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Kyoto Univ. and UTC Joint Summer Training Course of

Road Infrastructure Asset Management

Bridge Management (3)
Deterministic Deterioration Prediction

Osaka Univ.

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Research Experience

Vibration Engineering (1995-Present)

- Bridge Vibration Monitoring
- Structure Performance Evaluation
- Damage Identification

Asset Management (2001-Present)

- Statistical Deterioration Prediction
- Life Cycle Cost Analysis
- Policy Evaluation

→ Infrastructure Management

Professional Affiliation

Osaka University
Graduate School of Engineering
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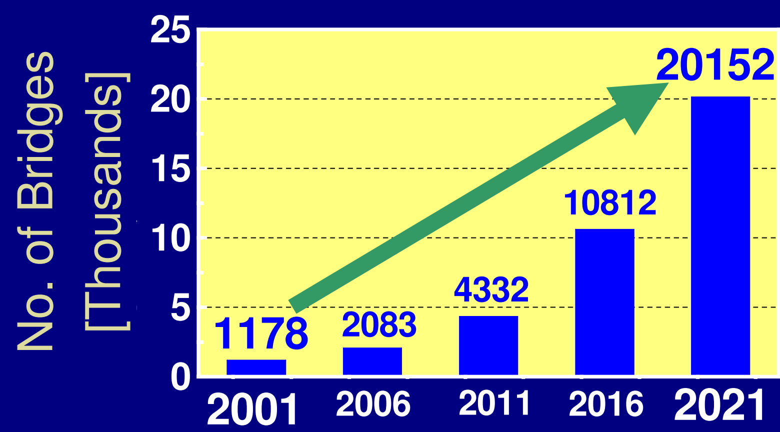
Current Status in Japan

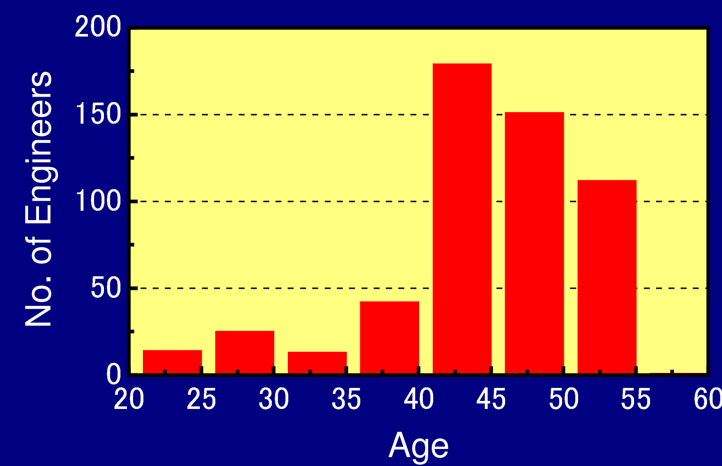
Changes in No. of Bridges over 50 Years (National Road & Highway)



(MLIT, 2002)

No. of Bridges over 50 Years increases to 17 times in 2020 due to concentrative construction in the high economic growth period in 1960's to 70's

Age Distribution of Civil Engineers in a Major Railway Company

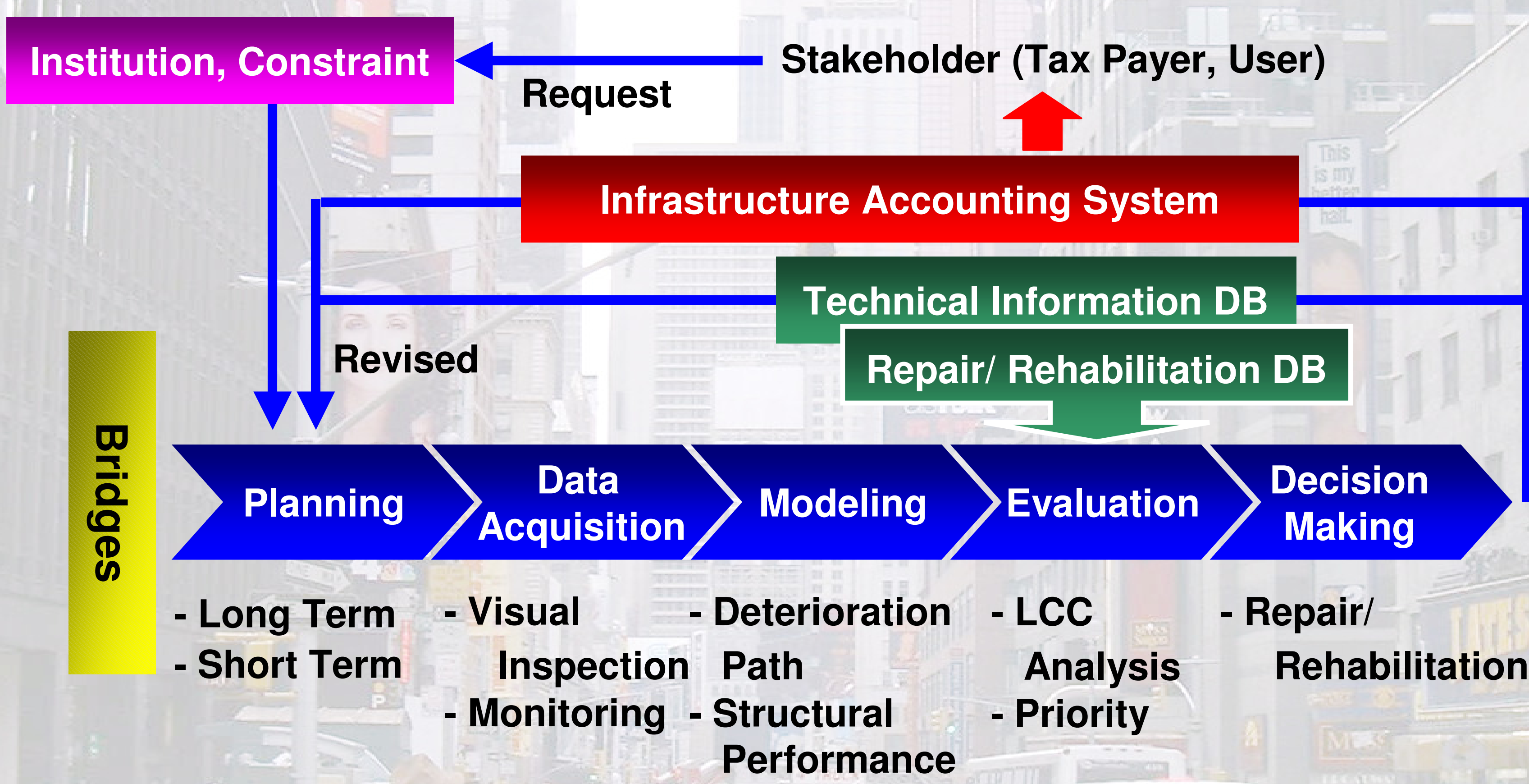


Experts in 40's and 50's account for 75%.

