Bridge deterioration models

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ABSTRACT

Title of Thesis: **BRIDGE DETERIORATION MODELS**

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The deteriorated condition of America's bridges raises the need for a proper and optimal method of bridge management, from the conceptual stage through the construction stage, and throughout the useful life of our bridges. State agencies need to expand their data collection process so as to include additional information pertinent to the formulation of a credible system. This is critical in order to accommodate increased research efforts to investigate the behavioral pattern/s of the nations bridges and to eventually optimize bridge management systems. This thesis looks at the bridge deterioration model as a vital tool in realizing more effective bridge management systems. The paper discusses past studies and their limitations, as well as the structure and use of these models in "aiding" the decision making process so that bridges will not only last longer, but, will also require less maintenance.

BRIDGE DETERIORATION MODELS

by

Christopher R. H. Howard

Thesis submitted to the Faculty of the Graduate School of the New Jersey Institute of Technology in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, 1991.

APPROVAL SHEET

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FOREWORD

Being involved in bridge design and construction at the start of my career, I was quite interested to learn that one of our learned faculty members, had a working interest in bridge engineering and related topics. After discussions with him I decided to investigate "bridge deterioration models" as part of my requirements to complete my masters' degree at NJIT.

After months of searching and researching relevant literature, I further decided to attempt to formulate a deterioration model or, at the least, check the validity of selected models applied to a dataset taken from the New Jersey population. With the assistance of personnel from A.G. Lichtenstein & Assoc. of Fairlawn, New Jersey, I reviewed the company's bridge records and attempted to apply the methodology used by other researchers to a small dataset of about 15 bridges from the Morris County population, since these included largely four-cycle inspection reports. I quickly realised that my approach would not yield comparable results since, primarily, the dataset was so small. I decided against increasing the dataset mainly due to lack of resources and time constraints to do a comprehensive study. My investigation was therefore limited to an outline of past research efforts and their limitations and a discussion of the approach I think necessary in order to structure effective and useful bridge deterioration models.

To my son Duane,
in whatever you do, be the best you can be.

To my wife Annette,
I live to love you

ACKNOWLEDGEMENT

The study described in this thesis was conducted under the expert supervision of Professor E.G. Dauenheimer, of the New Jersey Institute of Technology, Civil and Environmental Engineering Department. I wish to thank the staff of A.G. Lichtenstein & Associates and the Robert Van Houten Library for the assistance and time they so willfully gave in helping me to reseach and become better aquainted with my research topic.

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CHAPTER I

INTRODUCTION

1.0 BACKGROUND

Bridges last much longer than paved highways. Throughout its useful life, a bridge requires both routine and periodic maintenance and rehabilitation work before being entirely replaced. Although, sudden catastrophic failures caused by unpredictable events (eg. earthquakes, floods, etc.) cannot be accurately predicted, bridges do however, exhibit a normal progressive structural damage/deterioration that can be maintained, repaired, rehabilitated or replaced under an effective management system.

In 1989, the Federal Highway Administration (FHWA) report to congress indicated that as of June 30th, 1988, the National Bridge Inventory (NBI) included information on approximately 577,710 highway bridges, of which 23.5 percent were classified as structurally deficient and 17.7 percent functionally obsolete. Today, in 1991, it is felt that these figures could be much higher.

In reality, most of the nations bridges in service today were designed for 'less traffic, smaller vehicles, slower speeds and lighter loads than are presently found on the highway network', according to a 1987 Transportation Research Board report.[1] And further, the cost of rehabilitation and replacement was estimated, in 1989, to be in excess of $50 billion of which only approximately $3 billion is available annually to address the problem. According to a recent article published by the ACP, between December 1982 and mid-1988 only 14,839 deficient bridges were replaced or rehabilitated, or 2,698 bridges per year. At this rate, it would take approximately 88 years just to repair or replace the existing deficient bridges.[2] Further, by the turn of the century, approximately 75% of these bridges would have exceeded their 50 year design life. While these statistics do not outright reflect the magnitude and scope of the problem, they do however draw attention to a

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(1) **S.W Hudson et al**, "*NCHRP Report 300: Bridge Management Systems*" TRB National Research Council, Washington,D.C. 1987, page 4.
(2) ACP Special Feature, "*Searching for Solutions to the Bridge Dilemma*".

potential crisis and demonstrate the need for effective bridge management systems, (BMS), to manage America's aging bridge systems.

2.0 SCOPE OF STUDY

Today, there is a greater effort by State agencies to implement BMS, with perhaps the Pennsylvania DOT being the most advanced in terms of implementation. However, still very little research has been done in the area of predicting or modelling the deterioration of bridges. In general, for a BMS to be effective, it should contain the following or be able to perform the following functions, which in some cases can only be done through properly constructed deterioration models:

* Registration and description of the individual bridge;
* Prediction of future behavior resulting from deterioration;
* Actual condition of the bridge;
* Allocation of funds to specific structures on a priority basis;
* Manpower needs for repairs or replacement;
* Maintenance strategies and design;
* Short term budget requirements;
* Life cycle cost; and

* Engineering support for load rating, design and drafting to ensure uniformity, consistency and increased productivity.

This paper presents an overview of bridge deterioration models, and includes:

* A definition of bridge management systems;
* Causes and modes of bridge deterioration;
* A brief review of past studies and an assessment of their limitations;
* The data requirements for modelling deterioration;
* The structure of such models; and
* A brief look at their intended and probable uses.

CHAPTER II

BMS REVIEW

In general, BMS covers various aspects of bridge design, construction, maintenance and management. The review presented in this chapter is limited to outlining bridge management systems and the bridge rating process.

1.0 BRIDGE MANAGEMENT SYSTEMS

A bridge management system (BMS) can be described as a systematic approach for making decisions about bridge management activities to ensure that a bridge remains fit for its purpose throughout its design life without the need for excessive maintenance. One of its most important aspects is to ensure that the experience gained from observing how older bridges are performing is reflected in improvements to new bridge construction practices.

Whilst its development has lagged considerably behind that of pavement management systems, during the past decade many state agencies responsible for bridges, both here in the United States and abroad, have been actively involved in the development of such systems. This however should not be interpreted to mean that bridge-related activities were not managed in the past. As time passed, the number of bridges and their needs grew. For the past generation, more emphasis has been placed on building new bridges rather than preserving the old, resulting in what we describe today as a bridge crisis.

A comprehensive and effective BMS requires a database or system of databases which is capable of supporting the various analyses involved in the various sub-models of the BMS. FIGURE I shows a basic schematic for the development of a BMS in Finland.[3] FIGURE II shows an arrow diagram for the work flow network developed in Canada.[4] It should be noted from both figures, that input information, derived from the process of bridge inspections, is the most crucial for the success of any BMS, since it forms the basis of the

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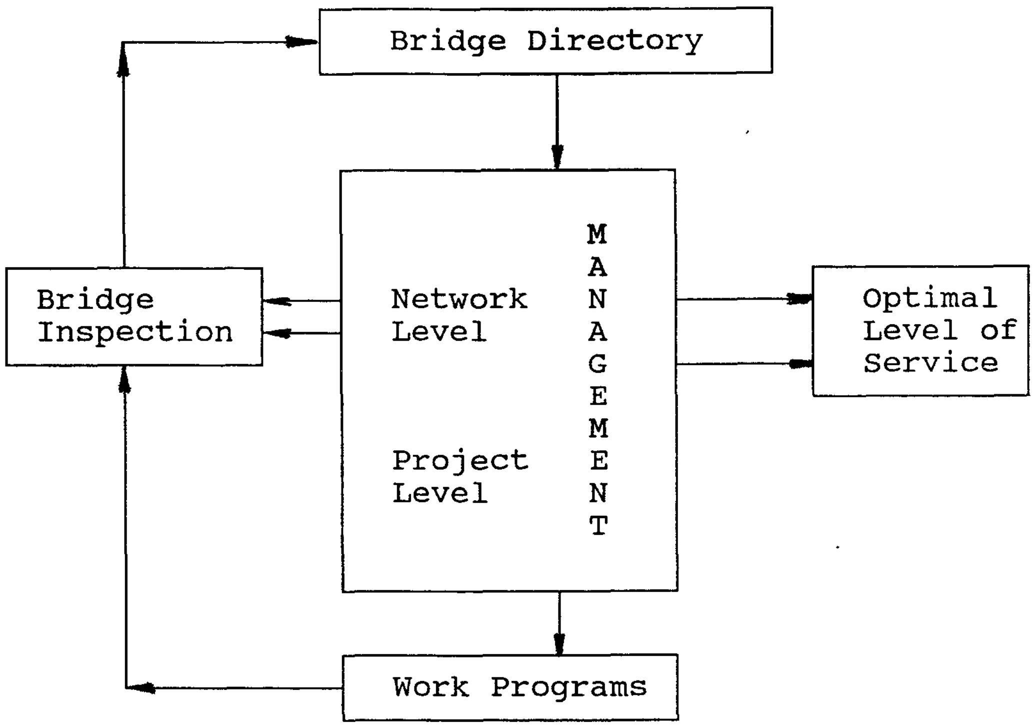
(3) **Ari Kahkonen, Allen R. Marshall**, "*Optimization of Bridge Maintenance Appropriations with the help of a Management System - Development of a Bridge Management System in Finland*".
(4) **Skelton, R.**, "*Condition Survey, Evaluation and Rehabilitation of Concrete Bridges in Ontario*", JIE-CSCE Workshop on Bridge and Pavement Engineering, Feb.1988, Kingston, Jamaica. pp 245-285.



