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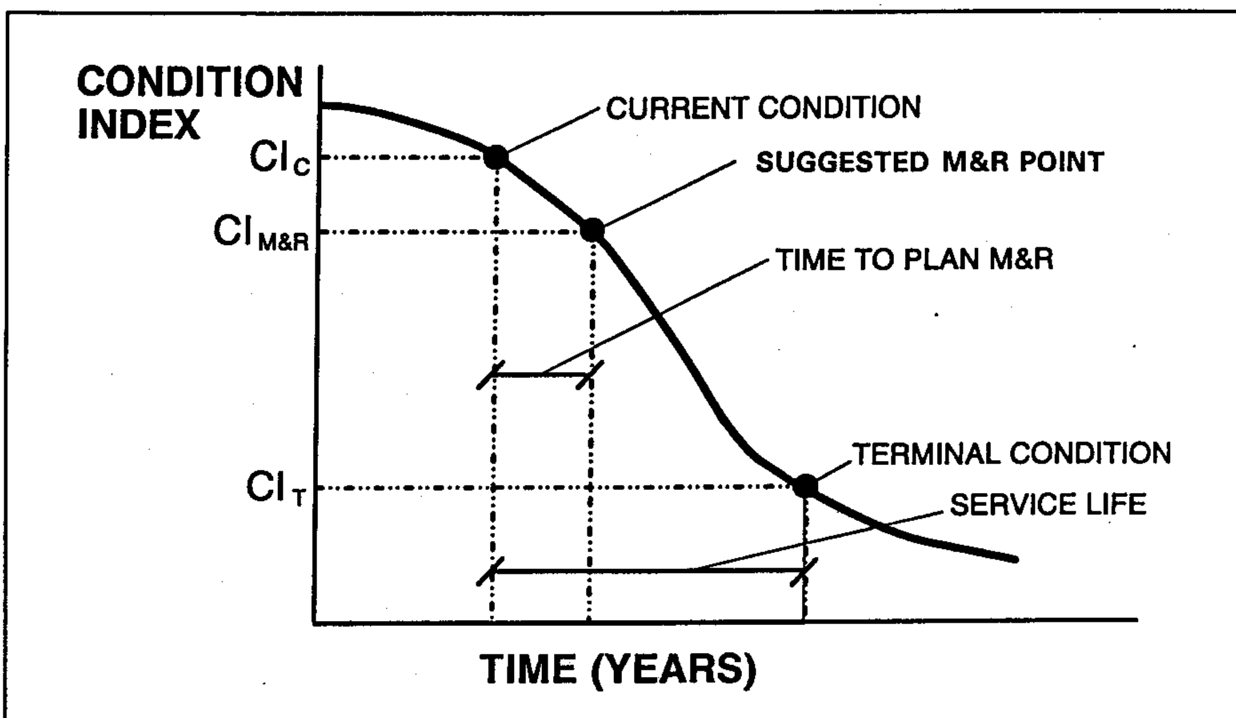
Development of Condition Indexes for Building Exteriors

by
D.R. Uzarski, Philip A. Weightman, Samuel L. Hunter, and Donald E. Brotherson



The Army's significant annual investment (about $1.1 billion) in building maintenance and repair (M&R) dictates that facility managers use some simple, practical condition assessment method to identify and prioritize maintenance requirements for all buildings. The U.S. Army Construction Engineering Research Laboratories (USACERL) is developing the BUILDER Engineered Management System (EMS), a microcomputer-based decision support system specifically designed to standardize and add structure to the maintenance management of military buildings, but also generally applicable to all public and private buildings. BUILDER will use an objective, repeatable condition assessment method—in the form of condition indexes—to help facility managers: (1) assess current conditions, (2) predict future conditions, (3) establish deterioration rates, (4) determine and prioritize current and long range M&R needs, (5) formulate budgets, and (6) measure the effectiveness of M&R. BUILDER will require condition indexes for all the component/material combinations that comprise the many diverse building systems. This study developed a methodology to derive the needed condition indexes for exterior closure systems.

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Foreword

This study was conducted for Northern Division, Naval Facilities Engineering Command (NORTHNAVFACENGCOM) and Assistant Chief of Engineers, Office of the Chief of Engineers (OCE) under Project 4A162720A896, "Environmental Quality Technology"; Work Unit CN4, "Builder Engineered Management System." The Navy technical monitor was Richard Caldwell, NORTHNAVFACENGCOM and the Corps technical monitors were Chester Kirk, Bryan Nix, and David Williams, CECPW-FB-P.

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COL James T. Scott is Commander and Acting Director of USACERL, and Dr. Michael J. O'Connor is Technical Director.

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Background

The U.S. Navy and U.S. Army together own over 300,000 buildings (NAVFAC P319, 1993 and FEH Annual Summary of Operations Report, 1993), all of which undergo normal cycles of deterioration from use and climatic factors. The Army alone devotes approximately 55 percent of its annual installation real property maintenance funds (about $1.1 billion) to building maintenance and repair (M&R) in an effort to rectify that deterioration. This significant maintenance investment dictates that facility managers should use a simple, practical condition assessment method to identify and prioritize maintenance requirements for all buildings, regardless of their primary use, whether for operations, support, recreation, or housing.

The U.S. Army Construction Engineering Research Laboratories (USACERL) is developing the BUILDER Engineered Management System (EMS), a microcomputer-based decision support system specifically designed to standardize and add structure to the maintenance management of military buildings, but also generally applicable to all public and private buildings (Uzarski, Lawson, Shahin, and Brotherson 1990). The BUILDER EMS will use an objective, repeatable condition assessment method—in the form of *condition indexes*—to consistently help facility managers to:

- assess current conditions
- predict future conditions
- establish deterioration rates
- determine and prioritize current and long range M&R needs
- formulate budgets
- measure the effectiveness of M&R.

BUILDER will require condition indexes for all the component/material combinations that comprise the many diverse building systems. For example, one of the 12 systems identified for use in BUILDER is "exterior closure," which includes walls, doors, windows, etc., each of which may be constructed from a variety of materials. This study focuses on developing a simple, consistent method to derive the needed condition indexes for construction materials and components.

Objective

The overall objective of this research is to develop unbiased, repeatable condition indexes for the many components comprising the exterior closure system. The specific objective of this initial part of the research was to develop a single underlying method to develop condition indexes for a variety of exterior closure system components.

Approach

Inspection and condition assessment practices were surveyed to outline the state-of-the-art in building exterior condition evaluation and facility management (Chapter 2). The concept for the development of an exterior component condition index was independently developed, and exterior components needing indexes were selected (Chapter 3). A subjective rating panel approach was devised to develop exterior indexes (Chapter 4). This procedure was applied to develop the condition indexes (Chapter 5). An alternative to the relatively time-consuming panel approach to index development was explored (Chapter 6), and conclusions and recommendations were drawn to further the development of a complete body of condition indexes for use with the BUILDER EMS (Chapter 7).

Scope

This report presents the methodology being used to develop condition indexes for a variety of exterior closure system components. Separate indexes will be developed for individual component/material combinations, which will be compiled later into an overall exterior closure condition index.

The development of the exterior closure component condition indexes generally follows the concepts used to develop the pavement condition index (PCI) (Shahin, Darter, and Kohn 1976; Shahin and Kohn 1979), the roofing membrane condition index (MCI), and the roofing flashing condition index (FCI) (Shahin, Bailey, and Brotherson 1987), presently in widespread acceptance and use. Condition indexes for clay brick masonry walls (Weightman, Uzarski, and Hunter 1994) and concrete masonry walls (Wittleder, Uzarski, and Hunter 1994) have been developed using the procedures described in this report. A model for compiling these indexes into an overall exterior closure condition index is forthcoming.

Mode of Technology Transfer

The condition indexes will be incorporated into the BUILDER EMS microcomputer software and will be distributed and supported through a BUILDER program support center (to be established). It is anticipated that users will be able to obtain BUILDER from the support center on request for a fee. Training on the indexes will be done in conjunction with a planned BUILDER EMS short course.

It is also anticipated that this condition index method will be documented in an Army technical manual (TM) describing building M&R management. Further promotion of index use may be achieved through articles and papers in trade journals and other industry print media.

Metric Conversion Factors

U.S. standard units of measure are used in this report. A table of metric conversion factors can be found below.

1 ft	=	0.305 m
1 in.	=	2.54 cm
1 mile	=	1.61 km
1 ton	=	1016 kg

2 Current Inspection and Condition Assessment Practices

Condition assessment implies an inspection process to gather essential information on which to base the assessment. Any method developed for condition assessment must take into account the type and amount of inspection information gathered and the method used for that gathering. Thus, the inspection process itself must contribute to the assessment purpose and method.

Building Inspection Categories

Different types of inspections have different purposes that imply different levels of effort. Inspection of building systems generally falls into either: facility-level or project-level inspections. Facility-level building inspections are done on a frequency determined by a building's use and condition. These inspections generally do not result in the collection of large amounts of data, but instead focus on collection of data to identify when and where building maintenance management must occur, and how much it will cost. Such inspections are meant to give managers a general overview of the condition of the facility and to help them develop a plan for a practical M&R program.

Project-level inspections are those necessary to definitize projects within the plan. They may range from relatively small projects to be done by in-house personnel to major capital investment projects done by outside contractors. Inspection frequency varies, but project-level inspections will generally be less frequent than facility-level inspections. Project-level inspections may be performed alone, or in conjunction with facility-level inspections. The level of detail in project-level inspections must always be sufficient to finalize projects and quantify work needs.

Inspection Approaches

Presently, the inspection approaches leading to condition assessment for building exterior closure systems are visually based and consist of identifying deficiencies and developing needs lists. Regular inspections are the exception rather than the rule.

Inspections are often done only when immediate action is needed to restore the integrity or utility of the system or component. This overall approach is inherently subjective and leads to reactive rather than proactive M&R programs.

Condition Assessment Methods

A number of inspection-based methods for assessing conditions have been or are being used. The Association of Higher Education Facilities Officers (Kaiser 1993), the National Association of College and University Business Officers (Rush 1991), and the American Public Works Association (Melvin 1992) are among organizations that promote systematic inspection of facilities to identify deficiencies and develop needs lists. These include condition codes, condition ratings based on repair costs, and various quality indexes. None of these systems are considered industry standards and none provide the prediction tools required for the BUILDER.

Building Engineered Management System (BUILDER)

BUILDER consists of field-tested component identification, inventory, inspection information collection procedures, and software for data analysis. Essential to BUILDER implementation and use is the identification of logical management units. Each management unit consists of a major component in a building divided by material and age, if required. Table 1 lists the major components for the exterior closure system.

The BUILDER approach to building management makes extensive use of the management unit concept. In part, each of these is rated to form the basis for work planning and budgeting. BUILDER presently uses condition indexes for assessing condition.

Table 1. Exterior closure major components.

Appurtenances
Chimneys
Doors
Finishes
Insulation
Ornaments
Walls
Windows

BUILDER is designed to permit the user to manage buildings individually or in groups at both facility and project management levels (Uzarski, Lawson, Shahin, and Brotherson 1990). Only through the introduction of condition indexes developed using inspection procedures can these activities be fulfilled. The following discussion briefly explains how condition indexes will be used for building management.