Caused by management's rationalization after privatization of JNR

Expected declining birthrate and a growing properties of elderly people

Asset Management



Contents of Today's Lecture

1. Importance of Visual Inspection

   - Through a Case Study of Bridge Management in New York City

2. Deterministic Deterioration Prediction

   -Methodology : Deterioration Rates

   -Empirical Study : Painting Period

3. Probabilistic Deterioration Prediction

   -Methodology : Markov Chain Model

   -Empirical Study : Reinforced Concrete Deck

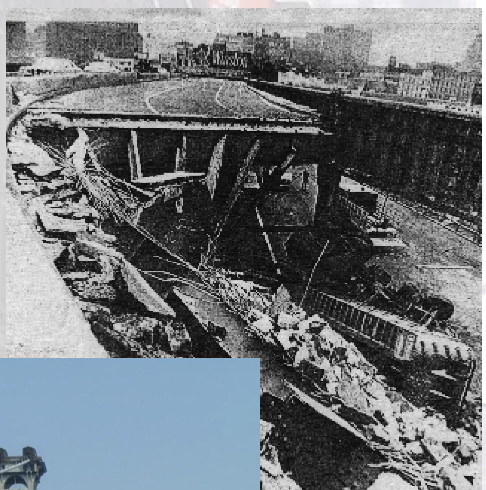
   : Information Infrastructures

Importance of Visual Inspection

- Case Study of New York City -

Strong Awareness for Bridge Management

West Side Highway



Williamsburg Bridge

NYC is responsible for 764 bridges (2000)

- **Average Age: about 75 years   Aging**
- **Severe Condition in Winters   Corrosion**
- **Capital City of the World   Fatigue Crack**
- **Bitter Experience in the Past**
  Collapse of West Side Highway,
  Closure of Williamsburg Br.
- **Existence of Some Landmarks: Brooklyn Br., George Washington Br.**

<u>Systemization of Bridge Management based on Visual Inspection</u>

General Outline of Visual Inspection

Complies not with *Bridge Inspection Manual by FHWA* but with *by State of New York, Department of Transportation*

- **Carried out for all bridges at least every 2 years**
- **Applied for 25 members of superstructure and 22 of substructure**
- **Evaluate the performance by rating from 1 to 7**

(7:new construction → 1 : limit in service)

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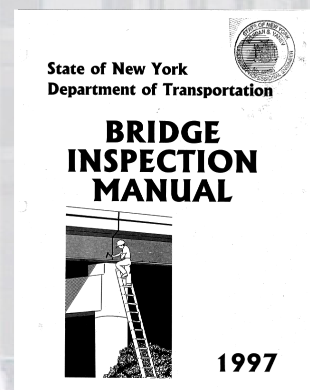
Subjective
Empirical < **Simplicity**
Fastness



Rating System

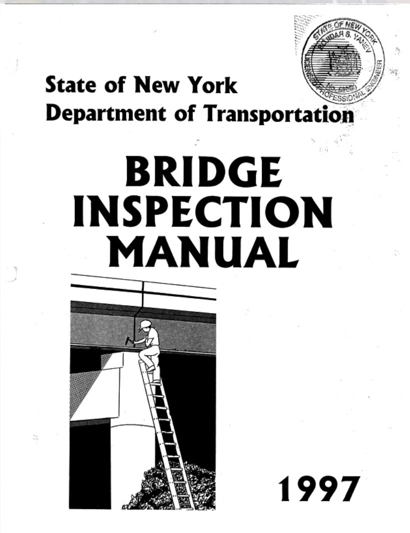
Rating System

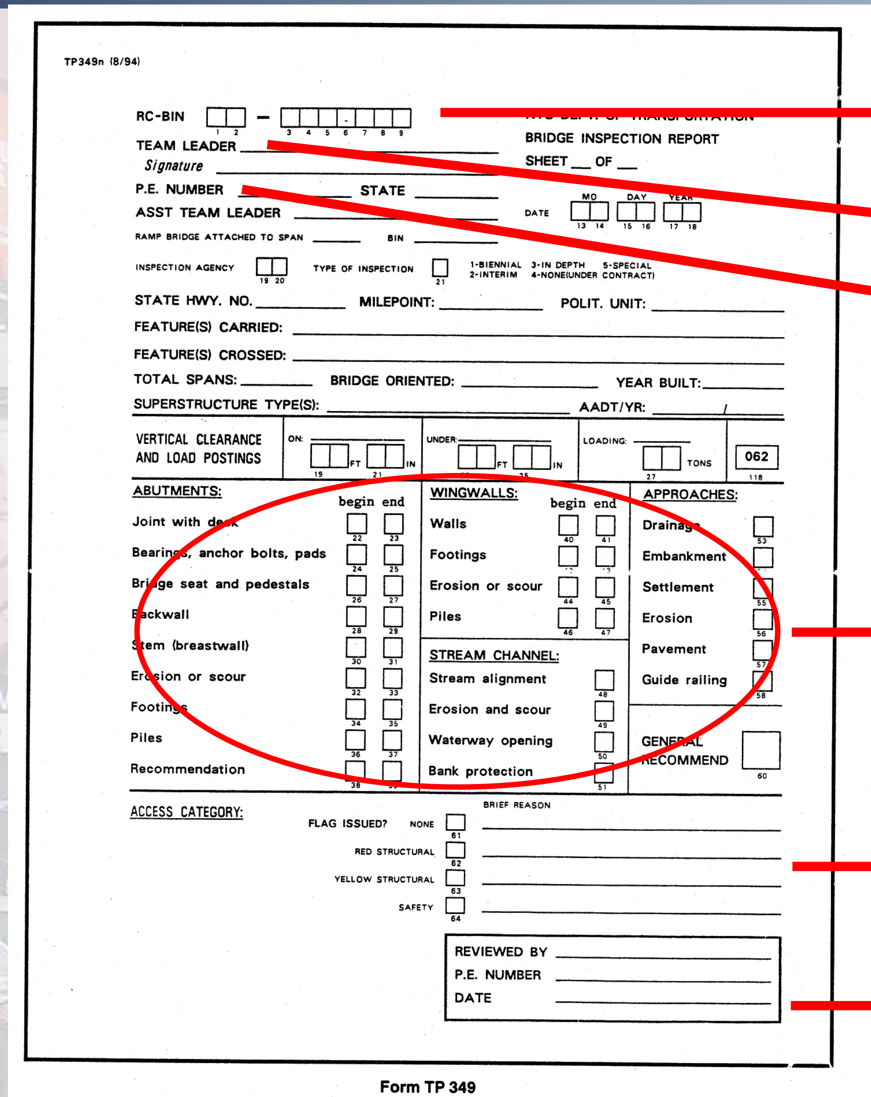
Rating	Physical Meanings
7	New Construction
6	Between 7 & 5
5	Graze Damage Satisfying with the required performance
4	Between 5 & 3
3	Serious damage or not Satisfying with the required performance
2	Between 3 & 1
1	Collapse or Potential Hazard

