EXPLORATORY INVESTIGATION OF LEGACY BRIDGE DATABASES IN VIRGINIA

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ABSTRACT

This report is an investigation of data mining of legacy bridge databases, focusing on the Pontis and National Bridge Inventory databases maintained by the Virginia Department of Transportation (VDOT). This project is applied in nature as it was sponsored by the Virginia Center for Transportation Innovation and Research (VCTIR). Exploratory data analysis was performed using Microsoft Excel, and resulted in patterns and projections that were unavailable directly from the raw inspection report data.

Data mining techniques were applied to 6 sub-studies conducted in response to VDOT interests. First, district-based trends in various element condition states across Virginia were determined and the results were summarized using graphs created from the Pontis element data. Second, a state-wide identification of potential inspector data-entry errors was conducted. Third, as part of a wider VCTIR study, the effectiveness of zinc-based coating systems was investigated by looking at deterioration of steel girders using National Bridge Inventory (NBI) and Pontis data; deteriorated sections of girder elements on the same set of bridges were also identified. Fourth, joint closures occurring between 1995 and 2010 were discovered and categorized. Fifth, priority bridges were identified around Virginia, and trips to the nine VDOT district offices were taken to investigate which maintenance actions caused improvements to specific elements on those bridges. Lastly, linear least squares regression and Markov chain condition state transition modeling were performed on selected elements to predict deterioration.

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Lastly, I wish to thank my mother, Althea Johnston, for her continued support and encouragement.

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INTRODUCTION

This introduction is divided into three sections. The first section, Project Development, describes how this investigation came about and how it was guided by various internal VDOT forces. The second section, Motivation, presents the incentive behind the two main subtopics of the study and how other sub-studies emerged. The final section, Scope and Summary, outlines the format of the data mining process and its results.

Project Development

The National Bridge Inventory (NBI) and Pontis databases were created in 1972 and 1991, respectively, in response to developing congressional demands for stricter bridge inspection and management practices. These databases have provided the means for the Federal Highway Administration (FHWA) to determine funding priorities in bridge maintenance. The primary use of these databases has been by the Federal Highway Administration to manage the National Bridge Program. This project investigates data mining of these legacy databases and seeks to find previously unknown deterioration and improvement trends in Virginia bridges.

The NBI uses condition ratings to quantify the condition of each of 5 major components of the bridge: superstructure, substructure, deck, channels, and culverts (if present). A condition rating of 9 means that component is in pristine condition while a 0 means that component has failed. Pontis breaks these major components down further into elements such as compression joint seal (element 301) and steel open girder – painted (element 107); the full list of these elements and associated codes is available in Appendix A of this report. Pontis stores a condition state for each quantity (linear feet, square feet, each) of these elements on a bridge to quantify their condition, with 1 representing a pristine section of element, and a 3, 4, or 5 (depending on element) representing a severely deteriorated section of element.

The methods of Knowledge Discovery in Databases (KDD), specifically exploratory data mining, are predicated on the fact that the researcher does not know what the data can tell them when beginning the analysis. As Tukey pointed out, “exploratory data analysis can never be the whole story, but nothing else can serve as the foundation—as the first step” (Tukey, 1977). This project reduced the raw Pontis data to several usable tables and found unknown trends; additional studies of this data could produce additional patterns and conclusions.

The Virginia Center for Transportation Innovation and Research in Charlottesville, Virginia created a Bridge Information Systems Laboratory for Virginia to encompass the scope of this project. A project advisory group, comprised of VDOT bridge personnel, was also created to oversee and guide the work conducted by this Laboratory. The members of this group are Mr. Adam Matteo, Mr. Jeffrey Milton, Mr. Rex Pearce, Dr. Steven Chase, Dr. Michael Brown, and Mr. Prasad Nallapaneni. Monthly meetings were held to review ongoing work and generate ideas for the direction of the exploration to take in the month to follow. This active interaction and discussion was a key component of the project.

Motivation

Two main subtopics were identified for the initial explorations: an investigation on the effectiveness of maintenance actions and a study on the performance of zinc-based coating systems on girders. The objective of the maintenance study was to ascertain what specific actions were being undertaken to maintain various bridge elements, and to begin to analyze the effectiveness of these actions in the years since they were taken. This study was undertaken because there is no adequate and readily available bridge maintenance system in place for VDOT currently. Each of the 9 VDOT-maintained districts is in charge of its own system, and while some districts have elected to start an online repository of maintenance actions in recent years, others still use only paper reports for maintenance information.

The zinc performance study examined the coating performance of four groups of bridges. These were: simply supported bridges built after 1983 (group 1), continuous bridges built after 1983 (group 2), simply supported bridges built before 1984 and repainted after 1984 (group 3), and continuous bridges built before 1984 and repainted after 1984 (group 4). All bridges were VDOT-maintained, active, non-posted, with steel beams or girders, and concrete decks from across Virginia (district was ignored). The bridges were divided into these groups to investigate possible differences in performance between structures that had been shop-coated (groups 1 and 2) and structures that had been field-coated (groups 3 and 4). Also, it was postulated that there might be a difference in performance between simply supported structures and continuous structures due to the presence of additional bridge joints in the simply supported structures. This investigation was part of a larger VDOT project investigating the zinc-based coating that has been the primary paint system used on Virginia bridge girders since 1983. The task for this project was to identify Pontis condition state trends for these girders (element 107).

Due to the emergent nature of this project, several side studies arose. During the preparation of the raw data for analysis, condition state improvement and deterioration trends based on year of inspection were discovered and graphed. An investigation of condition state histories related to bridge age since improvement aimed to find more accurate element-based deterioration rates. Another side study was a state-wide identification of potential inspector data-entry errors. Another special analysis requested by VDOT was a classification of different types of joint closures that occurred between 1995 and 2010. Additionally, as an addendum to the zinc coating study, deteriorated sections (defined as quantity in condition state 4 and 5) were identified on element 107 (Steel Open Girder - Coated). Lastly, linear least squares regression and Markov chain condition state transition modeling were performed on selected elements to predict deterioration.

Scope and Summary

This project was applied in nature and focused more on refinement and application of previously developed methodologies than on developing new approaches. These methods were used to investigate legacy Pontis and NBI bridge condition data for VDOT. The project began with a review of exploratory data mining literature, followed by a selection and application of methods that were suitable for the problems posed by the project advisory group.

For the zinc study, various data filters were applied to the VDOT Pontis and NBI data to create data sets of bridges with zinc-based coatings. The data sets were analyzed and several descriptive statistics were produced. These were: the average element 107 condition state for each structure, the total quantity of element 107 and the percent in each condition state, the distribution of average condition states for element 107, the average superstructure condition rating, the distribution of superstructure condition ratings, the percentage of bridges with superstructure condition rating of 7 or higher, and the average years built and painted.

For the maintenance study, six elements were selected by perceived criticality, two each of beams, joints, and bearings. Improvements were identified in the Pontis data for these elements based on a condition state decrease of more than 1.00 from the maximum recorded condition state (between 1995 and 2010) to 2010 values. District visits were made to correlate likely maintained bridges (forty per district) with maintenance actions noted on inspection reports. These records are stored as physical written reports at each of the district offices. The results were further reported by classification of the road carried: interstate, primary, or secondary.

In the analysis of condition state trends, elements were first selected by count within each district. The raw Pontis data were reduced to condition state histories between 1995 and 2010, and trends were found for bridges that did and did not have a significant improvement noted. Bridges of varying sizes were given the same weight for most of the analysis. A study was performed using the total quantity of each element per district to investigate if there were any substantial differences in results, and no significant difference was discovered. Investigations of potential inspector errors and noted joint closures were also performed by applying filters to Pontis data. Summary tables and long lists of federal bridge ID numbers were produced and reported to VDOT.

The Linear Least Squares regression analysis required several custom macros that were applied to the Pontis data to generate deterioration trends. The Markov chain modeling produced transition probability matrices and associated deterioration prediction graphs. Both models were applied to element-level data at the state and district level.

Pontis element-level condition state data is sometimes converted to NBI condition ratings using a translator program to conform to established reporting procedures, but the translation results do not always correlate well to corresponding NBI data (Aldemir-Bektas & Smadi, 2008). This project investigated unmodified NBI data in the zinc coating study, but the main focus was on mining the raw Pontis element-level condition state data.

REVIEW OF THE LITERATURE

Summary of NBI

The National Bridge Inspection Standards (NBIS) were created in response to the 1967 failure of the Silver Bridge between West Virginia and Ohio that resulted in the death of 46 people. Implemented in the early 1970s by the Secretary of Transportation, under pressure from Congress, the NBIS set the specifications on the inspection of bridges on public roads. Information from these inspections is stored in the National Bridge Inventory (NBI) database, created in 1972. FHWA uses the NBI to allocate funds to the states for bridge replacement, rehabilitation and to some extent maintenance (Small, Philbin, Fraher, & Romack, 1999).

History of Pontis

Pontis is a Bridge Management System (BMS) that has been adopted for use by 39 states / territories and 7 other agencies in the US, as well as 7 systems internationally. It was created and is maintained through the American Association of State Highway and Transportation (AASHTO)'s joint software development program, which allows agencies to create a unified management system through pooled resources. Pontis has thus been cheaper (to each agency) to both implement and maintain, plus it creates an industry standard of best practice to help standardize bridge management at the national level (Robert, Marshall, Shepard, & Aldayuz, 2003).

Unlike the NBI database, which stores all information in one massive file, Pontis is based upon a Relational Database Management System. This means that the information is stored in tables that are interconnected, in order to more efficiently reference data in related tables. These tables store records in separate rows and data fields in separate columns. The tables are related to each other by key data fields in other tables (unit prices, probabilities, etc.). These systems provide methods to efficiently enter, store, and generate reports from data (Chase, 2011).

Pontis was created in 1991 in response to the Intermodal Surface Transportation Efficiency Act (ISTEA) from Congress requiring each state Department of Transportation (DOT) to implement a more functional / detailed BMS. Funding came from the federal level via contract to industry. A previous system, the NBIS, provided overall condition ratings for each bridge at the deck, superstructure, substructure, channel, and culvert component levels. That was determined to be too subjective (based too heavily on the experience of the bridge inspector), with funding ultimately believed to be going to the wrong bridges (Gutkowski & Arenella, 1998).

In response to this, Pontis was developed and is a more quantitative BMS that looks at structures at the element level. These elements are well-defined subdivisions of bridge systems such as girders, joints, decks, and railings, each of which is further broken down by material type. Thus, each component of the NBIS (such as superstructure) is broken down into many more detailed elements. Being able to know which specific elements contribute most to the deteriorated state of a bridge allows funding to more effectively be used on maintenance. Additionally, Pontis supports the entire bridge management life cycle, providing methods for inventorying, inspecting, performing needs assessment, strategy development, and project / program growth (AASHTO, Pontis User Manual, 2005).

The NBI database stores condition information on five aggregate structural units (deck, superstructure, substructure, channel, and culvert) by assigning a condition rating (occasionally abbreviated CR in tables / graphs) to each of these components of a bridge on a scale from 9 (perfect) to 1 (severe deterioration / failure). Pontis, on the other hand, assigns each defined element a condition state (occasionally abbreviated CS in tables / graphs) on a scale from 1 (perfect) to 3, 4, or 5 (severe deterioration / failure), depending on the element. Inspectors using the NBIS would apply an average condition rating to each component of the bridge while those using Pontis break down the condition assessment into the units each element is assigned.

