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Infrastructure Component Assessment Using the Condition Index System: Literature Review and Discussion

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Abstract: Recent requirements in component management of building systems have focused on the requirement for improving methods and metric tools to support component condition assessment and appropriate decisions for infrastructure owned facilities. Although engineers and researchers have focused on developing methodologies for component assessment in recent years but there is not enough attention dedicate to facilities and components that have been constructed. This paper is a literature study of scientific papers within the topic of component condition index system (CCIS) in the period 1976 to 2009. Infrastructure component condition index had existed for some 40 years. The purpose of this paper is to provide an overview of CCIS to identify the suitable method for component condition assessment during its service life. This paper finds that the focus of CCIS, surveyed in several aspects during the 40 years that have been investigated, from technology to measurement and from assessment function to component maintenance as an integrated part of the infrastructure component management. This study offers help to researchers in understanding the selection of an appropriate method for component condition assessment in building and non-building systems.

Keywords: Component Condition Index System (CCIS), Infrastructure systems, Facilities, Methods

I. INTRODUCTION

When building operation is started, asset managers will be faced with many difficult decisions regarding when to effect repair or replacement of building components. Components classification and installation, methodologies, investigation, and procedures for the integrated building facilities management concerning determination of on-time maintenance are planned at providing the essential information and transforming raw data into the analysis system (Madanat et al. 1997, Harper et al. 1990, Carnahan 1998). Recent requirements in component maintenance management of building have focused on the requirement for improving methods and metric tools to support component condition assessment and appropriate decisions for infrastructure owned facilities. Although engineers and researchers have focused on developing methodologies for component assessment in recent years but there is not enough attention dedicated to facilities and components that have been constructed (Ahluwalia 2008). Component condition assessment by condition index (CI) is the most important work in the facilities maintenance process as this method is the base or the first step for other tasks such as the decisions to time and cost of building facility maintenance (repair, replacement, renewal, restoration and others).

Systematic prediction by condition assessment method offers help to researchers in understanding the cost decision making in the best time for building component maintenance. Condition index (CI) presents the ability to form a basis for measuring rates of deterioration and prediction of condition for each component or facilities. On the other hand, Condition index provides the tool to measure the overall health of the components and facilities and correlate to maintenance requirements and the needed budget levels (Shahin et al. 1977a, Shahin et al. 1977b, Reichelt et al. 1987, and Bailey et al. 1989). Although there is a diversity of techniques and technologies in carrying out the condition assessment of maintenance time, past experiences during visual inspection and the nature of building facilities due to the variety of the components should be included. Eventually, based on the studies and researches done, no support mechanism exists to help the assessor to differentiate among assessment categories (good, fair, poor, or very poor). Existing systems do not provide sufficient guidance for the execution of correct prediction for component condition. Therefore, an overview should be done to identify the suitable method to assessing and predicting the future of component condition by appropriate method (Ahluwalia 2008).

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of condition assessment that is more structured and stronger that supplies accurate results. There is a need to identify systematic method of component condition assessment.

CCIS have been in use in western countries (USA, Canada et al.) some 35 years and are today a natural tool for many components assessment activities. In what way has component condition index system (CCIS) made advances during the 40 years of existence? This question will be investigated using literature as a basis. After reviewing literature about CCIS several times the author has not yet found a literature study describing the development of CCIS. To fill this gap, we will in this paper present a literature review over the topic of CCIS focusing on the development of the concept specifically, and in comparison with the development of corporate CI in general. This study reviews much of the literature on CCIS. The literature is collected from major books, journals, technical reports and conference proceedings, the period covered is from 1976 to 2009. This paper shows a comprehensive review of various areas that are related to the condition assessment system, comprising evaluation mechanisms and comparison in selecting the appropriate method for assessing component, and condition index analysis.

