / use after construction was completed.
   ____________ days

2. Total number of days budgeted to prepare for occupancy / use.
   ____________ days

3. Total number of maintenance personnel manhours required to prepare for occupancy / use of the building / structure.
   ____________ manhours

4. Total number of maintenance personnel manhours budgeted to prepare for occupancy / use of the building / structure.
   ____________ manhours

WEIGHT ESTIMATES FOR CRITERIA AND SUB-CRITERIA

EVALUATION OF DESIGN CRITERIA

RANK		WEIGHT
_____	Accuracy of the design documents	_____
_____	Usability of the design documents	_____
_____	Cost of design effort	_____
_____	Constructability	_____
_____	Economy of design	_____
_____	Performance against schedule	_____
_____	Ease of occupancy / start-up	_____
	SUM =	100

EVALUATION OF DESIGN SUB-CRITERIA

RANK		WEIGHT
	ACCURACY OF THE DESIGN DOCUMENTS	
_____	Drawing revisions / total number of drawings	_____
_____	Revised drawings / total number of drawings	_____
_____	Specification revisions / total number of specifications	_____
_____	Specifications revised / total number of specifications	_____
_____	Manhours of rework / total number of manhours	_____
	SUM =	100
	USABILITY OF THE DESIGN DOCUMENTS	
_____	Drawing size	_____

RANK		WEIGHT
	<u>USABILITY</u> (continued)	
_____	Number of drawings	_____
_____	Number of cross references	_____
_____	Field engineering manhours / total engineering manhours	_____
_____	Clarity	_____
_____	Completeness of drawings	_____
	SUM =	100
	<u>COST OF DESIGN EFFORT</u>	
_____	Design cost / construction cost	_____
_____	Design manhours expended / design manhours budgeted	_____
	SUM =	100
	<u>CONSTRUCTABILITY</u>	
_____	Unrealistic tolerances vs. quality expectations	_____
_____	Number of crafts	_____
_____	Compatibility with current materials and technology	_____
	SUM =	100
	<u>ECONOMY OF DESIGN</u>	
_____	Building layout efficiency	_____
_____	Amount of overdesigned members	_____
_____	Amount of overspecified materials	_____
	SUM =	100

RANK		WEIGHT
	PERFORMANCE AGAINST SCHEDULE	
_____	Percent of construction document release dates attained	_____
_____	Percent of intermediate release dates attained	_____
	SUM =	100
	EASE OF OCCUPANCY / START-UP	
_____	Occupancy preparation days required / days budgeted	_____
_____	Number of maintenance personnel required / number budgeted	_____
	SUM =	100

ESTIMATES OF INDUSTRY AVERAGES
FOR EVALUATION CRITERIA

10 - Optimal   3 - Current performance   0 - Minimum acceptable

ACCURACY OF THE DESIGN DOCUMENTS

Drawing revisions / total number of drawings

10. --   3.--   0.--

Revised drawings / total number of drawings

10.--   3.--   0.--

Specification revisions / total number of specifications

10.--   3.--   0.--

Revised specifications / total number of specifications

10.--   3.--   0.--

Manhours for rework / total number of construction manhours

10.--   3.--   0.--

USABILITY OF THE DESIGN DOCUMENTS

Field engineering manhours / total engineering manhours

10.--   3.--   0.--

COST OF DESIGN EFFORT

Design cost / construction cost

10.--   3.--   0.--

Design manhours expended / design manhours budgeted

10.--   3.--   0.--

PERFORMANCE AGAINST SCHEDULE

Percent of construction document release dates attained

10.-- 3.-- 0.--

Percent of intermediate release dates attained

10.-- 3.-- 0.--

EASE OF OCCUPANCY / START-UP

Occupancy / start-up preparation time required / preparation time budgeted

10.-- 3.-- 0.--

Number of maintenance personnel required / number budgeted

10.-- 3.-- 0.--

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VITA

Michael Anthony Peek was born in McAllen, Texas, on January 31, 1958, the son of Max Harry Peek and Viola Flores Peek. Upon graduation from Incirlik High School, Incirlik Air Force Base, Adana, Turkey, in 1976, he entered Wright State University, Dayton, Ohio. Michael transferred to Texas A&M University in 1977, and graduated with a Bachelor of Science in Industrial Engineering in 1980.

After graduation, he received a commission as an Ensign in the United States Navy, Civil Engineer Corps. Michael's career in the Navy has included assignments with the U.S. Navy Support Facility, Diego Garcia, British Indian Ocean Territory, the U.S. Navy Support Office, La Maddalena, Sardinia, Italy, and Naval Mobile Construction Battalion SIXTY TWO. Michael has been awarded the Navy Commendation Medal and the Navy Achievement Medal, and presently holds the rank of Lieutenant.

Selected for the Navy's Postgraduate Education Program in 1983, Michael entered the Graduate School of the University of Texas at Austin in June 1986.

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