Elements can also be quantitative. For example, girders are assigned linear footage while elements such as bearings are assigned “each”, thereby quantifying the total number of bearings on a given bridge. Pontis is thus a more descriptive inspection tool enabling the determination of how much of a certain element of the bridge is in a truly deteriorated condition. Pontis also contains “smart flag” elements that track types of deterioration different from those listed in the structural element condition state definitions. Smart flags, such as scour and traffic impact damage, are used to record conditions on the bridge that “do not exhibit a logical pattern of deterioration” (VDOT, 2007). This thesis used data from both databases but focused on Pontis data because it was more detailed.

Pontis Details

Element Definitions

The Virginia Pontis Element Data Collection Manual defines 111 elements and associated condition states that can be tracked on bridges in the state of Virginia. One hundred of these are known as Commonly Recognized (CoRe) elements. These CoRe elements have identical definitions between agencies in order to facilitate more uniform data collection and analysis nationally. The Pontis guidelines allow users to add their own additional elements to track the condition of further components states wish to track, and the other eleven elements were uniquely defined by the Virginia DOT. These 111 elements define common bridge components in terms of component function and material, such as 'Steel Open Girder – Coated', 'Timber Bridge Railing' and 'Elastomeric Bearing'. Additionally, in Virginia, there are nineteen smart flags recorded, eight of which are CoRe and the remaining eleven are uniquely defined by the Virginia DOT (VDOT, 2007). The full list of the 111 elements and nineteen smart flags is presented in Appendix A.

Inspection Report Guidelines

The National Bridge Inspection Standards set forth the requirements and the general guidelines for responsibility of inspection of state and federal bridges. These include the qualifications for different levels of inspection personnel, different types of inspections and suggested associated frequencies, general inspection procedures, and fields in common data collection tables (Chase, 2010). The specific procedures for inspection and reporting are outlined in the AASHTO Manual for Bridge Evaluation (AASHTO, 2011), the Bridge Inspector's Reference Manual (Ryan, Hartle, Mann, & Danovich, 2006), the Recording and Coding Guide (FHWA, 1995), and the AASHTO Maintenance Manual for Roadways and Bridges (AASHTO, 2007). These documents explain in detail the different bridge members, explain common defects, and define the associated condition ratings for the superstructure, substructure and deck. The Pontis Element Data Collection Manual defines the condition state guidelines for the Pontis element-level inspection reporting (VDOT, 2007).

PDI Output

Pontis Data Interchange (PDI) files are text files recognizable by Pontis either as imports from another program or as exports in the form of reports. The PDI files contain the data for all bridges in the database and formatting information such as Metric / English units, date format, left / right justification, and other rules that are either column-specific or table-wide. The columns and tables used by Pontis in storing bridge / inspection data are thereby converted into PDI files which can be imported into Microsoft Excel as Comma Separated Values Files.

Five of these PDI-based Excel files were used over the course of this project. The Bridge table contains physical, administrative, and operation characteristics of structures. The ElemInsp table contains the Pontis element-level inspection reports including quantity of each element in each condition state for a bridge per inspection cycle. The InspEvnt table contains one entry per inspection, reporting specifics such as inspection type, inspector identification, and structure-level results. The Roadway table contains information about all roadways on and under each structure, with fields such as route number, truck traffic, detour length, and number of lanes. The UserBrdg table is defined by the agency and contains additional information about bridges; VDOT uses fields such as approach pier type, utilities present, year repainted, and drain dimensions (AASHTO, Pontis Technical Manual, 2005).

Repairs and Improvements

Pontis makes a distinction between repairs and improvements. The former comprises routine maintenance (girder painting, deck overlays, patching, etc.) whereas improvements aim to fix functional deficiencies such as vertical clearance, bridge width, or strength capacity. Maintenance is considered a dynamic and ongoing process, while improvement is dealt with as a one-time solution to a deficiency and is considered static (Golabi & Shepard, 1997). An “improvement” (decrease) in element condition state would likely be achieved by either of the above types of work. The associated improvement for a bridge in the NBI database would be a condition rating increase.

Deterioration Modeling

Two main types of modeling available for deterioration prediction are deterministic and stochastic. Deterministic models include regression analyses that can create trends that follow data linearly or in a quadratic / cubic / higher power manner. The stochastic model is more probabilistic and attempts to account for more of the perceived randomness associated with deterioration of a bridge element such as the paint system (Zayed, Chang, & Fricker, 2002).

Linear Least Squares Regression

The most commonly used deterministic model is linear least squares regression in which a line is fit to a set of data. The form of the solution is $y = f(x;\beta) = \beta_0 + B_1 x_1 + \beta_2 x_2 + \cdots$. This method does not always result in a straight line product; the "linear" merely refers to a one-to-one mapping between the known coefficients and unknown parameters (NIST/SEMATECH, 2012). The equation of the solution is calculated by minimizing the sum of the squared differences between the y values of the data set with the y values of the model.

Markov Chains

A stochastic model that lends itself well to the finite condition state description associated with Pontis data is Markov chains. In this type of model, a probability is assigned to each possible transition, which in this case correlates to changes from condition state 1 to 2, 2 to

3, etc. in a given time period (one year in this case). These transition probabilities can be determined based on averages from historical deterioration for each element or from expert judgment from experienced bridge engineers. The single table of deterioration probabilities created from historical averages does not take into account the history of each specific element; it is limited to the average of the entire population and / or experts' experiences (Morcous, 2006).

Knowledge Discovery in Databases and Data Mining

As computational power increases in the digital age, our ability to store vast quantities of data has greatly increased. The flood of information that is generated by our advanced data collection methods can be difficult to make sense of, generating a need for advanced techniques for application of statistical techniques (Frawley, Piatesky-Shapiro, & Matheus, 1992). The field of Knowledge Discovery in Databases (KDD) aims to develop more efficient tools for exploring large volumes of data with the end goal being a more thorough understanding of the results. As Fayyad, Piatetsky-Shapiro, & Smyth stated in 1996, the value of data storage is determined by "our ability to extract useful reports, spot interesting events and trends, support decisions and policy based on statistical analysis and inference, and exploit the data to achieve business, operational, or scientific goals" (Fayyad, Piatetsky-Shapiro, & Smyth, 1996, p. 27).

A distinction can be made between KDD and "data mining", where KDD is the entire procedure of drawing meaningful conclusions from patterns found in raw data while data mining is specifically the extraction of results from reduced data sets (Fayyad & Stolorz, 1997). Reducing the data to usable form, mining that information, and analyzing the types of results obtained are all necessary steps to the KDD process, often taken in an iterative manner. The application of these methods was explored in this project. Pre-defined report-generating processes often do not work well for new types of analysis as it may be difficult to know what results to expect, so new methods must often be developed over the course of the exploration.

The ultimate goal of KDD, as implied by its name, is an increased knowledge of the data. This is accomplished through identification of valid, useful, novel, and understandable patterns. Validity can be verified through certainty measures such as accuracy of predictions made. Usefulness can be quantified by a (predicted or actual) monetary gain or savings in time due to modifying a process. Novelty here means the results are new to the system being analyzed, if not also the user specifically, and is somewhat subjective. Understandability, to the researcher and the audience of the findings, is also rather subjective and can be partially represented by the simplicity of the results (Fayyad & Stolorz, 1997).

Effective investigation of data requires both the tools and the understanding to direct the analysis. The tools encompass different analytical techniques (as well as the computers themselves), while understanding the nature of the data and the expected results helps guide which types of studies to pursue. Exploratory data analysis is a useful detective method to determine trends on which to perform more judicial confirmatory data analysis. Providing summary statistics, such as averages and extrema, can be useful tools in dealing with large sets of data, but they necessarily reduce the full value of the details stored in each piece of data (Tukey, 1977).

In exploratory data analysis, the precise types of results to be created are often not known at the beginning of the exploration. Researchers must therefore “examine the data, in search of structures that may indicate deeper relationships between cases or variables” (Hand, Mannila, & Smyth, 2001, p. 53). These deeper relationships provide statistics to more easily infer significant conclusions and suggest meaningful recommendations. Visualization was frequently utilized;

this method uses the pattern-finding ability of the human brain to detect trends when data is presented in certain ways, such as different types of graphs (Hand, Mannila, & Smyth, 2001).

National Bridge Maintenance Database

One of the primary motivations for this project was that a comprehensive database for bridge maintenance information collection and storage does not exist. Hearn, Thompson, Mystkowski, and Hyman (2010) describe a suggested framework for such a resource, the National Bridge Maintenance Database (NBMD). This proposed database aims to create a uniform format to collect, report, and store information on bridge maintenance actions while allowing the various DOTs to continue their current practices for in-the-field data recording. As such, it would be a recipient of data, and the condition and inventory data would conform to the existing U.S. NBI and Pontis systems. As in any database, the NBMD would become more useful as more data is collected from around a given state, in terms of years of condition history and number of bridges reporting.

The NBMD report contains an implementation plan outlining general steps to follow to guide this database into effective widespread use. First, funding would be secured through a supporting agency, which could be a research organization, a federal group, or a pool of state agencies. Next, a technical working group of DOTs would sign on for a certain number of years, committing to annual data upload of maintenance, inventory, and condition values. They would also evaluate the NBMD outputs to assess the effectiveness and recommend new applications as they see fit. A contractor would be brought on board to perform system maintenance, develop the specific data processors, provide technical support, maintain table standards, and in general execute regular upkeep. Next is smoothing the integration with Pontis so that NBMD element-level maintenance costs can effectively be used to update the Pontis preservation model. Lastly, methods would be developed to integrate NBMD with DOT enterprise software. (Hearn, Thompson, Mystkowski, & Hyman, 2010).

The NBMD is a maintenance event archive, storing data on the structure, the maintenance operation / date, the resources used, and the outcome. Fourteen bridge "components" are used as objects of maintenance actions, including the 5 from the NBIS (Deck, Superstructure, etc.) and 7 more that many DOTS use (such as Joints and Bearings), as well as overall Bridge and non-Bridge repairs. Eight standard maintenance operations are defined, including cleaning / clearing, coating, partial replacement, and emergency response work. Each of these in turn has several activities associated with it (e.g. spot painting and chemical treatments for "coating") as well as frequent uses of these activities in practice. For example, chemical treatments are used as preservatives for timber decks / superstructures / etc. while herbicides and pesticides are used on earth slopes and banks.

Overall, the report presents a framework for a database that is designed to assist DOTs with maintenance data storage and assessment at minimal levels of additional cost and effort per result, especially as more states would adopt it into use. An important aspect of the NBMD is that the methods of evaluation (e.g. discount / inflation rates and cost data) come from users, so its results are more customizable to each DOT's specific conditions (Hearn, Thompson, Mystkowski, & Hyman, 2010).

The project advisory group was curious if there was any correlation between the general geographic environments bridges were in around Virginia and their element deterioration, as well as the maintenance actions performed on them. This resulted in many of the results of the project being subdivided into the different VDOT districts.

