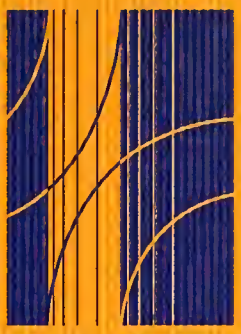

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FHWA/IN/JTRP-98/21

Final Report

Steel Bridge Protection Policy

Volume I of V
Main Report

Luh-Maan Chang
Tarek Zayed
Jon Fricker

May 1999

Indiana
Department
of Transportation

Purdue
University

FINAL REPORT

STEEL BRIDGE PROTECTION POLICY

VOLUME I

MAIN REPORT

FHWA/IN/JTRP-98/21

by

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Prepared in Cooperation with the
Indiana Department of Transportation and
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The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views of the Federal Highway Administration and the Indiana Department of Transportation. This report does not constitute a standard, a specification, or a regulation.

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16. Abstract

The study identifies various painting systems that are successfully used in Indiana's surrounding states and other industries. The identified systems are further screened and evaluated. After prudently comparing INDOT's inorganic zinc / vinyl system with the waterborne acrylic system, the moisture cure urethane coating system, and the 3-coat system of zinc-epoxy-urethane, the results show that the new 3-coat system fulfills INDOT's needs with the most benefits. Therefore, the 3-coat system is recommended to replace INDOT present inorganic zinc / vinyl system.

To deal with the problems facing the lead-based paint, a comparison between full-removal and over-coating alternatives is made. Results show that over-coating might provide a good protection for less than half the cost of full-removal; however it delays the lead full-removal process and does not completely solve the environmental problem.

The metalization of steel bridges is seemingly a potential protection policy. After reviewing standards and specifications on metalization, it is shown that metalization jobs require a higher degree of control. It suits on-shop practices, however, the initial cost is considerably high.

This study also describes a life cycle cost analysis that was done to determine an optimal painting system for INDOT. Herein, a deterministic method of economic analysis and a stochastic method of Markov chains process are used. The analysis not only reconfirms that the 3-coat system is the comparatively better painting system, but also generates an optimal painting maintenance plan for INDOT.

To assure the quality of paint material and workmanship after substantial completion of the painting contract, the development of legally binding and dependable warranty clauses is initiated in this study. The developed painting warranty clauses were primarily derived from the painting warranty clauses used by IDOT, MDOT, and INDOT's pavement warranty clauses. A comparative study was conducted on eleven essential categories. Among them, it was found that the warranty period, the definition of "defect", and the amount of the warranty bond all need further evaluation.

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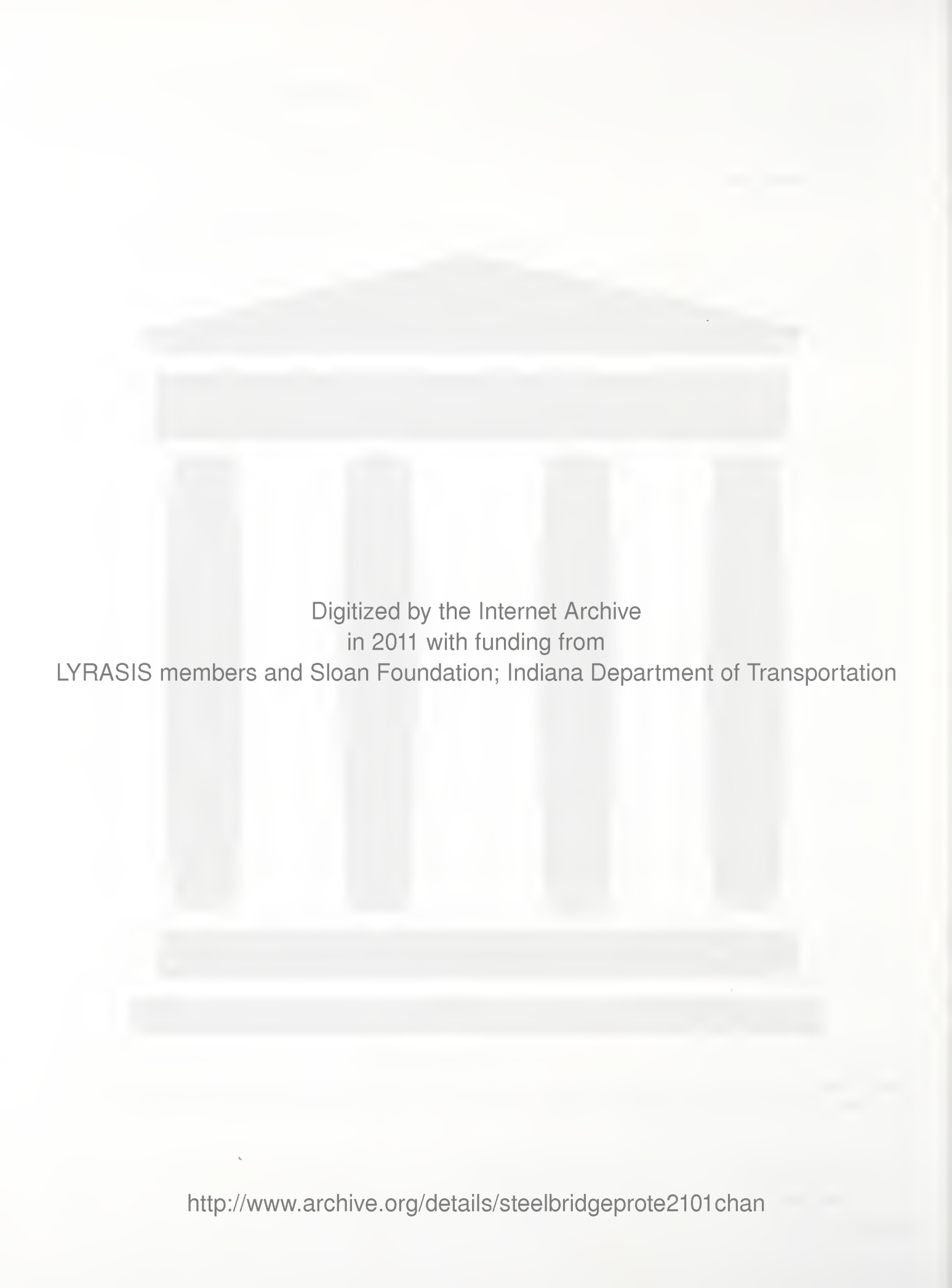
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STEEL BRIDGE PROTECTION PLOICY