II. Component Condition Index System

Since the 1980, condition assessment methods of infrastructure systems have been developed solely for individual kinds of infrastructure system assets. For instance, the association of Higher Education Facilities Officer (Kaiser 1993), PAVER was developed for pavement management (Shahin 1992), BRIDGER for bridges (Lee 1997, PONTIS 1993), DAMMER for dams (Greimann 1997), BUILDER for building management (Uzarski and Burley 1997, Elhakeem 2005, ADOE 1997), ROADER for highway and road management (WSDOT 2000), TOBUS (2002), NCES (2003), and DfES (2003) are supplement developed condition assessment tools for school buildings. Other researchers have done in this field include the roofing membrane condition index (MCI), and the roofing flashing condition index (FCI) (Shahin et al. 1987), condition indexes for clay brick masonry walls (Weightman et al. 1994), and concrete masonry walls (Wittleder et al. 1994). Also in the past few years, USACERL has developed a number of condition indexes for various types of components and facilities include the roof condition index (RCI) for built-up roofs (Shahin et al. 1987), the corrosion status index (CSI) of certain piping systems (Kumar et al. 1986), and railroad track Structure condition index (Uzarski 1993). In additional, this research institute developed a family of condition index for various kinds of civil tasks structures (Koehn and Koa 1986).

III. Condition Index Concept

In any system, the values of the condition scales support the methods of comparing the condition of different components. The condition index scale for infrastructure components is commonly from 0 to 100 and A to D where 0 or D represents a critical (failure) condition and 100 or A presents a new condition or excellent. A condition scale presentation can be obtained from the numeric or lexical values.

The concept of the condition of civil structures using an index correlation condition rating is based on rating scale theory (Uzarski and Burley 1997). These indexes provide a suitable assessment for showing present condition, survey of rates of deterioration, comparing condition between different subcomponents, components, systems, and condition prediction about each of the components. Condition index (CI) presents the ability to form a basis for measuring rates of deterioration and prediction of condition for each component or facilities. Condition index provides to measure the overall health of the components and facilities and correlate to maintenance and repair requirements and needed budget levels (Shahin et al. 1977a, Shahin et al. 1977b, Reichelt et al. 1987, and Bailey et al. 1989). The modeling indexes can be used to predict the future of conditions, when is mixed with facilities deterioration models (Kumar et al. 1986, Bailey et al. 1989, Shahin 1994, and Uzarski 1993).

IV. Condition Index Methods

This section focuses on the condition assessment methods, and provides a discussion on the specific rating scale used in the component condition development. TOBUS (2002) is the most recent framework developed by the European commission in the JOULE II program. Its condition assessment provides the scale and extent of physical deterioration and the action essential to renew office buildings. The TOBUS condition indexes were divided into four condition categories from A to D (Table 1).

TABLE I
TOBUS Condition Scale and Linguistic Presentation

Condition scale	Linguistic representation
A	Good
B	Some
C	Mean
D	Repair immediate

ADOE (1997) has developed a condition scale method for assessing education facilities condition. This department (Alaska Department of Education) supports engineers, assessors, and facilities managers with a tool that supports decisions related to when, and where for best to maintain schools buildings and their key components. ADOE condition indexes were designed to provide a purpose for component condition assessment with common language. The scale used in all of ADOE index scales from 1 to 4 and is divided into four condition categories (Table 2).

TABLE II
ADOE CONDITION SCALE AND LINGUISTIC PRESENTATION

Condition scale	Linguistic representation
1	Good
2	Fair
3	Poor
4	Unsatisfactory

Lee and Aktan (1997) have developed a condition scale for facilities of bridges. Lee's condition scale was designed to provide facilities condition assessment with a common language among users. This condition scale includes condition indexes and condition prediction capabilities. The scale is used in all of the components and facilities of bridges ranges from 1to 4 and is divided into four condition categories (Table 3).

TABLE III
LEE CONDITION SCALE AND LINGUISTIC PRESENTATION

Condition scale	Linguistic representation
1	No
2	Slight
3	Moderate
4	Severe

DFES (2003) has developed condition index model for survey building condition. DFES (Department for Education Schools) performs building condition assessment in schools and other local authority buildings. This institute has a good practice guide for local authority assessment management plan condition assessments. The DFES condition indexes were designed based on condition category for assessing component condition related to schools. The condition scales were divided into four condition categories from (A-D) (Table 4).