Original State Evaluation of NYC

Rating	Verbal Meanings
7-6	Very Good
6-5	Good
5-3	Fair
3-1	Poor

Inspection Sheet for Substructure





TP349n (8/94)

RC-BIN __ __ – __ __ __ __ __ __ __

BRIDGE INSPECTION REPORT

SHEET __ OF __

TEAM LEADER

Signature

P.E. NUMBER ______ STATE ______

ASST TEAM LEADER ______ DATE MO DAY YEAR

RAMP BRIDGE ATTACHED TO SPAN ______ BIN ______

INSPECTION AGENCY __ TYPE OF INSPECTION __ 1-BIENNIAL 2-INTERIM 3-IN DEPTH 4-NONE(UNDER CONTRACT) 5-SPECIAL

STATE HWY. NO. ______ MILEPOINT: ______ POLIT. UNIT: ______

FEATURE(S) CARRIED:

FEATURE(S) CROSSED:

TOTAL SPANS: ______ BRIDGE ORIENTED: ______ YEAR BUILT: ______

SUPERSTRUCTURE TYPE(S): ______ AADT/YR: ______ /

VERTICAL CLEARANCE AND LOAD POSTINGS | ON: FT IN | UNDER: FT IN | LOADING: TONS | 062

ABUTMENTS:	begin	end	WINGWALLS:	begin	end	APPROACHES:	
Joint with deck	22	23	Walls	40	41	Drainage	53
Bearings, anchor bolts, pads	24	25	Footings	42	43	Embankment	54
Bridge seat and pedestals	26	27	Erosion or scour	44	45	Settlement	55
Backwall	28	29	Piles	46	47	Erosion	56
Stem (breastwall)	30	31	STREAM CHANNEL:			Pavement	57
Erosion or scour	32	33	Stream alignment		48	Guide railing	58
Footings	34	35	Erosion and scour		49		
Piles	36	37	Waterway opening		50	GENERAL RECOMMEND	60
Recommendation	38	39	Bank protection		51		

ACCESS CATEGORY:

FLAG ISSUED? NONE 61 — BRIEF REASON

RED STRUCTURAL 62

YELLOW STRUCTURAL 63

SAFETY 64

REVIEWED BY ______

P.E. NUMBER ______

DATE ______

Form TP 349

B.I.N

Team Leader

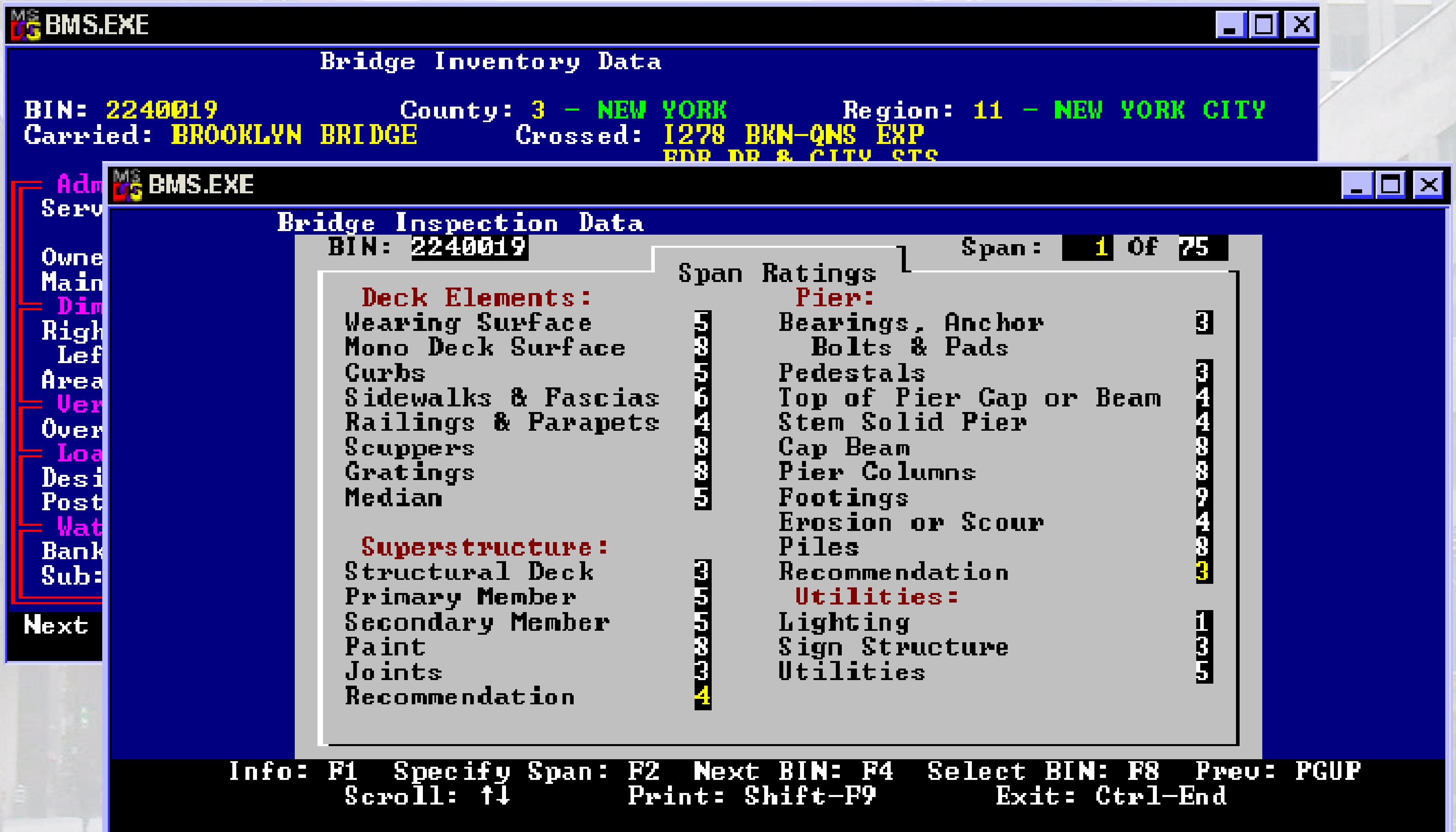
P.E. No.