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STEEL BRIDGE PROTECTION POLICY

INTRODUCTION

For many years, corrosion has been the most serious threat to steel structures. To date, it is well established that corrosion is the result of an electrochemical process involving an anodic reaction. During this reaction the metal goes into solution as an ion, and a cathodic reaction takes place. Because of steel's natural tendency return to its original state after it has been extracted from its ore, the steel reacts with its environment and corrodes. The process of corrosion requires four elements including 1) an anode, 2) a cathode, 3) an electrolyte, and 4) a conductor. Only when these four components are present at same time, can corrosion occur. Methods such as protective coatings and cathodic protection protect against corrosion by eliminating any of the required elements above.

Steel contains both anodes and cathodes due to grain boundaries, grain orientation, thermal treatments, surface roughness and strains. Additionally, steel serves as an efficient conductor. The atmospheric moisture serves as the electrolyte. Without protection, corrosion will thus occur on steel structures. For most steel structures, paint is applied to protect the steel by separating the steel surface from atmosphere moisture, thus preventing the corrosion process.

Although use of paints has met with varying degrees of success, it is not uncommon for them to cause earlier failure and discoloration of the steel bridge surface, thereby degrading the aesthetics of the structure and threatening the public safety. In addition, new paint systems emerge on the market almost every day. Many highway engineers continually face the challenge of selecting a proper system for steel bridge painting projects. Moreover, some of the paint systems contain hazardous compounds such as lead, chromium, and so forth. Therefore, paint systems that contains these compounds need to be avoided for use on new steel bridge projects. Moreover, paints that contain hazardous compounds that have been applied to existing bridges need to be removed or over-coated.

STUDY OBJECTIVES

This study was initiated in order to prevent the early failure of paint systems on steel bridge surfaces and to ensure public safety and health. The purpose of this research was to develop a policy to facilitate INDOT personnel in selecting a proper paint system and to generate cost effective plans for efficiently maintaining the protection of paint systems on the surface of INDOT's steel bridges.

The research project was also broken down into the following specific objectives:

1. To identify the specific paint systems that are successfully used in surrounding states, and other industries.

2. To evaluate the identified paint systems.

3. To review paint systems coated on the existing INDOT steel bridges.

4. To assess alternative strategies for full-removal, over-coating, and metalization.

5 To perform life cycle cost analysis painting systems that INDOT currently use as well as on potential alternative systems.

6. To develop efficient painting maintenance plans.

7. To explore the feasibility of using warranty clauses in INDOT painting contracts in order to improve quality and contractor accountability.

8. To conduct inspector training sessions for applying the findings found in the research into daily procedure.

METHODOLOGY

To achieve the aforementioned objectives, the methodologies can be summarized as follows:

1. An extensive review of the existing paint systems used on INDOT steel bridges was performed to understand their current paint status, INDOT's current practice, their classification, the degree of hazardous compounds, the parameters contributing to good painting quality, and pitfalls causing early failure.

