

**Asset Management System for Communication Towers Operated by the Missouri
Department of Transportation**

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Abstract

Construction of the Missouri Department of Transportation (MoDOT) two-way radio network was initiated in the 1950's and was motivated primarily by the need to provide state-wide communication for civil defense issues. Today, the system is one of the largest in the state for voice and data communications associated with field operations as well as during times of emergency. Increasing reliance on the network is envisioned to support interagency communication (e.g., police and fire) and to support and data transfer for intelligent transportations system infrastructure. Concern regarding the network's performance during natural hazards, most notably significant earthquakes from the New Madrid Seismological Zone, has stimulated the desire for a comprehensive analysis of the network. This paper describes the development of a systematic condition indexing (CI) system developed to quantify the physical condition of guyed communications towers. Use of the system is demonstrated for two towers in the MoDOT network (Taum Sauk and Ashland) selected to represent towers in relatively poor and relatively good condition, respectively. The overall CI for the Taum Sauk tower is 54 out of 100, which corresponds to "Fair: moderate deterioration but function is still adequate." The overall CI for the Ashland tower is 85 out of 100, which corresponds to "Excellent: no noticeable defects; some aging or wear may be visible."

Introduction

A condition indexing (CI) system is an asset management tool that may be used to systematically define the physical condition of a facility or network of related facilities. The output of a CI system is a quantitative condition index, or number, typically between 0 and 100. The lowest possible index (CI = 0) represents the “worst” condition possible for the facility. The highest possible index (CI = 100) represents the “best,” or ideal, condition. Output from the system becomes a valuable quantitative parameter to rationally allocate resources for repair and rehabilitation activities.

This paper describes a condition indexing system that has been developed to assess the physical condition of communications towers owned and operated by the Missouri Department of Transportation (MoDOT). The communication network, which comprises approximately 50 free-standing or guyed communications towers, provides nearly statewide coverage and is one of the largest two-way radio networks in Missouri. Primary functions of the system include support of voice communications for daily operations between field vehicles, district offices and maintenance buildings, support of data communications for field devices and instrumentation (e.g., traffic signals, weather stations), and support of interagency communications during natural disasters and other emergencies (e.g., police, fire). The long-term demand placed on the network is envisioned to include all of these requirements, as well as increased reliance for support of wireless interoperability between public safety agencies part of emergency and disaster response and increasing support of wireless data transmissions associated with intelligent transportation system (ITS) infrastructure.

These current and anticipated demands on MoDOT’s radio network have generated significant motivation to systematically assess the physical condition of the infrastructure that supports it, most notably the towers. There is significant variability in tower age, type, height (~ 70 ft to 350 ft), physical condition, underlying soil and rock properties, and significance with regard to successful operation of the overall communication network. Many of the towers are over 40 years old and in relatively poor physical condition.

General Rationale and Methodology

A variety of CI systems have been implemented by state and federal agencies responsible for managing complex infrastructure networks made up of numerous similar facilities or structures. Notable CI applications include, for example, those developed by the U.S. Army Corps of Engineers (USACE) for managing paved road networks, shore protection structures, and earth dams (e.g., Andersen and Torrey, 1995; Andersen et al., 1999a, 1999b, 2001).

In each of these cases, a rational ranking procedure is used to quantify the physical condition of the individual components comprising the larger, more-complex system (e.g. the guy wires comprising a guyed communications tower). Qualitative and quantitative parameters are defined that may be observed and recorded during site inspections (e.g., corrosion of the guys, paint loss on the central mast, cracking of soil around the foundation, etc). Each component is assigned a quantitative value based on these observations to represent the physical condition of that

particular component and is then weighted to capture the relative importance of that component to the overall health and performance of the structure. Weighted condition values for all of the system components are summed to generate an overall condition index for the facility. Overall condition may also be weighted by the severity of anticipated environmental loads at the structure's location (e.g., seismic, wind, ice) and by the relative importance of that particular structure in the performance of the overall network (e.g., the number of communication channels linked to a particular radio tower). The output from the CI system is a numerical value that reflects the structure's level of deterioration or loss of functionality, which may in turn be used as a rational basis for recommended action and a corresponding basis for the managing agency to allocate funds for repair, evaluation, maintenance, and rehabilitation (REMR) activities.