VDOT Districts

There are nine districts in VDOT that maintain roads in different regions of Virginia. The regional boundaries are shown in Figure 1. The VDOT-assigned district numbers (1-9) were used throughout this project for reference and are:

1 – Bristol

2 – Salem

3 – Lynchburg

4 – Richmond

5 – Hampton Roads

6 – Fredericksburg

7 – Culpeper

8 – Staunton

9 – Northern Virginia

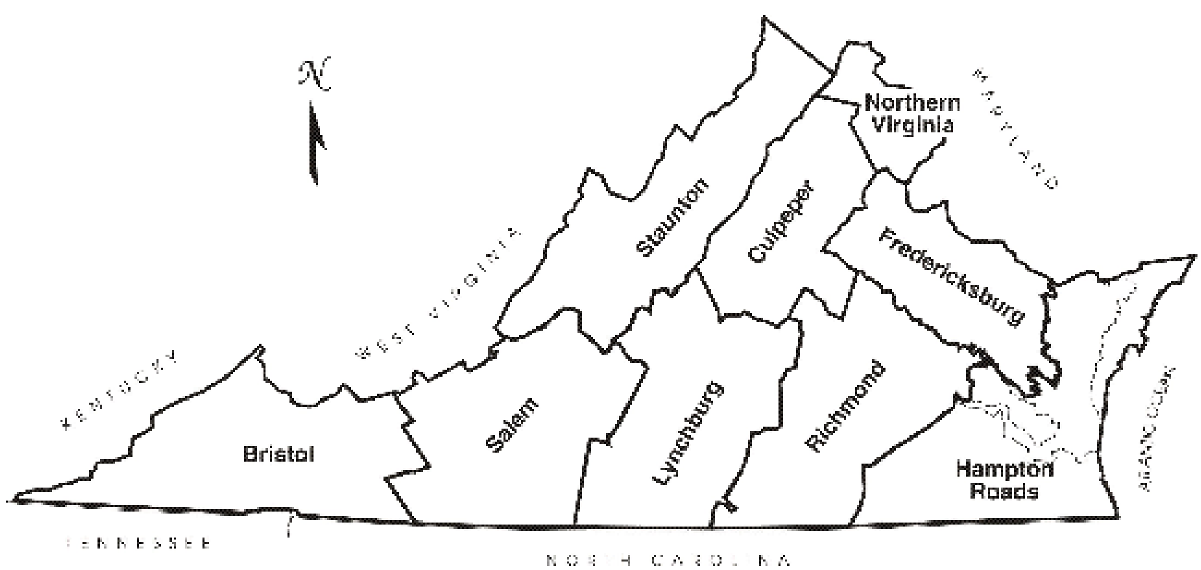

Figure 1 – Map of VDOT Districts (Courtesy of VDOT)

METHODS

This study included several different investigations suggested by the members of the project advisory group. This section is organized into those subtopics as they were investigated for this project, employing different data mining methods and techniques. The subsections are: Original Pontis Analysis by District, Potential Errors, Zinc Coating Study, Joint Closures, Priority Bridges and District Visits, and Linear Least Squares and Markov Modeling.

Original Pontis Analysis by District

The data analysis portion of this work began with a large PDI file containing text strings of information from the Pontis database for all of the bridges in Virginia over the period 1995 - 2010. Visual Basic for Applications (VBA) code was used to separate the needed information by district into 9 different Excel files. The tables created contained each inspection report in a separate row and each unique extracted piece of information in a separate column. Several user-defined columns were created to be used in the analysis of the inspection report data, including numerous cells converting digits contained within quotation marks (as text strings) into Excel-recognized numbers. Also included was a column calculating the average condition state (marked AVG CS) for the given element and bridge. This data provided the basis for the analyses in this section of the report. An example of some of the extracted data is shown in Table 1. The “PCT#” columns represent the percent of the given element in each condition state for each inspection report, and the QTY columns represent the quantity of the given element in each condition state (in linear feet, square feet, or each, depending on the element).

ElemKey	YR Built	Inspection Date	PCT1	PCT2	PCT3	PCT4	PCT5	AVG CS	QTY1	QTY2
241	1969	1998/02/06	89.000	11.000	0.000	0.000	0.000	1.110	74.000	9.000
241	1969	1996/03/04	92.600	7.400	0.000	0.000	0.000	1.074	77.000	6.000
241	1969	2000/02/03	89.000	11.000	0.000	0.000	0.000	1.110	74.000	9.000
241	1969	2002/02/05	83.100	15.800	1.100	0.000	0.000	1.180	69.000	13.000
241	1969	2004/03/12	83.100	15.800	1.100	0.000	0.000	1.180	69.000	13.000
241	1969	2006/02/17	83.100	15.800	1.100	0.000	0.000	1.180	69.000	13.000
241	1969	2008/02/22	83.100	15.800	1.100	0.000	0.000	1.180	69.000	13.000
241	1969	2010/02/09	83.100	15.800	1.100	0.000	0.000	1.180	69.000	13.000
298	1969	2010/02/09	100.000	0.000	0.000	0.000	0.000	1.000	2.000	0.000
299	1969	2010/02/09	100.000	0.000	0.000	0.000	0.000	1.000	4.000	0.000
361	1969	2008/02/22	100.000	0.000	0.000	0.000	0.000	1.000	1.000	0.000

Table 1 – Example Selection of Raw District Analysis Data (District 1)

There were too many element types that are routinely inspected to reasonably analyze all of them for each district, so a selection process was implemented to choose the most numerous elements. In a new worksheet, a table was created with each of the bridges in a given district in a separate row and all of the elements present on each bridge in that district in separate columns. A count-if function was performed on each cell (bridge / element intersection), which resulted in the number of inspection reports from 1995-2010 for that element and bridge. Table 2 shows an example portion of this table for District 1; for example, bridge 16747 had 7 recorded inspection reports containing element 12. The number of reports was totaled and ordered from highest to lowest along with the top 10 smart flags and top 20 elements selected from each district for analysis. A summary of the top elements and smart flags for each district is presented in Table 24 through Table 26. Throughout this project, elements and smart flags were tracked of using their 3-digit numeric designation; if the corresponding text was desired (i.e. Element 234 is 'Reinforced concrete pier cap') a link was created to that element in a separate reference sheet in Excel. This worksheet served as a lookup table for element and smart flag numbers to corresponding description. This was as documented in the Pontis element definitions, and is reproduced in this report as Appendix A.

ID	012	013	014	018	022	026	028	030	031	032	038
"000000000016737"	0	0	0	0	0	0	0	0	0	0	0
"000000000016738"	0	0	0	0	0	8	0	0	0	0	0
"000000000016739"	0	0	0	0	0	0	0	0	0	15	0
"000000000016742"	0	0	0	0	0	0	0	0	0	0	5
"000000000016747"	7	0	0	0	3	0	0	0	0	0	0
"000000000016748"	0	0	0	0	0	0	0	0	10	2	0
"000000000016749"	0	0	0	0	0	0	0	0	0	0	8
"000000000016750"	0	0	0	0	0	0	0	0	0	0	1
"000000000016752"	0	0	0	0	0	0	0	0	0	12	0
"000000000016753"	0	0	0	0	0	0	0	0	0	0	8

Table 2 - Example Selection of Counting Table for Element and Smart Flag Selection (District 1)

For the elements that were selected for analysis, the corresponding BridgeIDs, years built, inspection dates, and average condition states were copied into separate worksheets titled with the respective element numbers. A subsequent table was constructed with unique bridge numbers in each row and the years 1995-2010 in separate columns. For each cell in the table, a formula was used that averaged any condition states for that element from reports matching the given bridge and inspection year. Cells were color-coded to be grey when there was no inspection report (marked as condition state 0.00), green when the average condition state was between 1.00 and 1.99, yellow for 2.00 to 2.99, orange for 3.00 to 3.99, and red for 4.00 to 5.00. Several additional columns were created; one for the most recent condition state as of 2010, one for the age of the bridge in 2010, and lastly a column for whether there was an "Unexpected Improvement". This final column reported TRUE or FALSE. If the maximum condition state of the given bridge over the years 1995 – 2010 was more than 1.00 condition state points higher than the most recent condition state it was marked as 'true' and if not it was marked 'false'. This threshold was chosen to only identify bridges with significant improvements likely to be caused by major repairs. Table 3 shows a selection from this table for element 334 in District 5. Note that the bridge at the bottom displays a condition state decrease of 2.00, so it is noted as having an unexpected improvement. The decrease from a max of 3.00 to the current condition state was assumed to correspond to a significant repair. The amount of decrease associated with different interventions depends on the element, but for this project the >1.00 condition state decrease was used for all elements except joints. A separate, more lenient, improvement criterion was used for joint elements; this is described under the 'Priority Bridges and District Visits' heading later in this section.

2004	2005	2006	2007	2008	2009	2010	CR	Age	Unexpected Improvement
0.00	0.00	0.00	0.00	1.36	0.00	0.00	1.36	44	FALSE
1.00	0.00	1.00	0.00	1.00	0.00	1.00	1.00	33	FALSE
1.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00	59	FALSE
1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	81	FALSE
0.00	1.44	0.00	1.00	1.00	1.00	1.00	1.00	40	FALSE
0.00	1.77	0.00	1.52	1.52	1.52	0.00	1.52	49	FALSE
0.00	0.00	0.00	0.00	0.00	0.00	2.49	2.49	36	FALSE
1.00	0.00	1.19	0.00	1.19	1.23	1.00	1.00	36	FALSE
1.05	1.10	1.10	1.10	1.10	1.10	1.10	1.10	78	FALSE
1.00	0.00	1.00	0.00	1.00	0.00	1.00	1.00	49	FALSE
3.00	3.00	1.00	1.00	1.00	1.00	1.00	1.00	30	TRUE

Table 3 - Example Selection for Unexpected Improvement (Element 334 – District 5)

After preliminary analysis of the elements, the highest number of unexpected improvements occurred to element 107 (steel open girder - coated). After initial discussion with the project advisory group about potential inconsistencies in the analysis, it was revealed that there could be some irregularities with the steel open girder elements (107 and 108). The element 108 classification, as distinct from element 107, was created in 2006 to signify only the steel open girders under timber decks (these would likely have different deterioration rates and maintenance plans). This required additional work to segregate these bridges. The bridges listed as containing 108 were copied in Excel next to those originally containing 107 and a filter was created to identify those bridges which appeared in both lists. The data from the bridges that were reclassified by VDOT as having element 108, that had previously been marked 107, were appended to the existing 2006-2010 element 108 data. These bridges were analyzed separately from those that remained as 107 past 2005, and the final improvement count for each element was based upon the revised bridge lists. Figure 2 below shows the condition state histories for the same bridges in District 8 before and after this coding transition was accounted for. The top table shows just the inspection reports recorded after element 108 was coded while the bottom table has the elements previously coded as element 107 (that were ultimately 108) appended. As the new classification went into effect in the middle of 2006, some bridges had data from element 108 from that year and other had to be appended from the previous element 107 data.