2. An extensive search on the topic of steel bridge painting systems was made through the successful practice of other DOTs and related industries: particularly, the surrounding states' application and experiences.

3. To safeguard the reliability of the identified paint systems before INDOT approval for formal use and to list them as the recommended painting materials, many specialists from field, shops, material suppliers, and laboratories were interviewed to verify the information obtained from the aforementioned stages.

4. Using the similar aforementioned method, alternative strategies for removing or over-coating the old lead paint on the existing steel bridges were examined.

5. The current painting costs have dramatically increased. Therefore, the choice of the right cost-effective alternative based on long term performance of the painting system and life cycle cost becomes very critical. The data of initial cost, future cash flow, escalation rate, and the expected service life of the bridge and paint were collected and/or examined.

6. After thorough evaluation of alternative strategies and their associated life cycle cost analyses, an optimum maintenance plan for INDOT painting program was developed through regression theory, economic analysis, and the Markov chains process.

7. One of the research objectives was to develop warranty clauses applicable to INDOT paint contracts. Many warranty clauses used by other industries and DOTs were searched. Content analyses and comparisons with the current warranty clauses used by INDOT were conducted. A new pragmatic warranty clause was established to meet INDOT's specific need and special regulations.

8. Based on the above prudent studies, a final report was prepared and submitted to JTRP of INDOT for approval.

FINAL REPORT OVERVIEW

Figure 1 depicts the final report. The objectives of this research were primarily achieved through four parts of integrated sub-studies. Part (I) is this main report. Part (II) is the evaluation of bridge paint systems. This sub-study includes the evaluation of INDOT's current paint systems, various advancing paint systems, and the comparison between over-coating and full-removal of old lead paints. Part (III) is the review of metalization. This sub-study includes current practices and research of metalization in the United States and Europe, and develops metalization specifications. Part (IV) is a life cycle cost analysis on INDOT's existing and identified new painting systems. This sub-study uses various deterioration models and proposes a maintenance plan for INDOT's steel bridge painting program. Part (V) is warranty clauses. This sub-study examines the methodology of warranty clauses, and develops painting warranty clauses for INDOT. Each part of the study generates a lot of information; therefore, the authors decided to use four additional volumes to report the results of this research project.

The final report consists of five volumes. Volume I is this main report on the steel bridge protection policy. The other four volumes of the final report are:

Volume II: Evaluation of Bridge Coating Systems for INDOT Steel Bridges.

Volume III: Metalization of Steel Bridges: Research and Practice.

Volume IV: Life Cycle Cost Analysis and Maintenance Plan.

Volume V: Proposed Warranty Clause for INDOT steel Bridge Painting Contracts.