TABLE IV
DFES CONDITION SCALE AND LINGUISTIC PRESENTATION

Condition scale	Linguistic representation
Grade A	Good
Grade B	Satisfactory
Grade C	Poor
Grade D	Bad

NCES (2003) was developed by National Center for Education Statistics – facilities information management. This institute is the primary federal entity for gathering, analyzing, and presenting data related to education facilities in the United States and nations. NCES is assessment-based with functions that include assets of major building components and condition index. It has been used widely for school boards. The NCES condition scales were designed based on condition category. These categories include eight condition categories form 1 to 8 (Table 5).

TABLE V
NCES CONDITION SCALE AND LINGUISTIC PRESENTATION

Condition scale	Linguistic representation
1	Excellent
2	Good
3	Adequate
4	Fair
5	Poor
6	Non operable
7	Urgent building condition
8	Emergency condition

WSDOT (2000) has been developed by Washington State Department of Transportation. This department is responsible in constructing, maintaining, and performing the state highway system. WSDOT condition scale has been developed to support data collection and presentation for assessing component condition within road, railroads, and airports. The WSDOT condition scales were designed based on three condition categories from 1 to 4 (Table 6).

TABLE VI
WSDOT CONDITION SCALE AND LINGUISTIC PRESENTATION

Condition scale	Linguistic representation
1-2	Meets current standards
2-3	Adequate
3-4	Poor

PONTIS (1993) has developed a method for assessing bridge facilities. This model provides the degree and state of physical degradation and the action necessary for components in field bridges. The PONTIS's method was designed to support component condition assessment by assessors for accurate identification of component condition during service life. This method is divided into five condition categories from 1 to 5. This classification is based on deterioration process (Table 7).

TABLE VII
PONTIS CONDITION SCALE AND LINGUISTIC PRESENTATION

Condition scale	Linguistic representation
1	Protected
2	Exposed
3	Vulnerable
4	Attacked
5	Damage

Greimann (1997) has developed a condition scale for assessing infrastructure system components including locks and dams. Its condition assessment provides the degree and extent of physical deterioration and the action that is essential to renew dams and locks facilities. The Greimann condition scale was designed to provide an accurate assessment of facilities condition in field dams and locks. The scale has been divided into three condition categories. These ranges are from 0 to 100. The condition scale has been designed based on maintenance requirements (Table 8).

TABLE VIII
GREIMANN CONDITION SCALE AND LINGUISTIC PRESENTATION

Condition scale	Linguistic representation
100-70	No action is required
70-40	Only if economically feasible
40-0	Only after further

Elhakeem and Hegazy (2005) have developed a condition scale guide for assessing school components. Alhakeem's condition scale has been divided into five condition categories from 0 to 100. This scale is used for different facilities and component in field school buildings (Table 9).

TABLE IX
TABLE 9 ELHAKEEM CONDITION SCALE AND LINGUISTIC PRESENTATION

Condition scale	Linguistic representation
0-20	Excellent
20-40	Good
40-60	Fair
60-80 80-100	Poor Critical

USACERL (1990) has been developed by the U.S. Army corps engineers at the engineering research and development center. Construction Engineering Research Laboratories (CERL) in plain. This method supports engineers, assessors, and facilities managers with a toll that provides decisions regarding when, and where is the best to maintain and repair buildings and their key facilities and components. USACERL condition index method is condition-based with functions which comprise an asset of major building components; condition indexes; condition prediction skill; and comprehensive condition description for each CI value (Builder 2008). The USACERL condition indexes were designed to support a purpose and quantitative means for component condition assessment while supporting a common language and explanation among estimators and assessors. The scale used in all of the USACERL indexes ranges from 0 to 100 and is divided into seven condition categories (Table 10).