Ratings
1~7

Flags
Urgent need of repair/rehabilitation

Signature

Database


BMS.EXE
Bridge Inventory Data
BIN: 2240019 County: 3 - NEW YORK Region: 11 - NEW YORK CITY
Carried: BROOKLYN BRIDGE Crossed: I278 BKN-QNS EXP
Next
BMS.EXE
Bridge Inspection Data
BIN: 2240019 Span: 1 Of 75
Span Ratings
Deck Elements:
Wearing Surface 5
Mono Deck Surface 8
Curbs 5
Sidewalks & Fascias 6
Railings & Parapets 4
Scuppers 8
Gratings 8
Median 5
Superstructure:
Structural Deck 3
Primary Member 5
Secondary Member 5
Paint 8
Joints 3
Recommendation 4
Pier:
Bearings, Anchor Bolts & Pads 8
Pedestals 3
Top of Pier Cap or Beam 4
Stem Solid Pier 4
Cap Beam 8
Pier Columns 8
Footings 7
Erosion or Scour 4
Piles 8
Recommendation 3
Utilities:
Lighting 1
Sign Structure 3
Utilities 5
Info: F1 Specify Span: F2 Next BIN: F4 Select BIN: F8 Prev: PGUP
Scroll: ↑↓ Print: Shift-F9 Exit: Ctrl-End

Bridge Rating

Evaluation of Whole Bridge Rating

⬇

Weighted Average focusing on the major 13 members

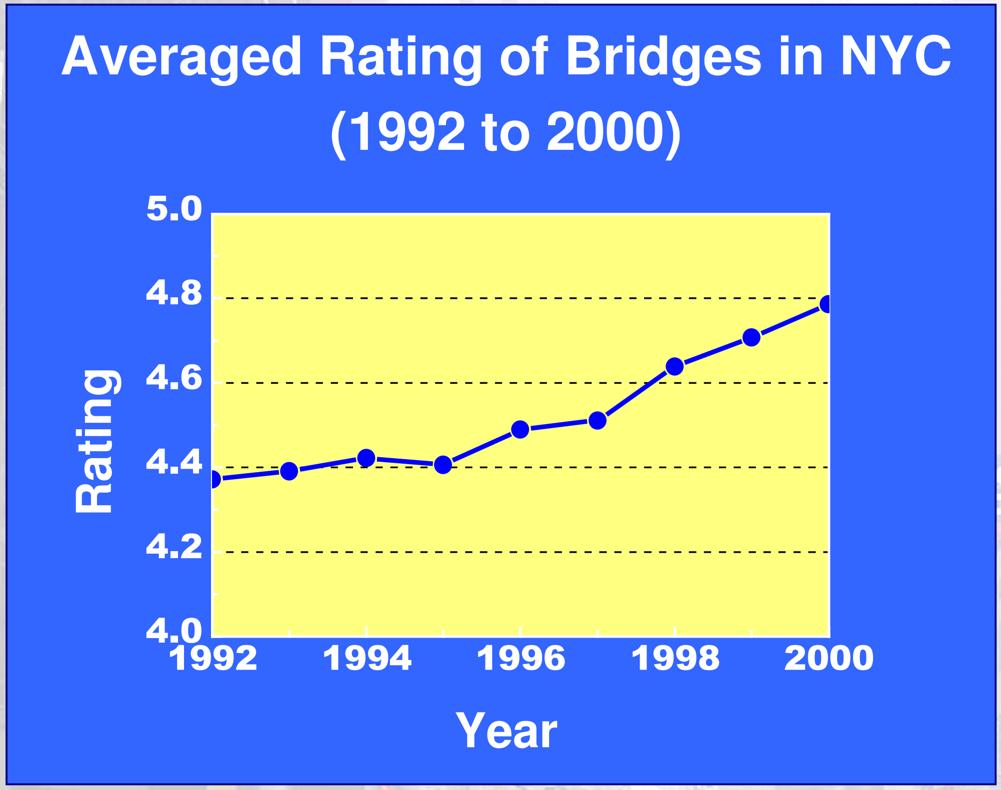
$$R = \sum_{i=1}^{13} w_i r_i \Big/ \sum_{i=1}^{13} w_i$$

R : Whole bridge rating
i : Member No.
r_i : Rating of Member i
w_i : Weight of Member i

Subjectively Selected 13 members, and decided the values of weights through the experience

No. i	Member	Weight w_i
1	Bearing	6
2	Back Walls	5
3	Abutments	8
4	Wingwalls	5
5	Bridge Seat	6
6	Primary Member	10
7	Secondary Member	5
8	Curbs	1
9	Sidewalks	2
10	Deck	8
11	Wearing Surface	4
12	Piers	8
13	Joints	4
		72

Example of Utilization



Utilizes for budget acquisition in the city assembly

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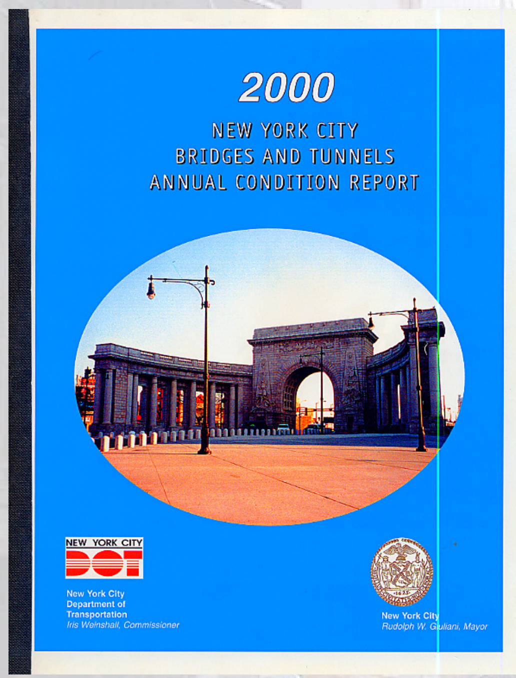
Positive, effective use of visual inspection data

- **Tends to be increased year by year**
- **reaches to rating 5 (Good) in 2010**

Discloser of Information

「New York City Bridges and Tunnels Annual Condition Report」 **(1982～)**



2001 Edition

- **Outline of repair/rehabilitation works, its costs and schedules**
- **Concept of Rating system**
- **Ratings of all bridges**
- **Description of Technical terms**