Facility-Level Management

Facility-level management encompasses all or selected components of discrete *facilities* such as buildings, and concerns itself with *what, where, and when* M&R should be performed and *how much* it will cost. The goal is to identify candidate components from a single or a group of buildings that are projected to need M&R within a specified future year (e.g., 5-year) planning horizon. The building components become candidates based, in large part, on when their projected condition drops below an established condition threshold (Figure 1). These candidates will be combined, as necessary, into project groups, which are then prioritized and become tagged for accomplishment or deferral in a given year at a given estimated cost. Costs may be estimated from a correlation of condition level with cost and, in some cases, a generalized knowledge of distress cause. Budgets are then formulated based on projected needs. Depending on the organization, this long-range planning process can be used to effectively allocate available budget funds or to actually plan realistic and defendable budgets.

Facility-level management with BUILDER will permit "what if" analyses. For example, the costs (budgets) associated with establishing a minimum acceptable condition index at various target levels could be computed. The effects of deferred maintenance or budget cuts, in terms of index value reduction, could also be determined.

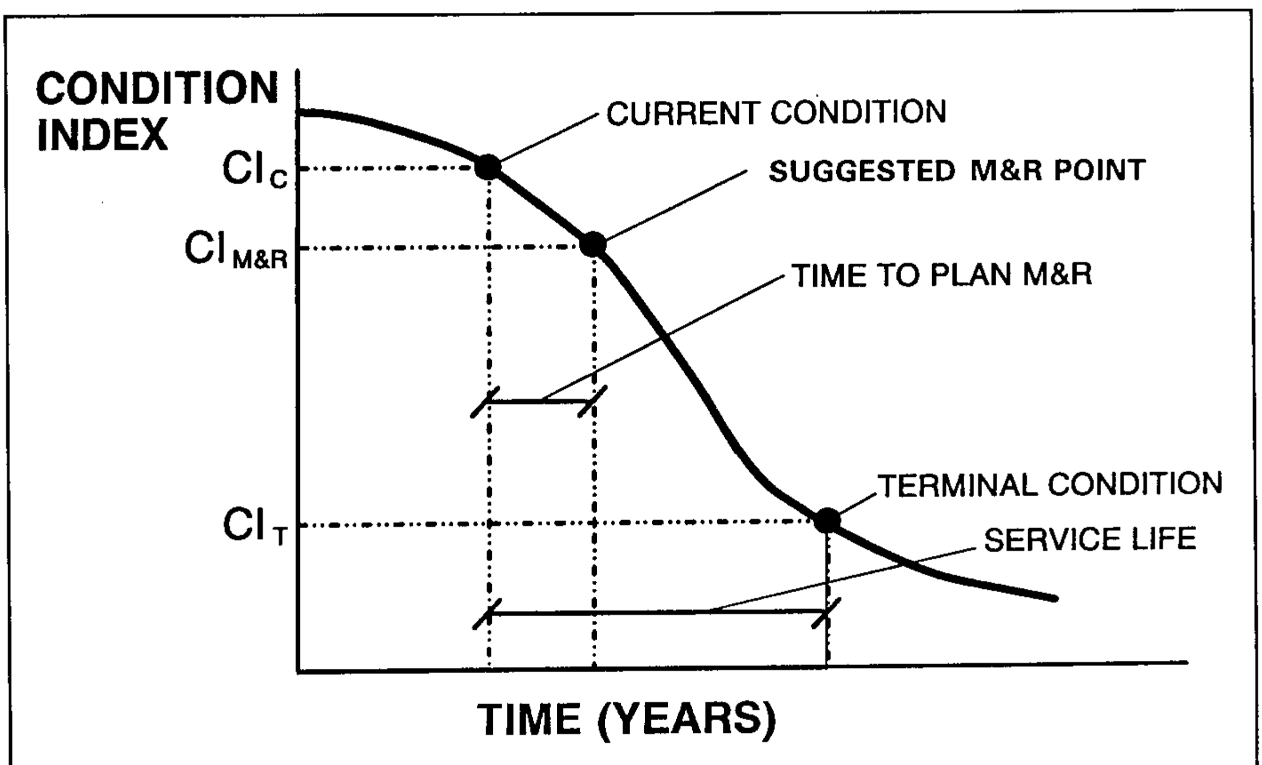

Figure 1. Facility component performance curve.

Periodic inspection information will be needed to make facility-level management successful. As part of the condition indexes development, a predominately visual inspection procedure called a "condition survey inspection" must be conducive to index computation.

Project-Level Management

Project-level management is only performed on specific major building components scheduled for M&R in the next annual work plan. This level focuses on problem diagnosis, cost analyses, and selection of the most appropriate M&R alternative. This is the *how best* phase of building management. The index flags the need for project-level efforts, but a detailed condition evaluation to supplement the condition index approach is needed for the diagnosis. Engineering diagnostic procedures exist for many components and material types.

In general, the development of condition indexes based on inspection procedures that are easily implemented will permit a full range of facility-level management activities. They will also help guide where project-level management activities should be concentrated, thereby enhancing the capabilities of the BUILDER EMS.

3 Exterior Closure Condition Index (ECCI) Concept

Condition Index Scale

USACERL has developed a number of condition indexes for different types of facilities over the past few years: the Pavement Condition Index (PCI) for airfield and road and street pavements (Shahin, Darter, and Kohn 1976 and Shahin and Kohn 1979); the Roof Condition Index (RCI) for built-up roofs (Shahin, Bailey, and Brotherson 1987); the Corrosion Status Index (CSI) of certain piping systems (Kumar, Riggs, and Blyth 1986); and railroad Track Structure Condition Index (Uzarski July 1993). USACERL is also developing a family of condition indexes for different types of civil works structures (Koehn and Kao 1986).

The USACERL developed condition indexes are designed to provide an objective and quantitative means for facility condition assessment, and a common language and interpretation among users. The scales used in all of the USACERL developed indexes range from zero to 100 and are divided into seven condition intervals (Figure 2), most based on identifying observable distresses. From an M&R perspective, the USACERL-developed indexes serve to measure the overall health of the facility and correlate to M&R needs and required budget levels (Shahin, Darter, and Kohn 1977a, Shahin, Darter, and Kohn 1977b, Reichelt, et al. 1987, and Bailey, et al. 1989). The indexes can also be used to historically map the facility condition over time (Figure 3) to help determine rates of deterioration. When combined with facility degradation models, the indexes can be used to predict future conditions (Kumar, Briggs, and Blyth 1986, Bailey, et al. 1989, Shahin 1994, and Uzarski July 1993). Knowledge of past, current, and projected conditions and deterioration rates can help facility managers establish a foundation for developing M&R strategies, budgets, and work plans.

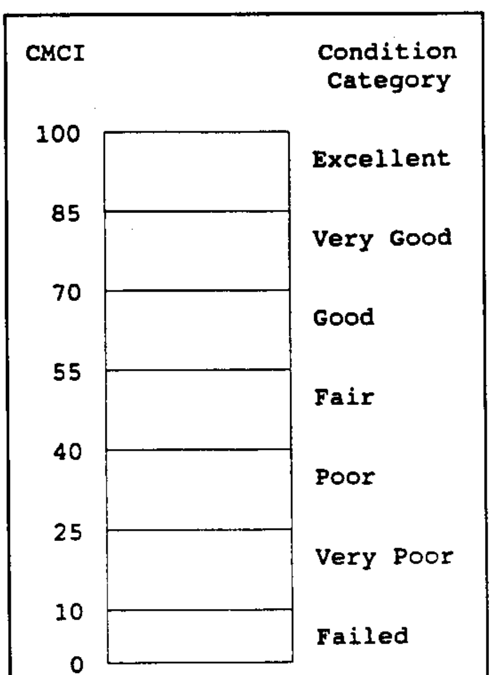

Figure 2. Condition index scale.

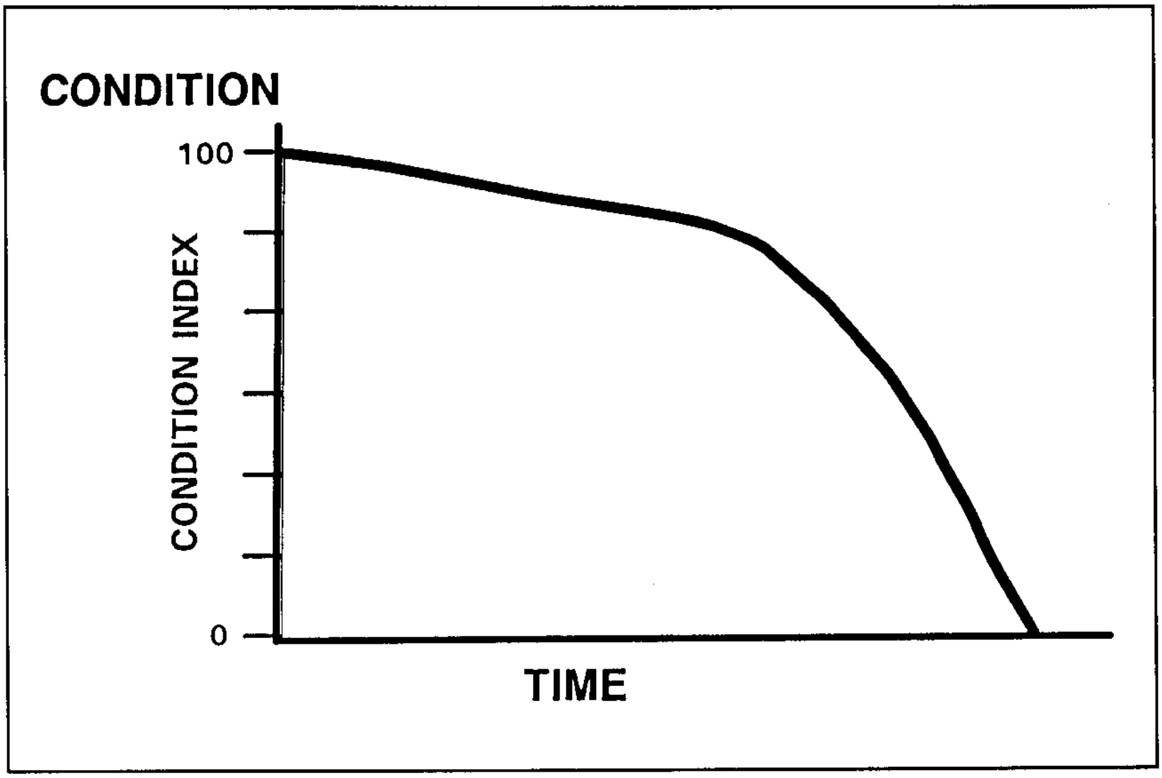

Figure 3. Condition index over time.

An identical zero-to-100 scale is used for evaluating buildings including the exterior closure components. Since within the military the building condition indexes will be used in conjunction with other USACERL-developed facility condition indexes, a similar scale may help the ECCI (and other building condition indexes) gain acceptance and usage. However, although the index scales may be the same for different facilities, the development method and index computational procedure are left to the discretion of the researchers based on what they believe is best.

Exterior Closure Components

A building's exterior closure consists of many different components. The initial listing of major components (Table 1) may need to be expanded (Kaiser 1993, Harris 1975).

Components Selection

The first challenge of ECCI development was to decide the specific components to consider. The various exterior closure components can be distinguished by their function, deterioration mode and cause, and required M&R actions. Because of these differences, a single condition index for building exteriors would not be adequate because no single number would indicate exactly where (in which components) the

M&R problems occurred. Problems could be in the walls, doors, a different component, or a combination of components. Thus, it would be difficult, if not impossible, to correlate the ECCI directly to M&R needs and budgets. Different indexes for the various components are needed as part of the overall ECCI development if accurate and meaningful condition representations are to be made.