Condition Indexing System for Guyed Communication Towers

Andersen and Torrey (1995) describe several steps required to develop a "function-based" conditioning indexing system. The CI system described in this paper for communication towers is based on the following simplified synthesis of that general approach:

- 1) Identify the functional components of the system.
- 2) Develop a component interaction matrix.
- 3) Code the interaction matrix to represent the strength of each interaction.
- 4) Define ranges between ideal and failed conditions for each component.
- 5) Develop weighting factors and formulate condition index scalar.

Step 1: Identify the functional components of the system

Most civil structures are complex systems comprised of numerous closely related and highly interactive functional components. Each of these components contributes in a different way to meet the overall objective of the structure. The overall objective of an earth dam, for example, is to retain a body of water or reservoir for an extended period of time under a variety of environmental loading conditions (e.g., precipitation events, seismic events, etc.). The overall objective of a communications tower is to provide the necessary elevation for antennas and associated communication components to function effectively. This objective must also be met over an extended period of time under the variety of environmental conditions expected to be encountered at the tower site over its design life.

Figure 1 is a schematic diagram of the basic components of a guyed communications tower. This includes: 1) a series of guys and associated guy anchoring systems, 2) the central mast, 3) the mast foundation system, and 4) environmental loading. The former three of these components are physical or "functional" components that may be directly assessed during inspections. Environmental loading is a "total system" component considered to consist of wind loading, ice loading, and seismic loading.

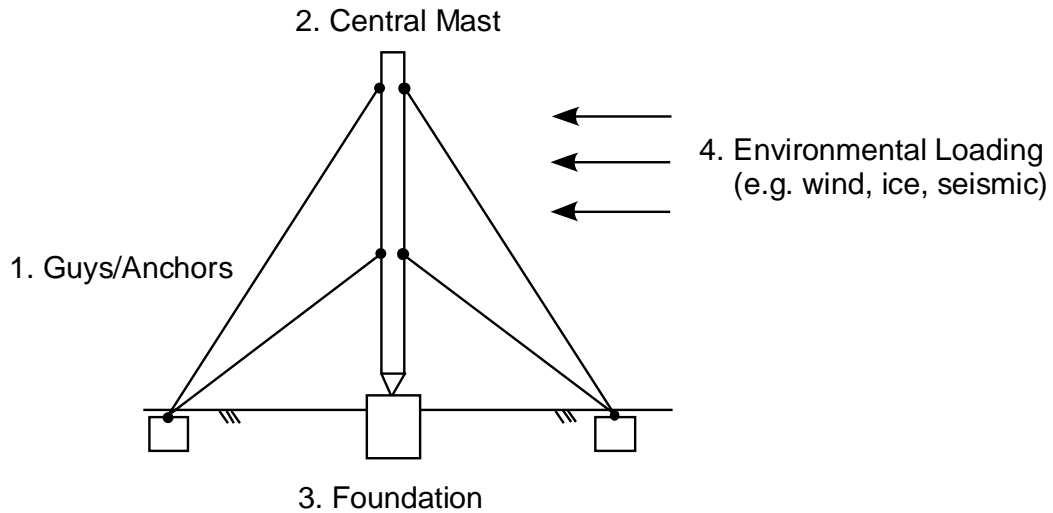


Figure 1. Four principal components of a guyed communications tower

Assessing the overall ability of the structure to meet its design objective requires one to consider not only the physical condition of the basic structural components, but also to identify how the individual components interact through cause and effect mechanisms. In other words, if the condition of one particular component is poor, how does this affect the condition of a related component? A key consideration in developing a rational condition assessment tool, therefore, is determining how the deterioration or loss of functionality of one particular component in the system can influence the ability of the other components to fulfill their role in the larger system (i.e., a “cause” mechanism). Conversely, how does the condition or performance of any one component influence the performance of any particular component (i.e., an “effect” mechanism)? These questions may be addressed by developing what will be referred to herein as an “interaction matrix.”