⬇

Disclosure of information

Deterministic Prediction

- Focusing on Deterioration Rates -

Motivation

The basic purposes of Asset Management

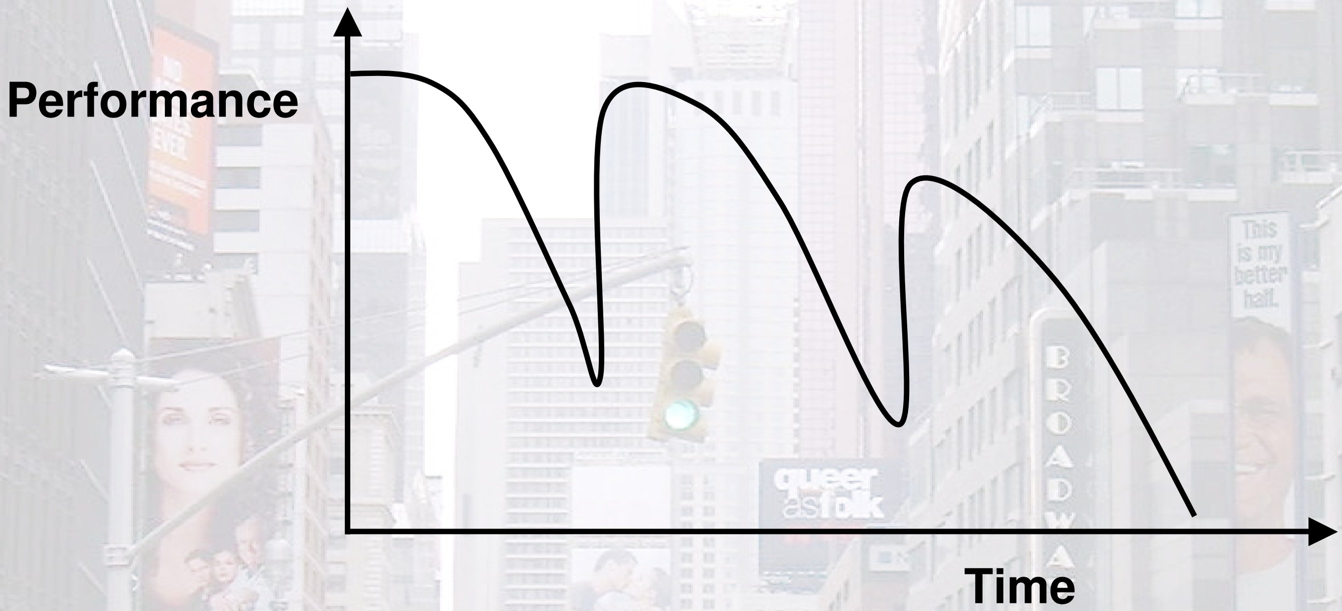
- **To lay the base for effective maintenance strategy under budgetary restrictions**
- **To enhance the accountability to the stakeholders(taxpayers)**
- **To obtain the necessary budget autonomously**

Minimization of Life Cycle Costs (LCC)

a cost minimization problem by treating the repair/rehabilitation costs and timing as variables

- Costs: Database of repair/rehabilitation
- Timing: Deterioration prediction method

Deterioration Prediction



How can we estimate a deterioration curve based on actual data?

- What kind of data are available in the filed side?
- Which methodology is appropriate?

Classification of Deterioration Prediction Methods

Based on the mechanical deterioration mechanisms.

Decision making about micro-level issues

such as the life time estimation of individual infrastructures and its repair/rehabilitation tactics

- **Physical method**
- **Statistical method**
  - **Deterministic methods** (Not taking uncertainty into consideration)
  - **Probabilistic methods** (Taking uncertainty into consideration)
    - **Aggregative methods**
    - **Disaggregative methods**

Based on inspection data carried out in the past.

Decision making about macro-level issues

such as the budgetary management of the whole infrastructure system and their maintenance strategy in the future

Objectives

Toward asset management system for infrastructures (bridges)

I. Construction of Methodology

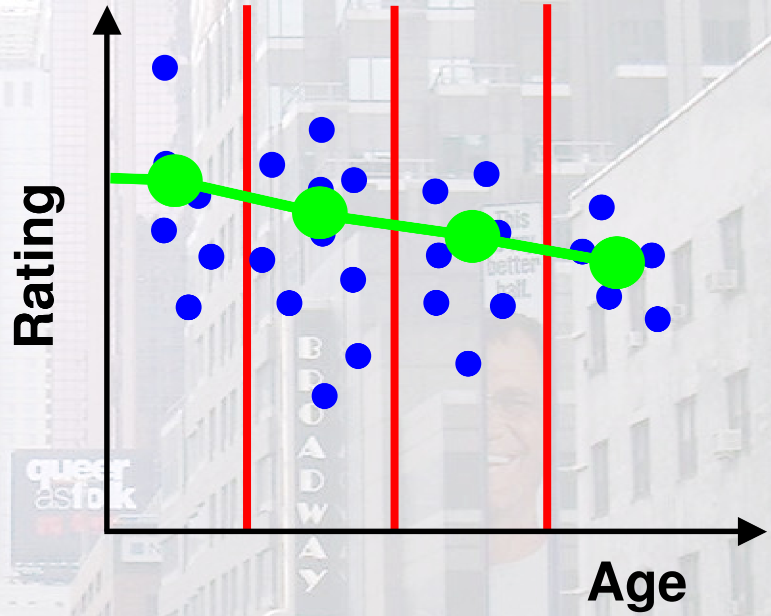
Deterioration prediction of bridge members based upon inspection data, focusing on deterioration rates

II. Verification Study

Making a decision of painting period using the prediction results

The Simplest Method and Disadvantage

1. Plot all ratings (inspection data) for their ages.
2. Classify them into several segments.
3. Calculate average ratings per each segment and connect them.



Difficulties

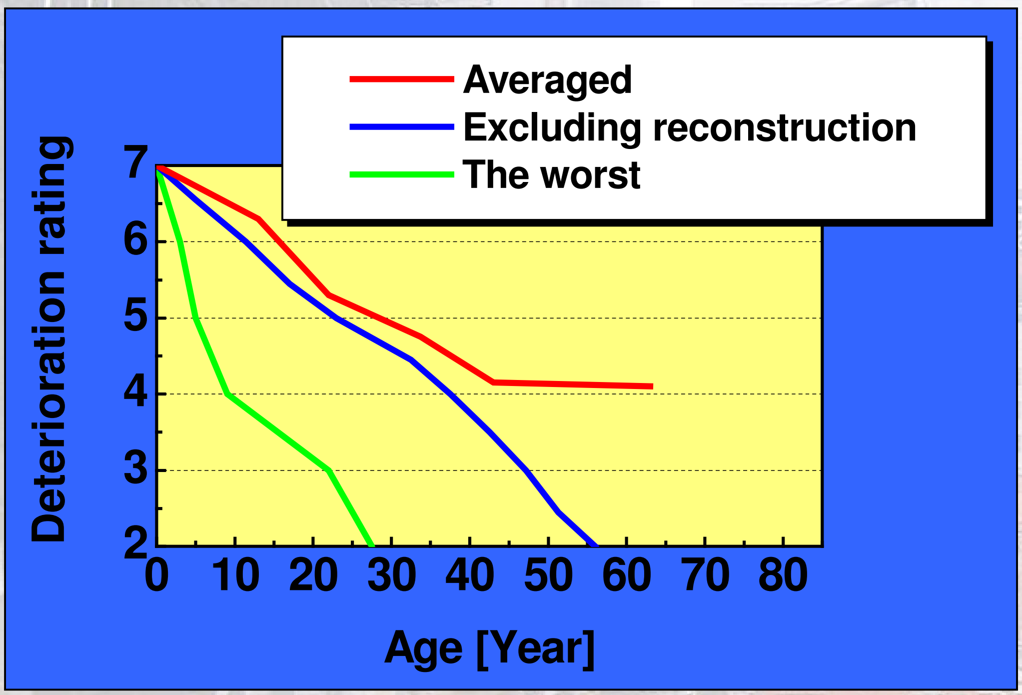
Deterioration curve by this method tends to be slower declines than real.