Material Considerations

Additionally, a very significant factor to consider in building management is material. Each of the major components could be constructed from a variety of material types. These different materials may exist in different buildings or in the same building. For example, a simple building with four exterior walls may have three constructed of concrete masonry units (CMU) and one of clay brick masonry. This same building could have an addition constructed later of wood cladding. Unfortunately, these different materials degrade at different rates and by different causes. Also, M&R budgets are strongly influenced by material. So, material, as well as component type, must be included in the development of the component condition indexes. These individual component/material CIs will be combined, mathematically, into the ECCI.

Facility Sections

Since component/material combinations form the basis for condition index development, they will also form the basis for establishing "facility sections" (one per major component/material combination) that are the management units for decisionmaking purposes. As a practical matter, age is also used to divide facility sections (here abbreviated simply to "sections") of the same component/material combination. This will allow for deterioration rate computation and facilitate the development and use of condition prediction models. So, each component/material/age combination will result in a section that has a condition index (CI) value derived from a procedure based on the unique component/material combinations. Examples include the clay Brick Masonry Condition Index (BMCI) (Weightman, Uzarski, and Hunter 1994) and the Concrete Masonry Condition Index (CMCI) (Wittleder, Uzarski, and Hunter 1994).

Figure 4 shows a sample exterior closure system divided into sections. The walls, doors, and windows make up the components, each consisting of different materials. Walls are masonry or metal, doors are wood or metal, and window frames are of wood.

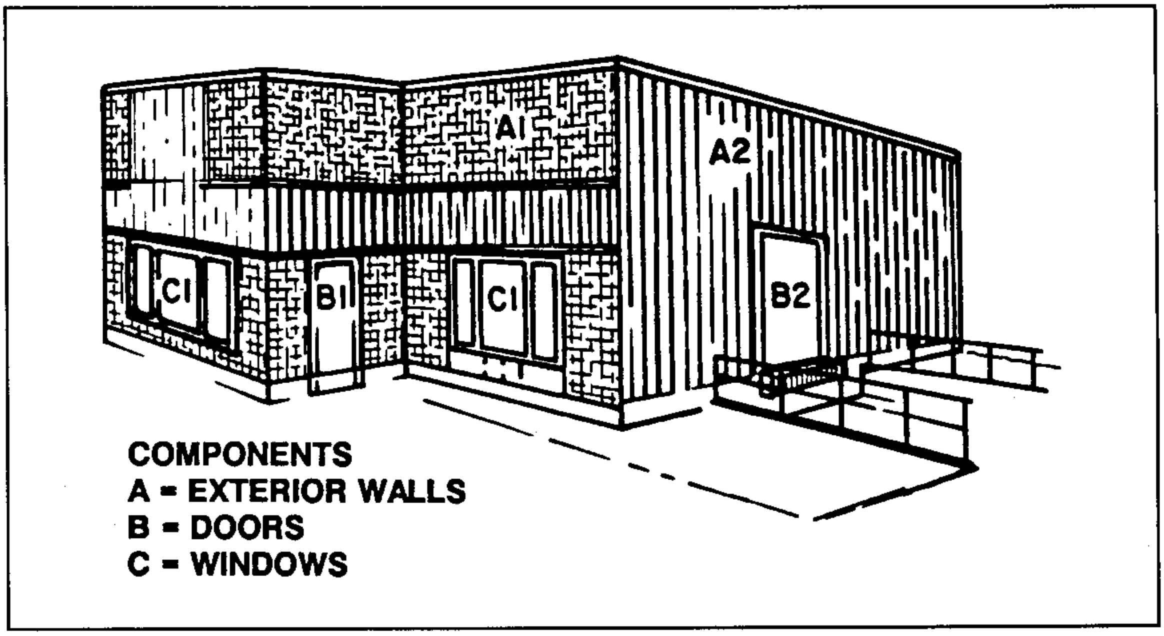

Figure 4. Exterior closure system divided into sections.

Index Representation

Given that the component/material indexes and ECCI range from zero to 100, a definition was developed of what the indexes are meant to represent. Also, the intent of the different condition categories was explained.

Index Definition

Each component/material index is intended to reflect: (1) the amount of distress present in the component, (2) that component's current physical ability to function as intended and (3) the component's maintenance, repair, or rehabilitation needs to sustain the desired level of performance.

Condition Category Guidelines

The seven condition categories that make up the index scale also required guidelines so that the computed indexes would indeed meet the stated index definition. Table 2 displays those guidelines. Note that guidelines are given to represent the categories instead of definitions because the use of definitions would induce rigid constraints on the formulation and use of the indexes. The flexibility of guidelines is critical to formulating the index.

Table 2. Condition category guidelines.

Condition Rating	Category	Condition Description (per sample unit)		
		Amount of Distress	Functionality	Type of M&R
86-100	Excellent	Minimal deterioration	Not impaired	Preventative or minor maintenance, or minor repair
71-85	Very good	Minor deterioration	Slightly impaired	Preventative or minor maintenance, or minor repair
56-70	Good	Moderate deterioration	Somewhat impaired	Moderate maintenance or minor repair*
41-55	Fair	Significant deterioration	Seriously impaired	Significant maintenance or moderate repair*
26-40	Poor	Severe deterioration over small portion of sample unit	Critically impaired	Major repair
11-25	Very poor	Severe deterioration over moderate portion of sample unit	Barely exists	Major repair but less than total restoration*
0-10	Failed	Severe deterioration over large portion of sample unit	Lost	Total restoration

* Major rehabilitation may be economically justified to ensure the optimum expenditure of funds for a life cycle.

Level of Inspection Effort

Concerns with the present inspection process for facilities were presented in the last chapter. The following inspection procedure will help overcome some of the problems and collect the required information needed for condition index computation.

Goal

Although the concepts of facility- and project-level management serve different purposes, both require inspection information for the decisionmaking process. Those inspection efforts are different since facility-level management generally requires less detailed information, more frequently, than project-level management.

BUILDER requires a facility-level inspection procedure that is compatible with project-level inspections. The facility-level goal is to collect the minimum amount of information necessary to make decisions, while the project-level goal is to accurately understand why the distress occurred in the first place. One solution is to inspect for the same distresses for both facility- and project-level, and to minimize facility-level inspection by sampling. Another approach is to collect less inspection detail at the facility level. The sampling approach was taken in developing the exterior closure component/material condition indexes. This will permit their direct use at both the network/facility and project levels. Also, as part of BUILDER development, a less detailed inspection approach is being investigated for facility-level management.

Sampling

Inspection by sampling is a procedure first used to collect information for the computation of the Pavement Condition Index (PCI) (Shahin, Dater, and Kohn 1976 and Shahin 1994). Statistically, the required number of sample units that need to be inspected is a function of how large an error can be tolerated, the probability that the computed PCI is within that error, the PCI variation from sample unit to sample unit, and the total number of sample units in the pavement section. Unfortunately, using a statistical approach for determining the number of sample units for facility-level inspections leads to a relatively high number of samples being required (frequently 100 percent). In reality, only about 10 to 25 percent of the pavement area is typically inspected for network/facility-level management (Shahin 1994; Uzarski and Soule 1986). These percentages evolved from field experience based on the goal of expending a minimum inspection effort to collect needed information (Shahin 1994 and Uzarski and Soule 1986). A similar approach was found to be valid for railroad track (Uzarski September 1993).

However, inspection by sampling is not readily used for buildings. One premise of this research is that the same logic used in pavement and railroad track inspections can be applied to buildings. The actual percentages of major components required for network/facility-level inspections have not yet been established, but certainly the percentages will be less than the current 100 percent.

Sample units must be established before a sampling procedure can be implemented. Sample unit identification and size will vary, but for exterior closure components, they should be based on identifiable discontinuities (e.g., north wall). Two draft USACERL technical reports (Weightman, et al. 1994; Wittleder, et al. 1994) for condition indexes for clay brick masonry and concrete masonry, respectively, will describe specific procedures for dividing exterior walls into sample units.

Indexes are computed for each sample unit and the results combined to compute the indexes for the major component/component combination as a whole. This is done by first inspecting representative sample units and then computing the component index for each. The sample unit indexes are then simply averaged to compute the major component/material indexes. However, if nonrepresentative (either much better or worse condition) sample units are discovered and inspected, the indexes are computed somewhat differently so that their effects do not overly influence the condition indexes of the component as a whole:

$$CI_{comp} = \frac{[(N-A)\,CI_1 + (A)CI_2]}{N} \qquad \text{[Eq 1]}$$

where :

CI_{comp} = CI of the major component (same material)
N = total number of sample units for the major component/material
A = number of additional sample units
CI1 = average CI of the representative sample units
CI2 = average CI of the additional sample units.

For walls, sample unit area is substituted for N and A in Equation 1 to account for differences in wall area from one sample unit to another.

As examples of index computation, a step-by-step procedure for inspection and condition index determination for clay brick masonry and concrete masonry is given in the two draft USACERL technical reports (Weightman, et al. 1994; Wittleder, et al. 1994, respectively).

Inspection Items

A large number of possible inspection items (distresses) is associated with building exteriors. These vary by component and material type. Each component/material combination requires a unique listing to ensure that the deterioration is adequately described and a meaningful index derived.

4 Rating Scale Concepts

Rating Scale Theory

Translating deterioration "problems" (inspection items or "distresses") into meaningful numerical condition indexes requires an application of rating scale theory. Scales can be developed in various ways depending on the intent and parameter being scaled. One approach uses rating panels for collecting rating information. With this approach, raters are presented with a physical stimuli and a rating is provided in response (Hutchinson 1963). A rating panel approach proved to be an ideal method for developing the exterior closure component/material condition indexes.

Rating Scale Classification

Rating scales can be classified in various ways. Although there is no single universally accepted classification system, the work of Stevens (1946) provides a good basis for an overview discussion. He classifies rating scales as nominal, ordinal, interval, and ratio. Interval scales were used in this development.

With interval rating scales, the size and differences between pairs of numbers have significance. The intervals are equal, but the origin can be located where convenient. Interval rating scales can be ordered and the statistics of mean and standard deviation have meaning. However, with interval scales, it is meaningless to imply that any given value is in proportion to any other value on the same scale.

Scaling Methods

Researchers can obtain interval scale ratings either directly or indirectly (Nick and Janoff 1983; Torgerson 1958). Either method must relate the physical stimuli (e.g., spalling of clay brick masonry) to the rater's judgement of the parameter (i.e., condition) to be scaled. The difference in methods is in the assumptions about the rater's ability to describe the stimuli at the desired level of measurement (Nick and Janoff 1983). In the direct approach, the rater quantifies his or her judgement directly on the interval scale. For example, it is assumed that a rater can view "clay brick masonry problems" on three separate walls and provide ratings of 39, 62 and 74. Indirect methods involve collecting the ratings on an ordinal scale and then using statistical methods to convert the data to an interval scale. As applied to the masonry example above, this would have a rater indicate that one wall was "better" than another, but "worse" than still another. The direct method was used to develop the condition indexes.

Rating Scale Development

The development of an interval rating scale using the direct approach in compliance with established principles requires that the rating panel members be thoroughly instructed in the task.