Step 2: Develop a component interaction matrix

Hudson (1992) proposed a generalized matrix-based approach for systematically describing complex cause and effect interactions in multi-component systems. If we consider, for example, a relatively simple system comprised of only two components, a 2×2 interaction matrix may be constructed to describe the cause and effect interactions between them. For example, Figure 2 illustrates a 2×2 interaction matrix for capturing the interactions between two arbitrary system components designated “A” and “B.” The diagonal cells of the matrix are the principal system components. The off-diagonal cells describe the qualitative interactions between the components and are considered in a “clockwise” fashion. In other words, the cell in row 1 and column 1 (R1:C1) describes the influence of component A on component B; the cell in row 2 and column 2 (R2:C2) describes the influence of component B on component A.

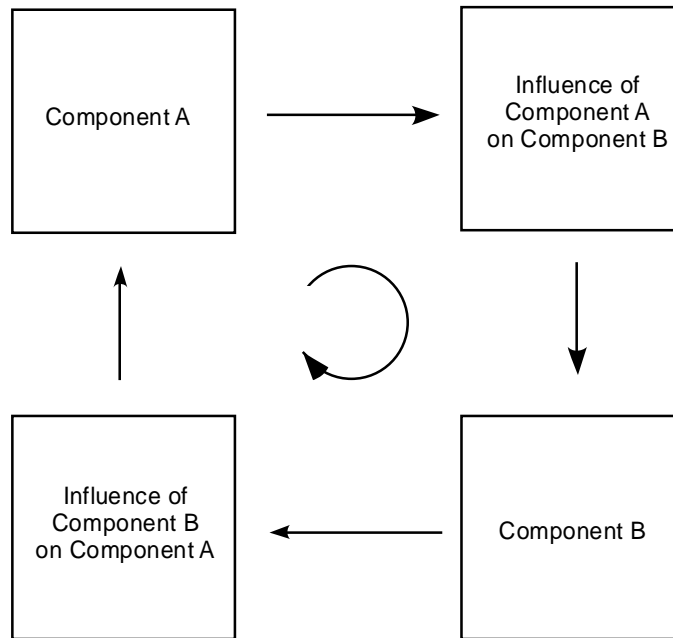


Figure 2. 2×2 interaction matrix for describing cause and effect interactions between components A and B in a two-component system. The circular arrow in the center of the figure illustrates the clockwise influence convention.

Interaction matrices have been developed to qualitatively and quantitatively describe the interactions between the three physical tower components identified in Step 1, their relevant sub-components, and their surrounding environment. Figure 3 is a generalized 4×4 interaction matrix for the four-component tower system. As before, the four principal components are represented in the diagonal cells of the matrix. Component interactions are described in the off-diagonal cells using the clockwise convention. If an interaction between any two system components is considered to be insignificant, then the corresponding cell in the interaction matrix is left blank. The actual nature of the interactions between the principal components is much more complex than can be described in the cell entries, but it is an efficient manner for representing the entire system in an organized manner.

Figure 4 is a more detailed 7×7 interaction matrix where several of the principal components have been divided into relevant sub-components. Here, the guy and guy anchor component has been subdivided into sub-components for the guy cables themselves and the guy anchoring systems. The latter, which is illustrated by the series of photographs in Figure 5, includes the anchor foundation block (typically a buried concrete block), the anchor rod (both above and below the ground surface), the anchor heads (gusset plates), the guy-to-anchor connections (e.g., cable wrap), the guy tensioning system, and, if present, any corrosion control system (e.g., cathodic protection). As also indicated on Figure 4, environmental loading has been divided into sub-components for (1) dynamic environmental loading, (2) static environmental loading, and (3) precipitation loading. The “dynamic” loading cell is intended to include dynamic loads from either wind (e.g., vortex shedding) or earthquakes. The “static” loading cell is intended to include so-called static environmental loads, primarily resulting from the build up

of ice on the various tower components. Finally, the “precipitation” loading cell includes loading from weather related events such as rainfall, freeze/thaw cycling, and soil saturation/desiccation cycling. Table 1 describes detailed qualitative interactions between each of the functional and total system components following the clockwise interaction convention

		COLUMN			
		1	2	3	4
ROW	1	Guys and Guy Anchors	relative tension governs twisting moment	total tension governs axial foundation load; relative tension governs lateral load	guy cross section governs extent of ice and wind load
	2	height of mast governs number of guy stay levels; outriggers form direct connection with guys	Central Mast	height of mast governs axial foundation load	size of mast members govern ice and wind load
	3	foundation settlement affects guy tension	foundation settlement affects mast orientation	Foundation	
	4	guy oscillation from wind and seismic loading; loading from ice; fatigue; corrosion	fatigue and static force from wind and ice loading; corrosion; paint loss	freeze/thaw soil movements; soil dessication; erosion; seismic liquefaction	Environmental Loading

Figure 3. 4 × 4 interaction matrix representing guyed communication tower system.