→ **The method does not take into account the effects of any repair/rehabilitation done to the bridge members in the past.**

Example: NY City

Deterioration curve under complete information

(Yanev, B. '97)



- **Using about 750 ratings in 1994**
- **Original bridge rating system ('82)**

  7 to1 (7: new, 1: failure)

Investigated repair and rehabilitation history for all bridges and excluded them.

Total Bridge No. used in his analysis

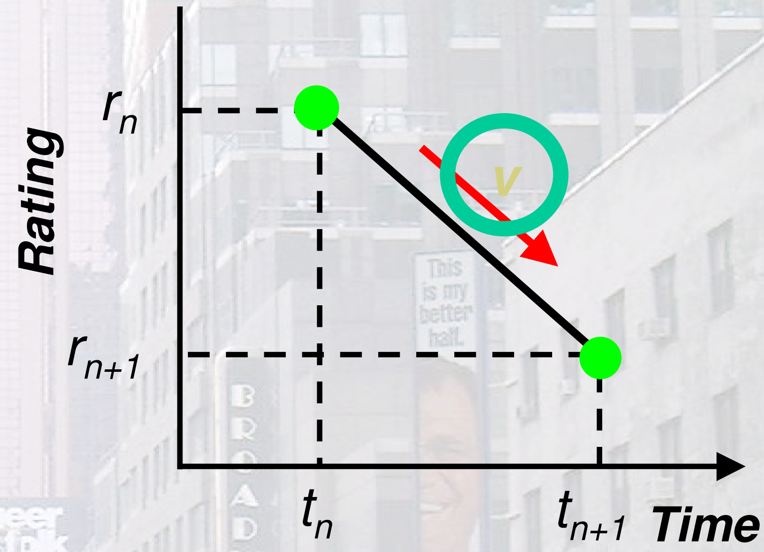
750 → 40

Reliable?

Proposed Method: Step1

1. Calculate deterioration rates between r_{n+1} and r_n.

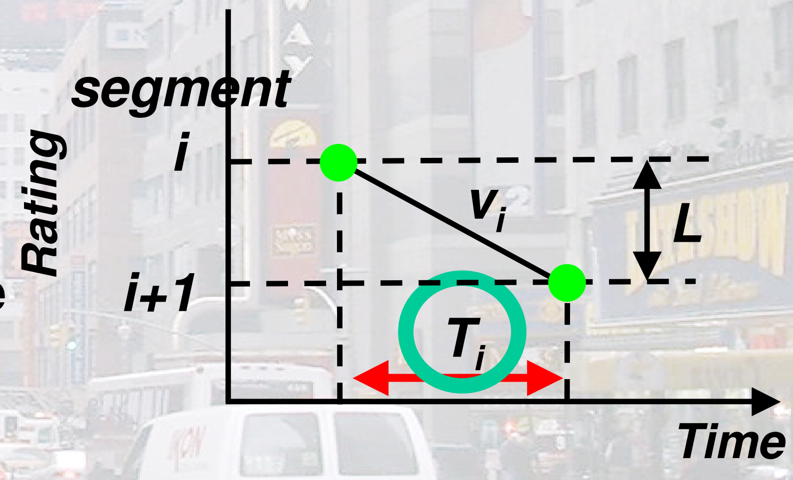
$$v = \frac{r_{n+1} - r_n}{t_{n+1} - t_n}$$



2. Make several segments for ratings and classify all ratings into the appropriate segments and put rate v in the same segment with the corresponded r_n.

3. Calculate average deterioration rates v_i per each segment, then give deterioration time T_i as the follows.

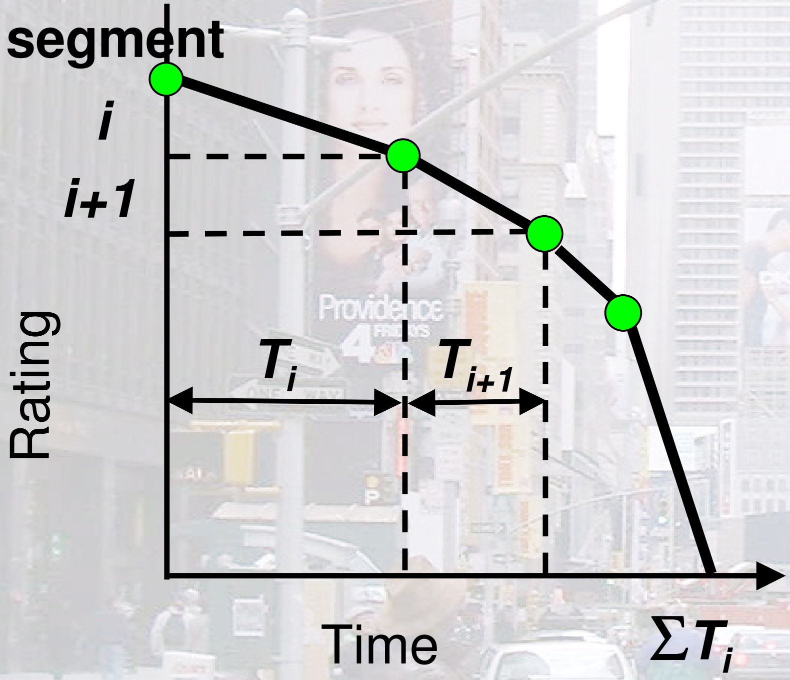
$$T_i = L / \overline{v}_i$$



Proposed Method: Step2

4. Accumulate averaged deterioration time for each segment to obtain total deterioration time.

$$T = \sum_i T_i$$



<u>Advantage</u>:

Only deterioration rates (a series of ratings and inspection dates) are required to calculate deterioration curve.

Comparison with the Existing Method

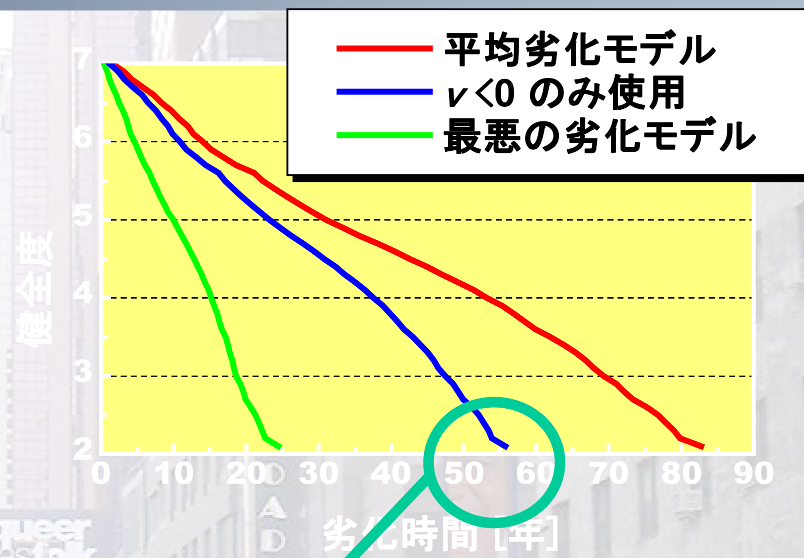
Database of Visual Inspection Data for Bridges in NY City (1992-2000)