Unique brkey	Unique YR Built	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
"000000000000901"	1992	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.13	0.00	1.13
"000000000001068"	1932	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.50	0.00	2.50	0.00	2.50
"000000000001069"	1932	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.63	0.00	2.63	0.00	2.63
"000000000001072"	1976	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.64	0.00	1.64	0.00	1.64
"000000000001073"	1932	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.15	0.00	2.15	0.00	2.15
"000000000001086"	1932	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.38	0.00	2.38	0.00	2.38
"000000000001093"	1932	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00
"000000000001094"	1932	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.20	0.00	1.20

⇩

Unique brkey	Unique YR Built	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
"000000000000901"	1992	0.00	1.00	0.00	0.00	0.00	1.00	0.00	1.13	0.00	1.13	0.00	1.13	0.00	1.13	0.00	1.13
"000000000001068"	1932	0.00	0.00	0.00	0.00	0.00	2.00	0.00	2.50	0.00	2.50	0.00	2.50	0.00	2.50	0.00	2.50
"000000000001069"	1932	0.00	0.00	0.00	1.10	0.00	2.00	0.00	2.63	0.00	2.63	0.00	2.63	0.00	2.63	0.00	2.63
"000000000001072"	1976	0.00	1.00	0.00	0.00	0.00	1.00	0.00	1.64	0.00	1.64	0.00	1.64	0.00	1.64	0.00	1.64
"000000000001073"	1932	0.00	0.00	0.00	0.00	0.00	2.00	0.00	2.15	0.00	2.15	0.00	2.15	0.00	2.15	0.00	2.15
"000000000001086"	1932	0.00	2.25	0.00	0.00	0.00	2.25	0.00	2.38	0.00	2.38	0.00	2.38	0.00	2.38	0.00	2.38
"000000000001093"	1932	0.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00
"000000000001094"	1932	0.00	0.00	0.00	1.00	0.00	1.00	0.00	1.20	0.00	1.20	0.00	1.20	0.00	1.20	0.00	1.20

Figure 2 - Example Addition of Element 107 Data to 108 Table (District 8)

It was noted that known painting that occurred on elements 107 and 108 could show up as "unexpected improvements". By comparing the year of the element improvements to the most recent year the bridges were painted (from the UserBrdg PDI file), only the improvements that were likely to be significant non-painting maintenance were counted in the final summary. Table 4 shows a selection from District 2 of element 108 where there were 4 bridges that fit the criteria for unexpected improvement, but 2 of those bridges (Paint Yr. 2009 and 2004) had the condition state decrease noted as the result of painting. The rightmost column is labeled "For Q. An." as this refined true / false distinction was also used in the quantity analysis that is discussed later in this section; it was also used in all further analysis containing 107 / 108 data.

2004	2005	2006	2007	2008	2009	2010	CR	Age	Unexpected Improvement	Paint Yr (Impr.)	Paint Improvement?	For Q An.
0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	78	FALSE			FALSE
2.40	0.00	2.40	0.00	3.39	2.38	0.00	2.38	78	TRUE	"2009"	TRUE	FALSE
2.48	0.00	1.00	0.00	1.00	0.00	1.00	1.00	78	TRUE	"2004"	TRUE	FALSE
4.57	0.00	4.57	0.00	2.79	0.00	1.00	1.00	78	TRUE	"1980"	FALSE	TRUE
0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	78	FALSE			FALSE
0.00	3.22	0.00	4.44	2.72	0.00	1.00	1.00	78	TRUE	"1976"	FALSE	TRUE

Table 4 – Example Selection for Painting as Known Improvement (Element 108 – District 2)

A separate workbook was created to perform additional analysis on the most numerous elements across the state. The elements chosen for further analysis of condition state trends between and within districts were selected by ranking the most numerous elements both in terms of bridges listing inspection reports for that element and by the number of 'unexpected improvements' that occurred (as shown in Table 27, Table 28, and Table 29 in the Results section of this report). For each of these elements, the yearly data from the separate district files were copied into a new worksheet, separated by those with unexpected improvements and those without, and then further separated by district. From here, the average condition state per year per district could be calculated in addition to the number of bridges in different ranges of condition states. The average condition state data were used to create line graphs over time, such as Figure 4, showing condition state trends across districts and the entire state.

"100% stacked column" plots, such as Figure 5, were created to show the percent of bridges in the given district or across the state in various condition state ranges by year for the given element. These ranges were 1.00 to 1.99 (marked as a green bar), 2.00 to 2.99 (yellow), 3.00 to 3.99 (orange) and 4.00 to 5.00 (red). A separate analysis was run on the quantity (linear feet, square feet, each, etc.) of the same elements across the state, with the intent of providing more weight to the condition states of elements in larger bridges (as compared to the original analysis which placed equal value on bridge of all sizes). 100% stacked columns were created from this quantity analysis as well, such as Figure 7, for comparison to those from the original analysis. Each graph type was created for the bridges that were found to have had an unexpected improvement, and for those that had not. Similar analyses were performed on 6 smart flags and 6 elements to investigate the condition state improvement based on the year the improvement occurred in, referred to as the year of improvement analysis, and deterioration based on the age in years of each bridge since improvement, referred to as the age since improvement analysis. These investigations were performed to explore the trends in improvement of different elements and when deterioration began after these improvements occurred.

For the year of improvement analysis, additional columns were created for each inspection report denoting the year of improvement, and the condition states before and after improvement. This was accomplished using Visual Basic code that found the year in which a condition state decrease of greater than 1.00 occurred and reported the lower number as the condition state after, and the higher value from the previous report (regardless of how many years earlier it was) as the condition state before. The data from these last two columns were then put into a new table using an averageif command, averaging the associated before and after improvement condition states for each year of improvement. This information is presented in tables in Appendix B.

For the age since improvement analysis, a table was created with the year the improvement occurred heading the columns and the year inspected heading the rows. The cells in this table were filled in with the total summed condition states for all inspection reports matching both criteria for the given element. A selection from this table used in the analysis of element 334 is shown in Table 5. Additional tables with the same headings were created to denote the age of each cell (as in Table 6), and the total count of reports for each cell (as in Table 7). The table showing age displays "-1" if the inspection year of a cell is before the associated construction year, in order to not show up in the summary table.

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
1995	0	0	0	1	0	0	0	0	7.5	0
1996	0	0	0	8.5	0	6.072	1	12.694	11.99	4.912
1997	0	0	0	6.515	10	17.54	12	19.11	15.47	7.11
1998	0	0	0	6.633	2.5	9	11.976	28.9	14.48	13.978
1999	0	0	0	4	4	16.521	6.401	32.472	27.97	10.707
2000	0	0	0	8.633	1	12.947	20.949	34.51	16.98	25.023
2001	0	0	0	3	3	5.6	9.5	33.061	29.97	19.015
2002	0	0	0	6.633	1	14.6	9.5	16.744	17.48	28.632

Table 5 – Example Selection for Summed Condition States (Element 334)

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
1995	0	-1	-1	-1	-1	-1	-1	-1	-1	-1
1996	1	0	-1	-1	-1	-1	-1	-1	-1	-1
1997	2	1	0	-1	-1	-1	-1	-1	-1	-1
1998	3	2	1	0	-1	-1	-1	-1	-1	-1
1999	4	3	2	1	0	-1	-1	-1	-1	-1
2000	5	4	3	2	1	0	-1	-1	-1	-1
2001	6	5	4	3	2	1	0	-1	-1	-1
2002	7	6	5	4	3	2	1	0	-1	-1

Table 6 - Example Selection for Age since Improvement (Element 334)

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
1995	0	0	0	1	0	0	0	0	3	0
1996	0	0	0	3	0	4	1	6	5	2
1997	0	0	0	2	3	6	4	7	6	3
1998	0	0	0	5	1	2	6	11	5	6
1999	0	0	0	2	4	5	3	12	10	4
2000	0	0	0	5	1	8	6	13	6	12
2001	0	0	0	1	3	3	8	11	10	8
2002	0	0	0	4	1	8	5	15	6	10

Table 7 – Example Selection for Count of Reports by Improvement Year and Inspection Year (Element 334)

The total summed condition states and total inspection report counts per year since improvement were then calculated using "sumifs" Excel commands. The inputs for this command summed over the desired age in the "Age since Improvement" table using the associated cells in the "Summed Condition State" and "Report Count" tables. The first 8 years of this table are shown for element 334 as Table 8, and is reproduced in full in Appendix B as Table B-16.

Age	0	1	2	3	4	5	6	7	8
Total	145.49	51.65	121.14	45.58	103.83	38.77	66.33	28.95	37.84
Count	125	40	101	38	86	31	55	23	33
Average	1.16	1.29	1.20	1.20	1.21	1.25	1.21	1.26	1.15

Table 8 – Example Selection of Condition State Trend by Age since Improvement (Element 334) – Reproduced in Part from Table B-16

Potential Errors

Upon closer analysis of specific inspection report data, it became apparent that several of the data entries contained conflicting pieces of information. The most important data for this analysis were the condition states, so it was important to ensure correctness of the information in those cells. An analysis was performed to identify those inspection reports which might contain errors.

To accomplish this, a new column was created in the original district workbooks to note if, for any condition state, the amount listed in the "quantity" cell was more than 10% different from the quantity calculated from the percent in the corresponding condition state multiplied by the total quantity. This threshold was chosen to select only those differences that were significant enough to not likely be attributed to rounding errors in quantity calculation. A workbook was created containing all data (for all elements) for bridges with inspection reports with likely errors based on this criterion. This list could be used for checking the accuracy of the reports for those bridges and a potential investigation into correcting the inaccuracies in these Pontis data. Table 9 below shows several reports that were identified as having this type of error; notice how the reported quantities ("QTY#") do not show agreement with the associated quantities calculated from the reported percent fields ("QP#").

brkey	QTY1	QTY2	QTY3	QTY4	QTY5	TotQty	QP1	QP2	QP3	QP4	QP5
"000000000001322"	0.000	0.000	1242.000	0.000	0.000	1242.000	1242.000	0.000	0.000	0.000	0.000
"000000000001322"	0.000	0.000	1242.000	0.000	0.000	1242.000	1242.000	0.000	0.000	0.000	0.000
"000000000001339"	0.000	1735.000	0.000	0.000	0.000	1735.000	0.000	0.000	1735.000	0.000	0.000
"000000000001340"	0.000	2497.000	0.000	0.000	0.000	2497.000	0.000	0.000	2497.000	0.000	0.000
"000000000001340"	0.000	2497.000	0.000	0.000	0.000	2497.000	2497.000	0.000	0.000	0.000	0.000
"000000000001365"	4.000	0.000	0.000	0.000	0.000	4.000	0.000	0.000	0.000	0.000	0.000
"000000000001382"	0.000	0.000	349.000	0.000	0.000	349.000	0.000	349.000	0.000	0.000	0.000

Table 9 – Example Error Finding Process – Selection from District 3

Zinc Coating Study

The zinc coating sub-study was originally performed on data current to the end of 2010 and then later updated with data current as of September 17, 2012. In order to streamline this update process, the same bridges were considered between the two dates, as opposed to redefining the structure list with the few new bridges built in the intervening twenty months. PDI Export files were obtained from VDOT for the 2010 and then the 2012 Pontis databases. Visual Basic code was written that extracted data from tables in the PDI export file, namely the Bridge, Element Inspection, Roadway, User Bridge, and Inspection Event Tables. Four separate worksheets were created, one for each of the four prescribed groups.

A quantity analysis was performed for each group, for each of the years 2000-2012. The early years (1995-1999) often had inconsistent or incomplete data and were thus ignored for this analysis. The quantity in each condition state and total quantity were summed for each group, and the percentage in each condition state was calculated. A table was created for each group with the inspection years as column headings and condition states as row headings; an example of the first 7 years of this is shown in Table 10 for Group 1 bridges. Bar graphs were produced from these tables and are shown in Figure 11, in the Results section of this report.