	Column						
Row	1	2	3	4	5	6	7
1	Guys	3	3				
2	2	Guy Anchors					
3	2		Mast	1			2
4	1	1	1	Foundation			
5	3	1	3	2	Dyn. Env. Loading		
6	2	1	2	2	2	Static Env. Loading	
7		2	2	2			Precip. Loading

Figure 4. Total system interaction matrix for assessment of overall tower structural integrity.

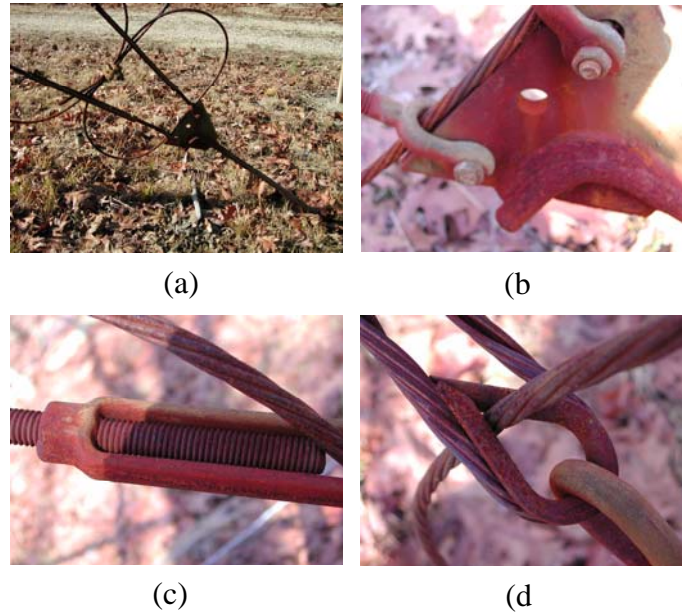


Figure 5. Components of guy anchor system: (a) guy anchor; (b) detail of gusset plate; (c) detail of tensioning system; (d) detail of cable-to-anchor connection.

Table 1. Interaction descriptions for guyed communications tower.

Row	Column	Interaction Description
1	2	corrosion in guy can proceed to anchor; excess tension can overstress anchor; guy oscillations can lead to fatigue in guy/anchor connection
1	3	excess tension or slack in guy produces twisting moment in mast (stress on bracing members); overstress in guys increases axial load in mast members; guy rupture induces dynamic loads in mast and increases static forces; variations in guy tension alters dynamic response of mast
2	1	movement of anchor may cause slackening in guy
3	1	excess twist, out of plumb, or loose members can cause excess tension/slack in guys; rocking of mast can lead to galloping in guys.
3	4	excess twist, out of plumb increases lateral loads to foundation
3	7	clogged drain holes can lead to corrosion from precipitation
4	1	movement and settlement can lead to changes in guy tension
4	2	movement or settlement relative to anchor foundations may lead to differential guy stress; overturning or rocking can lead to excess anchor stress
4	3	movement or settlement can alter mast orientation
5	1	wind and seismic loads introduce oscillations leading to potential overstress; fatigue
5	2	multiple support excitation can lead to differential guy tension
5	3	wind loading (vortex shedding) causes stresses in mast members; fatigue; base shear from seismic loading
5	4	seismic loads can lead to foundation soil liquefaction; seismic induced settlement; wind loads transmitted as lateral load
6	1	build up of ice can increase static tension, changes natural frequency
6	2	ice sliding down guy can damage guy/anchor connection (LeBlanc, 1988)
6	3	build up of ice increases gravity load; falling ice may induce significant dynamic vibrations
6	4	build up of ice increases gravity load
6	5	build up of ice increases wind load from increased member cross section (radial accumulation); build up of ice changes reactive mass of mast leading to modified dynamic response
7	2	precipitation may soften anchor foundation soils; freeze/thaw and desiccation loading may cause movement of anchor foundation
7	3	precipitation may lead to corrosion
7	4	precipitation may soften foundation soils; freeze/thaw and desiccation loading may cause movement of foundation