* Adopted from the Finnish RWA

FIGURE I: BRIDGE MANAGEMENT SYSTEM

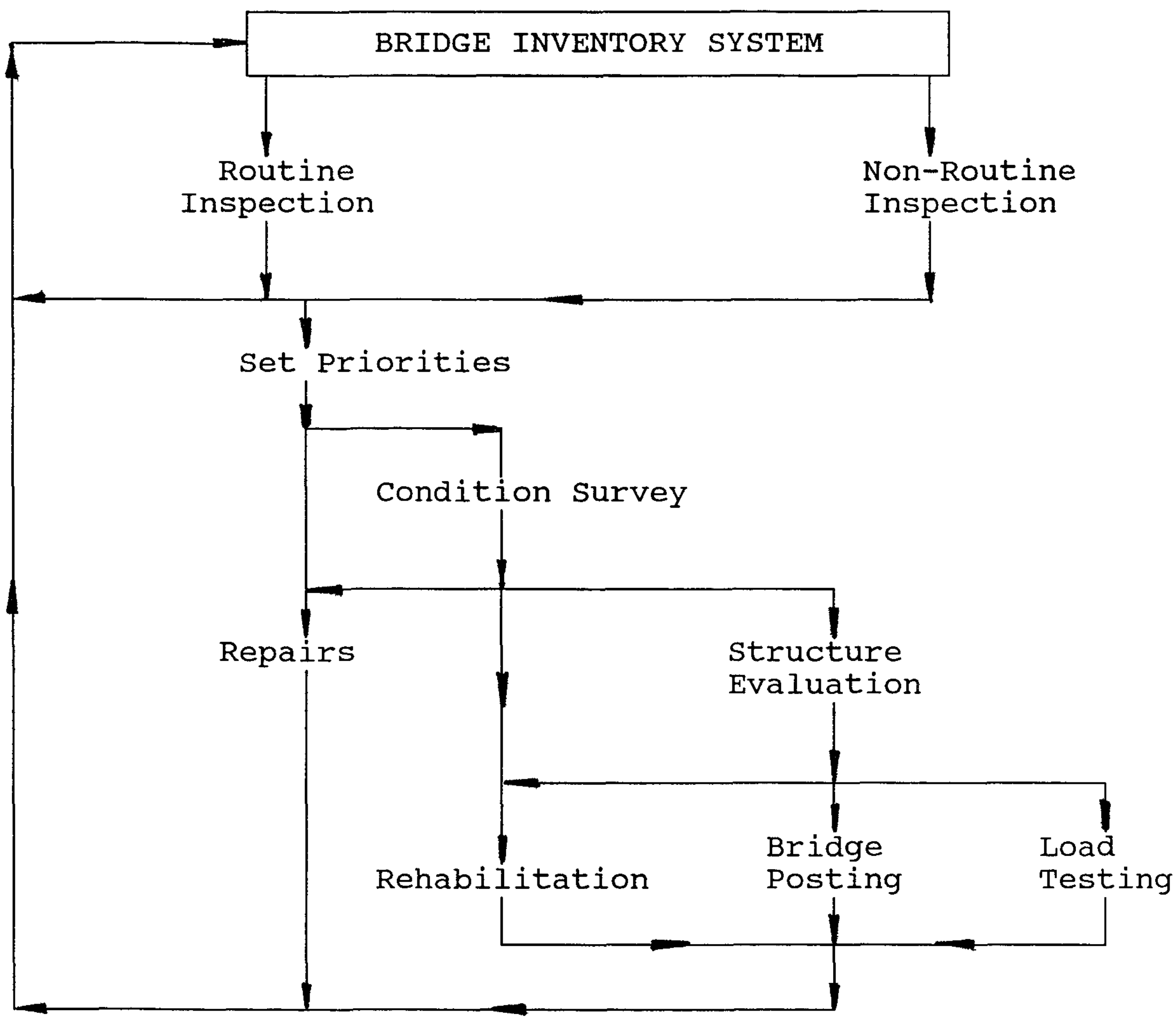


FIGURE II: WORK FLOW DIAGRAM

whole BMS structure. Information to the inventory is constantly being updated and improved to facilitate a better understanding of the behavioral pattern of bridges.

Even more crucial, however, is the consistency and accuracy of such information derived from the inspection process from cycle to cycle. As a result of this, it is vital that management be introduced from as early as the conceptual stage, since much can go wrong at this stage.

Areas of concern may include:

* Design details that cause difficulties for inspection;
* Provision of access for inspection; and
* Design for maintenance.

In general, on a net-work level, the BMS should provide:

* Present as well as future program needs such as maintenance, rehabilitation, replacement;
* Monitoring and evaluating;
* Program effectiveness under a variety of assumption and scenarios; and
* Prompt and extensive sorting of available information for reporting.

With respect to the project-level, the BMS should provide:

* Evaluation of current and prediction of future individual bridge needs;
* Prediction of remaining service-life under a variety of scenarios; and

* Available life-cycle strategies and their impact on required maintenance and life expectancy.

2.0 BRIDGE RATING

Bridge rating is the datum from which the whole bridge management system is developed. The FHWA rates the structural performance of bridges based on condition and appraisal ratings (see TABLE I) on a scale of 0 to 9, from bridge closed to excellent condition, respectively. Each category is further divided into a number of sub-categories. The bridge inspector is expected to assess each sub-category and assign a rating to each from which a rating for each major category can be evaluated. The rating of the sub-category is derived by selecting the lowest rating of any element of that sub-category.

A structurally deficient bridge is defined, by the FHWA, as one with a condition rating of 4 or less for either the deck, superstructure, or substructure, or an appraisal rating of 2 or less for either the structural condition or waterway adequacy. Further, the FHWA describes a condition rating of 4 as "*Poor condition - advanced section loss of primary structural elements. Potential exists for major rehabilitation*" (see TABLE II), whilst an appraisal rating of 2 is noted as a "*basically intolerable condition requiring high priority of replacement.*"

TABLE I: RATING CATEGORIES

CONDITION RATING	APPRAISAL RATING
superstructure	structural condition
substructure	waterway adequacy
deck	

It should be noted that whilst the condition assessment of each sub-category requires the inspectors personal judgement, general guidelines on how to assess the condition of the various sub-categories are described in the inspector's manual. Therefore, even though two inspectors may differ on the rating of a sub-category, their differences in the rating of the major category should not be significant. TABLE III shows 'condition rating' for a concrete deck evaluation as prepared by the FHWA.

TABLE II: NBI CONDITION CODES

Code	Condition Description
N	Not Applicable
9	Excellent Condition
8	Very Good Condition - no problems noted
7	Good Condition - some minor problems
6	Satisfactory Condition - some minor deterioration of structural elements
5	Fair Condition - minor section loss of primary structural elements
4	Poor Condition - advanced section loss of primary structural elements. Potential exists for major rehabilitation.
3	Serious Condition - seriously deteriorated primary structural elements. Repair or rehabilitation required immediately.
2	Critical Condition - the need for repair or rehabilitation is urgent. Facility should be closed until indicated repair is completed.
1	Imminent Failure Condition - facility is closed. Study should determine the feasibility for repair.
0	Failed Condition - facility is closed and beyond repair.

* Revised NBI Condition Codes adapted from the files of A.G. Lichtenstein & Assoc., Fairlawn, NJ

TABLE III: CONDITION RATING

- concrete bridge deck evaluation -

Category Classification	Rating	condition indicators (% deck area)			
		Spalls *	Delaminations *	Electrical Potential *	Chloride Content
Category #3 Light Deterioration	9	none	none	0	0
	8	none	none	none - > 0.35%	none - > 1.0%
	7	none	< 2%	< 5% - > 0.35%	none - > 2.0%
Category #2 Moderate Deterioration	6	< 2% spalls or sum of all deteriorated and/or contaminated deck concrete < 20%			
	5	< 5% spalls or sum of all deteriorated and/or contaminated deck concrete 20 - 40 %			
Category #1 Extensive Deterioration	4	> 5% spalls or sum of all deteriorated and/or contaminated deck concrete 40 - 60%			
	3	> 5% spalls or sum of all deteriorated and/or contaminated deck concrete > 60%			
Structurally Inadequate Deck	2	Deck structural capacity grossly inadequate			
	1	Deck has failed completely. Repairable by replacement only			
	0	Holes in deck - danger of other sections of deck failing			

* Table III is an extract from the Coding Guide for Structural Inventory and Appraisal Sheet prepared by FHWA.

CHAPTER III

BRIDGE DETERIORATION

The deterioration of bridges plays a major role in any bridge management system since primarily, such systems seek to minimize deterioration. Structurally, a bridge can be described as a complex entity with interconnections among many elements. A review of engineering literature, indicates that several factors have been identified that are considered to have aided in the deterioration of the nation's bridges. These can be classified as:

* The age of the bridge;
* Those related to the initial design of the bridge;

* Quality of construction methods and materials;
* The external environment of the bridge;
* Previous major maintenance and corrective actions;
* Those related to the effects of the weather and deicing chemicals;
* Average daily traffic (ADT);
* Average loadings from the ADT counts; and
* Decisions to defer maintenance due to budgetary constraints.

Resulting from any combination of these factors, the modes of deterioration may include:

* Paint failure;
* Corrosion of structural and reinforcing steel;
* Leaking expansion joints;
* Poor deck drainage;
* Deterioration of the roadway surface;
* Damage to the parapets and handrails;
* Structural cracks on the surface; and
* Spalling of the concrete.

Other modes of deterioration resulting from natural disasters such as floods, seismic activity, and hurricanes can cause:

* Structural damage;
* Erosion of bridge approaches;
* Undermining of bridge foundations;

* Heavy siltation of the hydraulic openings under river bridges; and
* The accumulation of debris in river channels.

Whilst studies and investigations, done by bridge related agencies, have indicated possible reasons why the nation's bridges are deteriorating, still very little is known, definitively, about the rates of deterioration and how each factor causing deterioration impact on the whole deterioration model of a specific bridge. In other words, how does a singular factor (all others being constant) impact on the deterioration of a bridge over time?

CHAPTER IV

REVIEW OF PAST STUDIES

It remains, that only a handful of Federal and State agencies have been involved or are currently involved in studies directed at modelling the deterioration of bridges. This chapter describes what has been done, through research efforts and outlines their limitations.

1.0 A NATIONAL BRIDGE DETERIORATION MODEL

Based on data contained in the NBI, the Transportation Systems Center (TSC) in Cambridge Massachusetts, embarked on a project to develop a national bridge deterioration model using linear regression theory. Primarily, the study indicated that condition ratings were a function of time and average daily traffic (ADT).

In order to obtain the best quality data from the NBI reports it was first necessary to filter the information in order to:

* Eliminate duplicate records;
* Eliminate records containing wrong coding, implausible data coding, missing values or misinformation about the bridge;
* Eliminate bridges coded as having been reconstructed, since this affects present condition ratings; and
* Eliminate bridges over 25 years to account for the "healing" process.[5]

Ultimately, only 151,933 records were included in the data set for analysis.