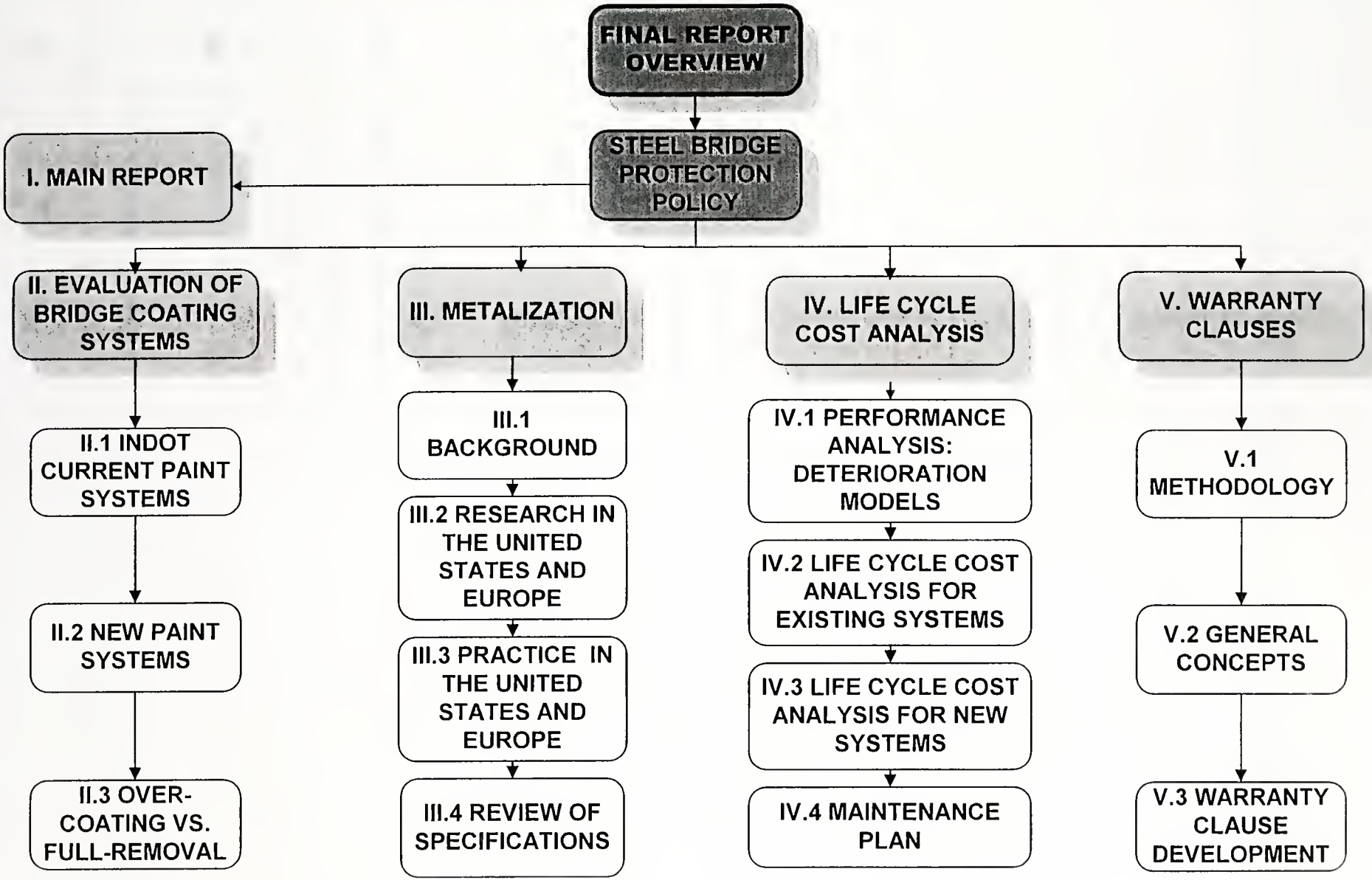

Figure 1: Steel Bridge Protection Policy: (Final Report Overview)

EVALUATION OF BRIDGE COATING SYSTEMS FOR INDOT STEEL BRIDGES

In this study, various bridge coating systems were identified and reviewed along with the INDOT present system of inorganic zinc / vinyl. The problems and weaknesses of each system were identified. In recommending which new steel bridge coating system that INDOT should use, different aspects of selection criteria were considered. The problems facing the lead-based paints and the need for reduced VOC levels were also evaluated. All the coatings systems presented in this report consist of various comments recorded by the bridge owners who have utilized the system and/or by paint experts with testing data, such as Turner-Fairbanks Highway Research Center.

The three-coat system, which consists of inorganic / organic zinc, epoxy, and urethane coats, was found as the comparatively better coating system and was recommended for use by INDOT. Evaluation factors that were considered for this conclusion include the useful life of this coating, environmental issues, cost, and comments from other bridge owners with climates similar to Indiana. The new 3-coat system has also been successfully used by MDOT, PennDOT, and ODOT. It has combined merits of longer durability in the field and laboratory, fewer requirements in surface preparation, relatively lower initial and maintenance cost, environmental compliance, high gloss and low chalking topcoat, and sustaining chloride-contaminated weather.

There are advantages and disadvantages to over-coating and full-removal. For full-removal, the merits are that there is less risk of premature coating failure, the bridge will be safer from lead contamination, and the owner will no longer have pressure from the EPA for the lead contamination. On the other hand, some disadvantages of full-removal are: it is expensive, it may cause a substantial risk of environmental contamination, it poses a health threat to workers, and it draws higher critic from the public because the lead removal process is highly visible.

Numerous advantages of over-coating can be realized. The biggest advantage is that the cost of over-coating is approximately 2 to 3 times less than the full-removal process. Due to this

significant cost saving, many DOTs are pursuing over-coating approach. With over-coating, the risks of contaminating the environment are much less than those for full-removal. The risk to workers is significantly reduced because most lead is not disturbed and less fracturing of the paint occurs.

The major disadvantage of over-coating is the possibility of early failure of the coating system. This is usually due to the incompatibility between paints, osmotic blistering from soluble salts under the coating, or excessive undercutting on over-coated rust. Moreover, the estimation of the useful life of the over-coating system is difficult. There is high probability that the system may fail 3 or 4 years after application.

It can be concluded that over-coating might provide a good protection for less than half the cost of full-removal. However, the over-coating of bridges only delays the hazardous lead removal process and it does not completely solve the environmental issues facing the lead removal.