Step 3: Code the interaction matrix for interaction strength

The numerical values in the off-diagonal cells of the interaction matrix designate the relative strength of the interactions between the functional and total system components. The interactions follow the clockwise interaction convention introduced previously. For example, the cell (R1:C2) in Figure 4 describes the influence of the guy wires on the guy anchors of the tower. This interaction was identified qualitatively in Table 1 as: “corrosion in guy can proceed to anchor; excess tension can overstress anchor; guy oscillations can lead to fatigue in guy/anchor connection”. The strength of this particular interaction is assigned a numerical value on a scale from zero to four, in this case three. As summarized on Table 2, this corresponds to a “strong” interaction.

As noted by Andersen and Torrey (1995), interaction strength values are ideally assigned by analytical expressions or numerical algorithms and their strengths directly compared upon some uniform basis. This would give the most detailed representation of the actual nature of the interactions, but is impractical in most cases. Moreover it is not possible to accurately quantify many of the interactions without fundamental research. Interaction strengths are therefore more commonly assigned using engineering judgment of experts familiar with the overall behavior of the system under consideration. Hudson (1992) refers to this as “expert semi-quantitative” (ESQ) coding.

Table 2. Interaction strength levels for expert semi-quantitative (ESQ) coding.

Qualitative Description of Interaction Strength	Numerical Value
No significant interaction	0
Weak interaction	1
Medium interaction	2
Strong interaction	3
Critical interaction	4

Once the individual cells of the interaction matrix are coded for interaction strength, the interaction matrix can be interpreted in terms of cause and effect. The goal of this interpretation is to quantify the relative dominance of any one particular functional or total-system component. The physical condition of the dominant functional components may then be heavily weighted towards assessing the overall physical condition of the multi-component structure.

For any particular component in the interaction matrix (i.e., for any diagonal cell), all of the off-diagonal cells contained in its row describe how that component influences the rest of the system (cause). Similarly, all of the off-diagonal cells contained in its column describe how the other components in the system influence it (effect). Dominant components are those that have the greatest influence on the rest of the system. Subordinate components are those that are most influenced by the rest of the system. Because the off-diagonal cells in the matrix have each been assigned a numerical value to reflect the strength of that particular interaction, the relative dominance or subordination of any particular component can be quantified. In other words, the sum of the numbers in its row, or “cause score,” is a relatively large number for dominant system components. The sum of the numbers in its column, or “effect score,” is a relatively large

number for subordinate system components. These scores are used subsequently to develop weighting factors for the physical condition of each component in the system (Step 5).

Step 4: Define ranges between ideal and failed conditions for each component

To develop an overall condition rating for a structure, the individual functional components of the system must be quantitatively rated in a rational, repeatable, and relatively universal manner. To reduce subjectivity often associated with quantitative rating of functional system components, focus can be placed on considering deviations from ideal and failed conditions. The condition of any particular component may then be assigned a value from 0 to 100 to reflect deviation from the ideal condition. Ideal and failed conditions for each component, however, must first be defined.

In order to develop an overall condition index for a particular tower, the physical condition of the functional components must be individually ranked from 0 to 100. These component rankings are then weighted by considering “cause” and “effect” scores for each functional component.

The functional components (guys, guy anchors, foundation, and central mast) are ranked based on observed deviation from the ideal condition. Ideal conditions have been designed to include observations for the condition of items complying with Annex J (Maintenance and Condition Assessment) of Standard ANSI/TIA/EIA-222-G. These include the structural condition of the central mast, finish (e.g., paint condition), lighting, grounding, antennae and lines, appurtenances (safety, climbing facilities, etc), guy cables, foundations, and anchors. Proposed definitions for corresponding ideal conditions of the four function components are provided in Table 3. Each of these components should be assigned a value from 0 to 100 following Table 4 based on the amount of observed deviation from the ideal conditions defined in this manner.

Table 4. Indexing scale for quantifying condition of system components.