Also, the rating sessions must be administered properly (Nick and Janoff 1983; Moore, Clark, and Plumb 1987). Failure to do so introduces error and distorts the findings. Proper instruction and administration can also reduce error. Finally, the development of a rating scale requires certain assumptions.

Assumptions

The development of condition indexes through the use of subjective panel ratings represents a psychological model. Certain well-documented assumptions must be invoked for the model to be feasible (Hutchinson 1963; Torgerson 1958):

- Condition is a measurable attribute.
- Raters are capable of making quantitative judgements about condition.
- The judgement of each rater can be expressed directly on an interval scale.
- Variability of judgement is a random error.
- Raters are interchangeable (equally capable of making the required judgement of condition).
- Averaging individual rating values can be used to estimate rating scale values.

Instruction

Before the raters can provide any meaningful subjective data, they must be given a set of instructions to follow (Moore, Clark, and Plumb 1987; Nick and Janoff 1983; Zaniewski, S.W. Hudson, and W.R. Hudson 1985; Nakamura 1962; Weaver and Clark 1977; Weaver 1979). The instructions provide guidance and direction on specifically what raters are to do and how they are to do it. The instructional process must include a definition of what the rating scale represents. Also, specific anchors and cues (discussed below) on the scale must be explained.

An anchor provides a point of reference from which the ratings are based (Hutchinson 1963; Nick and Janoff 1983; Weaver and Clark 1977; Weaver 1979). As mentioned earlier, the condition indexes use a rating scale that ranges from zero to 100. For reasons that will become evident later in this chapter, the primary anchor for that scale is 100. By definition, a rating of 100 indicates that the component sample unit is free of observable distress. Figure 2 shows the rating scale divided into 15-point intervals (except for one). Each interval boundary also serves as an anchor.

Cues lead the rater to an understanding of what the different portions on a rating scale represent (Hutchinson 1963; Nick and Janoff 1983; Weaver and Clark 1977; Weaver 1979). Table 2 shows the association of a category label and a condition description with each interval. Those condition descriptions provide the cues for the ratings. Note that three sets of cues are superimposed on the descriptions. Because the ratings are intended to relate to the extent of deterioration, the effect on exterior closure component functionality, and M&R considerations, the raters were advised to consider all these effects in their ratings. (Cues for all are provided.) The purpose behind these multiple considerations is that certain distresses may be minor in extent, but very detrimental to functionality. Also, some distresses may be widespread, but relatively easy and inexpensive to correct.

The category labels do not serve as cues. Using those words alone is not recommended since it will lead to a broad interpretation among raters (Hutchinson 1963). Their use as cues could also invoke error. Throughout the rating sessions, letters were used to label the categories. This was done to eliminate the error. The words "Excellent," "Very Good," etc. were substituted for the letters after all ratings were completed. This provided a common language among all of the condition indexes developed by USACERL (Table 2).

Administration

Special care was taken in administrating the data collection and analysis. The panel was selected based on qualifications and representation. The actual condition ratings were performed randomly based on a set of representative exterior closure "problems." The panel was thoroughly instructed before each rating session. Each individual rated independently without knowing the panel mean or the ratings of any others. Each panel member rated the identical "problem." Also, breaks were held during the rating sessions to relieve rater fatigue. Adherence to these principles, including the analyzing of the data, was designed to eliminate certain errors and minimize others (Moore, Clark, and Plumb 1987; Nick and Janoff 1983).

Weighted Deduct-Density Model

The collection of rating panel information, in itself, did not result in the desired condition indexes. A model was needed to translate inspection information on which the ratings were made to condition indexes. In fact, the condition indexes are mathematical models for estimating the mean subjective ratings of an experienced rating panel. For the model to function, building inspection results must be used for input. The weighted deduct-density model proved to be ideal for this application. It was used to develop the condition indexes for clay brick masonry and concrete masonry, to date, and can be used for other component/material combinations.

Model Concepts and Theory

USACERL researchers first used the weighted deduct-density model in the development of the PCI for airfields (Shahin, Darter, and Kohn 1976) and later for the development of the PCI for roads and streets (Shahin and Kohn 1979), built-up roofs (Shahin, Bailey, and Brotherson 1987), and railroad track (Uzarski July 1993). The degree of deterioration to a component and material (e.g., clay brick masonry walls) is a function of three specific characteristics:

- types of distress (e.g., surface deterioration)
- severity of distress (e.g., ≤ ¼ in. and ≤ 20% in 8 sf)
- amount of distress, commonly expressed as a percentage to indicate density (e.g., 50 percent of wall affected).

Since each of these has a profound effect on determining and quantifying condition, each must be included in a condition index mathematical model.

Within any given component and material combination, many distresses can occur. Different types, severities, and densities of distress can all be present in the same component sample unit. The model must consider each type, severity, and density separately and in combination to derive a meaningful index. Since each distress can potentially affect the derivation in an unequal fashion, weighting factors are needed. The model assumes that a component condition index can be estimated by summing the appropriate individual distress types over their applicable severity and density levels by the use of appropriate weighting factors. The model for this estimation is:

$$CI = C - \sum_{i=1}^{p} \sum_{j=1}^{m_i} a(T_i, S_j, D_{ij}) F(t, d) \qquad \text{[Eq 2]}$$

where:

C = Constant equal to 100 for this application

$a()$ = Deduct weighting value depending on distress type T_i, severity level S_j, and distress density D_{ij}

i = Counter for distress types

j = Counter for severity levels

p = Total number of distress types for component group under consideration

m_i = Number of severity levels for the *ith* distress type

$F(t,d)$ = Adjustment factor for multiple distresses that vary with total summed deduct value, *t*, and number of individual deducts over an established minimum value, *d*.

The following terms describe concepts related to research activities involved in defining the distresses and determining the deduct weighting values and adjustment factors:

- *Distress types and severity levels.* The various distress types and severity levels for each component and material combination must be defined in a way that makes them easy to identify during the inspection process. This is because routine condition survey inspections are intended to be used to generate the required data for index computation.
- *Deduct weighting values.* The deduct weighting values resulted from the panel's subjective condition ratings of individual deterioration problems. Those same deterioration problems corresponded to distress types and severity levels over a range of densities so that the deduct values could be compiled. Since the deduct values are a function of the distress type, severity level, and density, they can be represented graphically though deduct curves (Figure 5).
- *Adjustment factor for multiple distresses.* Mathematically, nonlinearity is a requirement for the model; otherwise negative condition indexes conceivably could occur. From a rating perspective, it was found that, as additional distress types and/or severity levels occurred in the same sample unit, the impact of any given distress on the condition rating became less. To account for this in the model, an adjustment factor must be applied to the sum of the individual deducts. This results in the necessary correlation between the panel ratings and the computed indexes. The correction factors are a function of the component group, the summed total of the individual deduct values, a minimum individual deduct value, and the number of different distress types and severity level combinations found in the sample unit. These correction factors can be graphed as a family of correction curves (Figure 6). The development of those curves resulted from rating panel data.

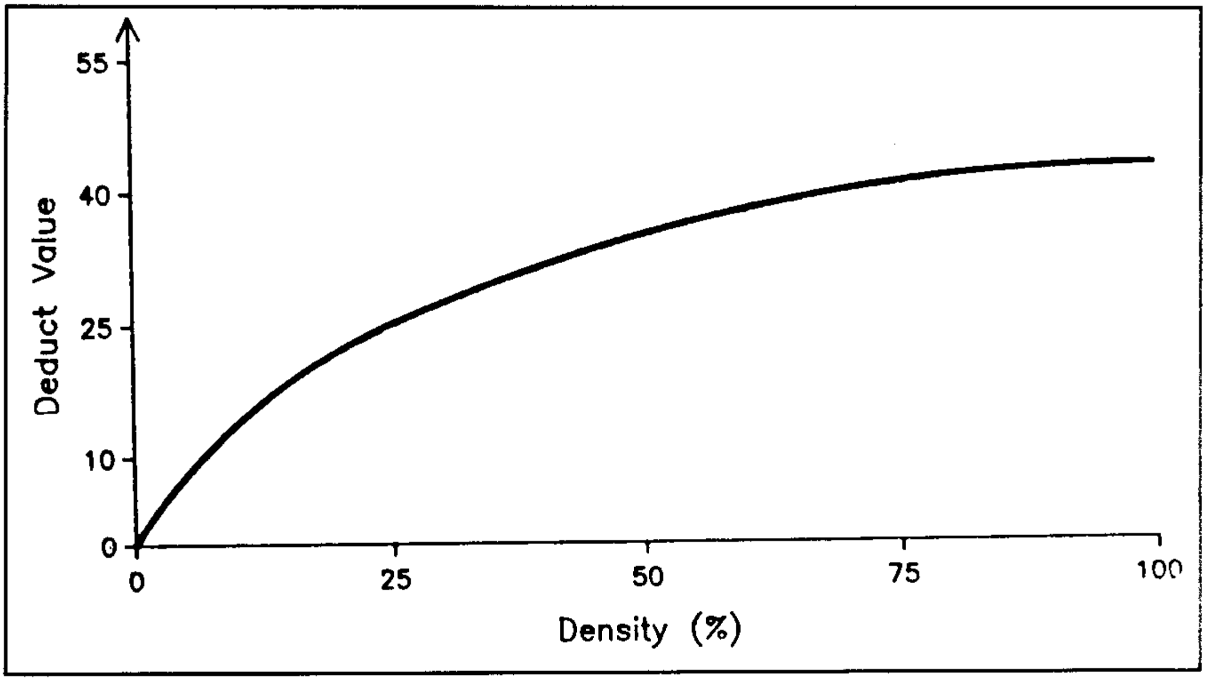

Figure 5. Deduct curve.

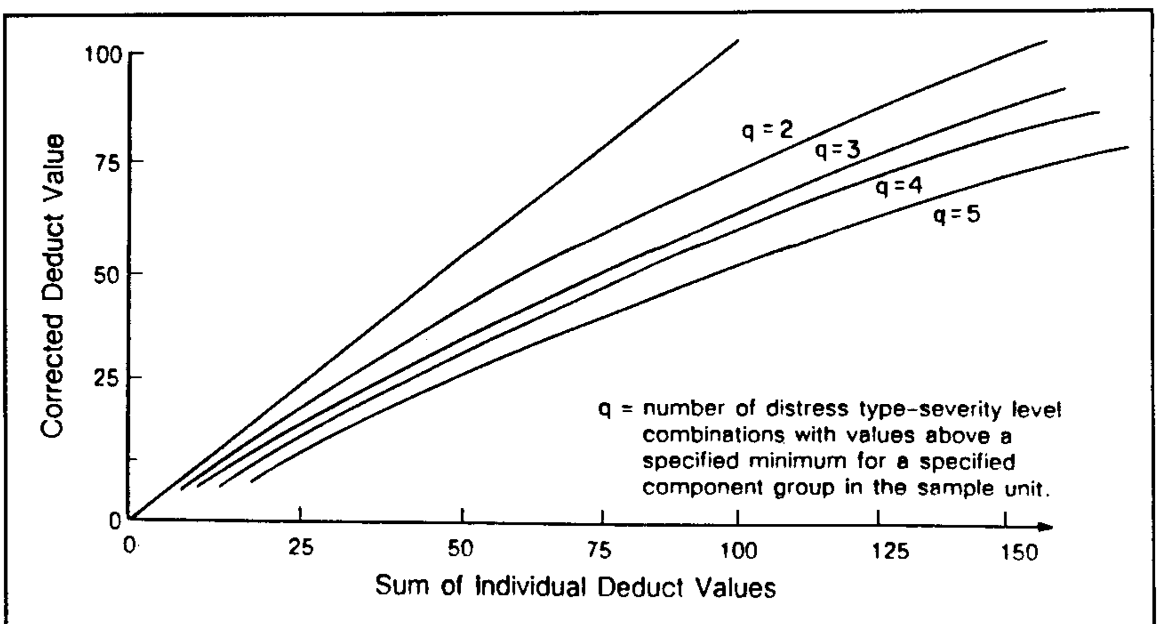

Figure 6. Correction curve.