No. of Bridges: 828

No. of Samples: 8241

excluding $v > 0$

Width of Class: 0.1, No. of Class: 71

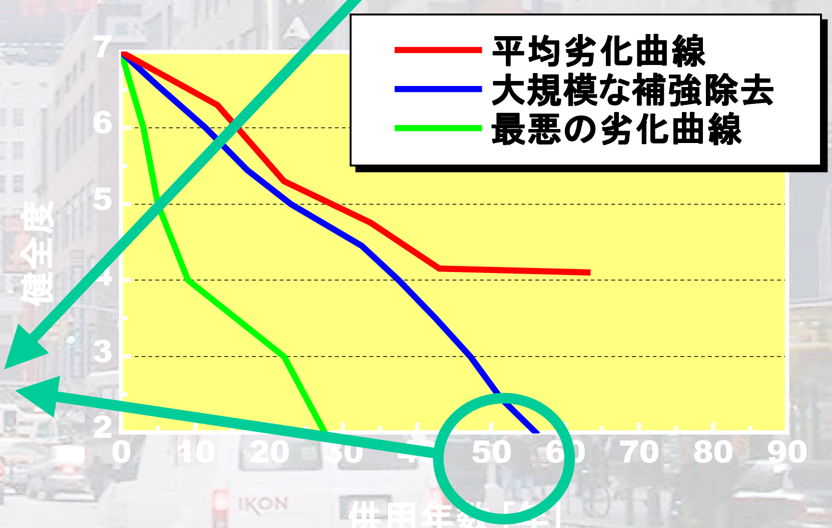


<u>Results of Analysis</u>

Expected Life Time: about 80 years

The Worst Case: 25 years

Almost Similar to the results of the existing method



Actual Inspection Results

Visual Inspection results for painting deterioration of about 3,500 steel girders since 1987

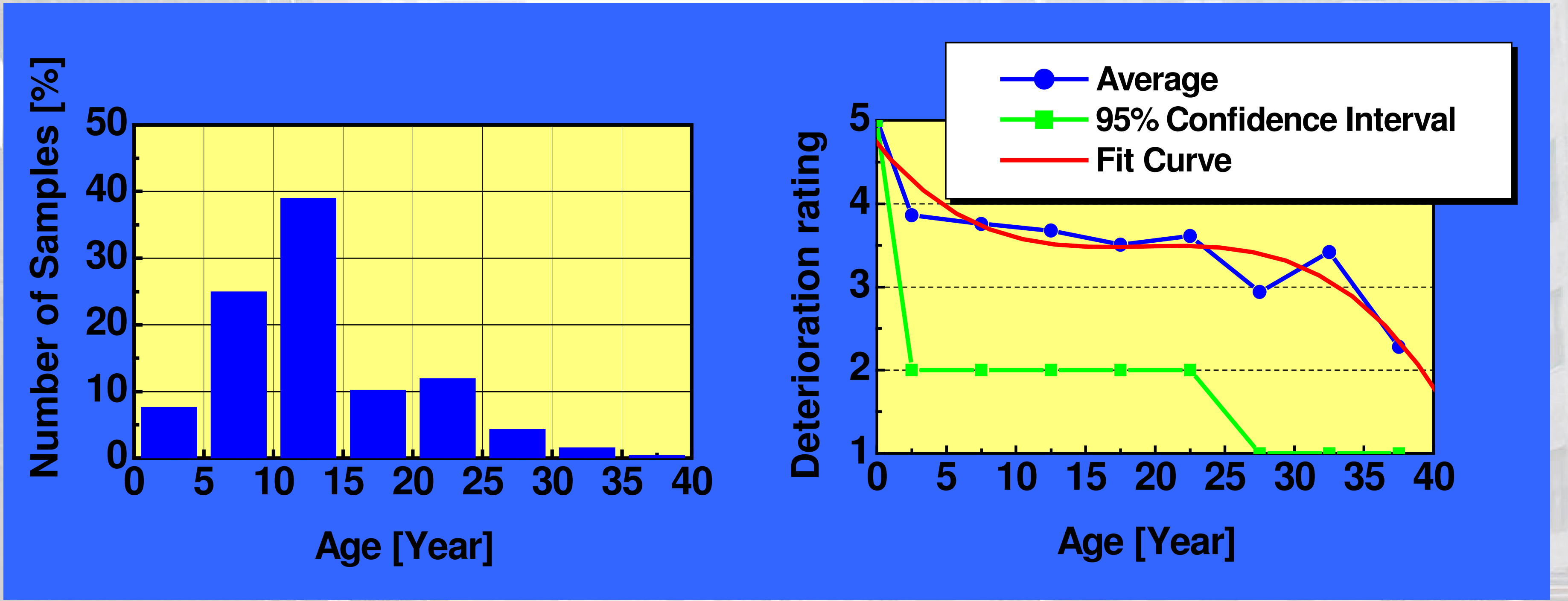
4,313 samples

Rating	
5	***Fine***
4	***Good***
3	***Permissible Damage***
2	***Potential hazardous condition***
1	***Failure or imminent failure***