Condition Index	Condition Description
85 – 100	Excellent: No noticeable deviation from ideal condition
70 – 84	Very Good: Only slight deviations from the ideal condition are evident
55 – 69	Good: Some deviation from the ideal condition evident but function is not significantly affected
40 – 54	Fair: Moderate deviation from the ideal condition evident but function is adequate
25 – 39	Poor: Serious deviation from ideal condition in at least some portion of the component; function is inadequate
10 – 24	Very Poor: Extensive deviation from ideal condition: Component is barely functional
0 – 9	Failed: All or a portion of component is missing or has failed

Table 3. Definitions of ideal and failed conditions for functional components guyed communication tower (ideal conditions based on consideration of ANSI/TIA/EIA-222-G).

System Subunit	Definition of Ideal Condition
Guy Cables	No cut or missing guy cables No visible corrosion, breaks, nicks, or kinks Guy tension well within design tolerance No significant deviations in guy tension for given stay level
Guy Anchors	No visible corrosion of anchor rod above or below ground surface (inspection requires temporary excavation) Anchor heads (gusset plates) clear of ground surface and corrosion No visible settlement of anchor blocks No visible cracking or heaving of earth surrounding anchor block Corrosion control measures in place (if applicable) No excessive growth of vegetation around anchor Cable connectors secure Cable clamps properly applied and bolts tight Cable wraps properly and fully wrapped Poured sockets secure and showing no separation Shackles, bolts, pins, and cotter pins secure Tensioning device free of corrosion, bending
Central Mast	No damaged, loose, or bent members No missing members No loose or missing bolts and/or nut locking devices No flaking of paint or loss of galvanization No visible corrosion or pitting of members No water collection in members (clogged drain holes) Plumb and twist within tolerance (ANSI/TIA/EIA-222-G, Annex J)
Foundation	No visible settlement or lateral movement No visible cracking, spalling, chipping, or splitting in concrete No visible erosion or undermining of foundation soil No visible corrosion of mast/foundation connection No standing water on foundation or surrounding soil; no low spots to collect standing water No excessive growth of vegetation around foundation

Step 5: Develop weighting factors and formulate condition index scalar

The final step in producing an overall condition index for a complex multi-component system is to systematically “weight” the component physical conditions assigned in Step 4 to the overall condition of the structure. This may be done in a simple linear fashion by considering the “cause” and “effect” scores of the individual components identified in the coded interaction matrix (Step 3). Specifically, we can define a “total” score for a particular component as the sum of its cause and effect score. A weighting factor for the numerical condition of any one component may then be defined as the ratio of that component’s “total” score to system’s total score. The weighted conditions for each component may then be summed to generate an overall condition index for the structure.

An expression for the overall condition index of a guyed tower may be developed by considering the “cause” and “effect” scores for each functional component in the interaction

matrix. Table 5 summarizes these scores and computes the weighting factors for each functional component.

Table 5. Development of weighting factors from guyed tower interaction matrix.

Subunit	Cause Score	Effect Score	Total Score	Weight	Weight Factor
Guy Wires	6	10	16	16/52	0.31
Guy Anchors	2	8	10	10/52	0.19
Central Mast	5	11	16	16/52	0.31
Foundation	3	7	10	10/52	0.19
Total	16	36	52	---	---

Note that of the four functional components, the guy cables and central mast are the most interactive within the total system (highest weighting factors). The guy anchors and foundation are the least interactive (lowest weighting factor). An overall condition index may be computed using these weighting factors as

$$CI_{gt} = CI_{gc}(0.31) + CI_{ga}(0.19) + CI_{cm}(0.31) + CI_{fd}(0.19) \quad (1)$$

where CI_{gt} is the overall condition index of the guyed tower, CI_{gc} is the component condition index of the guy cables, CI_{ga} is the component condition index of the guy anchors, CI_{cm} is the component condition index of the central mast, and CI_{fd} is the component condition index of the foundation. The overall condition index for the tower ($0 < CI < 100$), may be correlated to a qualitative description and recommended action as summarized in Table 6.

Table 6. Proposed condition indexing scale for guyed towers.