Based on theories obtained from engineering literature, the TSC expressed deterioration as being:

$$C = f\ (\ D,\ Q,\ E\ ) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad [1]$$

(5) After some time the likelihood that a bridge is in good condition will begin to increase due to unrecorded maintenance activities that improve the condition rating of the bridge. This is known as "healing". Studies, done by Busa et al, indicated that this occurred generally after age 20 to 25 years depending on the State where the bridge was located. For this study 25 years was assumed.

where: C is the condition rating

D is bridge design (structure type, skewness, no. of spans, wearing surface)

Q is quality of construction (construction methods and materials)

E is the external influences such as traffic counts, environment, etc.

It was then noted that only two factors of the model could be obtained through NBI data, namely traffic volume associated with external factors and bridge design factors. Other factors were obtained by using alternates (eg. the proxy for environmental factors and maintenance policies was taken as the State where the bridge was located).

An analysis of the relationships between deck condition and the variables that affected it, found that:

* Skewed bridges deteriorated faster than non-skewed;
* Multiple span bridges deteriorated faster than single span;
* County bridges had the smallest deterioration rate when compared to city and state bridges;
* Asphaltic concrete (unprotected) had the least deterioration rate than other surfaces considered in the survey; and
* Prestressed stringers deteriorated faster than prestressed box, steel stringers, and concrete T-beam.

It was noted that the regression equation had been taken to be linear and the intercept was constrained to equal nine reflecting the condition of a new bridge.

The estimated model of condition was then expressed symbolically as:

Condition = f { Age [State, structure type, span, skew, custodian], traffic} .... [2]

where it was understood that age and traffic were continuous variables, while State, structure type, span, skew and custodian were categorical and represented classes of bridges.

The final regression equations used in the statistical models for condition ratings were:

Deck = 9 - a_1{age[nested variables]} - a_2{ADTage} ...... [3]

Superstr = 9 - b_1{age[nested variables]} - b_2{ADTage} .. [4]

Substr = 9 - c_1{age[nested variables]} - c_2{ADTage} .... [5]

where:

ADTage = ADT x age / 10

$a_1, a_2, b_1, b_2, c_1, c_2$ were tabulated for various combinations of the five other variables.

Coefficients for six different versions of these equations were then generated by nesting various combinations of the five variables mentioned above.

The study concluded that:

* The models were designed to predict overall condition of the system and not the condition of any one bridge.
* Bridge deterioration was affected by a number of factors.
* Bridge decks deteriorated faster than either superstructure or substructure, which both deteriorated at approximately the same rate.
* There were indications that interactions existed among the factors influencing deterioration thus making it even more difficult to model.

Limitations

Limitations of the study included:

* The study included only selected bridge types;
* Bridges have more of an exponential decay function with a "healing" process occurring around age 20 - 25 years, however for simplicity, a linear model was used to analyze the data set;
* In using the linear regression analysis approach, it was assumed that the dependent

variables (condition codes) were continuous, which was not the case;

* Lack of sufficient relevant data such as:
    - composition of ADT counts and related imposed average loading,
    - information relating to precipitation and freeze thaw cycles as well as deicing procedures adopted by owner agencies, and
    - proxies were introduced to account for variables which could not otherwise be quantified;
* Bridges which had been rehabilitated and those over 25 years were not included in the data set so as to avoid the effects of rehabilitation; and
* The model was extrapolated for ages greater than 25 years by making the assumption that bridges older than 25 years will keep the same trend as the younger bridges. There was no conclusive evidence to substantiate this assumption.

2.0 DETERIORATION OF NEW YORK STATE HIGHWAY STRUCTURES

In an effort to optimize maintenance strategies, the New York Department of Transportation (NYSDOT) Highway Maintenance Division, embarked on a project to estimate the present deterioration rate of New York State highway structures.

Using condition ratings data from 1977-78 and 1979-80 inventory reports, which were based on a scale of 1 to 7, NYSDOT developed a plot, based on five year intervals, for the mean of all ratings for all structures built within that group and the mean age for that group. An obvious linear trend was shown for structures 15 -80 years old. Further, there were two distinct and parallel curves for structures more than 15 years old (see FIGURE III).

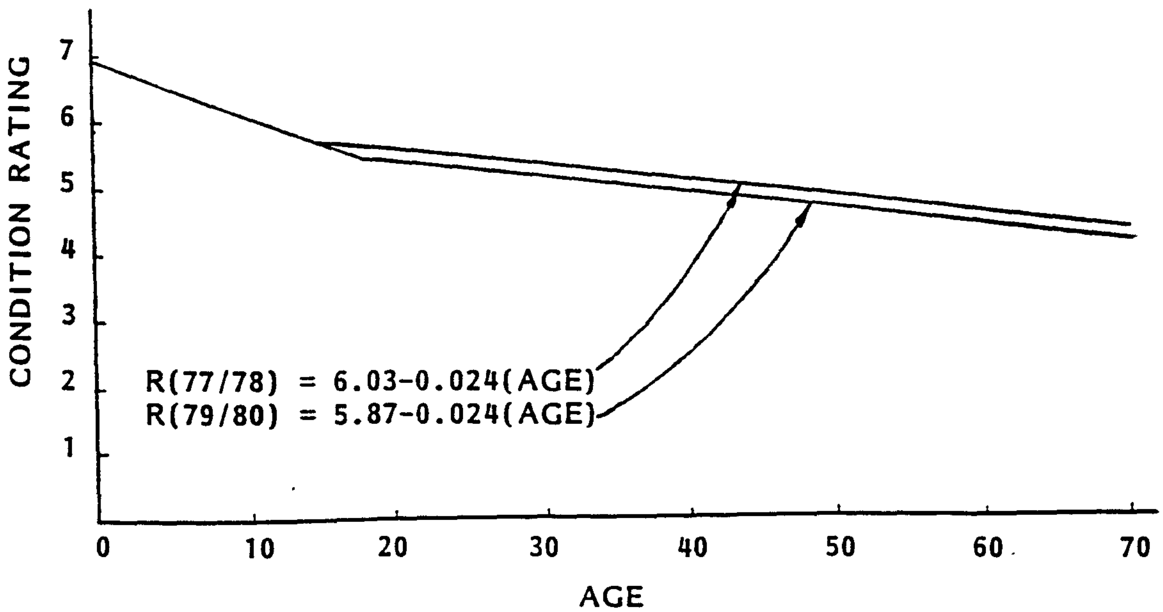
Based on the analysis given, the study concluded that:

* Between 1900 and 1965, all structures on the average began to deteriorate at a rate of 0.023 rating points per year.
* The present average annual rate of deterioration, at the time of the study, was computed at 0.122 rating points per year or approximately five times the historical rate (there was not, however , conclusive evidence to infer what factors may have been attributable).

Limitations

Limitations of the study included:

* Only two cycles of inspection reports were used in the analysis;



<u>**FIGURE III: RATING versus AGE -- 2 year data**</u>

* Again, linear regression analysis was used to model the behavior of bridges in the study;
* Only the age of bridges and their related condition ratings were considered in the analysis (all other factors were neglected); and
* The model was designed to predict overall condition of the system and not the condition of any one bridge .

3.0 NONLINEAR DETERIORATION MODEL FOR ESTIMATION OF BRIDGE DESIGN LIFE

The study, conducted by the Pennsylvania Transportation Institute was done in several phases.

First, a comprehensive literature review was done to determine what had been done by other researchers in the area of bridge deterioration.

A questionnaire was then circulated amongst bridge engineering organizations to solicit the opinions of individuals who worked in the various areas of bridge engineering. Over 95% of the respondents returned valuable feedback from the questionnaire. It was then confirmed that the most common method, in practice, of estimating remaining life of a structure was "engineering judgement".

Finally, several studies were identified and selected methods were applied to the Pennsylvania data. It was found that the approaches used by other researchers produced reasonable results when applied to the Pennsylvania data. However it was felt that two vital components had to be included, namely:

* the nonlinear nature of deterioration; and
* a mechanism to account for rehabilitation;

to obtain a more realistic product. FIGURE IV shows a plot of average deck condition rating versus age for all of the Pennsylvania bridges used in the study. A nonlinear deterioration model was then developed that expressed condition rating as a function of age using an exponential decay function coupled with a rehabilitation "spike" to provide the sudden increase in rating that accompanies bridge rehabilitation.

The refined version of the model for non-linear deterioration was given by:

$$C(t) = [1-X][1-Y]\beta_1 e^{(-t/\beta_2)} + X\,[\beta_1 e^{(-t_r/\beta_2)} + \beta_3] e^{\{-(t-t_r)/\beta_4\}} + Y\,[\beta_1 e^{(-t_r/\beta_2)} + \beta_5]\, e^{\{-(t-t_r)/\beta_6\}} \quad \ldots\ldots\ldots\ldots [5]$$

where:

C(t) = bridge condition as a function of age

e = 2.7183 = base of natural logarithms

t = bridge age

t_r = bridge age at major rehabilitation

β_1 = Y(t) for t = 0

β_2 = exponential decay coefficient before rehabilitation takes place

β_3 = the "spike" introduced due to reconstruction occurring at an age equal to or less than 25 years

β_4 = exponential decay coefficient after reconstruction; used in conjunction with B_3

β_5 = the "spike" introduced due to a rehabilitation occurring after age 25 years

β_6 = exponential decay coefficient after rehabilitation; used in conjunction with B_5

X = 1.0 if t_r less than or equal to 25; otherwise, X=0.0

Y = 1.0 if t_r greater than 25; otherwise Y=0.0

which represented a six parameter model. The model is represented graphically in FIGURE V. The model was found to be flexible in that, if rehabilitation data was lacking, then the model could easily be reduced to a four-parameter or two-parameter model by manipulating the 'X' and 'Y' terms. It was further noted that the four- and six-parameter models could only be used when there was a significant number of well documented rehabilitations within the sample.