	2000	2001	2002	2003	2004	2005	2006
Total	56315.0	51695.0	55094.0	47326.5	63517.0	53080.3	56858.0
CS 1	54784.1	51152.5	53576.7	46434.5	61649.8	51970.3	54627.2
CS 2	1510.7	542.5	1490.8	888.8	1823.5	1104.5	2174.8
CS 3	20.3	0.0	20.3	3.1	35.5	4.3	49.2
CS 4	0.0	0.0	6.2	0.0	6.2	0.0	6.2
CS 5	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 10 – Example Selection from Zinc Study of Yearly Condition State by Quantity (Group 1)

Another set of tables was created based on percentages of bridges in various condition states, normalizing the quantity of element 107 per bridge. For each group, a table was created, with bridge IDs in separate rows and years 2000 thru 2012 in separate columns. The cells at the intersection of these headings summed up the total condition states for all inspection reports that occurred in the given year for the given bridge ID. A similar table was created that summed the number of inspection reports per bridge per year. These two tables were used to produce a third table which divided the condition state summation by the number of inspections per year to get the average condition state per bridge per inspection year. Thus the number of bridges in each condition state range (1.00 - 1.99, 2.00 - 2.99, 3.00 - 3.99, and 4.00 - 5.00) was determined. Normalizing these values by the number of bridges inspected each year produced the graphs shown in Figure 13.

Summary statistics for the NBI superstructure condition ratings were also requested. Tables similar to the condition state analysis were created, referencing a column of superstructure condition ratings instead of the element 107 condition states. These tables were graphed similarly to the previous analysis (but on the 9 to 1 NBI scale as opposed to the 1 to 5 Pontis scale), and are shown in Figure 14. Because the primary focus of this special project was to examine the performance of VDOT's zinc-based coating system, an additional analysis of the Pontis data was conducted which determined the age of the coating system of each bridge in each group at the time of each inspection. The results are summarized in Figure 15. The results were also used to calculate the average condition state for Element 107 for different coating ages. Graphs of the average condition states of Element 107 by age of coating and average superstructure condition ratings by age of coating are presented as Figure 16 and Figure 17. Six year moving average trendlines were added to the graphs to show the gradual change in condition with coating age. The six year moving average trendlines for the four groups were graphed for the element 107 condition states and superstructure condition ratings as Figure 18 and Figure 19.

Following the coating study, a list of bridges was created with quantities of element 107 (steel open girder – coated) in their most deteriorated form. All of the bridges that met the criteria for the coating study were further filtered for any non-zero quantity of condition states 4 and/or 5. These were compiled in a new spreadsheet along with another column which showed which group from the coating study each of these deteriorated state bridges fell in.

Joint Closures

The project advisory group requested a study on joint closures to complement the zinc-based girder coating analysis. The requested information was a list, separated by district, of every bridge in the state that had had all or part of any of the joint elements eliminated over the past 15 years. To implement the desired filter, all the inspection report rows were copied into each district's worksheet from the earlier Pontis-extracted Excel data, including the corresponding bridge IDs, the element number, the inspection date, and the total quantity of the element in each row. The inspection reports for all joint elements were included because if the joint was entirely removed, that element would not show up in the next report. The only way to know would be to compare an earlier report that did have the element to a later report containing only other elements. Bridges where a joint element was replaced with a different joint element, or the quantity was reduced (but not entirely eliminated), were also found using the method described below.

A new column extracted the year from the inspection date, and then the entire workbooks were sorted on bridge ID and then inspection year, to chronologically order the data by ascending bridge ID. Separate columns were created for each of the joint elements (300, 301, 302, 303, and 304), and these columns were populated with the corresponding quantity of each element if that row contained that element, or 0 if it did not. Another column was created for each joint element that found the maximum value of the given inspection year and bridge; this would populate with the quantity of the given joint element if it was inspected in a certain year, or 0 if it was not. The value of next column was determined by an IF statement, marking TRUE for any entry that had a >10% decrease in quantity in any of the 5 elements from the row directly above it, as long as the bridge ID was the same. 10% was chosen as a threshold for when the decrease was likely due to actual closure and not just due to a rounding error or a different calculation of the linear footage of the given joint element on the bridge. Therefore, the bridges marked as TRUE had a reduction in any of the 5 joint element quantities between two consecutive inspection reports, from a non-zero number to 0 or at least a decrease of >0.1 times the previous quantity. The next column, "Date of Change", displays the year the quantity decreased or "N/A" if there is none. The total number of >10% quantity reductions for any joint elements in that district were also calculated.

Table 11 is a selection from the District 9 joint elimination Excel file. Note there are 27 linear feet of element 300 in 2003, so the corresponding cell in "300 FULL" has 27 in it and the "300 MAX" column is filled in with 27 for all rows matching the bridge ID and inspection year. In 2005, there is no record of element 300 from this data, so 0 is filled in for those columns and the "ELIMINATION" column shows TRUE, with 2005 as the "Date of Change". A final column was added to denote if the change resulted in a complete elimination (as seen in Table 11), a decrease in quantity (between the 10% minimum criteria and a 99% decrease), or just a one-to-one change in joint type (for example, pourable joints replaced with compression joints).

brkey	ElemKey	Inspection Date	TotQty	Insp Year	300 FULL	301 FULL	302 FULL	303 FULL	304 FULL	300 MAX	301 MAX	302 MAX	303 MAX	304 MAX	ELIMINATION	Date of Change	TYPE
6185	12	2003/02/03	620.000	2003	0	0	0	0	0	27	0	0	0	0	FALSE	N/A	
6185	106	2003/02/03	271.000	2003	0	0	0	0	0	27	0	0	0	0	FALSE	N/A	
6185	205	2003/02/03	6.000	2003	0	0	0	0	0	27	0	0	0	0	FALSE	N/A	
6185	215	2003/02/03	28.000	2003	0	0	0	0	0	27	0	0	0	0	FALSE	N/A	
6185	234	2003/02/03	27.000	2003	0	0	0	0	0	27	0	0	0	0	FALSE	N/A	
6185	286	2003/02/03	2.000	2003	0	0	0	0	0	27	0	0	0	0	FALSE	N/A	
6185	300	2003/02/03	27.000	2003	27	0	0	0	0	27	0	0	0	0	FALSE	N/A	
6185	313	2003/02/03	12.000	2003	0	0	0	0	0	27	0	0	0	0	FALSE	N/A	
6185	321	2003/02/03	2.000	2003	0	0	0	0	0	27	0	0	0	0	FALSE	N/A	
6185	331	2003/02/03	91.000	2003	0	0	0	0	0	27	0	0	0	0	FALSE	N/A	
6185	701	2003/02/03	1.000	2003	0	0	0	0	0	27	0	0	0	0	FALSE	N/A	
6185	12	2005/01/25	610.373	2005	0	0	0	0	0	0	0	0	0	0	TRUE	2005	ELIM
6185	106	2005/01/25	271.000	2005	0	0	0	0	0	0	0	0	0	0	FALSE	N/A	
6185	205	2005/01/25	6.000	2005	0	0	0	0	0	0	0	0	0	0	FALSE	N/A	
6185	215	2005/01/25	28.000	2005	0	0	0	0	0	0	0	0	0	0	FALSE	N/A	
6185	234	2005/01/25	27.000	2005	0	0	0	0	0	0	0	0	0	0	FALSE	N/A	
6185	286	2005/01/25	2.000	2005	0	0	0	0	0	0	0	0	0	0	FALSE	N/A	
6185	313	2005/01/25	12.000	2005	0	0	0	0	0	0	0	0	0	0	FALSE	N/A	
6185	321	2005/01/25	2.000	2005	0	0	0	0	0	0	0	0	0	0	FALSE	N/A	
6185	331	2005/01/25	91.000	2005	0	0	0	0	0	0	0	0	0	0	FALSE	N/A	
6185	701	2005/01/25	1.000	2005	0	0	0	0	0	0	0	0	0	0	FALSE	N/A	
6185	12	2007/02/08	610.373	2007	0	0	0	0	0	0	0	0	0	0	FALSE	N/A	
6185	106	2007/02/08	271.000	2007	0	0	0	0	0	0	0	0	0	0	FALSE	N/A	
6185	205	2007/02/08	6.000	2007	0	0	0	0	0	0	0	0	0	0	FALSE	N/A	
6185	215	2007/02/08	35.662	2007	0	0	0	0	0	0	0	0	0	0	FALSE	N/A	
6185	234	2007/02/08	27.000	2007	0	0	0	0	0	0	0	0	0	0	FALSE	N/A	

Table 11 - Example Joint Elimination Processing (District 9)

Priority Bridges and District Visits

A separate workbook on priority bridges was created to store the data for bridges containing the most numerous elements that were deemed important based on the experience of the Principal Investigator of the project, Dr. Steven Chase. The three main categories were deck / girder systems, joints, and bearings, each of which contained two elements that had been analyzed previously. The resulting list of six elements was: 107 (steel open girder - coated), 108 (steel open girder with timber deck – coated and uncoated), 301 (pourable joint seal), 302 (compression joint seal), 311 (moveable bearing), and 313 (fixed bearing). The previously calculated color-coded yearly condition state data and year built were copied for each of the chosen elements into a corresponding worksheet and kept in order by district.

The number of unexpected improvements for the joints (elements 301 / 302) was lower than expected by the project advisory group, which was attributed to the >1.00 condition state decrease criteria being too large for most joint improvements. A much more lenient 0.05 condition state decrease at any point criteria was then implemented in order to include many more subtle improvements to the joints. This revised criteria increased the number of bridges with improvements noted for those elements anywhere from about 2 to 11 times depending on the district (compare the “301>1” and “302>1” row totals to the more lenient “301” and “302” row totals in Table 37).

For each of the 9 VDOT districts, 40 bridges were chosen that contained unexpected improvements to the six elements listed above. Bridges containing the more lenient 0.05 condition state decrease criteria for joint elements (301 & 302) were included, but bridges where the improvement to the girder elements (107 & 108) had been noted in Pontis as repainting (as discussed above) were omitted, as the type of maintenance was known. Selection was made from the available bridges by element, attempting to keep the number of bridges containing each of the 6 elements approximately equal. There were few significant improvements made to the bearing elements (311 & 313), so almost all of them were included in the respective districts while the large number of bridges with improvements to the joint elements (301 & 302) meant a random selection of about 10 per district was made. The summary table of the number of improvements per element per district can be found as Table 37.

Table 12 shows the first twenty rows of the priority bridge selection worksheet for District 2. Each column represents the federal IDs for bridges that were shown to have an improvement to the given element. The modified criteria of no noted paint maintenance is applied to elements 107 and 108, while "301 new" and "302 new" denote the more lenient 0.05 condition state decrease improvement criteria for those joint elements. You can see that there are far fewer bridges with the bearing elements (311 and 313) than the other elements for this district. The total available count per element for District 2 is: element 107 – 21 bridges, 108 – 64, 301 – 88, 302 – 139, 311 – 5, and element 313 – 1 bridge. The last column, "Multiple", is a listing of all bridges that contained improvements to multiple elements; these bridges were automatically selected to maximize the inspection results obtained from 40 reports. Bridge 3450 is bolded because it has 3 elements (107, 301, & 302) that were improved.