Corrosion

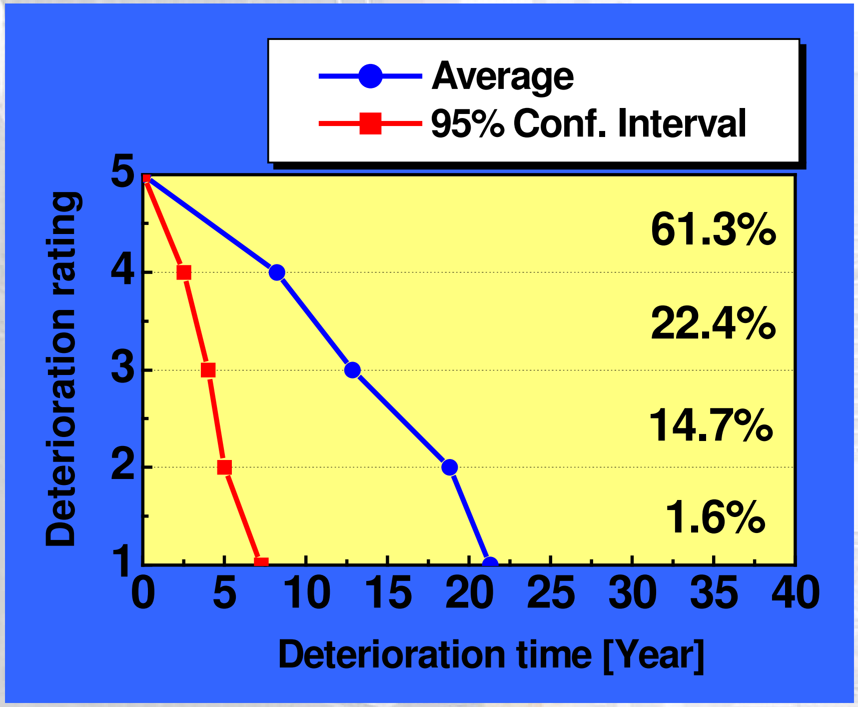
5	4	3	2	1
23.2%	43.5%	10.2%	20.9%	2.23%

Results by the Existing Method



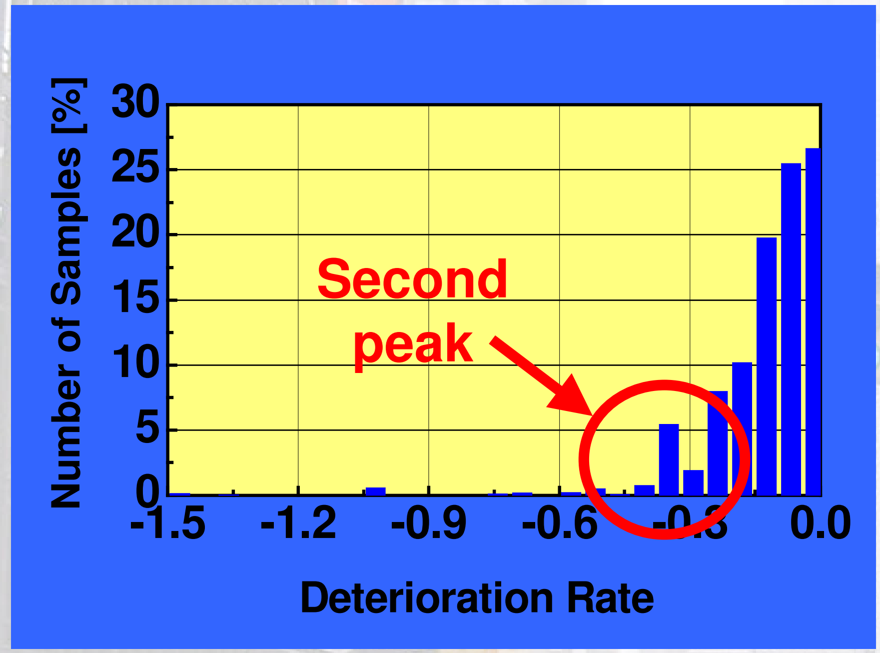
- Deterioration rating of painting goes down in more than 40 years on average.
  - The painting period would be 25 years on 95% confidence interval.

Result by the Proposed Method

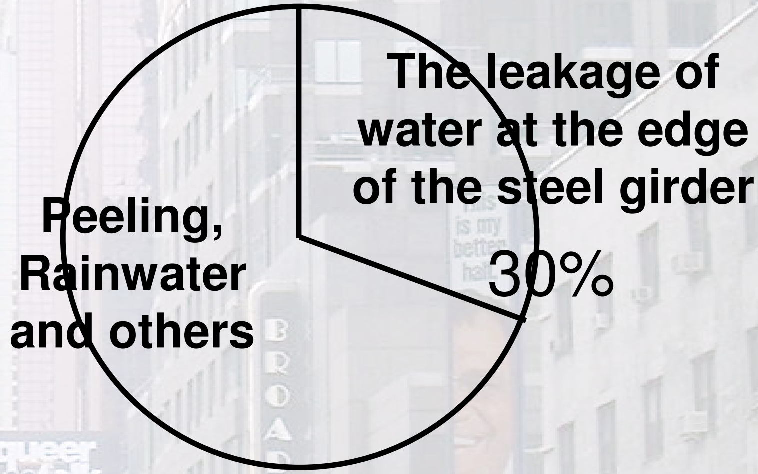


- Painting is durable for 20 years on average.
- The current painting period 8-15 years is reasonable from 95% confidence interval.
- The lower classes do not have enough samples, reliability of quantity still remains.

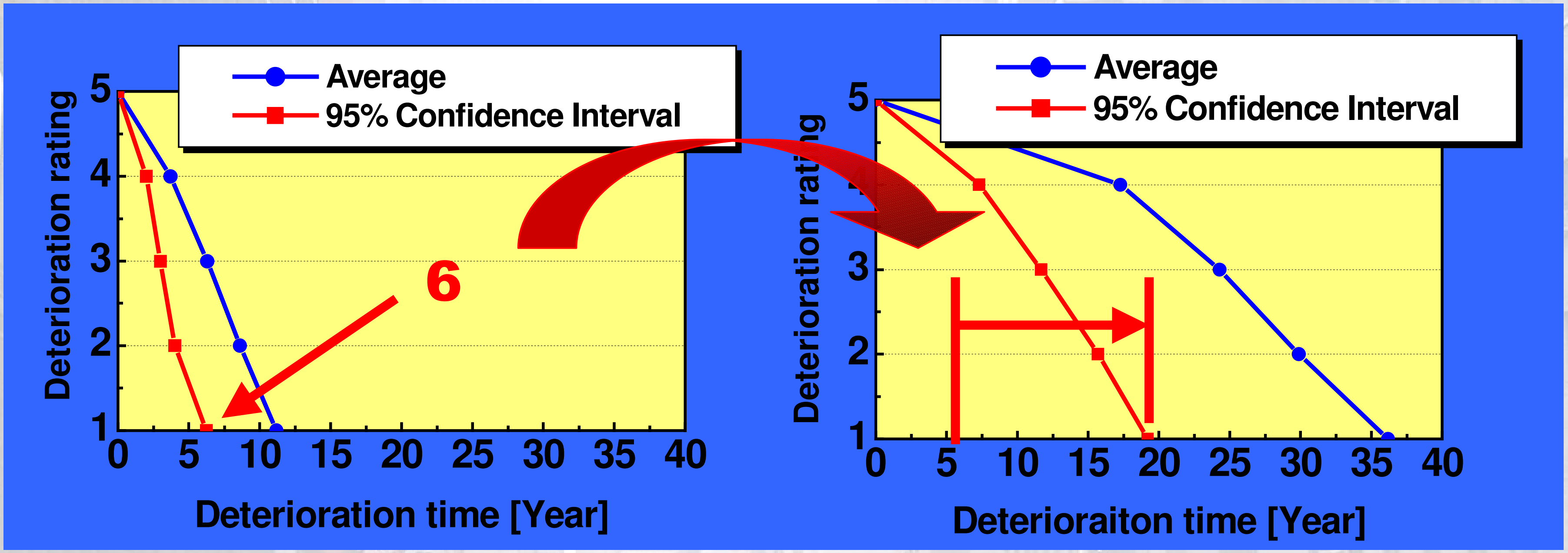
Investigation of Cause of Corrosion



Histogram of deterioration rates



Painting Period



- **Corrosion gives crucial damage to steel member in 10 years.**
- **Doing actively preventive maintenance for corroded member, painting period can be extended up to 20 years with 95% confidence interval.**

→ **LCC can be saved in some cases, and the accountability for necessity of painting is possible to be carried with this quantitative results**