METALIZATION OF STEEL BRIDGES: RESEARCH AND PRACTICE

The term thermal spray, or metalization, describes a family of coating technologies associated with the application of thick coating onto the bridge substrate in order to reduce or eliminate the debilitating effects of wear and corrosion. Thermal spraying of bridges is not a new idea. Since the 1930s, zinc spraying has been extensively utilized in Europe, and in many countries zinc spraying is specified as the only corrosion protection system for new bridge construction. To date, several hundred bridges have been thermally sprayed to provide long-term corrosion protection.

Metalizing steel bridges is viewed as a promising protection policy that has a high potential for success in the future. Several State Departments of Transportation have become more interested in investigating this technology in greater detail. The first metalization project on

a bridge in Indiana was carried out in April of 1997. Metalizing this particular bridge followed a complete rehabilitation activity of the steel superstructure. This project is regarded as a basic step in the experimental stage of metalizing steel bridges in Indiana.

The investigation conducted in this portion of the study revealed that both ODOT and ConnDOT have gained a lot of experience in this field during the past ten years. Therefore, their metalizing programs were carefully examined. Moreover, a thorough review of the standards and specifications regulating the application of metalization coatings have been performed throughout this part of study. Based on the study, the ANSI/AWS C2.18-93 indicated that metalization jobs require higher degrees of control, which suits on-shop practices. A complete process of surface preparation, metalization, and application of paint coats is attainable on-shop. The latest metalization job in Connecticut was being totally carried out on-shop where the structure was fabricated and then coated with the three-coat system. After being erected on-site, further field touch-up will be performed to repair any coating damage.

The primary barrier facing the metalization of steel bridges is the high installation costs of the system. However, distributing the installation costs over the expected long life span of the system could lower the life cycle cost. Another factor to consider is that the costs of metalization have decreased over the last ten years allowing higher competitiveness of metalization against other conventional paint systems. If the trend continues in the coming years, metalization could become even more competitive, while providing a superior performance over an ultra long lifetime (40-60 years).

LIFE CYCLE COST ANALYSIS AND MAINTENANCE PLAN

As the discussion in volume II report, the 3-coat system, inorganic/organic zinc primer, epoxy intermediate coat, and polyurethane topcoat, was identified as the most potential alternative coating system. To generate optimal maintenance plans and policies for use by INDOT, life cycle cost analysis was performed among the INDOT structures presently using zinc

primer / vinyl topcoat system, 3-coat system, and metalization systems. This study presents the results of the life cycle cost analysis and the corresponding maintenance plans. In the analysis, a deterministic method of economic analysis, and the stochastic method of the Markov chains process were used as the stone corner for steel bridge paint deterioration models.

The data and experiences obtained from the literature search, a series of meetings, and discussions with various state highway department personnel, representatives of the paint material supplying industry, and bridge painting contractors, were incorporated into the economic analysis and the Markov chains process. However, the two methods resulted in an indecisive conclusion. In order to enable the generation of a maintenance plan, an in-depth literature review was followed. The review confirmed that the two methods might not necessarily arrive at the same conclusion. Nevertheless, the economic analysis represents a comparatively simple, realistic, and accurate method for INDOT personnel. The results of the economic analysis were used for further sensitivity analysis under various scenarios. Interest rates, the inflation factor, age, the inspection rating factor, initial costs, rehabilitation costs, and traffic disruption costs were all formulated into the present value (PV) and equivalent uniform annual cost (EUAC) equations during the economic analysis.

The final results showed that the 3-coat was the optimal system. The PV for 3-coat paint system was \$4.55/ $ft^2$and the corresponding EUAC was \$0.324/ ft^2. These numbers were the minimum when compared with the zinc/vinyl and metalization systems. Therefore, it was concluded that the best paint system was the 3-coat system for INDOT. The results also indicated that the optimal scenario for the 3-coat system rehabilitation plan was doing spot painting every 15 years over bridge life, whether or not the paint is zinc-based or lead-based. Sensitivity analysis was further made to generate the best scenario: doing spot painting every 15 years. The results further pointed out that spot painting every 15 years for the 3-coat system will be the best scenario under the following conditions: (1) the initial cost is less than \$8.85/ft^2; (2) the bridge paint condition rating reaches 7 after 12 years; and (3) when the old paint was zinc based. It is also the best scenario when: (1) the initial cost is less than \$9.8/ft^2; (2) the bridge paint condition

rating reaches 7 after 12 years; and (3) the old paint was lead-based. The spot painting of the 3-coat system is still the best scenario for the steel bridge protection policy in INDOT.