107 - No Paint	108 - No Paint	301 New	302 New	311	313	Multiple
3183	2673	2576	2587	4569	12120	3183
3230	2676	2592	2651	8372		**3450**
3232	2694	2600	2652	10166		4569
3450	2719	2709	2717	12120		8372
4569	2725	2903	2865	22513		8374
4571	2739	3183	2882			8375
4750	2890	3196	2901			12120
8335	2914	3198	3220			12290
8336	3357	3200	3222			12357
8374	4624	3202	3229			14571
8375	4648	3218	3234			14863
10126	4663	3219	3235			22510
12290	4681	3345	3236			
12357	4691	3366	3276			
14571	4752	3438	3277			
14863	5496	3450	3353			
14899	5497	3528	3450			
14901	5527	3533	3527			
21744	5544	4554	4542			
22416	5555	4632	4543			

Table 12 - Example Selection of Priority Bridge Choices (District 2)

Once the 40 bridges per districts were selected, arrangements were made to investigate the paper inspection reports in person at the bridge inspection divisions at the 9 VDOT district offices. For each district, the list of 40 bridges had additional columns added to cross reference the county the bridge was in, the route number carried, and the Virginia structure number in addition to the federal ID; an example of some of the bridges for District 9 is shown in Table 13. These columns used the "lookup" Excel command, searching in the following PDI output tables (for the desired information): Bridge (for "County"), Userbrdg (for "VA Structure #"), and Roadway (for "Route #"). These lists were sent ahead to the districts to have the reports ready upon arrival, and dates selected to extract the desired information.

Federal ID	County	VA Structure #	Route #
6189	"029"	"2191"	"00674"
6200	"029"	"5002"	"00495"
6297	"029"	"1120"	"00066"
6301	"029"	"1122"	"00050"
6370	"029"	"2218"	"00495"
6656	"029"	"6097"	"00603"

Table 13 - Example Selection of Bridge Information for Report Finding (District 9)

Site visits were then made to the districts to look at the inspection reports from the 360 total selected bridges in order to determine what maintenance actions were recorded as having been taken to cause the condition states to improve. Before each visit, an Excel table was created with each expected improvement for the chosen 40 bridges in that district as well as the year that the extracted Excel data showed an improvement for each element and bridge. Another set of columns was filled in ahead of time for the condition state of the selected element before and after the improvement occurred. An example of the table taken to the different districts is shown in Table 14 for the first several bridges in District 2. Because the criteria was a greater than 1.00 decrease from maximum condition state to current condition state, there was not necessarily a two report period for each improvement, as occasionally the decrease would be split between multiple years. The element 107 condition state for Bridge 12290 in Table 14, for example, decreases by exactly 1.00 from 2006 to 2008, which wouldn't show up under the improvement criteria except it further decreases in the 2010 report. Bridges that had improvements to multiple elements had a different entry (row) for each improvement noted.

Element	Structure ID	Years Expected	Year Performed	Work Performed	Condition State Before	Condition State After
107	3183	2008 2010			2.13	1.10
107	3450	2006 2008			3.22	1.00
107	4569	2005 2007			3.12	1.00
107	8336	2005 2007			3.50	1.51
107	8374	2005 2007			2.88	1.00
107	8375	2007 2009			2.40	1.00
107	12290	2006 2008			2.12	1.12
107	12357	2001 2003			3.28	1.05
107	14571	2007 2009			2.67	1.22
107	14863	2007 2009			2.64	1.00
107	21744	2006 2007			2.64	1.00
107	22510	2000 2002			3.00	1.00
108	2694	2008 2009			3.35	2.30

Table 14 - Example Selection of Table Taken to District Visit (District 2)

A column was filled in on-site with the type of work performed (or lack thereof) and the year in which this work was done (or the year in which improvement with no maintenance was noted); these codes are explained in Appendix C in Table C-25. Table 15 shows a selection from the completed table of data from the visit to District 6 (Fredericksburg), displaying the information prepared before the visit and the data added in the field. An additional column was added after the visits to include the quantity of the element in each row, and another for the road type. These columns were filled in by using a lookup command to reference the corresponding quantity and road type from the Quantity field in the InspEvnt PDI table and the Functional Class field in the Roadway PDI table, respectively. The Road Type numbers refer to the detailed descriptions in Appendix C as Table C-26, which were reduced to Primary, Secondary, and Interstate roads for the road classification distinction used in the analysis.

Element	Structure ID	Years Expected	Year Performed	Work Performed	CS Before	CS After	QTY	Road Type	Road Classification
107	17926	2004 2006	2006	CP	3.12	2.12	633.039	14	Primary
107	17926	2006 2008	2008	NM	2.12	1.01	633.039	14	Primary
107	17991	2000 2002	2002	CP	2.10	1.00	312.861	17	Secondary
108	10571	1998 2000	1998	TE	3.68	1.13	57.000	9	Secondary
108	18035	1995 1996	1995	TE	4.00	3.01	67.000	9	Secondary
108	18035	2001 2002	2002	NM	3.01	1.85	67.000	9	Secondary
301	4398	2008 2009	2009	NM	2.73	2.00	10.029	6	Primary

Table 15 - Example Selection of District Visit Complete Information (District 6)

Linear Least Squares and Markov Modeling

A macro was written to perform linear least squares (LLS) regression for each bridge to forecast the average condition states over the next several years. The number of years after 2010 to predict the average condition state is user-defined in the code. The macro calculated the average condition states, by inspection year, of all the bridges (for a certain element) in a certain district that were not marked as having an unexpected improvement. LLS regression was then performed on these average values in order to calculate an average slope for the bridges that deteriorated (or improved less than the 1.00 max-to-current condition state criteria). Finally, the macro applied this slope to the most recent condition state of each bridge in order to forecast the condition states and select which bridges might have important elements reaching advanced deterioration levels. The y-intercept of this prediction line is back-calculated from the slope and most recent condition state. Another option that was coded was to perform LLS on each bridge separately, projecting the calculated slope out from the most recent condition state for that bridge. This required creating certain rules if there was 0 or negative slope, or if there was only one data point for that bridge; namely, at that point using the average slope for that district and element and projecting that from the most recent condition state.

Table 16 shows the first several additional columns that the individual LLS regression macro added to the element 215 information for District 1. Everything left of the "Slope" column was created for the earlier condition state trend analysis (such as Table 3). The columns headed with years are the condition state predictions from the given slope and intercept, and they continue the user-defined number of years after 2010. For the individual LLS macro results shown below, the slope and intercept information are unique to the condition state history of each bridge analyzed. Below all the individual bridge rows, the LLS regression for the average condition state history for the selected element on all bridges in the given district is performed.

2010	CR	Age	Unexpected Improvement	Slope	Intercept	2011	2012
1.15	1.15	69	FALSE	0.001	-1.535	1.157	1.158
0.00	1.21	61	FALSE	0.013	-24.939	1.276	1.289
0.00	1.17	69	FALSE	0.004	-7.403	1.167	1.167
1.00	1.00	63	FALSE	0.000	1.000	1.000	1.000
1.04	1.04	60	FALSE	0.001	-0.834	1.042	1.042
1.00	1.00	60	FALSE	0.000	1.000	1.000	1.000
1.11	1.11	60	FALSE	0.005	-8.510	1.115	1.115
1.12	1.12	60	FALSE	0.001	-0.702	1.122	1.122
1.09	1.09	45	FALSE	0.004	-6.680	1.112	1.116
1.28	1.28	42	FALSE	0.008	-15.173	1.283	1.287
1.47	1.47	38	FALSE	0.020	-38.364	1.472	1.472

Table 16 – Example Selection of Linear Least Squares Appended Data – Element 215 – District 1

Linear least squares regression was also performed based on age of bridge on the same set of structures (all bridges without the desired elements undergoing "unexpected improvements") for the beam elements, 107 and 108. This analysis began by calculating the average condition states for each bridge, based on quantity in each condition state. The averageif command was then used, matching the number of years that elapsed between bridge construction and the inspection report with the age in the corresponding column in order to quantify the average deterioration of the given element as the bridges age in that district. 10 years of these averages are shown for element 107 in Table 17 below, each column representing a different age of bridge while each row represents a different district or total state. These averages were then graphed over the 100 year timeline for all cells with bridges representing that age in the given district (or total state). Trendlines (and the associated best fit equations) were added using Excel's linear least squares trendline function; this process produced graphs such as Figure 20 in the Results section.

CS History>	0	1	2	3	4	5	6	7	8	9	10
D1	1	1	1.001741	1	1.002964	1.000045	1.006963	1.000675	1.00524	1.008593	1.012153
D2	1	1	1	1	1.138458	1	1.000282	1	1.157983	1	1.133187
D3	1	1	1	1	1.000165	1	1.006977	1.000216	1.009315	1.000176	1.002346
D4	1	1	1.000216	1	1.001473	1	1.001411	1	1.013046	1.000847	1.026772
D5	1	1	1	1	1	1	1.006799	1.004338	1.002548	1.013529	1.013078
D6	1	1	1	1	1	1	1	1	1.000302	1	1.224734
D7	1	1	1		1	1	1.002261	1	1.002447	1	1.011917
D8	1	1		1	1	1.001236	1	1.076451	1.492331	1.062262	1.302296
D9	1	1.001274	1	1.000704	1.001693	1	1.009456	1.004671	1.020688	1.00434	1.013046
Total	1	1.000498	1.000247	1.000391	1.011182	1.000036	1.00555	1.005785	1.028075	1.008529	1.03205

Table 17 – Example Selection for LLS Analysis Based on Age of Bridges – Element 107

The yearly values from the linear trendlines were calculated using the slope and intercept from the best fit equations Excel produced. Residuals were calculated for each year by subtracting the actual condition state from the modeled condition state. These data sets were graphed against bridge age, such as Figure 21 in the Results section. The number of bridges reporting for each age was also kept track of in order to understand when there is a significant amount of data for a condition state data point and when the results are more easily skewed by a few bridges. This statistic is represented in tables like Table 18 below (columns representing age of bridges reporting) and also graphed by each district such as in Figure 22 in the Results section.

Count by Age>	0	1	2	3	4	5	6
1	32	6	37	10	40	15	54
2	30	11	38	4	43	7	48
3	19	2	19	7	27	7	41
4	33	16	40	20	40	20	70
5	21	13	26	10	37	18	38
6	6	4	9	5	8	5	9
7	12	1	8	0	15	1	16
8	2	1	0	3	5	5	8
9	45	24	67	53	84	52	84
Total	200	78	244	112	299	130	368

Table 18 – Example Selection for Number of Bridges Reporting by Age – Element 107

The form of the solution of the linear least squares regression based on inspection year is: $Condition\ State_{any\ year}\ (time) = Condition\ State_{2010} + Deterioration\ Slope *$ $(\#\ of\ years\ since\ 2010)$. The form of the solution for the regression based on age of bridge is similar: $Condition\ State_{any\ age}\ (time) = Condition\ State_{0\ years} + Deterioration\ Slope *$ $(\#\ of\ years\ since\ construction)$. The independent variable in both cases is time (in years), and the dependent variable is the resulting condition state.