The study concluded by applying the model/s to various bridge components of selected bridge types from a Pennsylvania bridge population, which had been carefully filtered from four consecutive PennDOT reports to FHWA, in order to determine the coefficients for each application. A

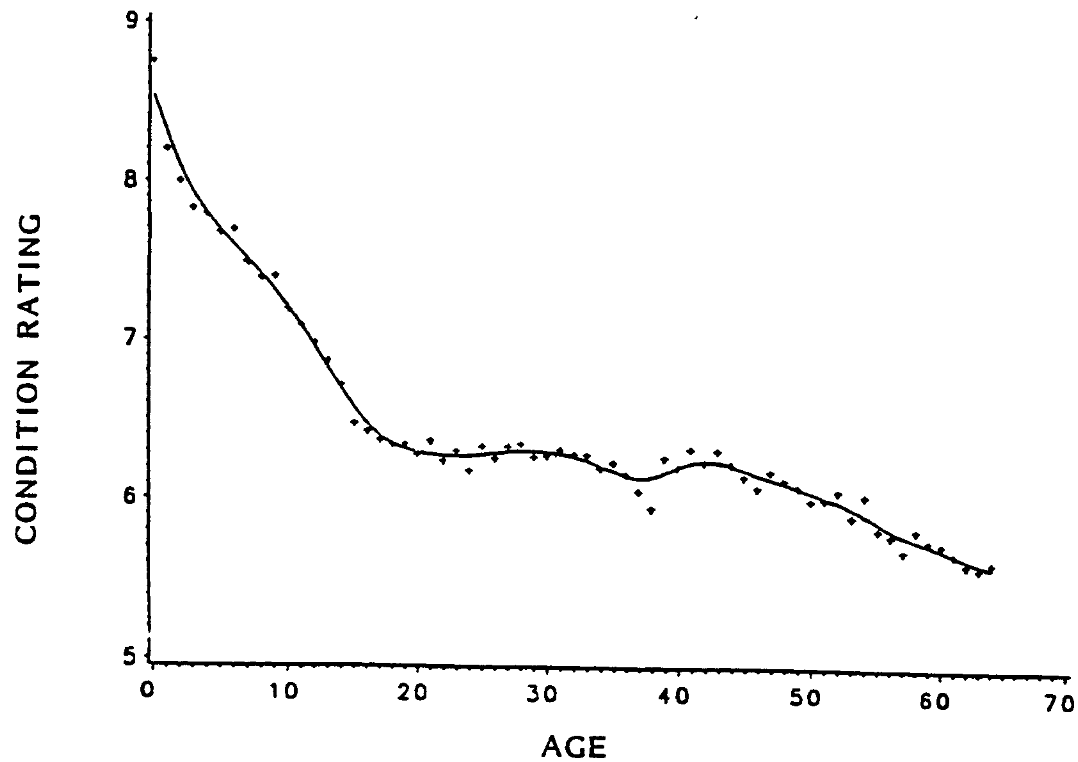
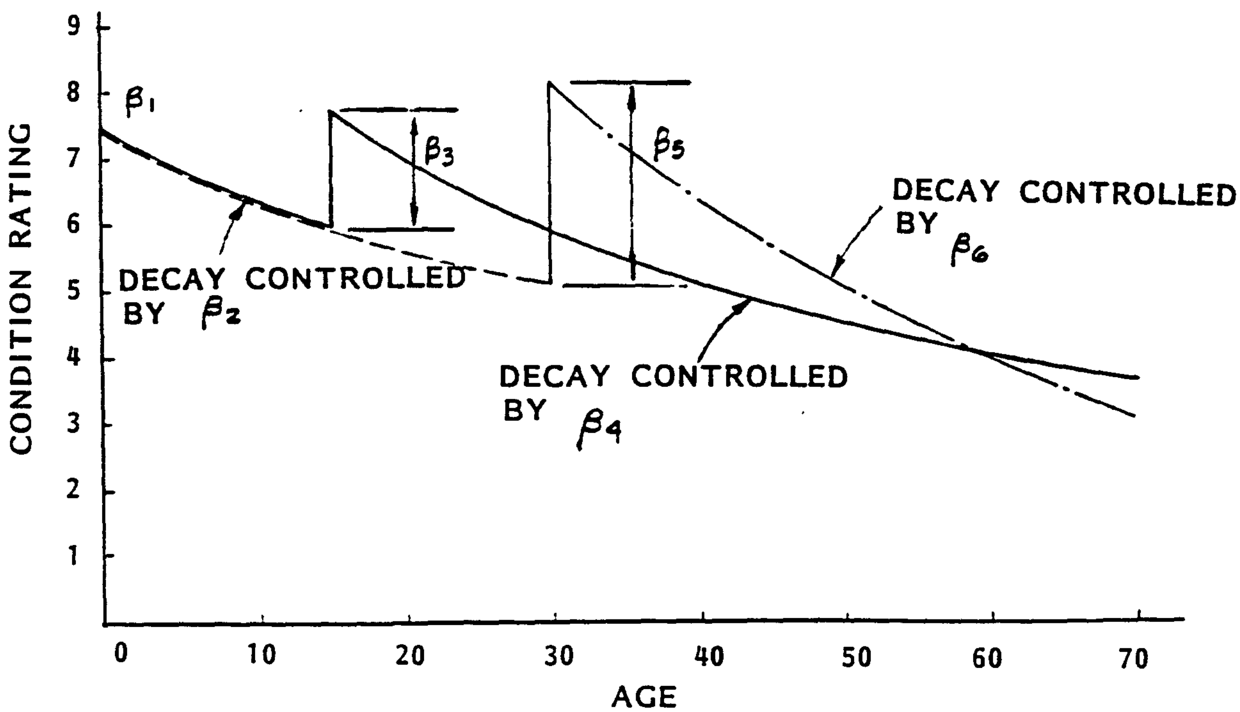


FIGURE IV: AVERAGE BRIDGE DECK CONDITION RATING versus AGE



<u>**FIGURE V: SIX-PARAMETER MODEL**</u>

sample of the resulting 25,020 bridges, was then used to make comparisons between the individual components of each bridge type and between similar components of three bridge types. The use of the models as a predictive tool to estimate bridge life and remaining life, was then demonstrated by applying the equations to probable conditions.

It was noted that:

* An increase in condition rating associated with a rehabilitation was normally coincided with an increasing ADT.
* The model had a greater success on the decks and superstructure of prestressed and steel structures.
* The rate of deterioration was greater for bridges that had undergone rehabilitation, and also, post-rehabilitation deterioration was found to be greater than pre-rehabilitation.
* Prestressed concrete bridges appeared to deteriorate faster than steel or reinforced concrete. One explanation to account for this trend is that, since prestressed bridges are younger, their condition ratings invariably do not contain undocumented maintenance activity, whilst that of their counterparts do.
* Substructures deteriorated faster than other bridge components (it should be noted that this

observation contradicts the findings of the TSC which noted that decks deteriorated faster than superstructures and substructures).[6]

Limitations

Limitations of the study included:

* The study excluded inspection data prior to 1981 due to inconsistencies in inspection and reporting procedure;
* The study only considered three structural types, namely steel, prestressed concrete and reinforced concrete;
* There were insufficient data and historic records, with respect to maintenance, and rehabilitation, for a more comprehensive study of the application of the models developed;[7]
* The sophistication of the models developed exceeded that of the available data;
* The condition ratings used in the study were highly subjective (typical of all studies done that uses condition rating as a base), and were therefore dependent upon factors that did not relate to the true condition of the bridge;
* The condition ratings included to some extent the effects of unrecorded activities

(6) refer to page 21 of this thesis.
(7) refer to limitations of the TSC model outlined on page 21 & 22.

(repainting, minor patching, etc.) that inhibit deterioration but are not attributed to rehabilitation (again, typical of any model that uses condition ratings);

* By not constraining the value of β_1, it was shown to have value of between 7 and 8, which is contrary to a designated new bridge condition. This results from an apparent rapid early deterioration which cannot be traced by the models;
* The models are more reliable when used on a set of bridges with reasonable homogeneity, ADT over 10,000 and a minimum of unrecorded rehabilitation activity; and
* The models did not produce satisfactory results when applied to reinforced concrete bridges. It was thought that these bridges, being quite old, contained several masked maintenance activities that adversely affected present condition ratings.

4.0 OTHER STUDIES

Other studies worth mentioning, but not detailed, due to lack of sufficient information about the studies include:

Bridge Maintenance Under a level of Service Concept Providing Optimum Improvement Action. Time and Budget Prediction

Conducted by North Carolina State University Center for Transportation Engineering Studies in 1987, the study was done out of concern about unreported or undocumented repairs to bridges that improved bridge conditions and thus masked the actual deterioration of bridges in the data base. Question: "*At what age does the condition rating of a bridge drop one point, assuming no major maintenance has been done?*"

Bridge Performance Prediction Model Using Markov Chain

Study performed by Purdue University, in 1987, in association with the Indiana Department of Highways, used Markov chain theory to develop bridge performance prediction model to:

* predict the percentage of bridges with a specified condition rating for each major category at a specified time;
* predict the performance of bridge decks versus time.

Modelling Concrete Deck Deterioration

Study done by Massachusetts Institute of Technology in 1985, used special statistical methods to overcome the discreteness of the condition appraisal scale set by FHWA. The study concluded that the deterioration function of decks was non-linear with age, and further, the discrete nature of the dependent variables (eg. 0 to 9 rating) required sophisticated estimation techniques.

The Least Cost Mix of Bridge Replacement and Repair Work on Wisconsin State Highways Over Time -- A Computer Simulation

Study done by WisDOT in 1983 attempted to establish a computer simulation model, using piecewise linear regression, to estimate the structural-condition appraisal relationship with the age of bridges. The technique was applied to various kinds of structures, steel deck girders, reinforced concrete deck girders, concrete slabs, and prestressed concrete bridges.

Bridge Condition Forecasting Using a Multinomial Logit Specification

Conducted by the TSC, in 1987, in conjunction with the U.S. Department of Transportation, the study attempted to implement a multinomial logit model to estimate bridge condition based on age and structural characteristics.

CHAPTER V

DATA

Currently, most States involved in setting-up bridge management systems are putting in place large data bases that contains records of all highway maintenance activities, including person hours, equipment hours, and materials expended for each maintenance as well as detailed inspection reports highlighting the condition ratings assigned to each bridge. The NBI, also has information on approximately 600,000 federally aided bridges throughout the U.S. Now that these data are available, they can be used to **begin** the process of analyzing existing deterioration rates within the nations highway structures and also to develop deterioration models for use in the prediction modules of bridge management systems.

The purpose of this section is to discuss the data collection, screening and management processes with respect to the related variables.