TABLE X
USACERL CONDITION SCALE AND LINGUISTIC PRESENTATION

Condition scale	Linguistic representation
100-85	Excellent
85-70	Very good
70-55	Good
55-40	Fair
40-25	Poor
25-10	Very poor
10-0	Failed

V. DISCUSSION AND SUGGESTION

The use of numeric rating has been used by TOBUS, DFES, PONTIS, Greimann, ADOE, WSDOT, Elhakeem, Lee, and NCES for assessing various infrastructure condition systems with regards to mission readiness. These ratings embody subjective opinion. Since they represent broad condition of the category ranges, minor or moderate change in condition cannot be ascertained. Therefore, these methods are wholly inadequate for building component assessment and these indices are not applicable or useful for accurate assessment of component condition. Most important issue for component condition assessment is an integrated system and a comprehensive guide for users (engineers, assessors, inspectors, etc). Users can estimate, assess, or predict component condition based on existing indexes and condition description related to each scale. Also, a condition scale should have extendable indexes for assessing components with high lifespan such as pipe or roof. Thus, those indicators are standard where their scales have amplitude in each value. For instance, methods of USACERL, Greimann, and Elhakeem have scales with amplitude in each value ((0-20), (20-40), …, etc) but other methods don't have this amplitude in each index value. This system is used for more accurate assessment of component condition and more obvious simulation results.

According to Elhakeem and Hegazy (2005), among the variety of techniques available for condition assessment, method of condition description based on visual inspection better suits the nature of infrastructure facility. Based on the experience gained during the design of the system for the assessment of components, it provides to be simple and efficient. Once the comprehensive condition description based on visual guidance is completed for all facility and components, it will become an integral module in infrastructure facility management. The condition index (CI) should provide a way of communicating the suitability of the component to provide requirement service in support of its specific task (Grussing et al. 2009). The condition category should provide a general classification of facility functional deficiencies. However, the conditions within each category must provide the depth and detail needed to suitability and objectively evaluation functionality loss. Each condition uniquely exhibits a facility-related problem that can be addressed by an actionable corrective process. Each condition category has a specific definition and visual or technical criteria that must exist. This definition and criteria provide a facility technician or a professional estimating the facility functionality with a set of instructions for measuring whether a particular condition is affecting the building facility. According to ADA (Americans and Disabilities Act), the assessor evaluates a building facility through a simple checklist and comprehensive guidance. The condition measurement process is a consistent and repeatable procedure through standardized list of facility condition and the explicitly stated criteria for each condition (Grussing et al. 2009).

Grussing et al. (2009) invoked a number of assumptions for identification of the appropriate CI method:

- CI is a measurable attribute;
- Assessors are capable of making quantitative judgment about facility condition (comprehensive condition description);
- The judgment of each assessor can be expressed directly on an interval scale (amplitude in each index value);
- Each assessor is equally capable of making the required judgment of condition;

USACERL method provides the comprehensive guideline for judging the condition scenario presented, determining which interval was the best fit, and selecting the actual score within each condition index value. Adherence to the guidelines ensured consistency and reduced error (Grussing et al. 2009).

TABLE XI
ANALYSIS OF CCIS

Methods	Type of project	Condition description	Number of scale	Extendable of scale
TOBUS	Building systems	No	4	No
DFES	Building systems	No	4	No
Pontis	Non-building systems	No	5	No
Greimann	Non-building systems	No	3	Yes
ADOE	Building systems	No	4	No
WSDT	Non-building systems	No	3	No
USACERL	Building and Non- building systems	Yes	7	Yes
Elhakeem	Building systems	No	5	No
Lee	Non-building systems	No	4	No
NCES	Building systems	No	8	No

Referring to Table 11 and discussions done the USACERL method has terms required for assessing infrastructure component system. This method has a comprehensive condition description for assessing and predicting the future of component condition assessment based on inspectors' and assessors' experiences in field component assessment during its service life. USACERL method has been used in more than 20 projects for building and non-building projects such as railroad, roof, building exterior, etc. This method includes seven condition indexes categories from 0 to 100 for accurate prediction of component condition with respect to the guidance table and assessors' experiences. Also, this condition scale is extendable into more details for component with high lifespan (more than 30 years). When condition index is divided into more index amplitude (among 0 to 100) results is more obvious and more reliable in the prediction process of component condition and more accurate simulation of the component condition assessment.