The second type of deterioration modeling performed on the Pontis condition state data for this project was Markov chain creation. Deterioration trends were predicted for 4 elements in this exploration: 107 (Steel Open Girder - Coated), 108 (Steel Open Girder with Timber Deck – Coated and Uncoated), 302 (Compression Joint Seal) and 32 (Timber Deck - with asphaltic concrete (AC) Overlay). The quantity of these elements in each condition state was used for this modeling, as compared to using the average condition state of an element on each bridge. This data was compiled in a large table comprised of the following column headings: bridge IDs, the year they were built, the quantity of the given element for each bridge in condition state 1, 2, 3, 4, and 5 for each of the inspection years 1995 – 2010, and finally the district the bridges are in. An example of this is shown in Table 19 below, representing the left 14 (out of 83 total) columns and top 17 (out of 3293 total) rows of the raw data table for element 107. As an example, the quantity of element 107 on bridge number 2994 from the inspection report in 1995 is 304.82 feet in condition state 1 and 152.18 feet in condition state 2.

To the right of this is a table of equal size, showing the age of each data point in the raw data table, calculated by subtracting the year each bridge was built from the inspection year corresponding to the current column; for example a bridge built in 1985 would show 10 10 10 10 10 11 11 11 etc. To the right of this is another table of equal size, showing the condition state each data point in the raw data table represents; A summary table is created that performs a sumifs function on the raw data to find the total quantity of each element in each condition state at each year of age since construction. An example of this is shown in Table 20 below, representing the left 13 (out of 506 total) columns of this summary data table for element 107, separated by district as D1, D2, etc. and total combined across the state. For example, the total quantity of element 107 in condition state 1 at 0 years after the respective construction of all bridges in District 1 is 12197.37 feet.

Unique brkey	Unique YR Built	1995	1995	1995	1995	1995	1996	1996	1996	1996	1996	1997	1997
	TOTAL	1	2	3	4	5	1	2	3	4	5	1	2
"000000000002960"	1927	324.00	0.00	0.00	0.00	0.00	324.00	0.00	0.00	0.00	0.00	0.00	0.00
"000000000002961"	1927	262.00	0.00	0.00	0.00	0.00	262.00	0.00	0.00	0.00	0.00	0.00	0.00
"000000000002963"	2008	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
"000000000002966"	1974	0.00	0.00	0.00	0.00	0.00	121.58	16.42	0.00	0.00	0.00	0.00	0.00
"000000000002978"	1987	274.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
"000000000002992"	1974	366.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	175.68	172.02
"000000000002993"	1974	366.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	173.85
"000000000002994"	1974	304.82	152.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	380.68
"000000000002996"	1974	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
"000000000002998"	1974	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	685.00	0.00
"000000000003000"	1974	0.00	0.00	0.00	0.00	0.00	683.00	0.00	0.00	0.00	0.00	0.00	0.00
"000000000003016"	1974	0.00	0.00	0.00	0.00	0.00	212.30	0.00	10.70	0.00	0.00	0.00	0.00
"000000000003019"	1974	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	325.19
"000000000003021"	1974	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	540.55
"000000000003022"	1974	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	152.50

Table 19 - Example Selection of Table of Raw Data for Markov Processing (Element 107)

Age	0	0	0	0	0	1	1	1	1	1	2	2
CS	1	2	3	4	5	1	2	3	4	5	1	2
D1	12197.37	0.00	0.00	0.00	0.00	943.35	0.00	0.00	0.00	0.00	17037.94	29.72
D2	12838.00	0.00	0.00	0.00	0.00	5037.38	0.00	0.00	0.00	0.00	16495.88	0.00
D3	3548.57	0.00	0.00	0.00	0.00	1638.70	0.00	0.00	0.00	0.00	4510.16	0.00
D4	21427.20	0.00	0.00	0.00	0.00	7505.43	0.00	0.00	0.00	0.00	21181.09	4.58
D5	29709.70	0.00	0.00	0.00	0.00	8564.33	0.00	0.00	0.00	0.00	38291.55	0.00
D6	1598.83	0.00	0.00	0.00	0.00	627.73	0.00	0.00	0.00	0.00	2332.85	0.00
D7	4550.34	0.00	0.00	0.00	0.00	280.00	0.00	0.00	0.00	0.00	3170.34	0.00
D8	1299.00	0.00	0.00	0.00	0.00	59.00	0.00	0.00	0.00	0.00	0.00	0.00
D9	24810.32	0.00	0.00	0.00	0.00	15780.24	20.13	0.00	0.00	0.00	35911.76	0.00
Total	111979.32	0.00	0.00	0.00	0.00	40436.16	20.13	0.00	0.00	0.00	138931.57	34.30

Table 20 - Example Selection of Summary Table of Raw Data Arranged by Age and Condition State (Element 107)

Separate workbooks were then created, for each district and the entire state, containing several tables to facilitate the Markov transition probability matrix creation. The first of these tables was a restructuring of the age and condition state data with the years 0 to 100 heading the rows and condition states 1 through 5 heading the columns, as well as a column for the total quantity at that age. The result is a table such as Table 21 for the data from the D1 row of Table 20 (from the raw data worksheet).

Age	1	2	3	4	5	Sum
0	12197.37	0	0	0	0	12197.37
1	943.35	0	0	0	0	943.35
2	17037.94	29.72	0	0	0	17067.66
3	4840.491	0	0	0	0	4840.491
4	17522.9	52.09248	0	0	0	17574.99
5	6830.186	0.305483	0	0	0	6830.491
6	21873.89	153.3767	0	0	0	22027.27
7	6762.196	4.57	0	0	0	6766.766
8	18427.81	97.07748	0	0	0	18524.88
9	8119.712	70.38	0	0	0	8190.092
10	21170.08	260.4405	0	0	0	21430.52
11	9462.404	209.5981	28.8	0	0	9700.802
12	18052.68	255.3376	4.26629	0	0	18312.28

Table 21 - Example Selection of Age-Based Condition State Data (Element 107 – District 1)

An equivalently sized table was then created with the quantity in each condition state per age divided into the sum of the quantity per age in order to get the percent of the bridges that were in each condition state at each year of age since construction. The next table is the estimated transition probability matrix such as Table 22 (similar to Table D-1 in Appendix D with the additional first column), with the column headings representing the condition state after transition. The first column represents the probability that bridges in each condition state will remain in that condition state over the next year, and is originally a guess that is later refined.

The likelihood, therefore, of any quantity falling into the next worse condition state is 1 minus the first-column-value. 0s fill in all other transition probabilities, resulting in an upper bidiagonal matrix. This approach limited the model to only reflect deterioration because the probability of any quantity of an element improving in condition was made to be 0.

	D1	1	2	3	4	5
0.990	1	0.990	0.010	0.000	0.000	0.000
0.972	2	0.000	0.972	0.028	0.000	0.000
0.976	3	0.000	0.000	0.976	0.024	0.000
0.961	4	0.000	0.000	0.000	0.961	0.039
1.000	5	0.000	0.000	0.000	0.000	1.000

Table 22 - Example Transition Probability Matrix - Element 107 - District 1

From this matrix, a table was created similar to the earlier table showing the percent in each condition state by age since construction. This new table, such as Table 23, is based on the theoretical values from the transition probability matrix multiplied by itself for each year up to 100. Seven transitions are illustrated in Table 22. The rows represent the age of the elements, and the columns represent the 5 condition states and the average condition state (calculated from the proportion in condition state 1 * 1 + the proportion in condition state 2 * 2, etc.).

	1	2	3	4	5	Average
0	1	0	0	0	0	1
1	0.989967	0.010033	0	0	0	1.010033
2	0.980036	0.019686	0.000279	0	0	1.020243
3	0.970203	0.028971	0.000819	6.8E-06	0	1.030629
4	0.96047	0.037899	0.001604	2.65E-05	2.62E-07	1.041188
5	0.950834	0.046482	0.002618	6.46E-05	1.29E-06	1.051918
6	0.941295	0.054729	0.003846	0.000126	3.78E-06	1.062815
7	0.931851	0.062652	0.005274	0.000215	8.64E-06	1.073879

Table 23 - Example Selection of Condition State Probability Prediction by Age - Element 107 - District 1

Finally, a table is created displaying the squared difference between each actual proportion (from the inspection reports) and theoretical proportion (from the transition probability matrix); the resulting table is again of equivalent size. All of these squared errors were then added together in a cell below the error table. The Excel Solver analysis tool was used to minimize this total error by changing the modeled transition probabilities (the first 4 values in the left column in Table 22) while keeping them between 0.00 and 1.00. This process is repeated iteratively to reach a smaller than $1.0 * 10^{-6}$ change in total error between successive attempts. Excel displays the transition probability matrix that produced the minimal total squared error when its results are compared to the actual data. The result is a deterioration model for that district and element. The process is repeated for each element and district desired; in this report, Markov chains were created for elements 107, 108, 302, and 32 in the different districts and total across the state. In this analysis, the state total is from the summed bridges with no regard to district, it is therefore weighted toward districts with more linear feet of the desired element.

These transition probability matrices are also graphically represented by creating 100% stacked area graphs over 100 years from the theoretical predicted data in tables such as Table 23, color-coded by condition state resulting in graphs such as the left, smooth graphs in Figure D-61. These predicted probability graphs are accompanied by their corresponding probability graphs produced from the actual Pontis data, such as the right, more jagged graphs in the same figure.

RESULTS

Original Pontis Analysis by District

The top 10 smart flags and the top 20 elements are summarized in Table 24, Table 25, and Table 26, as selected by the highest total number of bridges in the given district containing them. The tables are separated by district, with districts 1, 2, and 3 in Table 24, districts 4, 5, and 6 in Table 25, and districts 7, 8 and 9 in Table 26. For each district sub-table, the first column presents the number of improvements noted for the given smart flag or element, the second column displays the three digit element key, and the third column lists the number of bridges in the given district that that smart flag or element is present on. In the first column, red numbers represent smart flags while black numbers signify elements.

District 1			District 2			District 3		
# Improv.	Ekey	Count	# Improv.	Ekey	Count	# Improv.	Ekey	Count
1	295	2424	47	702	1771	3	295	1170
16	215	1968	17	215	1770	6	215	908
20	706	1645	3	295	1523	1	704	887
53	359	1514	21	107	1227	4	361	871
1	708	1366	1	361	1162	4	702	659
19	331	1309	6	704	996	4	107	647
3	361	1120	39	331	932	3	331	595
4	704	953	38	359	852	10	359	531
44	107	947	64	108	809	4	241	526
12	358	874	119	032	734	6	285	510
67	334	686	37	706	675	6	286	490
16	363	635	15	363	666	8	706	475
0	298	621	16	334	665	14	234	458
28	234	604	0	241	644	0	298	445
2	241	597	0	298	576	60	302	422
0	299	594	22	234	574	1	313	405
81	108	545	13	285	523	36	240	380
4	210	521	20	358	520	17	108	379
5	313	487	1	313	515	3	358	377
41	032	478	33	302	473	35	032	370
0	333	478	0	299	441	0	299	370
20	702	465	0	708	404	6	205	341
28	302	460	9	210	394	14	334	318
6	297	435	11	205	385	1	311	289
8	039	425	5	311	381	0	363	268
7	311	417	21	240	351	1	210	246
3	217	402	7	330	349	0	708	231
0	240	367	2	286	314	12	332	206
0	285	361	20	332	293	4	012	196
23	205	335	0	310	287	0	310	194

Table 24 - Element Count Summary - Districts 1, 2, and 3

District 4		
# Improv.	Ekey	Count
1	295	1384
28	215	1376
26	331	1099
2	704	977
24	107	957
36	234	868
15	313	861
11	285	851
21	706	770
6	358	759
23	702	744
17	205	740
2	241	684
51	359	683
131	301	681
12	311	665
3	361	613
7	321	591
1	298	561
2	299	521
4	707	464
9	286	438
0	026	414
21	012	413
2	330	413
27	302	408
0	310	357
15	240	356
4	363	315
15	108	247