The corrected deduct value (CDV) is further refined through the procedures described in ASTM D5340-93. Although the ASTM procedures were developed for the Pavement Condition Index (PCI), they were successfully adopted for the Track Structure Condition Index (TSCI) (Uzarski September 1993) and apply to these exterior closure component condition indexes. The procedure involves examining and ranking the individual deduct values, establishing the maximum number of deducts to use, and deciding which of those deduct values are to be used in the CDV determination. The maximum number of deduct values to use is found by:

$$m = 1.00 + (9/x)(100 - HDV) \leq 10 \qquad \text{[Eq 3]}$$

where:

9/x	=	Constant
x	=	97 based on the cutoff deduct value of 3
HDV	=	Highest Deduct Value.

Equation 3 is shown graphically as Figure 7.

If the number of individual deducts exceeds the maximum allowable, the number to use is reduced to "m," including the decimal (fractional) portion:

1. Compute "m." (Use Equation 3. For example, if the HDV is 32, "m" equals 7.31.)

2. Determine which individual deducts to use in the CDV calculation:
   - If the actual number of deduct values is less than or equal to "m," all of the values will be used in the analysis.
   - Rank individual deduct values, high to low.
   - If the actual number of individual deduct values is greater than "m," reduce the number of deduct values to "m" by eliminating individual deduct values, low to high. The fractional value of "m," if applicable, is multiplied by the "m + 1" deduct value and the resulting product is used along with the other "m" highest deduct values.

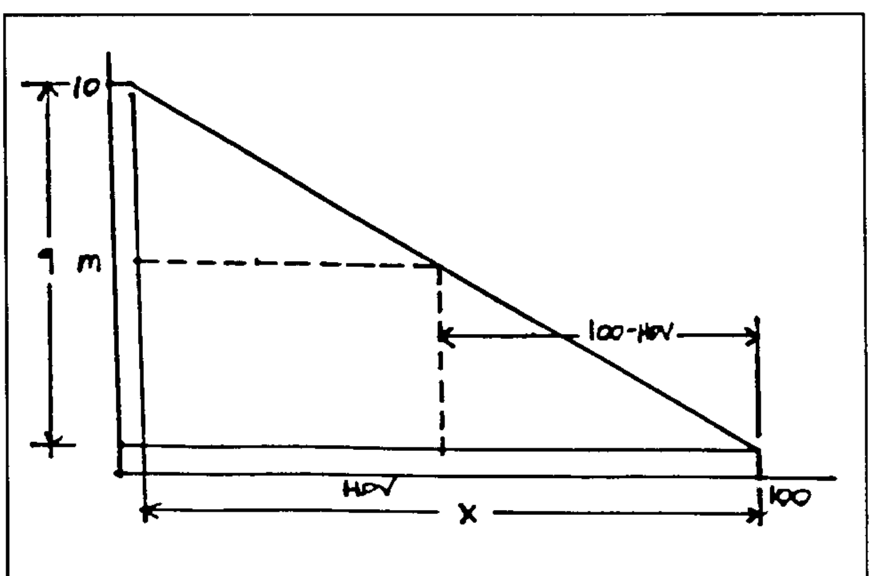

Figure 7. Determination of maximum allowable deducts.

- For example, use "m" of 7.31 as calculated previously, for computing the index. There are nine individual deduct values ranked, high to low, as 32, 29, 23, 21, 13, 8, 8, 6, 5. This means that the value of 5 is dropped and the seven values 32 to 8 will be used. The value of 6 is reduced by multiplying 6 by 0.31. This results in a revised value of 1.9. The individual deduct values that carry forward are in the analysis are 32, 29, 23, 21, 13, 8, 8, and 1.9.

The CDV is computed using the individual deduct values. They should be placed in a table with the first row consisting of the ranked values. Successive rows are created substituting the value "3" for the lowest value in each row that exceeds three. Each row is totaled (Table 3).

Once the individual deduct table is created, CDVs are computed for each row using the correction curves (Figure 7). The "q" values to use are the number of individual deduct values greater than three points (Table 4). The largest CDV is used to compute the condition index.

Note that the value "3" was derived empirically from the data collected for clay brick masonry and concrete masonry. It provides the highest correlation between computed indexes and panel ratings for these materials. Other component/material combinations may result in a different cutoff value.

Model Use Concept

Figure 8 shows how the model is used to compute the brick masonry condition index (BMCI). As can be seen, Equation 2 is used simplistically.

Table 3. Sample individual deduct value table.

Deduct Value								Total
32	29	23	21	13	8	8	1.9	135.9
32	29	23	21	13	8	3	1.9	130.9
32	29	23	21	13	3	3	1.9	125.9
32	29	23	21	3	3	3	1.9	115.9
32	29	23	3	3	3	3	1.9	97.9
32	29	3	3	3	3	3	1.9	77.9
32	3	3	3	3	3	3	1.9	51.9

Table 4. Sample corrected deduct value (CDV) table.

Total	q	CDV
135.9	7	49
130.9	6	47
125.9	5	60
115.9	4	69
97.9	3	72
77.9	2	67
51.9	1	51.9

Step 1.	Inspect the wall. Record all distresses found and determine the sample unit area. This example assumes only that the wall has corner vertical cracks and a sample unit area of 650 sq ft.
	B3. Corner vertical crack, medium severity, 9 linear ft (l.f.)
Step 2.	Calculate the densities (in percent) for each individual distress.
	B3, Medium: Density = 9 l.f./650 sq ft = 1.38
Step 3.	Determine Deduct Values (DV) from deduct curves.
	B3, Medium: DV = 20
Step 4.	Determine "m" from the following equation:
	m = 1 + (9/97) (100 – HDV), where HDV = highest deduct value; m = 8.42; since m is greater than the number of DVs (DV = 1) all are used.
Step 5.	Compute Total Deduct Value (TDV)
	TDV = sum of DV = 20
Step 6.	Determine "q" (total number of deduct values greater than 3 points), q = 1
Step 7.	Determine Corrected Deduct Value (CDV)
	since q =1, CDV = TDV = 20
Step 8.	Compute BMCI and determine condition category
	BMCI = 100 – CDV = 100 – 20 = 80 -> Very Good (Figure 2)

Figure 8. Index computation concept.

5 Research Activities

The major activities required to develop condition indexes were: (1) defining the distresses and severity levels, (2) collecting data, (3) establishing the deduct and correction curves, and (4) doing field validation. All activities included data analysis. Together, those activities made up a logical research process (Figure 9) that was repeated in developing the various exterior closure component condition indexes (ECCIs).

Distress Definitions

Recall that an inspection goal was to reduce the large number of possible defects likely to be found in any facility-level inspection. Attaining this goal required defining a relatively small number of component group distresses for inspection and index use. These critical definitions had to be thorough, easily identifiable for ease and speed of inspection, and directly related to the necessary deduct values so the resulting indexes would be meaningful. The distress definitions consist of two parts: distress types and severity levels.

Distress Types

Distress types for a given component/material combination are defined from the differing defects specific to each component. The initial distress type listing is developed from applicable inspection guides. For example, when two different clay brick masonry distresses include surface deterioration and sealant deterioration, those defects were defined as separate distresses.

By definition, design deficiencies or current inadequacies such as poor workmanship are not considered distresses. If present, those deficiencies will be reflected through relatively fast deterioration, which will be measured over time by the appropriate condition index.

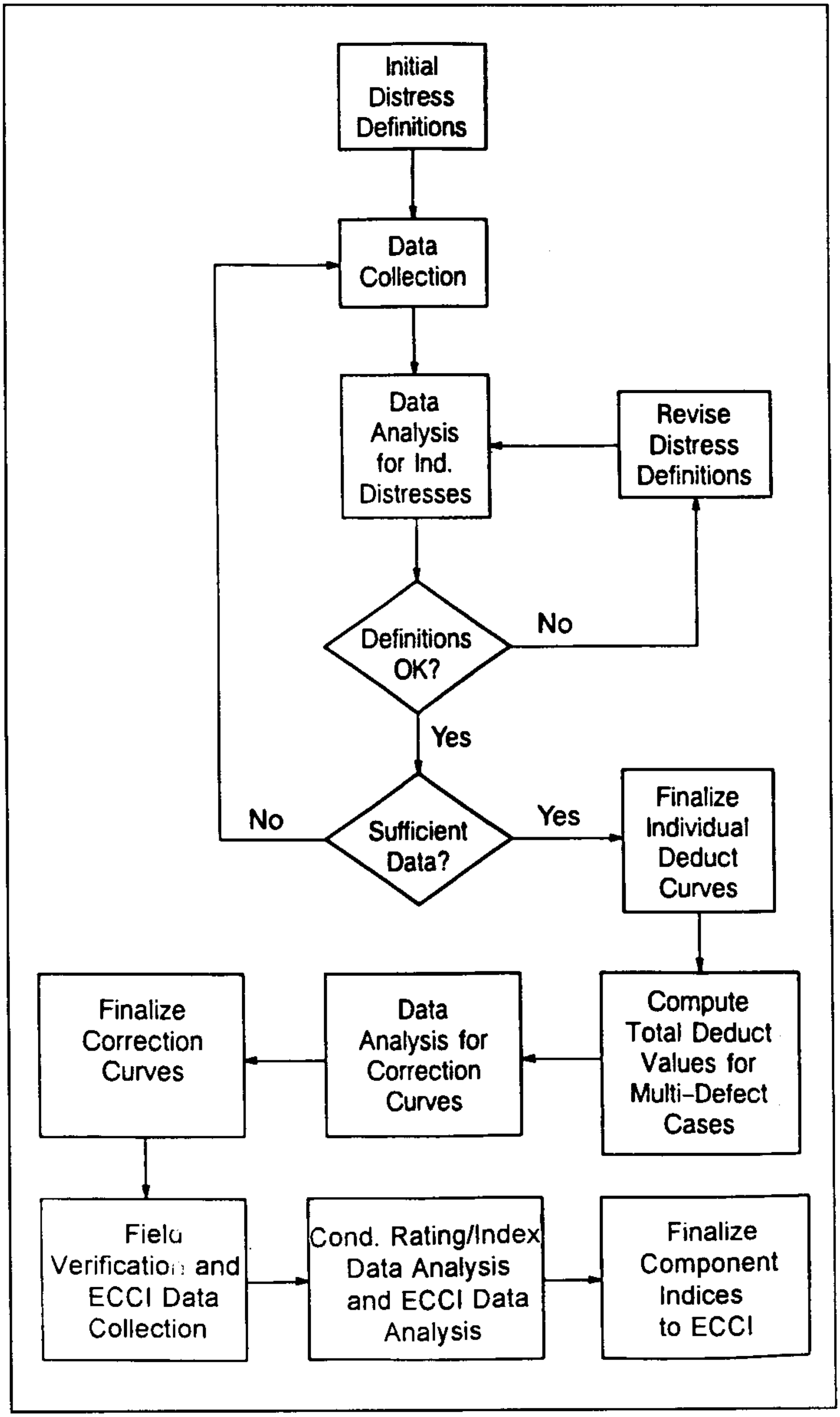

Figure 9. Index development process.