1.0 DATA COLLECTION

Information vital to the formulation of an effective deterioration model and which must be accessible from inspection reports include:

* Year bridge was built/ age;
* Structural type of bridge;
* Number of spans;
* Skewness of bridge;
* Maximum span length;
* Condition rating of individual elements;
* Load restrictions/ posting if any;
* Present as well as predicted future "average daily traffic" (ADT);
* Average daily loadings from the ADT counts;
* Custodianship;
* Historic records of previous inspections with particular emphasis on condition ratings;
* Maintenance and/or reconstruction records; and
* Environmental conditions that the bridge is subjected.

Age of Bridges

The definition of age must be explicit. The age of a bridge can either be referred to as the period of time after initial construction or the period of time after the last major reconstruction. Information regarding the date a bridge was built and recent major rehabilitation is usually contained in the Structural Inventory & Appraisal Sheet (SI&A) or within historical records of city and county agencies. However, as discussed later, information regarding earlier rehabilitation is not always readily available due to poor record keeping in the past. This information is however vital to the formulation of deterioration models, since all relevant factors causing deterioration must be examined within a perspective time span.

Structural Type

The structural type of the bridge is of primary concern, since typically it is expected that bridges of different structural types will have different behavioral patterns. Initial studies have so far indicated that there are differences in deterioration patterns amongst steel, concrete, and precast concrete bridges.[8] Information regarding the structural type of a bridge is contained in the SI&A sheets.

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(8) refer to page 30 of this thesis.

Design Features of the Bridge

Highway bridge design is governed by the American Association of State Highway and Transportation Officials' (AASHTO) specifications for highway bridges, and are modified yearly as new information becomes available. The specifications are usually supplemented by FHWA, State, county, or city standards. Included in the design features for input into deterioration models are the skewness of the bridge, the number of spans, the maximum length of spans, the wearing surface, the drainage adequacy and depth of cover. This information is readily accessible through inspection reports and design drawings.

Previous studies had indicated that there are relationships between a bridge's skewness, the number of spans and the span length with its deterioration. It is also known from engineering literature, that the smaller the cover to the reinforcement in concrete structures the more apt corrosion of that reinforcement will occur (of course the closer to the surface it is the more effective it is as a flexure member). The studies have also demonstrated that there are differences in the deterioration rates amongst the type of wearing surfaces used in the construction (some designs specify the use of a waterproofing membrane on top of the bridge deck in addition to a 2" asphalt layer to reduce the effect of the freeze-thaw action on the concrete surface).

Construction Practices

In some aspects, construction practices have a direct relation to design features, since a more technical design may require more intricate construction procedures. The professional ability of the contractor and the level of supervision and acceptance of the work performed comes under direct scrutiny. It is already known that poor construction practices, in terms of quality of concrete, cover to reinforcement, compaction of bearing surfaces, curing of concrete, and lack of strict monitoring of the work by design engineers, can lead to premature deterioration of newly built bridges. However it is not possible to quantify construction practices based on these parameters. For a more realistic approach the grade of the contractor could be included in the data for the bridge or, even less specific, the location of the bridge could be used as a proxy, since the location of the bridge usually determines the custodianship, who in turn determines the contractor.

Average Daily Traffic (ADT) and Load Posting

The volume and composition of traffic has obvious links to highway and bridge condition. The more a road or bridge is in use or the heavier the average loadings are, then the more the deterioration that bridge will experience due to use.

Traffic counts are available as an estimate of average daily traffic. In some cases, the figure is estimated, whilst in others, it is generated by actual traffic counts and in general may not be current. Further, the figures do not include the car-truck ratio or contain anything relating to the average loads of vehicles passing over the bridge. Also, some bridge types are more susceptible than others to fatigue when repeatedly loaded at or above capacity. Thus, in States where large numbers of overload permits are granted or trucks are commonly overloaded, reduction in the useful life of its highway bridges is anticipated. Load postings also have a similar effect on bridges as do average loadings, since by restricting the maximum load on a bridge, the average loading is directly affected. It is therefore imperative that this information be include in the data collection process, and also, be incorporated in deterioration models as one of the primary factors.

Condition Ratings

As outlined in chapter II, condition ratings are assigned to bridge elements, during the bridge inspection process, from which an overall rating is assigned to a particular bridge. Again, this information is accessible through the SI&A sheets. However, what is of great concern is the apparent disparities, between two inspectors assessment, that may occur when rating the sub-categories[9], since it will be necessary to rely on the ratings of the sub-categories when attempting to simulate the effects of the

(9) refer to page 11 of this thesis.

various factors on the elements of a structure. In short, ineffective inspection techniques and practices begets over-conservative ratings, which begets unnecessary bridge replacement/repair, which begets less money for other public works dire in need of rehabilitation.

Studies performed by Prof. Kumares C. Sinha et al of Purdue University, have attempted to promote uniformity in the condition rating process by incorporating the theory of fuzzy sets with the importance factors of the elements within the sub-category, derived through expert engineering judgement based on questionnaires distributed amongst knowledgeable and experienced individuals in the field.[10] Whilst, the approach seems logical, more research is needed to develop the theory and to eventually incorporate it in deterioration models.

Further to this, A.G. Lichtenstein & Associates, a reknown New Jersey consulting engineering firm, have been contracted by the Transportation Research Board in cooperation with the AASHTO Bridge Committee and the FHWA, to develop the revisions and additions to the 1983 Maintenance Manual. It is proposed to include more sophisticated technology in the evaluation and rating procedures of existing highway bridges, and also, to introduce more concise definitions to aid inspectors in rating the structural elements of such bridges. It also

(10) **Tee, A.B.; Bowman, M.D.; Sinha, K.C.;** "*Fuzzy Mathematical Approach For Bridge Condition Evaluation*", Civil Engineering Systems, v. 5, no. 1, Mar. 1988, pp 17-24.

proposes to upgrade the qualification of inspectors and include ongoing training to ensure that the rating practices of inspectors are consistent and that inspectors are keeping abreast of changes.[11]

The new procedures will be geared towards making the inspection and rating process more uniform and efficient.

Condition Rating of Individual Elements

In order to develop a realistic model for individual bridge performance and to determine the behavioral pattern for the major structural elements, it is imperative that the inspectors' condition rating of each element be included in the data base for analysis. The advantage of developing such a model is to provide design engineers with a tool with which they can better assess and further optimize the performance of major structural elements.

Maintenance and/or Reconstruction Records

The reason for any maintenance or reconstruction work on a bridge, is to keep it in a good working condition. This, however, directly affects the condition rating of a bridge. It is already known that maintenance and reconstruction policies vary considerably among States and are probably more dependent on available funding and public attitudes

(11) **Lichtenstein, A.G.; and Minervino, C.M.**, *"Proposed Revisions to AASHTO Manual for Maintenance Inspection of Bridges"*, Engineering Foundation Conferences- Managing America's Aging Bridge Systems: Issues and Directions. Proceedings., November 1989, pp 21-24.

than solely on concern for long-term bridge performance (some States rarely repaint steel bridges, even when faced with obvious severe corrosion). Also, very little is known about how rehabilitation affects the future deterioration of the structure and thus the remaining life. (Is the rate of deterioration greatly increased after rehabilitation has taken place?) Thus, without accurate and proper records of the maintenance and rehabilitation work performed on bridges, it is impossible to validate any model purporting to have contained in its structure, factors to deal with rehabilitation.

Environmental Conditions

Primarily, environmental conditions are related to the location of a bridge. Chlorides, whether from deicing chemicals or exposure to salt water, are factors that can be natural or the result of maintenance policies, common to that location. Moisture will also influence deterioration through the actions of humidity, precipitation, and freeze-thaw cycles. It would therefore be desirable to have freeze-thaw data, as well as some indication of the amount of deicing chemicals used, either in terms of dollar amount or preferably, volume. However, such information is not readily available. In past studies, the State where a bridge was located was often- time used to serve as a proxy for environmental conditions. However, it is known that environmental conditions are not synonymous within States.

In northern regions, freeze-thaw cycles may cause deterioration of exposed concrete with inadequate air entrainment. Also, in coastal regions, the marine environment is highly corrosive to most highway bridge materials. It is thus imperative that efforts be made to incorporate the required data into inspection reports for use in BMS modules. This can easily be done through coordinated efforts with State agencies and their relevant Metrological Offices and DOT-Maintenance Division.

Custodianship

The FHWA and the AASHTO organizations have set minimum standards by which all States are required, by law, to comply with in respect to maintenance, design, and construction of bridges. These are usually supplemented by State agencies depending on conditions in their locale. Thus, some States have stricter requirements than others. The custodianship of a bridge is therefore directly related to maintenance, design, and construction policies adapted by each State and further each county and city. In reality, custodianship is also dependent on location and, for simplicity, is therefore linked to environmental conditions.

2.0 DATA SCREENING

The data contained in the inspection reports must first be screened, as was done in previous studies, to eliminate duplicated reports and data with obvious errors. Also, coded variables must be decoded to avoid misleading prediction equations. Finally, the data set must be randomly divided into two sets:

* Data set "A" containing 2/3 of the observations; and
* Data set "B" containing the remaining 1/3.

Data set "A" will be used to derive a statistically determinant model to obtain a prediction equation, whilst data set "B" will be used to check its validity (discussed in the next chapter).

3.0 DATA MANAGEMENT

Due to the mass of data that is needed to effectively attempt the development of a bridge deterioration model, and also to facilitate the required ongoing data updating process for any BMS process, it is essential that the agencies involved be equipped with large data bases that can adequately store and retrieve the necessary data. Factors that should be considered include:

* Data Homogeneity - major revisions in data characteristics, such as changing the meaning of condition rating, may adversely affect the usefulness of past data.

* Data Accessibility - data for many structures may need to be accessed and evaluated simultaneously. Data that cannot be accessed through a computer may have no practical use in a network level analysis.
* It should be realized that often time the value of a specific data may not be apparent until after an accumulation over a number of years (eg. data needed to estimate life expectancy). Therefore special care should be exercised to avoid permanently erasing such data from the files.
* Relative Cost - The cost of gathering the additional data, not currently available as part of the NBI records, may not greatly affect the overhead costs for collecting and maintaining a core of data base.
* Quality control - the value of the analysis depends upon the quality of the data. One way of reducing errors is to eliminate, as much as possible, manual handling of data by employing field data entry using microcomputers.[12] This may also reduce staff time for processing NBI data.