Condition Index	Condition Description	Recommended Action
85 – 100	Excellent: No noticeable defects; some ageing or wear may be visible	Immediate action is not warranted
70 – 84	Very Good: Only minor deterioration or defects are evident	
55 – 69	Good: Some deterioration or defects but function is not significantly affected.	Economic analysis of repair alternatives is recommended to determine appropriate action
40 – 54	Fair: Moderate deterioration but function is adequate	
25 – 39	Poor: Serious deterioration and function is inadequate	Detailed evaluation is required to determine the need for repair, rehabilitation, or reconstruction.
10 – 24	Very Poor: Extensive deterioration; barely functional	
0 – 9	Failed: No longer functional	Safety evaluation is recommended.

Demonstration of Condition Indexing System

Procedures for conducting a condition assessment using the proposed CI system may be summarized as follows:

- 1) Rank the physical condition of each principal component (guys, guy anchors, central mast, and foundation) from 0 to 100 based on the observed deviation from ideal conditions using Table 2.8. This produces four numbers from 0 to 100, including CI_{gc} , CI_{ga} , CI_{cm} , and CI_{fd} .
- 2) Compute the overall condition index for the tower (CI_{gt}) by applying weighting factors using equation 1.
- 3) Correlate the overall condition index to a qualitative description and recommended action using Table 6.

Use of the proposed CI system is demonstrated in the following by considering two towers in the MoDOT network. These include towers located at Taum Sauk (Iron County) and Ashland (Boone County). The Taum Sauk and Ashland towers were selected to represent towers in relatively poor physical condition and relatively good physical condition, respectively.

Condition Index of Taum Sauk Tower

The Taum Sauk tower site was visited on December 7, 2004 for visual inspection and condition indexing following the procedures described above. Figures 6 through 8 show photographs of the overall tower and details of the functional components considered for inspection.

Table 7 summarizes corresponding condition indices assigned to each functional component using Tables 3 and 4 (guy tensions were not directly measured). The overall CI for the Taum Sauk tower based on equation 1 is 54, which, following Table 6 corresponds to “Fair: Moderate deterioration but function is still adequate.” Economic analysis of repair alternatives is recommended, which may be guided in part by considering the corresponding changes to condition index. If, for example, the guy cables were completely replaced with new cables ($CI_{gc} = 100$), the overall CI would increase to 70, or good/very good. The significant increase in CI reflects the dominance of the guy cable condition on the overall health of the multi-component structure.

Table 7. Summary of condition indices assigned for Taum Sauk tower.

Subunit	CI	Weighted CI
Guy Cables, CI_{gc}	50	15.5
Guy Anchors, CI_{ga}	50	9.5
Central Mast, CI_{cm}	60	18.6
Foundation, CI_{fd}	55	10.5
Total		54

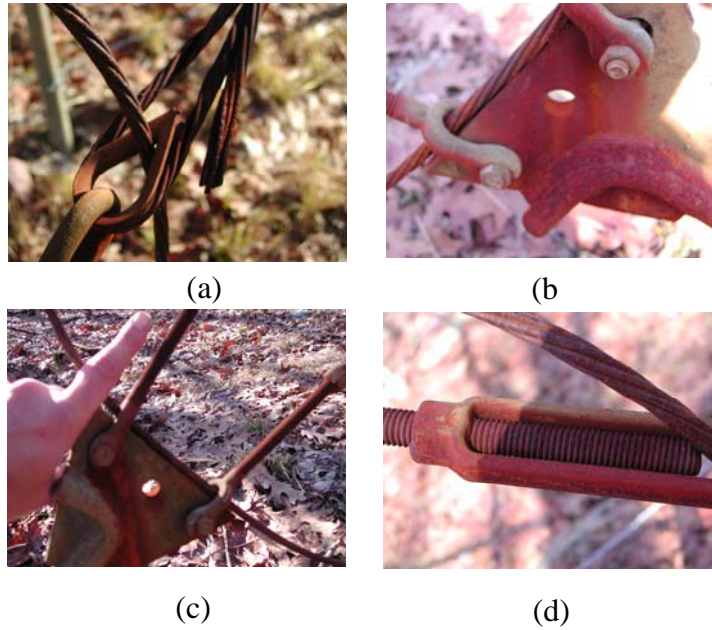


Figure 6. Details of guy and guy anchor condition for an anchor on Taum Sauk tower: (a) significant corrosion of guy cable at cable/anchor connection; (b) and (c) corrosion staining on gusset plate; (d) corrosion on tensioning system.