A. USACERL Condition Index Method

Referring to Table 11 and analysis done in the methodology about condition index method is determined that USACERL method has terms required for assessing building component system. This method has a comprehensive condition description for assessing and predicting the future of component condition and repair time based on inspectors' experiences and assessors in field component repair time during its service life. USACERL method has been used in more than 20 projects for building and non building projects such as railroad, roof, building exterior, etc. This method includes seven condition indexes categories from 0 to 100 for accurate prediction of maintenance time of component with respect to the guidance table and assessors' experiences. Also, this condition scale is extendable into more details for component with high lifespan (more than 30 years). When condition index is divided into more index amplitude (among 0 to 100) results is more obvious and more reliable in the prediction process of repair time and more accurate economic simulation of the component repair time. Based on the information and comparisons that have been performed, it is found that USACERL model is the best method for assessing and predicting repair time of component in this study.

B. Definition of USACERL Condition Index (CI)

The elements and components of buildings are electrical, mechanical construction, and plumbing system. Each component works with other components independently to support the activities for best quality operating building. As the components and facilities are physical asset, over time and increasing component age and deterioration, eventually destroy the operation and the reliability of the building. The best action is timely repair before complete failure of component which leads to the increasing service life and preventing replacement and restoration costs. Identification of timely repair of a component requires condition assessment to be used. One of these methods is the building condition assessment (BCA) metric (Uzarski and Burley 1997).

The development of the BUILDER engineered management system (EMS) (Uzarski et al. 1990) is a response to requirements of owner and building manager for component management and inventory condition assessment during building operation period. BUILDER uses repeatable building facility condition indexes to survey current conditions, identify deterioration rates, formulate maintenance and repair actions and predict future conditions. The component condition indexes are ultimately mixed with the building condition index (BCI).

C. USACERL Condition Index Scale

USACERL developed several condition indexes for different types of component and facilities in the past years. These assessments include the pavement condition index (PCI), for road and street pavements (Shahin et al. 1976, Shahin and Kohn 1979), the roof condition index (RCI) for built-up roofs (Shahin et al. 1987), corrosion status index (CSI) of piping system (Kumar et al. 1986). This method too has developed various types of civil works structures (Koehn and Kao 1986).

The USACERL condition indexes were designed to support a purpose and quantitative means for component condition assessment while supplying a common language and explanation among users (assessor, engineer, and inspector). The scale that is used in all of the USACERL indexes ranges from 0 to 100 and is divided into seven condition categories (Figure 1) (Uzarski 1993).

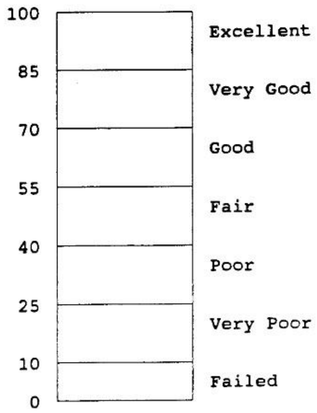

FIGURE I
USACERL CONDITION INDEX SCALE

The condition index is used to historically map the component condition over time (Figure 2) to determine the rates of degradation (Uzarski 1993). Overtime, condition index (CI) moves from 100 to 0. When engineers install a component or facility in a building, the condition index is 100 (excellent). Overtime, condition index for that component will reach below 10 value. Based on the definition of the CI scale, useful component failure happens when the CI falls around 10, which founds a functioning threshold limit for the model. For the unrepaired component lifecycle model, CI=10 when the time in service equals the expected service life. Hence, the profit of repair permits the deference of found rehabilitation required from component failure.