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(12) refer to page 40-42 for additional methods of controlling quality with respect to reducing ambiguity in the condition rating system.

In short, it is managements' challenge to assure that the data collected are of good quality, adequate, and appropriate to the analytical requirements and are also easily accessible.

CHAPTER VI

MODELLING BRIDGE DETERIORATION

Deterioration modelling is not a new concept. Studies have been done, as outlined in chapter IV, aimed at establishing deterioration rates and statistical models for deterioration.

This section briefly describes the statistical models that have been adopted for use in deterioration models and further outlines the structure and use of specific models to model the deterioration of bridges.

1.0 DATA CLASSIFICATION

The data collection process has already been outlined in the previous chapter. The next step that needs to be done is to classify the data according to interest. The purpose of this classification is to obtain homogeneous subgroups which leads to reduce variance and a model that best represents the actual data. Typical subgroups may include:

* Number of bridges, structural type, age;
* Structural type, age;
* Structural type, ADT, age;
* Structural type, ADT, average loading, age;
* Structural type, ADT, average loading, age, custodianship; and
* Structural type, ADT, average loading, age, maintenance or repair.

The subgroups are then further analyzed statistically using the available data and then checked for significance through statistical means. Due to the magnitude of the data involved it is pertinent to link the data base to a *SAS* system[13] from which the various analyses and classifications can be performed.

2.0 STATISTICAL MODEL

The basic need of any statistical model is historical data - and lots of it.

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(13) "*SAS Users' Guide: Statistics*", SAS Institute, NC, 1985

Basically, bridge deterioration modelling consist of two parts. Firstly, there is a statistically significant model and secondly the model is tested for validity and correlation with actual values of the dependent variables. Statistically, bridge deterioration can be classified as being heuristic, empirical or stochastic.

Heuristic Models

Heuristic is a procedure that combines sciences and arts for problem solving and generating a good, but not necessarily optimal, solution. It is sometimes described as the rule of thumb method. (eg. A State may specify that all bridges with a condition rating of 3 or less will be replaced.) Currently, this is the approach adopted by most States in assessing bridge needs.

Empirical Models

Empirical or regression based models assume that elements of a bridge deteriorate at a uniform or prescribed rate. However, as discussed in chapter III, this approach does not model the actual performance of bridges. The non-linear regression models developed by West et al based on an exponential decay function appear to be more logical.

Stochastic Models

The most commonly used stochastic model for representing the bridge deterioration process is the Markov chain approach. One disadvantage to this approach is that the stationary Markov chain assume that the transition from one state to the next is independent of the time that the bridge has occupied the present state. Observations have shown this to be false. The probability that a bridge will change to a lower state increases with time in any given state.

Statistical Check

The parameters of any proposed statistical model must be checked for significance, since only significant variables should be included in any prediction equation. Some of the test statistics that can be used to check the significance of a model and the independent variables include;

* the t- statistic;
* the F-statistics;
* the coefficient of determination (R^2);
* the lack of fit method;
* the residual analysis method; and
* the standard error of regression coefficient.

3.0 MODELS

Modeling can be a complex and time consuming process. As mentioned in section 1.0, the data base should be linked to a *SAS* system to facilitate more speedy analysis and retrieval of information. It should also be noted that, the analysis of the data is best done by first exploring the salient issues with simple models and later by adding substantial improvements, future bridge conditions and patterns of replacement, rehabilitation, and maintenance can be simulated in an effective, meaningful way.

Age Models

Age, unlike many other factors which affect bridge decisions, is an accurate and easily obtainable piece of data. One of the simplest models that can be developed is one based solely on the number of bridges at every age for a particular bridge population. FIGURE VI shows a probable distribution for a bridge population. If the mean average age for bridge replacement is assumed at say 70 years (ie. the heuristic is taken as "replace bridge after 70 years"), then in any given year the height of the ordinance of the bridge age distribution at age 70 years represents a rough estimate of how many bridges should be replaced that year. By simply shifting the age distribution curve to the left (see FIGURE VII), future bridge needs may also be predicted, and thus budgeted for. It should be noted that the model derived is not a good model for estimating short term needs, since it omits all information on the condition of the bridges. However it is a good technique for assessing long-term needs into the future.

Another approach links the age of bridges for a specific bridge type or population, as was done in the New York study, to that of their respective condition ratings. Again, all other factors are neglected. A typical plot (see FIGURE

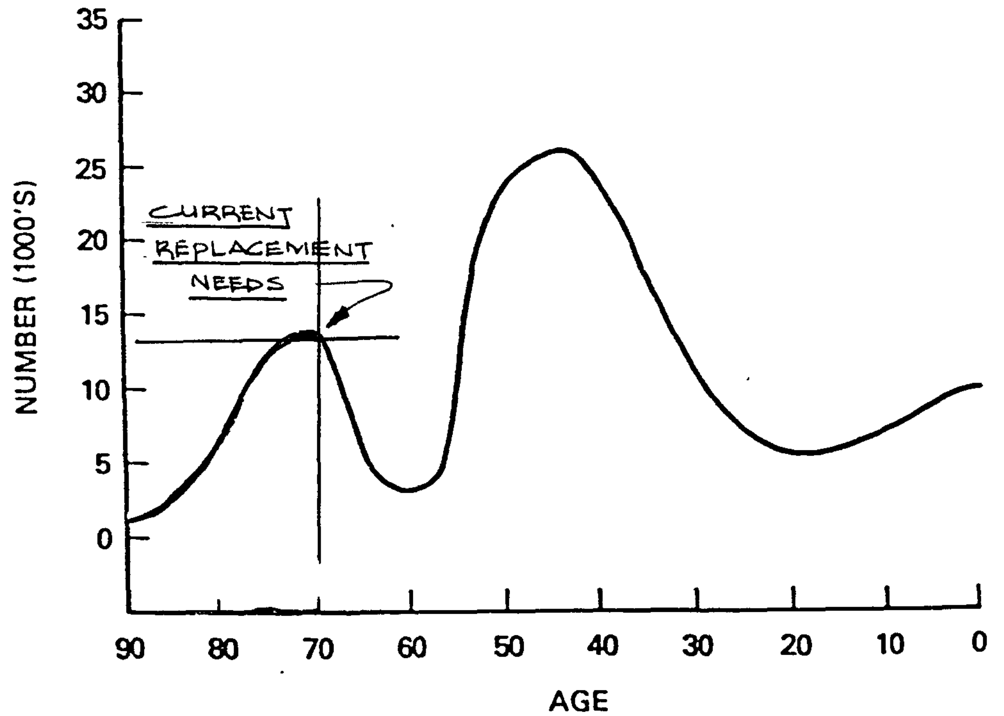

FIGURE VI: Probable Age Distribution Curve - A

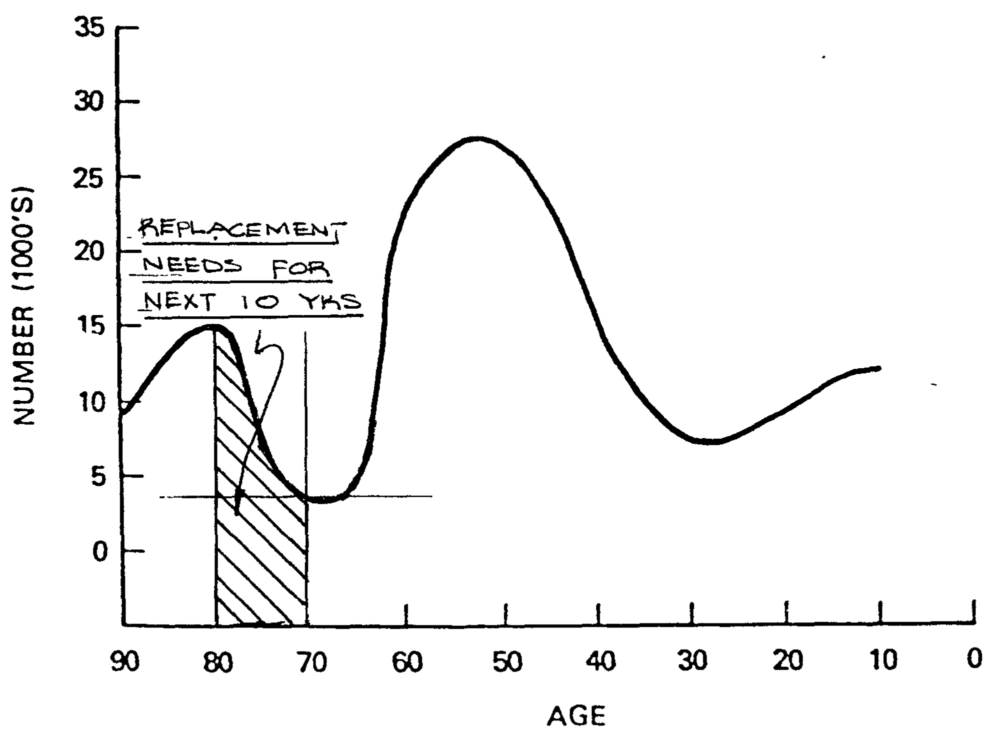

FIGURE VII: Probable Age Distribution Curve - B

III on page 24 of this thesis) can yield results that can serve as an indicator of future collective deterioration of the bridge population under consideration. For example, the New York study indicated that the current deterioration rate for the New York highway bridge population at the time of the study was 0.122. This value can then be used to predict the future collective needs of New York bridges assuming that the deterioration will continue at the same rate. Again this may not be an accurate assessment, since engineering technology will undoubtedly change in the future, but it is a good long term "guesstimate".

Complex Models

In order to develop more complex models it must be assumed that *given similar conditions and structural type, bridges will exhibit similar deterioration patterns*. Using this basic assumption, an analysis of the data subsets developed during the data classification stage can be carried out. Let's say that a bridge population is classified as follows:

- Subset 'A' - structural type , ADT;
- Subset 'B' - structural type, ADT, average loadings; and
- Subset 'C' - structural type, ADT, average loadings, custodianship.