Severity Levels

Simply defining distress types is not enough for a complete condition evaluation. A single distress type can have differing degrees of impact on an exterior closure system's ability to perform as intended. Distress type is further qualified by severity level as part of an overall distress definition.

Before specific distress severity levels can be defined, a general description is needed of how severity levels relate to the degree of impact a specific distress may have on exterior closure component performance. The description must be consistent among the different components and provide for a common interpretation among different users to avoid a complex and confusing usage of the terminology. Table 5 lists definitions of the three severity levels.

Not every distress type will require all three severity levels. Some distress types simply cannot become so critical that they require immediate attention. Some distress types (such as "staining" of clay brick masonry) require no severity levels because there are no distinct levels that would impact component performance.

Definition Evolution

The final distress definitions for any component/material combination evolve through an iterative process. Discussions with experts provide feedback on the initial distress list and revisions may follow. This two-step process results in preliminary definitions that form the basis for collecting the initial set of rating data (discussed below). Discussions held with the raters during the rating process lead to definition revisions. Data analysis and the graphing of the deduct curves result in still further modifications. As data collections progress with different raters, the revisions become fewer

Table 5. Severity level descriptions.

Severity Level	Description
Low (L)	Minor distresses that do not affect overall performance of the component. Maintenance and repair may be necessary in 3 to 5 years to prevent the distress from progressing to higher severity levels.
Medium (M)	Moderate distresses that begin to affect the performance of the component. Maintenance and repair should be planned for 1 to 3 years to prevent the distress from progressing to high severity.
High (H)	Major distresses that definitely affect the performance of the component. The component is not performing as intended. Maintenance and repair should be scheduled in the current budget cycle (< 1 year).

(a consensus is reached). Ultimately, the distress definitions that evolve are all-encompassing, easily identified in the field, and directly related to the necessary deduct values needed for index computation and use. Figure 10 provides a sample definition for clay brick masonry.

Data Collection

Data collection consists of three major elements: (1) determining what data are needed and how they will be collected, (2) creating a rating panel, and (3) having the panel actually perform the ratings.

Slides of Distresses for Ratings

Each combination of distress type and severity level requires collecting rating data over a range of densities so the deduct curves can be determined. Ideally, the rating panel would assess these different distress types, severity levels, and densities in the field. However, that approach for data collection is not feasible. Locations are not known that will result in the collection of all of the needed rating data, project funding does not permit sufficient travel for a rating panel to visit widespread locations even if they were known, and getting an entire group of experts together at one time to do the ratings is nearly impossible.

B3. CORNER VERTICAL CRACKS

Description: This structural distress is a vertical fracture in the wall through the mortar joints and/or brick units, located near building corners. If cracks occur at other locations on the wall, Distress B15. Wall Cracks, applies instead.

Severity Levels: Maximum crack width, as follows:

L	• ≥ Hairline but ≤ 1/16 inch
M	• > 1/16 inch but ≤ 1/4 inch
H	• > 1/4 inch

Note: Increase one severity level if displacement is present at crack.

Measurement: Lineal feet of crack. If multiple cracks are present, sum the measurement for each severity level.

Density: Total Affected Length / Sample Unit Area

Cause: Corner vertical cracking is due to restraint of brick expansion from water absorption or thermal changes, an inadequate number or width of expansion joints, and/or inadequate detailing or cleaning of expansion joints.

Figure 10. Sample distress definition (clay brick masonry).

For this study, the necessary data were provided on color slides that display different distresses for rating. The distress displayed on each slide represent a certain type and severity level at a density found on a component section sample unit. The slides come from a USACERL collection that continuously gathered from researcher's travels, and from consultants' and trade/professional organizations' collections.

Rating Panel

The rating panel must be assembled for each index being developed. Since the condition indexes must represent the mean subjective opinions of a group of experts, a panel with members having varied experiences should be sought out so distresses will be rated from different perspectives. Sources include individuals from military engineering support organizations, military and civilian public works organizations, research laboratories, universities, consulting businesses, and trade/professional organizations. Appendix A lists the rating panel used to develop the clay Brick Masonry Condition Index (BMCI) and the Concrete Masonry Condition Index (CMCI).

Required rating panel size is a function of the variance of the rating data. Variance determines the required number of raters needed to meet the desired confidence interval and allowable error (Nakamura 1962; Cheremisinoff 1987). Normally, this is a 95 percent confidence interval (indicating that the mean panel rating is plus-or-minus 5 points of the true rating). In other words, the deduct curve shown in Figure 5 is an estimate; it could be higher or lower by varying amounts along its length.

Because of the variance differences, each deduct curve theoretically requires a different number of raters to meet the desired statistical requirements. A separate research project that resulted in three indexes (Uzarski July 1993) found that the numbers ranged from 35 to 54 if the maximum interval width is used for the "worst" curve. If the average interval width is used for the "worst" curve, the numbers were reduced to a range from 16 to 26. Using the average requirements based on the maximum interval for all curves gave a range from 20 to 22. Finally, the average requirements based on the average interval resulted in a range from 8 to 10. Due to the similarity in definition and development approach, similar numbers are expected for the building exterior closure component indexes. Since it is impractical to have different numbers of raters for different curves and to assemble a large panel based on the maximum required, the panel size should be based, as a minimum, on the average number of raters needed for the desired statistics for the average interval for all curves for a given component/material combination. Any additional are desirable, especially if some raters cannot participate in the entire process due to individual availability, expertise, or preference.

Rating Sessions

The rating sessions will generally take place over several months. Sessions may be from ½ to 2 days in duration. Longer sessions are fatiguing and cause productivity to slip. Each rating session must be facilitated and all rating sessions should be conducted in the same way. The raters are first given general instructions by the facilitator. Each rater is then given a copy of the rating guidelines to use as rating cues and a set of rating sheets. A copy of the rating guidelines can be found in Appendix B. The facilitator answers questions and encourages the raters to discuss the distresses shown in the slides. Included in the discussion is a review of the distress definitions.

After a given set of slides is rated, the data are reviewed. Any individual rating that is more than 15 points, or two standard deviations (whichever is less) from the mean is flagged for a rerate. This is done to allow raters the opportunity to correct certain ratings that may have been marked by mistake due to misunderstanding, misinterpretation, distraction, or some other reason.

The rerate process is simple. The appropriate slides are presented to all of the raters, during another session, to be rated again. Generally, a short discussion of the distress will occur. The raters are never told if they are above or below the panel mean and they are under no obligation to change their ratings. Also, since the only intent of the rerates is to catch mistakes and clarify distress definitions, raters are always advised to rate their convictions and not to be concerned how others rated; differences in opinion are expected.

As discussed above, the slides need to be chosen based on a need to collect a range of data, to determine deduct curves, to support a family of distress types and severity levels. Later analysis may show that certain resulting deduct curves may not support the proposed definitions. This will lead to further revisions in the distress definitions (discussed earlier). Some definitions/curves may be combined, others may be separated for further analysis, and still others may simply be adjusted.

Developing the Deduct and Correction Curves

A regression analysis can be used to determine equations for deduct curves. This analysis can also be used to determine variance and estimate the required size of the rating panel. This method, however, is not recommended for producing the final curves. Rather, the best smooth curve fit approach is recommended. Because regression models a relationship based solely on mathematics, it ignores certain engineering logic. The deduct curves for a given distress type form a family, and as such, certain consistent trends for that family are expected. If one relies on regression alone for individual curve development, the family trend can become ragged and actually become a less logical representation of the physical occurrences. A best smooth curve fit of the final curves ensures that the trends are correct and consistent with the physical events. In the end, the regression curves and the best smooth fit curves may be very similar or identical. Key to closeness is having a range of data for many densities, which may not be possible or practical.

Deduct Curves

Once the distress definitions are finalized and the outliers removed from the data (any individual value exceeding three standard deviations from the panel mean), graphing the final deduct curves is a simple matter. The deduct and correction curves were developed by converting the rating data into deduct values and then plotting those values against an appropriate parameter. In all cases, the deduct values are simply 100 minus the mean rating values.

The deduct curves were created by plotting the mean deduct values against their respective densities for each distress type and severity level combination. Figure 11 shows the deduct curves for the clay brick masonry distress, "B3. Corner Vertical Cracks." The entire deduct curve family will be published in a forthcoming technical report (Weightman et al).

Correction Curves

As part of the rating sessions, sample units that illustrated various combinations of distress within the same component group are also rated. For example, cracks and spalls might occur together within the same sample unit. The procedures for rating data collection and analyses were the same as for the individual deducts.

The final deduct curves are used to compute the deduct values for each individual distress found for the combinations. These deduct points are summed for each combination and graphed against the deduct values resulting from the panel ratings. A family of curves results are based on the number of distress types and severity levels present and a minimum numerical cutoff for individual deduct values.

The correction curves were developed by plotting the mean deduct values, called the Corrected Deduct Values (CDV), against a summed total of the individual deduct values that make up the distress combination. The summed total is called the Total Deduct Value (TDV). A family of curves is developed by linking the data points when

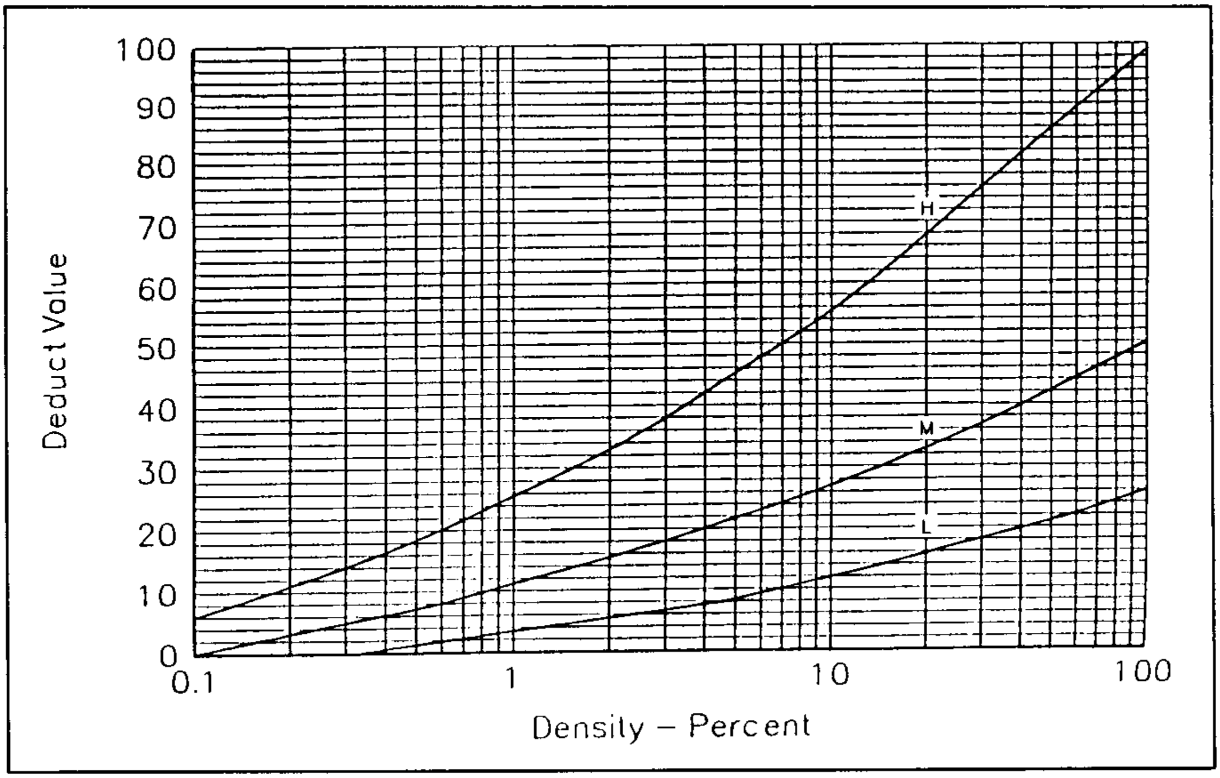

Figure 11. Sample deduct curves (clay brick masonry).

the number of individual distress type-severity level combinations (denoted "q") is the same. The procedure outlined in ASTM D5340-93 is also used to determine a "best fit." For both clay brick masonry and concrete masonry, the distress type-severity level combination had to be greater than 3 points. The 3-point minimum cutoff resulted in the best curve fitting for the data set for those examples. Figure 12 displays a sample of the correction curves.