WARRANTY CLAUSES FOR INDOT STEEL BRIDGE PAINT CONTRACTS

In the past few years, the Indiana Department of Transportation (INDOT) has adopted a continuous improvement strategy for its current practices. One of the major areas that seemed in need for such improvement is the quality of workmanship. In the field of steel bridges painting, INDOT has encountered an increasing number of fast-deteriorating painting systems after the substantial completion of the contract work. INDOT faces severe ramifications because of these deterioration rates in terms of the life expectancy of the steel bridges in Indiana.

One of the major causes for this fast deterioration is the lack of any legally binding agreement with the contractor. In other words, a warranty for the quality of work performed by the contractor after the contract period needs to be provided. Realizing this, an active movement towards developing a dependable warranty clause was initiated in this study. The report in volume V represents the study conducted to develop the first version of INDOT's steel bridges painting warranty clauses.

The literature review indicated that some painting warranty clauses are in practical use in the United States, although most of them are vague and poorly written (Hare, 1990). A survey was conducted to examine the current practices of the neighboring states, hoping that some warranty forms were being used in the steel bridges painting area. The survey revealed that both IDOT and MDOT have established an agreed-upon warranty form that has already been used in their painting contracts. The quick review of the available forms indicated an apparent difference in the administrative practices compared with those of Indiana. This fact stimulated the use of INDOT's pavement warranty clause as a reference document, in addition to taking advantage of its successful performance over the last few years.

The available four sources of information (IDOT, MDOT, and INDOT warranty clauses) constituted the foundation elements used in the development process. The drafted warranty clause was primarily dependent on the results of the comparative study conducted on eleven pre-identified categories existing on all the available forms. These categories include: warranty period, defects definition, inspection schedule, submittal of repair procedure and progress schedule, season of work, liability insurance, traffic control, supplementary performance bond, supplementary lien bond, surety company, and required work permits.

All of the constituents of the proposed warranty clause and the arguments around them are based on the currently available information. The proposed form is understood to be experimental where the different elements of this form will be subjected to further evaluations in the future. The most obvious elements that need to be reevaluated are: the warranty period, sufficiency of the defect definition, and the value of the warranty bond. The available set of information was incomplete when the report was prepared. Therefore, the report does not provide a clear-cut decision on how to modify the warranty clauses. Moreover, the reevaluation will enhance the efficiency of the proposed warranty clauses when they are put in use.

RESULTS AND FINDINGS

1- Many steel bridge coating systems have been reviewed through publications, interviews with paint manufactures, and bridge owners. Among them, those used in similar environmental conditions and that have successful performance records in the surrounding states have been identified for further analysis. Moreover, the inorganic zinc / waterborne acrylic coating system, the moisture cure urethane costing system, and the 3-coat system of organic / inorganic zinc, epoxy, polyurethane were chosen to compare with INDOT presents inorganic zinc / vinyl system. The results showed that the 3-coat system is the comparatively better system for use on INDOT steel bridges. The 3- coat system has merits of longer durability, less surface preparation, relatively lower cost, compliance with environmental requirements, high gloss and low chalking, and a better capacity to sustain chloride-contaminated weathering.

2- As an alternative to full-removal of bridge coating systems, over-coating might provide a good protection for less than half the cost of a full-removal. However, over-coating of bridges would likely delay the hazardous lead removal process and it would not fully solve the environmental issues facing the lead removal.

3- A thorough review of the standards and specifications regulating the application of metalization is presented in this report. The ANSI/AWS C2.18-93 indicated that metalization jobs require higher degrees of control, which suits on-shop practices. A complete process of surface preparation, metalization, and application of paint coats is attainable on-shop.

4- The primary barrier facing the metalization of steel bridges was the high installation costs of the system. However, distributing the initial costs over the expected long life span of the system could lower the life cycle cost. In addition, the cost of metalization has decreased over the last ten years. This allows better competitiveness of metalization against all conventional paint systems. If the trend continues in the coming years, metalization could become even more competitive, while providing a durable performance over a longer lifetime.

5- Life cycle cost analysis reconfirmed the recommendation to use inorganic / organic zinc, epoxy, and urethane system, the 3-coat system, because it was the optimal paint system among zinc/vinyl of INDOT, the existing 2-coat system, and INDOT is experimental metalization system. The present value (PV) for the 3-coat paint system was \$4.55/ $ft^2$and the equivalent uniform annual cost (EUAC) for that paint system was \$0.324/ ft^2. These numbers were the minimum among the three alternative paint systems. Therefore, it was recommended that the 3-coat system be adopted and used for replacing the existing zinc/vinyl, 2-coat system in the future.

6- INDOT just started implementing the 3-coat system. Therefore, there were inadequate data for life cycle cost analysis. However, based on MDOT data set, life cycle cost analysis

seemingly indicated that the optimal policy for 3-coat system rehabilitation was doing spot painting every 15 years or when paint condition rating reaches 7, regardless of the age of the paint on the steel bridge.