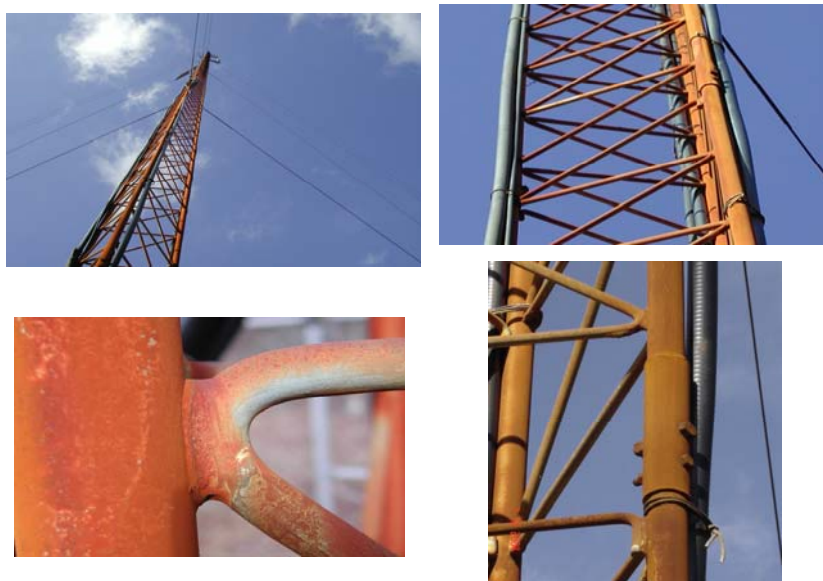


Figure 7. Various details of central mast of Taum Sauk tower showing corrosion and staining.



Figure 8. Various details of Taum Sauk foundation and foundation/mast connection.

Condition Index of Ashland Tower

The Ashland tower site was visited on April 12, 2005 for visual inspection and condition indexing. Figures 9 through 12 show photographs of the overall tower and details of the functional components considered for inspection.

Table 8 summarizes corresponding condition indices assigned to each functional component. The overall CI for the Ashland tower is 85, which corresponds to “Excellent: No noticeable defects; some aging or wear may be visible.” No immediate action is warranted.

Table 8. Summary of condition indices assigned for Ashland tower.

Subunit	CI	Weighted CI
Guy Cables, CI_{gc}	90	27.9
Guy Anchors, CI_{ga}	80	15.2
Central Mast, CI_{cm}	80	24.8
Foundation, CI_{fd}	90	17.1
Total		85



Figure 9. Detail of Ashland guy cable showing minimal corrosion.



Figure 10. Details of Ashland cable anchors.



Figure 11. Details of Ashland central mast. Significant paint flaking is observed but minimal loss of galvanization.



Figure 12. Details of Ashland foundation and shear pin.

Summary and Conclusions

MODOT installed radio towers about 50 to aid in civil-defense operations. The towers have aged and needs to be checked for their consistency especially under a natural hazard. Performing a detailed structural analysis on every tower or allocating funds for all the towers for repairs is not feasible. So to assist in repair, evaluation, maintenance, and rehabilitation (REMR) activities of the towers, a condition indexing (CI) system was developed. Using the CI the structural integrity of the towers can be rated and the most critical towers can be allotted the required funds. The CI system is based on the ideas USACE CI system for earth dams (Andersen and Torrey (1995)). The condition index has been developed consisting the following parameters: guy wires, guy anchors, central mast, foundation and environmental loading. The condition index was then calibrated for two crucial towers, one of which is known to be in a bad structural condition and the other in a good structural condition.

- ❑ It can be concluded that the condition index provides a reasonable estimate of the condition of the tower.
- ❑ The condition index is very adaptive, as it can be used to rate the structural integrity of the tower by any engineer by following the guidelines mentioned to rate the towers.
- ❑ The critical towers can be identified by rating all the towers and then ranking all the towers with their condition indices.
- ❑ Can apply the same technique to rate other facilities in critical state (eg., Pavements, bridges, culverts, etc).

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