Field Verification

The field procedure is simple. The group of raters will together inspect selected component sample units and agree on the distresses found. Each rater will then, individually, numerically rate the component based on all of the distresses present. Upon completion, the facilitator will lead a group discussion and ask each member to explain his rating to the other members of the group.

After the rating panel inspects and rates the sample units, the condition indexes are computed from the inspection data using the appropriate deduct and correction curves. The individual panel member ratings are averaged to obtain mean condition ratings for each component group. The computed index values are then compared to the mean ratings.

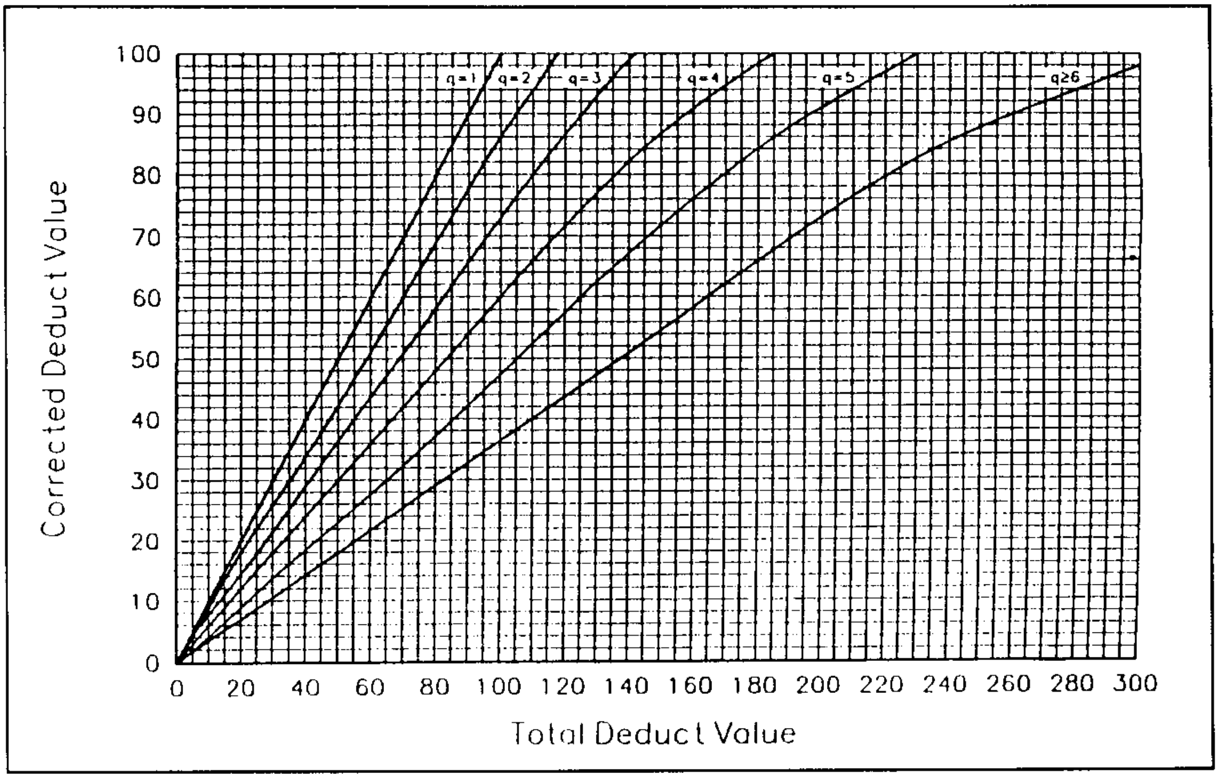

Figure 12. Sample correction curves (clay brick masonry).

The field work may lead to minor revisions in the distress definitions and to slight adjustments to a few deduct and correction curves. The numerical cutoffs for the correction curves may also be altered by a point or two.

6 Practical Considerations

The use of a rating panel approach and the weighted deduct-density model is valid for exterior closure component condition index development (and probably most other building components, as well). However, the development of the BMCI and CMCI revealed certain issues that must be considered for future condition index development.

Shortcomings

Two major shortcomings were found when developing the BMCI and the CMCI: developmental and implementational. The shortcomings stem from the wide variety of components and materials found in building exterior closure components. Simply put, there are too many combinations possible for all building systems to effect similar development and use on the broad scale needed to support BUILDER. Table 6 lists all of the major components considered in BUILDER. Each of these multiplied by an appropriate number to reflect the common materials used results in literally hundreds of possible combinations.

Table 6. Building major components used in BUILDER EMS.

Category	Component
Site	Building perimeter Fencing Site perimeter Storm drainage Traffic control/access Wall
Structural	Substructure Superstructure
Roofing	Roof deck Drainage Insulation Flashing Roof surface Specialty

Category	Component
Exterior Circulation	Balcony Breezeway Bridge Carport Deck Finishes Loading dock Patio Plaza deck Porch Ramp/stair+landing/stoop Tunnel Walkway
Exterior Closure	Appurtenance Chimney Door Finishes Insulation Ornament Wall Window
Interior Construction	Ceiling Door Finishes Fireplace Floor Ornament Ramp/stair+landing/stoop Specialty Wall Window
Plumbing	Equipment Fixtures Septic system Specialty systems Cold-supply water piping Hot-supply water piping Waste water piping Well
HVAC	Cooling Equipment Fuel handling network Heating Ventilation/exhaust

Category	Component
Electrical	Alarm system Communication Controls Electrical equipment Luminaries Service/distribution Specialty networks
Fire Suppression	Alarm system Piping/sprinkler system Pump system Storage tank Miscellaneous
Conveying	Elevator Escalator/moving walkway Other
Specialties	Recreational facility Interior amenity Site amenity Other

Developmental Issues

From the research perspective, developing a wide variety of condition indexes to support the requirements of BUILDER using the weighted deduct-density model as applied, thus far, is impractical. It is simply too expensive and time consuming to develop each one. The effort required to collect a wide array of slides, assemble a panel with the requisite number of raters, collect rating data, create the deduct and correction curves, and field test is significant. Although time accounting records were not kept for the development of the BMCI and CMCI, each required a dedicated research assistant for many months, excluding countless hours of the principal investigator and panel members. Each index took over 2 years to develop from inception to completion. BUILDER EMS funding and developmental time constraints do not permit a similar effort on a widespread scale.

Implementation Issues

A major concern of researchers and field practitioners alike is the level of inspection (condition survey) effort needed to implement the indexes. Each requires its own procedure for: identifying sample units (if applicable); identifying, quantifying, and recording distresses; and analyzing the data for index computation. Field resources are limited and, if the procedure is tedious, time consuming, or too detailed, implementation will be difficult. Certainly, the process can be tailored to reduce effort.

The use of sampling techniques, pen-based or laptop computers for data recording, and robust software for index computation all reduce the effort required of field personnel. However, distress detail and quantification are still human activities. The level of detail required will dictate acceptance. Although the weighted deduct-density model does not require an extraordinary amount of data to use, researchers should strive for meaningful indexes that can be computed from an absolutely minimum level of inspection effort.

A Generalized Condition Index Approach

A possible solution to overcome these two shortcomings is to develop a generalized condition approach. This approach needs to be studied further, but conceptually it could use the same seven-interval, 100 point, condition index scale, and take advantage of the guidelines listed in Table 2, but with application of a different model. Generic or generalized distresses could be compiled into a single list germane to the overall functionality of specific building systems. Building inspectors, with the help of clear rating guidelines and inspection criteria, could provide direct condition ratings along with their inspection findings. The inspection data would be curtailed to the absolute minimum necessary to support facility-level decisionmaking.

Such a generalized approach could be developed in far less time than the procedures described earlier in this report. This is due in large part to the elimination of rating panels and deduct curve development and through the aggregation of "generic" distresses.

This approach could provide several additional benefits. First, a successful completion of this development will provide BUILDER with a full-range condition assessment capability in a relatively short period of time. Second, the inspection effort will be minimized through reduced distress detail and quantification. Finally, if and when additional condition indexes similar to the BMCI and CMCI are developed for other component/material combinations, they can be substituted for the generalized approach to enhance the condition assessment process. Those component/material combinations needing a more robust condition assessment approach will become evident through use and feedback from BUILDER. Improvements in condition assessment can be handled as BUILDER enhancements.

7 Conclusions and Recommendations

Conclusions

This study has developed a method to develop condition indexes for a variety of exterior closure system components. Development of this method has yielded a number of corollary conclusions:

1. An interval rating scale proved to be a proper selection for developing track condition indexes.
2. The development of an interval rating scale using the direct approach also proved to be workable for this application.
3. The use of a weighted deduct-density model was a valid application for BMCI and CMCI development and is believed to be applicable to all exterior closure components. Also, due to the similarity of components for other building systems, this model should have a wider application.
4. The use of slides showing the necessary range of distresses applicable to specific component material combination is a practical method for obtaining rating data that can overcame the logistical shortcomings of locating all of the needed distress types and severity levels and transporting an entire panel to the various sites at the same time.
5. A sufficient number of experts are needed to rate the various distress types and severity levels so that, statistically, the developed deduct curves are within ±5 points of the true deduct curves with 95 percent confidence.
6. The condition index development work also requires the development of a facility-level condition survey inspection procedure. Using sampling techniques results in procedures that require a reduced inspection effort.
7. Although it is concluded that the development procedures described in this report are valid, the time, effort, and resources required to develop the wide variety of indexes needed for BUILDER EMS will likely limit the use of this method to certain component/material combinations.
8. To provide a full range of indexes for BUILDER EMS, another procedure is needed. This procedure should have a wide application and be very easy and quick to develop.