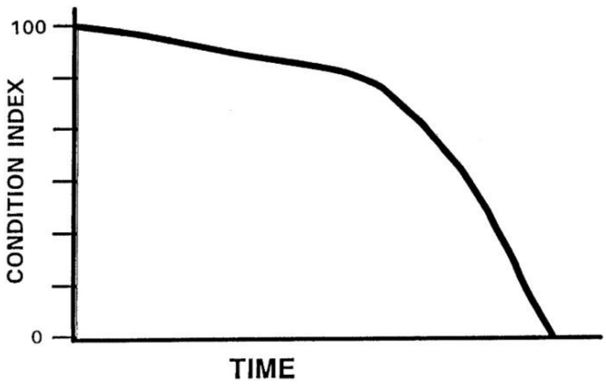

FIGURE II
CONDITION INDEX OVER TIME

D. USACERL Condition Category Guideline

The seven condition categories that sets the arrangement of the index scale also needs a guideline with the aim to set the computed repair time for a component would indeed encounter the index definition (condition description for each CI values) given above. Table 12 presents these guidelines (Uzarski 1991). It is very important that the guideline (condition description) displays the categories. This is because the use of definitions would influence integrated constraints on the formulation and the indexes for predicting repair time of component condition over time (Uzarski 1991).

TABLE XII
USACERL CONDITION INDEX GUIDE

Index	Category	Condition Description
86 - 100	Excellent	Very few defects. Component function is not impaired. No immediate work action is required, but routine or preventive maintenance could be scheduled for accomplishment.
71 - 85	Very Good	Minor deterioration. Component function is not impaired. No immediate work action is required, but routine or preventive maintenance could be scheduled for accomplishment.
56 – 70	Good	Moderate deterioration. Component function may be somewhat impaired. Routine maintenance or minor repair may be required.
41 - 55	Fair	Significant deterioration. Component function is impaired, but not seriously. Routine maintenance or minor repair is required.
26 - 40	Poor	Severe deterioration over a small percentage of the component. Less severe deterioration may be present in other portions of the component. Component function is seriously impaired. Major repair is required.
11 - 25	Very Poor	Critical deterioration has occurred over a large percentage or portion of the component. Less severe deterioration may be present in other portions of the component. Component is barely functional. Major repair or less than total reconstruction is required.
0 - 10	Failed	Extreme deterioration has occurred throughout nearly all or the entire component. Component is no longer functional. Major repair, complete restoration, or total reconstruction is required.

VI. RESULTS AND CONCLUSIONS

In this paper, literature related to condition assessment techniques has been reviewed and a method presented to enhance the process of component condition assessment. In addition to determining requirements condition for a component's current purpose, the approach described can be used to implement condition assessments to measure future requirements for a proposal purpose. The condition assessment process discussed above fills a requirements gap to completely measure and describe facility implementation. The purpose of this study is to provide an overview of CCIS in building and non-building systems. The paper provides required information about the current scenario and the past scenario of CCIS. This paper reviews much of the literature on CCIS. The authors have tried to make it reasonably comprehensive about appropriate method for component condition assessment, but existing systems do not provide sufficient guidance for the execution of correct assessment for component condition. In the present work the authors have only considered existing researches which have included assessment aspects of CCIS. The survey of CCIS reveals that the focus of USACERL method has surpassed in three aspects during the 40 years that has been investigated:

(1) From comprehensive condition description

(2) From number of scales

(3) From extendable scales

These shifts in focus are further discussed in the following:

A. Having comprehensive condition description as a guide

A condition description defines condition index in each scale. For example, when condition index is 100, the component condition is excellent and the condition description exhibits that any maintenance or repair is not required. When index is 45, the component condition is fair and condition description explains that the component needs moderate repair or maintenance. This description helps assessors in predicting the future of component condition in field repair time or action based on their experiences during the past years.

B. Number of Scales

Number of scales in each method affects on the variety of component condition assessment. More scales number result in more accurate field assessments and predicting component condition. Whenever the number of scales be more result in more accurate assessment and rating for each component.

C. Extendable Scales

When the condition scale is extendable into more amplitude (100 to 80, 70 to 40, etc) result in more obvious and more attractive in simulation results produced by the software. When the condition index is divided into more index amplitude results, it is more obvious and more reliable in the prediction process of component maintenance and more accurate simulation analysis of the component condition prediction in simulation software. Table 11 shows the analysis of various component assessment methods.

The USACERL method can be used for assessment and prediction of component condition by engineers, assessors, inspectors, and others. The study is a useful source of information for researchers working in the area of component maintenance in infrastructure systems.

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