By plotting the condition rating of each bridge in the subset versus their respective age, a relationship can be developed. The same is done for the other two subsets. It

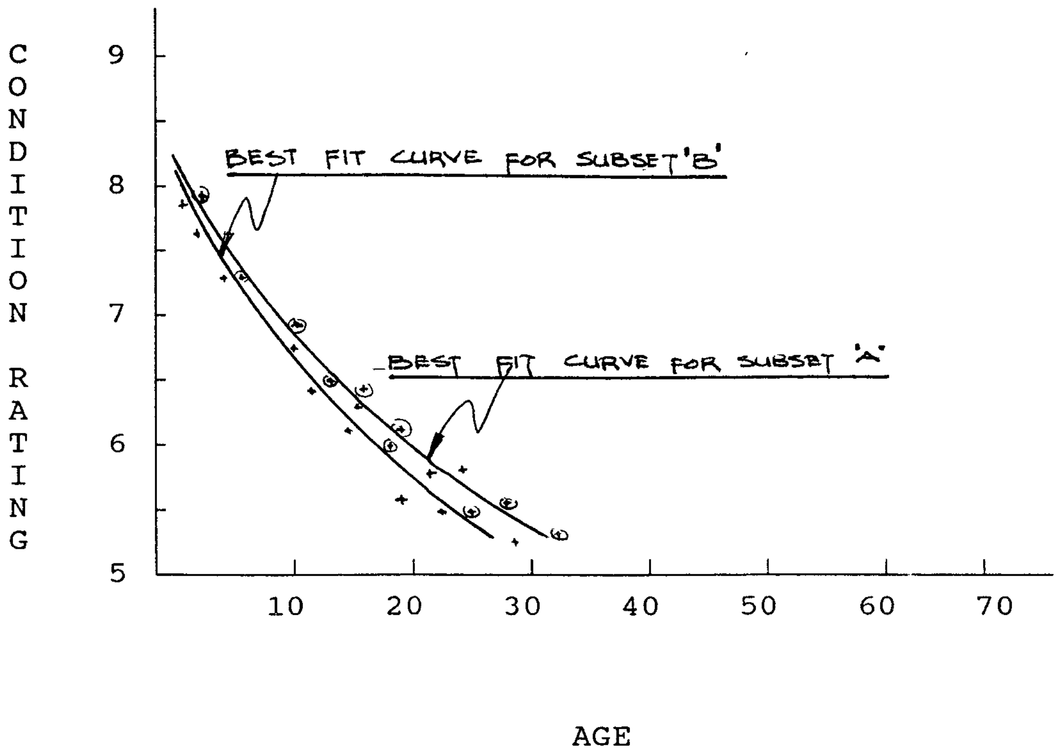

FIGURE VIII: Condition Rating vs Age for Subsets 'A' & 'B'

will then be assumed that any variation in the best fit curve for the plot will be attributable to the added factor/s. For example: Subset 'A' contains a set of bridges of similar structural type and ADT counts and yields a best fit curve shown in FIGURE VIII. Subset 'B' is a subset of Subset 'A' but contains only bridges of similar average loadings, also shown in FIGURE VIII. The variation in the best fit curve, if any, will then be attributed to the specifying of a particular range for average loadings in subset 'B'. To further improve the results, subset 'B_1' containing a different range of values for average loadings can be analyzed and likewise for subsets B_2, B_3,...B_n. Similarly, when subset 'C' is analyzed, the variation in the best fit curves will be assumed to be attributable to the custodianship factor. Again, an analysis of the curves can be done by varying the custodianship factor to determine its effect on deterioration. Similar relationships can then be developed for the other factors by varying only one factor in the subset.

One perceivable disadvantage to this method is the rapid reduction in useful data when the filters are applied to the data sets, since each subsequent subset is a subset of the its parent subset (see FIGURE IX). Statistically, this leads to increased variance, which can only be improved by including more cycles of data in the data set.

Another approach could be developed that would seek to plot the deterioration of individual elements of similar

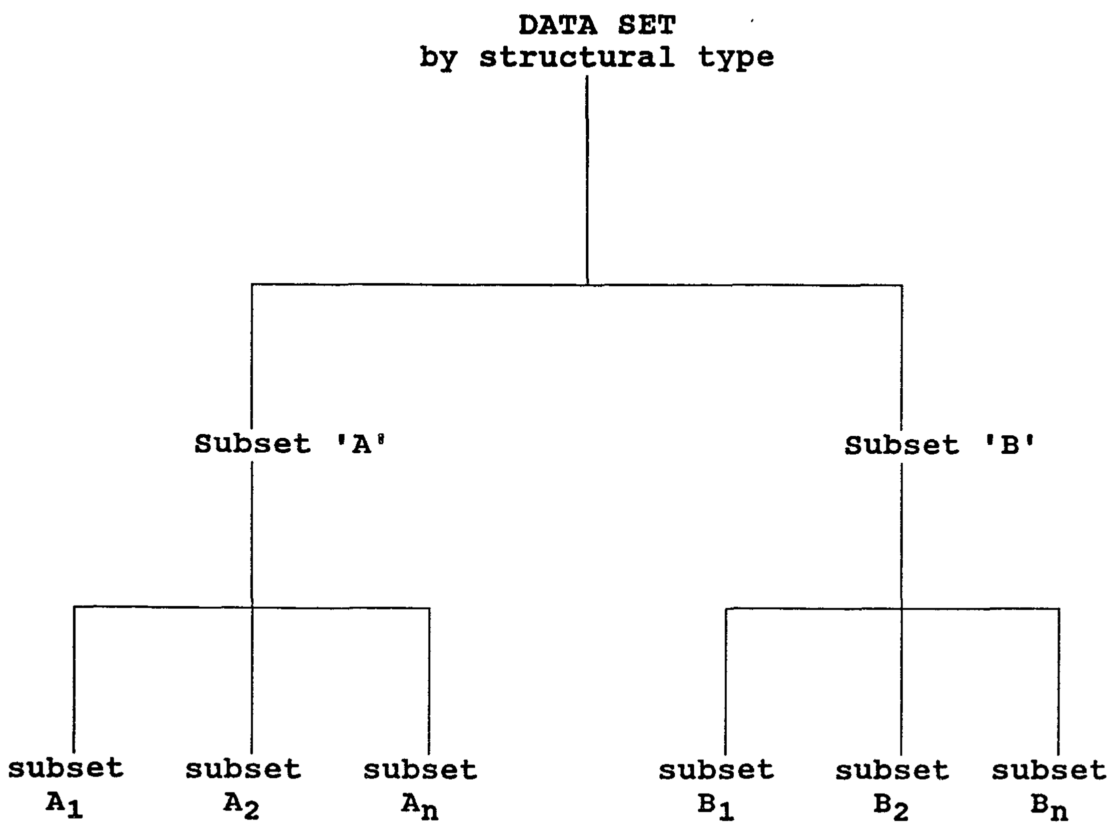

FIGURE IX: Flow diagram showing Data Sets bridges subjected to similar conditions. Again this requires the inclusion of more cycles of data. A similar methodology to the one described before could be used to analyze the data.

CHAPTER VII

CONCLUSIONS

An essential part of any BMS is the need to anticipate future bridge needs and thus be able to provide for future funding. Failure to do this will almost certainly result in increased cost in the long run. As demonstrated in this paper, a bridge deterioration model is an essential tool in realizing more effective BMS programs. However, studies conducted in this area have so far been limited, in that, in some cases:

* A linear model was chosen for simplicity, when in fact most bridges deteriorate along a curve;

* The age of bridges in the data sets were restricted;
* All studies were based on relatively short period of records (more cycles of data are needed);
* The effects of rehabilitation were neglected;
* Not all structure types were considered;
* Freeze-thaw data were not included;
* Data relating to deicing policies and related volumes were not included;
* All the studies related to collective bridge performance. None of them can be applied to individual bridge performance and prediction;
* The composition of the traffic count and its specific loading effect on condition ratings was not considered (due mainly to lack of relevant data); and
* None of the studies addressed the fact that condition ratings are subjective and thus has contained in its structure an element of human error.

However, on a more positive note, such studies do demonstrate a serious effort to address the problem.

As demonstrated in the Pennsylvania research, efforts to adapt models developed by other organizations to the Pennsylvania population produced differences in detail but showed somewhat similar general trends (eg. data showed that

Pennsylvania bridges displayed a higher deterioration rate than the national average found by using the TSC model). There are currently 52 States within the United States of America and each has varying conditions which impact on bridge deterioration differently.

* Design codes may vary.
* Environmental conditions often times differ.
* Traffic counts or ADT's are not always similar or even near similar.
* Traffic loadings may also differ.
* Custodian policies with respect to maintenance and de-icing differs.
* Construction procedures and techniques differ depending on the type of bridge and the contractor employed to do the job.

Even within States, conditions also differ. Thus, a deterioration model for Pennsylvania may not truly reflect conditions within the State of New Jersey. It is thus the business of each State to establish its own set of variables and coefficients for use in deterioration models. To date only about forty percent of the States either have in place to various degrees, or have definite plans to put in place, Bridge Management Systems. Still only a handful of these have allocated for the research of bridge deterioration as part of their proposed BMS program.

It must be noted that there are still those in the industry that believe that the nature of deterioration of bridges is so complex that an estimate of remaining life based on an experienced engineer's judgement is as good as any other method available. It is their opinion that studies in this area will only yield theoretical results which have no bearing on the actual deterioration of bridges in the field (thus perhaps, the reason for the lack of sufficient financial support to try and understand the nature of the deterioration of the nation's bridges).

Whilst there may be good arguments to substantiate their belief, such as:

* the subjective nature of condition ratings which forms the base of deterioration models;
* the lack of knowledge and understanding about how the factors causing deterioration interact and to what degree;
* the enormous cost of gathering the necessary data to undertake a proper study; and
* there is no guarantee that bridge deterioration can reliably be predicted after considering ALL factors, and also, based on the fact that engineering practices and technology will be different in the future;

the fact remains that there is still a great deal which is not known. Also, estimating remaining life should not be the sole purpose of establishing deterioration models. Deterioration models must be envisioned as **tools** for use by bridge engineers and managers to:

* Aid in predicting maintenance strategies of specific bridges;
* Aid in optimizing bridge ranking for repair, replacement or rehabilitation;
* Aid in the decision making process to determine if a bridge should be replaced or rehabilitated based on its remaining life after rehabilitation;
* Aid in predicting life-cycle cost;
* Aid in design optimization in terms of selection of structure type, wearing surface, etc.;
* Aid in optimizing material selection and construction procedures; and
* Aid in the load rating process of bridges by relating load posting to proposed remaining life.