7- A detailed maintenance plan was developed based on the economical life cycle cost analysis results derived from MDOT data set. Since INDOT just started to use the 3-coat system, and does not have available data, a framework for establishing more realistic maintenance plan applicable to INDOT environments must depend on appropriate data collected in the future.

8- A form of warranty clauses was developed and has been put in use by INDOT. The experimental warranty form was suggested to cover a warranty period of only two years. The two main reasons were to allow for a gradual change in the INDOT policy and to enable INDOT to fully take advantage of merits earlier if the experimental results are significant.

9- All of the constituents of the proposed warranty clauses and the arguments around them were based on the currently available information. The proposed form was understood to be experimental. The most obvious elements needing to be reevaluated were the warranty period, sufficiency of the defects definition, and the value of the warranty bond. The available set of information when the report was prepared was too incomplete to give a clear-cut decision. The reevaluation itself would depend to a great deal on the environmental performance of the warranty clause before a final decision can be made on them.

IMPLEMENTATION

As discussed previously, this research generates five volumes of reports based on four integrated sub-studies. The project objectives have been achieved through evaluation of coating systems, review of metalization, life cycle cost analysis, and development of warranty clauses. Many of the aforementioned findings have been adopted by INDOT and implemented as follows:

1- The research verified the 3-coat system, Inorganic/Organic Zinc/Epoxy urethane, as a comparatively efficient alternative. INDOT has officially adopted this system and has massively used it in the new bridge paint project.

2- The information and data obtained from the evaluation of the 3-coat system has been incorporated into INDOT construction specifications.

3- The synthesis of all the merits in INDOT in existing metalization specification and the specifications of ConnDOT, ODOT, and MDOT result in new metalization specifications. The recommended metalization specifications have been accepted by SAC of this research project and are ready for use in any new metalization project by INDOT.

4- The proposed warranty clauses have been applied to one INDOT demonstration project. The implementation is on the way and under close monitoring.

5- All the findings found in the research will be conveyed to INDOT bridge inspectors through training sessions scheduled in the spring of 1999. Thus, the findings can reinforce INDOT inspectors' background, awareness, and efficiency in implementing the findings resulting from this research into their daily practices.

PROPOSED MAINTENANCE PLAN

As well as the implementation described in the last section and based on the life cycle cost analysis for determination of the best rehabilitation scenario, a proposed maintenance plan and its procedural steps is summarized in Figure 2.

The steel bridge paint should be inspected, as usual, every two years by INDOT inspectors. During the inspection, the paint condition will be rated. If the rate of paint condition reaches 7 or below, spot painting must be done on the bridge, regardless of whether or not the