Recommendations

To foster the use of condition indexes and enhance their application, it is recommended that:

1. These BMCI and CMCI procedures should be incorporated into the BUILDER microcomputer software system as soon as possible.
2. Subsequent research should develop or apply existing condition prediction models that incorporate the BMCI, CMCI, and all future developed indexes into BUILDER. Predicting future conditions is required for developing long-range work plans and overall M&R strategies.
3. The shape of the performance curve (condition index vs time or age) should be established for the various component/material combinations so that remaining life and cost relationships can be estimated.
4. Different uses for the indexes for building management should be studied to maximize their management value.
6. The use of various handheld data recording tools such as electronic clipboards and handheld computers should be investigated to reduce the time and labor costs of the condition survey inspection.
7. The number of sample units to be inspected for facility-level management needs to be established.
8. A simple, easy-to-develop, condition index procedure that is applicable to a wide variety of component/material combinations should be developed as soon as possible to ensure that the BUILDER EMS has an all-encompassing condition assessment procedure. This development must include a choice of model, rating data collection procedures, and field application to provide a maximum BUILDER EMS capability with limited research and development funds and time.
9. The use of the development procedures described in this report should be reserved for the most common or special interest component/material combinations (such as slate roofs, which, while relatively uncommon, may generate high managerial interest).

References

Cited

ASTM D 5340-93, *1993 Annual Book of ASTM Standards* (ASTM, Philadelphia, PA 1993), pp 630-636.

Bailey, D.M., D.E. Brotherson, W. Tobiasson, and A. Knehans, *ROOFER: An Engineered Management System (EMS) for Bituminous Built-Up Roofs*, Technical Report (TR) M-90/04/ADA218529 (U.S. Army Construction Engineering Research Laboratory [USACERL], December 1989).

Bailey, D.M., D.E. Brotherson, W. Tobiasson, S.D. Foltz, and A. Knehans, *ROOFER: Membrane and Flashing Condition Indexes for Single-Ply Membrane Roofs-Inspection and Distress Manual*, TR FM-93/11/ADA272573 (USACERL, April 1993).

Cheremisinoff, Nicholas P., *Practical Statistics for Engineers and Scientists* (Technomic Publishing Co., Inc., Lancaster, PA, 1987).

Facilities Engineering and Housing (FEH) Annual Summary of Operations Report (Office of the Assistant Chief of Engineers [OACE], 1992).

Harris, Cyril M., *Dictionary of Architecture and Construction* (McGraw-Hill, Inc., 1975).

Hutchison, B.G., *Principles of Subjective Rating Scale Construction*, Highway Research Record No. 46 (Highway Research Board of the National Academy of Sciences, National Research Council, 1963), pp 60-70.

Kaiser, Harvey K., *The Facilities Audit: A Process for Improving Facilities Condition* (The Association of Higher Education Facilities Officers [formerly The Association of Physical Plant Administrators (APPA)], Alexandria, VA, 1993).

Koehn, E., and A.M. Kao, *Evaluation of Existing Condition Rating Procedures for Civil Works Structures and Facilities*, TR REMR-OM-1/ADA170391 (USACERL, May 1986).

Kumar, A., W. Riggs, and M. Blyth, *Demonstration of the Pipe Corrosion Management System (PIPER)*, TR M-86/08/ADA166807 (USACERL, April 1986).

Melvin, Eric, *Plan, Predict, Prevent: How To Reinvest in Public Buildings*, American Public Works Association (APWA) Special Report No. 62 (APWA, Kansas City, MO, 1992).

Moore, R.K., G.N. Clark, and G.N. Plumb, *Present Serviceability-Roughness Correlations Using Rating Panel Data*, Transportation Research Record No. 1117 (Transportation Research Board, National Research Council, Washington, DC, 1987), pp 152-158.

Nakamura, V.F., *Serviceability Ratings of Highway Pavements*, Master's Degree Thesis (Purdue University, 1962).

NAVFAC P319, *Statistical Tables of Military Real Property, Navy* (NAVFAC, September 1993).

Nick, J.B., and M.S. Janoff, *Evaluation of Panel Rating Methods for Assessing Pavement Ride Quality*, Transportation Research Record No. 946 (Transportation Research Board, National Research Council, 1983), pp 5-13.

Reichelt, E.F., E.A. Sharaf, K.C. Sinha, and M.Y. Shahin, *The Relationship of Pavement Maintenance Costs to the Pavement Condition Index*, Interim Report (IR) M-87/02/ADA179653 (USACERL, February 1987).

Rush, Sean C., *Managing the Facilities Portfolio: A Practical Approach to Institutional Facility Renewal and Deferred Maintenance* (National Association of College and University Business Officers, Washington, DC, 1991).

Shahin, M.Y., M.I. Darter, and S.D. Kohn, *Development of a Pavement Maintenance Management System, Volume I: Airfield Pavement Condition Rating*, AFCEC-TR-76-27 (Air Force Civil Engineering Center, 1976).

Shahin, M.Y., M.I. Darter, and S.D. Kohn, *Development of a Pavement Maintenance Management System, Volume III: Maintenance and Repair Guidelines for Airfield Pavements*, CEEDO-TR-77-44 (Civil and Environmental Engineering Development Office, Air Force Systems Command, 1977a).

Shahin, M.Y., M.I. Darter, and S.D. Kohn, *Development of a Pavement Maintenance Management System, Volume IV: Appendices A Through I, Maintenance and Repair Guidelines for Airfield Pavements*, CEEDO-TR-77-44 (Civil and Environmental Engineering Development Office, Air Force Systems Command, 1977b).

Shahin, M.Y., and S.D. Kohn, *Development of a Pavement Condition Rating Procedure for Roads, Streets, and Parking Lots, Volume 1: Condition Rating Procedure*, TR M-268/ADA074170 (USACERL, July 1979).

Shahin, M.Y., D.M. Bailey, and D.E. Brotherson, *Membrane and Flashing Condition Indexes for Built-Up Roofs, Volume 1: Development of the Procedure*, TR M-87/13/ADA190367 (USACERL, September 1987).

Shahin, M.Y., *Pavement Management for Airports, Roads, and Parking Lots* (Chapman & Hall, 1994).

Stevens, S.S., "On the Theory of Scales and Measurement," *Science*, vol 103, No. 2684 (1946), pp 677-680.

Torgerson, W.S., *Theory and Methods of Scaling* (John Wiley and Sons, New York, 1958).

Uzarski, D.R., E.D. Lawson, M.Y. Shahin, and D.E. Brotherson, *Development of the BUILDER Engineered Management System for Building Maintenance: Initial Decision and Concept Report*, TR M-90/19/ADA225950 (USACERL, July 1990).

Uzarski, D.R., *Development of Condition Indexes for Low Volume Railroad Track*, TR FM-93/13/ADA-273334 (USACERL, July 1993).

Uzarski, D.R., *Condition Indexes for Low Volume Railroad Track: Condition Survey Inspection and Distress Manual*, TR FM-93/14/ADA286604 (USACERL, September 1993).

Weaver, R.J., and R.O. Clark, *Psychophysical Scaling of Pavement Serviceability*, Soils Engineering Manual SEM-9 (New York State Department of Transportation, 1977).

Weaver, R.J., *Quantifying Pavement Serviceability as It Is Judged by Highway Users*, Transportation Research Record No. 715 (Transportation Research Board, National Research Council, 1979), pp 37-44.

Weightman, P.A., D.R. Uzarski, and S.L. Hunter, *Condition Index for Clay Brick Masonry*, Draft TR (USACERL, May 1994).

Wittleder, C.W., D.R. Uzarski, and S.L. Hunter, *Condition Index for Concrete Masonry*, Draft TR (USACERL, May 1994).

Zaniewski, J.P., S.W. Hudson, and W.R. Hudson, *Pavement Condition Rating Guide* (U.S. Department of Transportation, Federal Highway Administration, September 1985).

Uncited

Building Research Board, National Research Council, *Committing to the Cost of Ownership: Maintenance and Repair of Public Buildings* (National Academy Press, Washington, DC, 1990).

NAVFAC MO-322, vol 1, *Inspection of Shore Facilities* (NAVFAC, July 1977).

NAVFAC MO-322, vol 2, *Inspection for Maintenance of Public Works and Public Utilities* (NAVFAC, June 1975).

NAVFAC MO-323, *Inspection Maintenance and Operations Manual for Naval Reserve Centers (NRC)* (NAVFAC, April 1986).

Appendix A: Rater Listing for Clay Brick and Concrete Masonry

Rater ID	Name	Employer
1	Steven Sweeney	USACERL
2	Donald Brotherson	Building Research Council
3	Samuel Hunter	USACERL
4	Virgean Jenkins	USACERL
5	Steven Kibler	USACERL
6	Donald Uzarski	USACERL
7	Elizabeth Rutherford	USACERL
8	Mo Shahin	USACERL
9	Richard Humphries	USACERL
10	Ronald Rosendahl	Great Lakes Public Works Center
11	William Ginkel	Great Lakes Public Works Center
12	Daniel Abrams	University of Illinois
13	Rochelle Jaffe	Construction Technology Laboratory
14	Walter Laska	Masonry Advisory Council
15	John Matthys	University of Texas
16	David Wickersheimer	U of I / Wickersheimer Engineers
17	William Murphy	USACERL
18	Charles Wittleder	USACERL
19	Philip Weightman	USACERL
20	Joann Lavrich	USACERL
21	Richard Caldwell	NORTHDIVNAVFACENGCOM

Appendix B: Rating Instructions

1. Ratings are to be done in a *random* order.
2. Raters will rate independently.
3. Distress slides will be presented "one at a time" by the facilitator.
4. Distresses to other components that may be present on the slide will *not* be considered.
5. The distress of interest will be discussed by the panel prior to rating. The discussion will encompass the distress type, severity level, and quantity or density. The sample unit delineation will also be addresses. The facilitator will answer any questions from the panel.
6. The origin of the scale is 100. By definition, if the component is free of observable distress, a condition rating of 100 shall be assigned. For any combination of distress type, severity level, and density, an appropriate rating shall be assigned by the rater based on his/her best judgement.
7. When rating, first note the category in the attached rating scale that best describes the component condition. Using the cues on the attached table and rater judgement, the most appropriate interval shall be chosen. Once the category is chosen, provide a numeric rating within the category.
8. Rate the component with regards to (1) the amount of distress present in the component, (2) that component's current physical ability to function as intended and (3) the component's maintenance, repair, or rehabilitation needs to sustain the desired level of performance.
9. Raters should take special note that they are rating the *component* with the distress present, *not* the distress in the component, per se.
10. Comment on the major factors influencing your rating.
11. Any distresses not covered during the session that the raters feel have been overlooked should be brought to the attention of the facilitator.

Condition Category	Condition Rating	Condition Description (per sample unit)		
		Amount of Distress	Functionality	Type of M&R
A	86-100	Minimal deterioration	Not impaired	Preventative or minor maintenance, or minor repair
B	71-85	Minor deterioration	Slightly impaired	Preventative or minor maintenance, or minor repair
C	56-70	Moderate deterioration	Somewhat impaired	Moderate maintenance or minor repair*
D	41-55	Significant deterioration	Seriously impaired	Significant maintenance or moderate repair*
E	26-40	Severe deterioration over small portion of sample unit	Critically impaired	Major repair
F	11-25	Severe deterioration over moderate portion of sample unit	Barely exists	Major repair but less than total restoration*
G	0-10	Severe deterioration over large portion of sample unit	Lost	Total restoration

* Major rehabilitation may be economically justified to ensure the optimum expenditure of funds for a life cycle.

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