The FHWA encourages States to implement BMS programs, but more needs to be done. It is clear that since only less than half of the States have shown positive interest in establishing BMS programs, the magnitude of the bridge problem is not yet realized by all. Even for those States that have not reached a 'crisis' level, it should be realized that the time to act is now. Economic trends, indicate that the cost of money seldom decreases, if ever.

As we approach the twenty-first century, engineers will be faced with the ever challenging task of providing new cities and towns to accommodate the ever increasing population. This means new roads, new bridges, replacing the old, and repairing the not so new. Without research, without knowledge of bridge deterioration, without tools, bridge engineering and bridge management will remain in the dark ages.

For the future, it is hoped that, through the benefits of research:

* Professionals, in the bridge related disciplines, will have the benefit of deterioration model computer software to simulate the effects of the various conditions on the proposed bridge design, whilst varying field parameters both actual and predicted.
* Bridge design and construction contracts can conclusively be awarded based on predicted life-cycle cost associated with each alternative and not on proposed construction cost only. It is particularly suited when evaluating multiple alternatives which have unequal life expectancy and maintenance requirements.
* State agencies will be better able to manage bridge systems by prioritizing bridge needs, after carefully simulating the effects of the various factors and conditions on existing bridges (may also be pertinent to link

Geographic Information Systems (GIS) to BMS modules to aid in re-routing optimization).

In the end, I believe, with ongoing research into the parameters that affect bridge deterioration, we will eventually approach an era when bridges can, not only be designed and built economically, but will also have durability and require a minimum of maintenance.

APPENDIX

BUREAU OF BRIDGES & STRUCTURES - STRUCTURE INVENTORY AND APPRAISAL

STATE ERROR NO
FEDERAL ERROR NO
LAST UPDATE 042489
IMP.COSTS ARE IN THOUSANDS
INSP.COSTS ARE IN HUNDREDS

A ROUTE 9014 8 STR.NO. 1400183 8 STRUCTURE NAME KINNELON RD OVER BEAVER BROOK

IDENTIFICATION

1 STATE NEW JERSEY
2 HIGHWAY DISTRICT 01
3 COUNTY MORRIS
4 TOWN BOONTON TWP.
5 INVENTORY ROUTE 141006180
6 FEATURES INTERSECTED BEAVER BROOK
7 FACILITY CARRIED KINNELON ROAD
9 LOC. .7 MI NO OF KINCAID RD
10 VERTICAL CLEARANCE 99 FT 99 IN
11 MILEPOINT 000 00
12 ROAD SECTION NUMBER 0000
13 DEFENSE BRIDGE LETTER
14 DEFENSE MILEPOINT 00 00
15 DEFENSE SECTION LENGTH 00 0 MI
16 LATITUDE 40D 57 5M
17 LONGITUDE 074D 24 8M
18 PHYSICAL VULNERABILITY 3
19 BYPASS DETOUR LENGTH 09 MI
20 TOLL ON FREE ROAD
21 CUSTODIAN COUNTY
22 OWNER COUNTY
23 FED-AID PROJECT NO.

CLASSIFICATION

24 FEDERAL-AID SYSTEM 14 FA URBAN
25 ADMINISTRATIVE 4 OTHER
26 FUNCTIONAL CLASS 14 MINOR ARTERIAL URBAN
C NON-INV-FEATURE WATERWAY
D ADMINISTRATIVE STATE
EA ALTERNATE AGENCY
EB ALTERNATE STRUCTURE NO.

27 YR BLT/RECONS. 29/00
28 LANES ON/UNDER 02/00
29 ADT 003700
30 YR OF ADT 88
31 DESIGN LOAD UNKWN
32 APP.RDWY WIDTH 020 FT
33 BR MEDIAN NONE
34 SKEW 25 D
35 STRUC.FLARED NO
36 SAFETY FEATURES 0000
E BR RAILING TYPE 18
F RAILING HT 3FT02IN
G CHLK.FEN HT FT IN
37 HISTORIC SIG 5
38 NAVIG. CONTROL NO
39 NAV.VERT.CLEAR 000 FT
40 NAV HOR.CLEAR 0000 FT
BB FENDER SY NONE
CA SPEED POSTING MPH

STRUCTURE DATA

41 OPEN/CLOSED/POSTED (LOAD/SPEED) OPEN
42 TYPE OF SERVICE HIGHWAY / WATERWAY
43 STRUC TYPE MAIN SPAN STEEL STR/MB GR
44 STRUC TYPE APPR SPANS NONE
45 NUMBER OF SPANS MAIN 001
46 NUMBER OF APPROACH SPANS 0000
47 TOTAL HORIZONTAL CLEARANCE 37 2 FT
48 MAXIMUM SPAN LENGTH 0022 FT
49 STRUCTURE LENGTH 000026 FT
50 SIDEWALK / CURB LEFT 00 0 FT RIGHT 00 0 FT
51 BRIDGE RDWY. WIDTH CURB TO CURB 037 2 FT
52 DECK WIDTH OUT TO OUT 040 0 FT
53 VERTICAL CLEARANCE OVER DECK 99 FT 99 IN
54 MIN. VERTICAL UNDERCLEARANCE 00 FT 00 IN
55 MIN LAT.UNDERCLEARANCE RIGHT 99.9 FT
56 MIN.LAT.UNDERCLEARANCE LEFT 00 0 FT
57 WEARING SURF. ASPHALTIC CONC-NO PROT.SYSTEM
CB SURF.TREAT. NOT APPLICABLE
CC REBAR PROT. NO COATING ON REBARS
CD SPEC.CONC. NOT APPLICABLE

H SLOPE PROT NONE
J ABUT. FULL HEIGHT
K PIER NONE
L FILL OVER STRUCTURE FT
CE UTILITY

REPAIR QUANTITIES

CN DK REPL CU YDS
CO DK RESUR SQ YDS
CP SUBSTRUC REPLACEMENT CU YDS
CQ PAINTING STEEL T
CU STEEL REPL LBS
CS GUIDE RAIL NEEDED 0200 FT

REPAIRS MADE

AP ITEM PAINTED
AQ DT.PAINT.CONT. /
AR TH RESUR.UNDER IN
AS DT.RESUR.CONT. /
AT TH.RESUR.OVER IN
AU DT.RESUR CONT. /
AV TY.DECK REPL.
AW DT.DK REPL CONT /
AX TY.SAFETY CONT.
AY DT.SAFETY CONT /

CONDITION RATING

58 DECK 6
59 SUPERSTRUCTURE 6
60 SUBSTRUCTURE 5
61 CHANNEL AND CHAN PROTECTION 6
62 CULVERT AND RETAINING WALLS N
65 APPROACH RDWY CONDITION 7
63 ESTIMATED REMAINING LIFE 10 YRS
64 OPER.RATING 496
66 INV. RATING 465

REMARKS

CF (58) SPALLED UNDER DECK; EXPOSED REBARS;
CG (59) ENCASEMENT DETERIORATION
CH (60) MEDIUM/WIDE CRACKS; SEVERE SPALLING; SEVERE SCALING;
CI (61)
CJ (62)

PROPOSED IMPROVEMENTS

73 YEAR NEEDED 00 82 YR.RDWY IMPR. 00
74 TYP SERV. HIGHWAY 83 TY RD.IMP NA
75 TYPE OF WORK 352 84 IMPR.COST 00043
76 IMP.LENGTH 000000 FT 85 PE COST 000
77 DESIGN LOAD 0 86 DEMO. COST 000
78 ROADWAY WIDTH 0000 FT 87 SUBSTR.COST 00000
79 NUMBER OF LANES 00 88 SUPER.COST 00000
80 DESIGN ADT 000000 89
81 YEAR OF ADT 00 90 LATEST INS 091688
EK INSPECTION TYPE S
AN DESCRIPTION OF PROPOSED IMPROVEMENTS
INSTALL BR&APR RAIL,PAINT SUPER,PATCH SPALL ,SCALING IN SUB,UNDERDECK;SEAL CRACK IN SUB ,BR&APR ROADWAY;CLEAR CHANNEL;FILL ASPHALT POTHOLES.

OTHER INSP DATES

ED INSP.BEF PREV. 06/84
EE DIVING INSP /
EF MECH-ELEC INSP /
EG DECK COND SURV /
EH SPEC TESTING /
EI INTERM INSP /
EJ INTERM FREQ. MO
BC PLAN AVAIL. NO

APPRAISAL RATING

67 STRUCTURAL CONDITION 5
68 DECK GEOMETRY 5
69 UNDERCLEARANCE VERT. & LAT N
70 SAFE LD CAP. 8
71 WATERWAY ADEQ. 6
72 APPR RDWY ALIGNMENT 7
EU DESIGN EXCEPTIONS

REMARKS

CL SUBSTRUCTURE
Y PERCENT OVERSTRESS
ECB DIVING NOT REQUIRED
CM

RATINGS (TONS)

ITEMS	INV. T-X&RY	OPER. M-S&RS
H TRUCK/LD1	46	68
HSTRUCK/LD2		
TYPE 3 /LD3	65	96
TY.3S2 /LD4	99	99
TY.3-3 /LD5	99	99
MIL.LD /LD6		
GROSS LOAD		

DECK STRESSES (KSI)

AA CONCRETE 0 203
AB STEEL / TIMBER 05.7
AC MISC. RATING

INSPECTION DATA

AD INSP. CREW 003 F
AE NEXT INSP.DATE 09/90
EV CONSUL. A G LICH
AK PREV.INSP.DATE S09/16/86
PRV CONS
AL CYCLE NUMBER 04
AM FEDERAL REPORT YES
DJ BRIDGE LIST
EM SPECIAL EQUIPMENT
EN SPECIAL TESTING
EO SPECIAL MATERIAL
EP ADD. STRUCT. TYPE
EQ WIDENING TYPE

ER FATIGUE DETAILS
LOC 1
LOC.2
LOC.3

SUFFICIENCY RATING (NOT DEF) 082.1

RAILROAD ITEMS

RA USRA LINE CODE
RB RR.TRKS ON/UNDER /

PROGRAMMING

FJ FED JOB NO. BR NBIS322
SJ STATE JOB NO. 8711112

A: SI&A SHEET

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