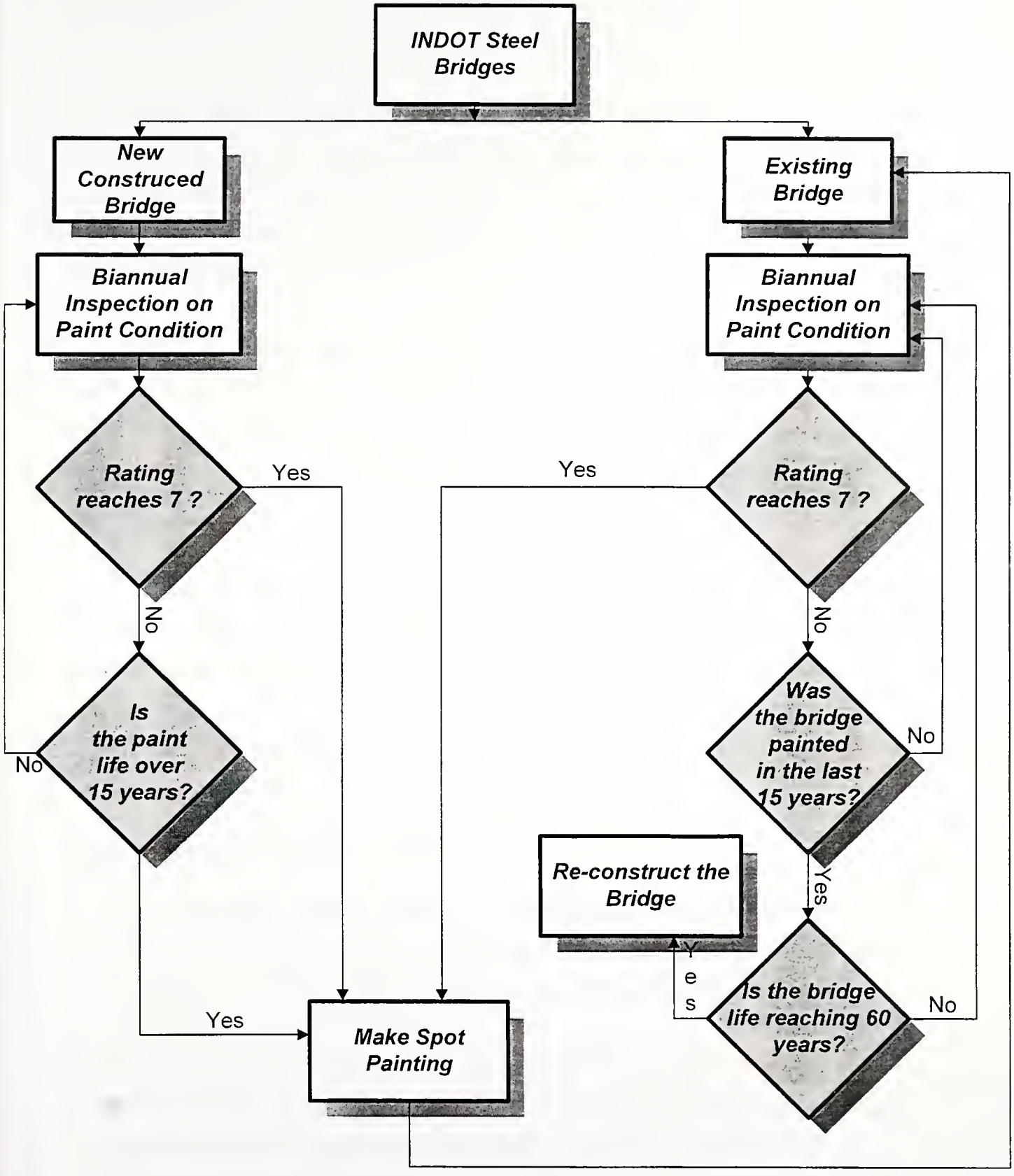

Figure 2: *Maintenance Plan Procedure Flowchart*

paint is new. In case of new paint, the question to the inspector is, Is the paint life over 15 years? If the answer is Yes, the spot painting will be automatically performed, even if the rating of the paint condition is away above 7. If the bridge has been painted within 15 years, the bridge still goes through routine biannually inspection. In other words, nothing is done to the paint job until the rating reaches 7 or the paint life is over 15 years.

When an old paint condition rating is above 7, the inspector should ask, "Was the bridge painted in the last 15 years?" If the bridge has not been painted in the last 15 years, the spot painting should be automatically done. Based on the recommendation of life cycle cost analysis, spot painting every 15 years is the most economic policy, despite the condition rating not reaching 7.

In case a bridge was painted in the last 15 years, the inspector should examine the factor of bridge life. When the bridge life is reaching 60 years, there is no point in repainting the bridge, since the bridge will be reconstructed or demolished.

After being spot-painted, any bridge can be categorized as an "old bridge". Thereafter, the maintenance procedures should be repeated until the bridge is reconstructed.

RECOMMENDATIONS AND FUTURE WORK

1- Many of the findings resulting from this research project have been implemented. Continuous observation and monitoring of the implementation of the warranty clauses, the new 3-coat system, and metalization in INDOT demonstration projects are necessary in the future.

2- Maximizing the benefit of budget allocation for INDOT is a very important issue. The INDOT steel bridge paint rehabilitation budget could be allocated every year to different bridges according to their importance. Dynamic Programming or Mixed Integer Programming techniques based on the Markov chains results are recommended to optimize

the benefit of INDOT budget allocation for steel bridge paint rehabilitation projects in future study.

3- Multimedia can be used as an effective training tool for the inspectors to apply the evaluation criteria and to set up inspection procedures for steel bridge painting. This approach can not only shorten the training process, but also enhance the present inspectors' knowledge and experience.

4- It is recommended to further study the Markov Decision Process of life cycle cost analysis. This method is based on the stochastic method. The method needs considerably more data to substantiate its analysis and to determine the optimal maintenance plan. INDOT just started to use the 3-coat system. The experimental data from the field are still few and new. The continuous collection of field data and the establishment of a generic Markov Decision Process is necessary for assessing any future advanced coating system emerging in the market.

5- The present measurement procedure used for identifying the deterioration-related failures of the painting system in INDOT is quite subjective. The procedures mainly rely on visual inspection. This means that the decision can vary from one inspector to another. A study on the use of photographs showing different deterioration ratings on actual bridge components will provide a better sense of reality and will help to reduce the amount of discrepancy in the data collection. The development of computer visual image processing is recommended.

6- The deterioration model is the key element to determine an efficient warranty period. The further study of the deterioration curves as a function of the various environmental conditions can enhance the decision making of the optimal painting maintenance program.