District 5		
# Improv.	Ekey	Count
5	215	865
2	331	758
1	295	643
0	234	630
4	107	570
8	285	565
0	313	494
0	311	484
1	205	483
1	706	481
0	704	429
3	361	424
0	321	409
14	302	405
6	359	400
16	301	369
0	707	353
4	358	340
0	241	310
0	298	280
2	701	269
6	018	261
3	026	248
8	702	243
0	299	227
3	334	204
2	109	182
10	108	159
0	310	158
10	032	155

District 6		
# Improv.	Ekey	Count
0	295	584
4	361	430
7	704	426
0	298	372
1	241	337
0	215	317
0	299	310
2	331	263
0	708	247
2	359	213
2	706	193
2	107	191
5	234	189
2	358	183
0	313	147
0	363	142
3	285	137
0	360	137
3	205	119
2	334	119
0	333	116
1	311	115
3	012	108
3	286	104
4	302	102
0	321	96
0	310	95
10	301	94
1	240	92
2	108	78

Table 25 - Element Count Summary - Districts 4, 5, and 6

District 7		
# Improv.	Ekey	Count
1	295	966
6	215	913
1	361	871
1	704	673
13	359	625
5	331	545
19	107	484
2	241	468
0	298	353
0	299	331
18	334	327
4	363	289
4	234	284
9	108	246
0	706	232
35	240	223
0	313	214
2	210	198
0	333	197
4	039	192
4	285	192
3	205	191
9	302	172
0	311	165
7	032	164
6	018	159
1	330	156
5	358	128
0	708	89
1	360	79

District 8		
# Improv.	Ekey	Count
1	295	2067
14	215	1968
19	359	1341
8	331	1180
2	704	1174
5	241	1056
3	361	815
21	107	804
17	234	632
4	706	609
41	302	568
2	299	566
20	334	556
1	313	544
6	210	515
1	298	506
1	330	441
6	205	437
22	032	435
19	108	427
3	285	420
0	039	409
2	311	401
14	702	382
4	363	354
3	358	351
1	360	251
12	240	204
8	012	193
3	013	169

District 9		
# Improv.	Ekey	Count
4	295	1386
3	704	951
3	215	865
5	241	792
18	331	713
0	298	691
4	361	683
0	299	659
5	706	646
1	313	540
3	107	505
0	358	498
7	234	492
0	707	478
2	321	471
3	285	432
2	311	431
11	359	403
0	205	402
0	026	391
9	302	389
0	708	342
5	334	315
7	701	288
2	310	237
3	210	216
2	286	213
1	092	210
17	301	201
4	300	172
13	108	63

Table 26 - Element Count Summary - Districts 7, 8, and 9

The most often improved smart flags and elements, as ordered by the average number of improvements per district, are displayed in Table 27 and Table 28. Not all districts had the same top smart flags and elements by improvement, so not every smart flag and element was present in all 9 districts. A cut-off of 6 out of 9 districts reporting was chosen to encompass smart flags and elements that were adequately represented across the state in this analysis.

In Table 27, elements are shown, with the top 9 well-represented elements highlighted in yellow, denoting those with an average of more than 10 improvements per district. In Table 28, the smart flags are shown, with the top 7 well-represented smart flags highlighted in red, denoting those with more than 2 improvements per district.

Table 29 shows the top smart flags and elements organized by the average number of bridges containing them per district, with the top 8 elements highlighted in orange and the top 9 smart flags highlighted in blue; the cut-off was 400 bridges with the given smart flag or element per district. The purpose of highlighting above certain thresholds was to denote those smart flags and elements that were relatively prolific (by total count or by improvement count) among similar categories. For this project, only the top elements by improvement were analyzed; element 295 (reinforced concrete wingwalls), for example, was present on the most bridges but rarely received a significant improvement in condition state; therefore, it was not analyzed.

The improvement thresholds (in Table 27 and Table 28) are different for smart flags and elements because of a much lower number of improvements showing up in this analysis for smart flags. In Table 27, Table 28, and Table 29, the first column is the 3 digit element key, the second column is the number of districts represented for that smart flag or element, the third column is the total number of improvements or bridge count per smart flag or element, the fourth column is the number of improvements or bridge count per district per smart flag or element, and the fifth column is the textual description of the given smart flag or element.

Element	Districts	Total Improvements	Divided Improvements	Description
301	4	174	43.50	Pourable Joint Seal
032	6	234	39.00	Timber Deck - with asphaltic concrete (AC) Overlay
108	9	230	25.56	V Steel Open Girder with Timber Deck – Coated and Uncoated
302	9	225	25.00	Compression Joint Seal
334	8	145	18.13	Metal Bridge Railing - Coated
240	7	120	17.14	Metal Culvert
332	2	32	16.00	Timber Bridge Railing
107	9	142	15.78	Steel Open Girder - Coated
234	9	133	14.78	Reinforced Concrete Pier Cap
331	9	122	13.56	Reinforced Concrete Bridge Railing
215	9	95	10.56	Reinforced Concrete Abutment
012	4	36	9.00	Concrete Deck - Bare - with Uncoated Reinforcement
205	9	70	7.78	Reinforced Concrete Column or Pile Extension
018	2	12	6.00	Concrete Deck - Thin Overlay (less than 1”) - no AC Overlay
297	1	6	6.00	V Other Material Wingwalls
285	9	51	5.67	V Slope – Protected
286	5	22	4.40	V Slope - Unprotected
210	6	25	4.17	Reinforced Concrete Pier Wall
039	3	12	4.00	Concrete Slab - with AC Overlay - without Membrane
300	1	4	4.00	Strip Seal Expansion Joint
311	9	30	3.33	Moveable Bearing (Roller, sliding, etc.)
013	1	3	3.00	Concrete Deck - with AC Overlay - without Membrane
217	1	3	3.00	Other Material Abutment
330	4	11	2.75	Metal Bridge Railing - Uncoated
313	9	24	2.67	Fixed Bearing
241	9	21	2.33	Concrete Culvert
321	4	9	2.25	Reinforced Concrete Approach Slab
109	1	2	2.00	P/S Concrete Open Girder
295	9	15	1.67	V Reinforced Concrete Wingwalls
026	3	3	1.00	Concrete Deck - Bare - with Coated Reinforcement
092	1	1	1.00	V Reinforced Concrete Sidewalk
310	6	2	0.33	Elastomeric Bearing
333	3	0	0.00	Timber Bridge Railing

Table 27 - Element Count Summary

Smart Flag	Districts	Total Improvements	Divided Improvements	Description
359	9	203	22.56	Smart Flag - Soffit of Conc
702	6	116	19.33	V Smart Flag - Drains
706	9	98	10.89	V Smart Flag - Soffit of Overhang of Conc
363	7	43	6.14	Smart Flag - Section Loss
358	9	55	6.11	Smart Flag - Deck Cracking
701	2	9	4.50	V Smart Flag - Utilities
361	9	26	2.89	Smart Flag - Scour -
704	9	26	2.89	V Smart Flag - Roadway Over Culverts
707	3	4	1.33	V Smart Flag - Soffit of Conc
360	3	2	0.67	Smart Flag - Settlement
299	9	4	0.44	V Smart Flag - Culvert Wingwall
298	9	2	0.22	V Smart Flag - Culvert Endwall/Headwall
708	6	1	0.17	V Smart Flag – Debris in Channel -

Table 28 – Smart Flag Count Summary

Element #	Districts	Total	Divided	Description
295	9	12147	1349.67	V Reinforced Concrete Wingwalls
215	9	10950	1216.67	Reinforced Concrete Abutment
704	9	7466	829.56	V Smart Flag - Roadway Over Culverts
331	9	7394	821.56	Reinforced Concrete Bridge Railing
361	9	6989	776.56	Smart Flag - Scour -
359	9	6562	729.11	Smart Flag - Soffit of Conc
702	6	4264	710.67	V Smart Flag - Drains
107	9	6332	703.56	Steel Open Girder - Coated
706	9	5726	636.22	V Smart Flag - Soffit of Overhang of Conc
241	9	5414	601.56	Concrete Culvert
234	9	4731	525.67	Reinforced Concrete Pier Cap
298	9	4405	489.44	V Smart Flag - Culvert Endwall/Headwall
313	9	4207	467.44	Fixed Bearing
358	9	4030	447.78	Smart Flag - Deck Cracking
299	9	4019	446.56	V Smart Flag - Culvert Wingwall
708	6	2679	446.50	V Smart Flag – Debris in Channel -
285	9	3991	443.44	V Slope - Protected
297	1	435	435.00	V Other Material Wingwalls
707	3	1295	431.67	V Smart Flag - Soffit of Conc
217	1	402	402.00	Other Material Abutment

334	8	3190	398.75	Metal Bridge Railing - Coated
321	4	1567	391.75	Reinforced Concrete Approach Slab
032	6	2336	389.33	Timber Deck - with asphaltic concrete (AC) Overlay
205	9	3433	381.44	Reinforced Concrete Column or Pile Extension
302	9	3399	377.67	Compression Joint Seal
311	9	3348	372.00	Moveable Bearing (Roller, sliding, etc
026	3	1053	351.00	Concrete Deck - Bare - with Coated Reinforcement
210	6	2090	348.33	Reinforced Concrete Pier Wall
039	3	1026	342.00	Concrete Slab - with AC Overlay - without Membrane
330	4	1359	339.75	Metal Bridge Railing - Uncoated
301	4	1345	336.25	Pourable Joint Seal
108	9	2953	328.11	V Steel Open Girder with Timber Deck – Coated and Uncoated
286	5	1559	311.80	V Slope - Unprotected
363	9	2669	296.56	Smart Flag - Section Loss
240	7	1973	281.86	Metal Culvert
701	2	557	278.50	V Smart Flag - Utilities
333	3	791	263.67	Timber Bridge Railing
332	2	499	249.50	Timber Bridge Railing
012	4	910	227.50	Concrete Deck - Bare - with Uncoated Reinforcement
310	6	1328	221.33	Elastomeric Bearing
018	2	420	210.00	Concrete Deck - Thin Overlay (less than 1”) - no AC Overlay
092	1	210	210.00	V Reinforced Concrete Sidewalk
109	1	182	182.00	P/S Concrete Open Girder
300	1	172	172.00	Strip Seal Expansion Joint
013	1	169	169.00	Concrete Deck - with AC Overlay - without Membrane
360	3	467	155.67	Smart Flag - Settlement
013	2	169	84.50	Concrete Deck - with AC Overlay - without Membrane

Table 29 – Smart Flag and Element Count Summary – Total Count

The condition state trends from 1995 to 2010 for the top 6 elements and the top 6 smart flags, based on number of improvements, are shown in Appendix B from Figure B-1 to Figure B-56, only including smart flags and elements represented in at least 6 districts. The graphs for element 32 have been reproduced as Figure 3 through Figure 8 as examples for the results and analysis sections. The 32 graphs from the elements were also created separately for the 9 VDOT districts (containing just the data for bridges within each district), and these 288 graphs are available in a separate Excel file through VDOT.

The first type of graph, exemplified by Figure 3, is a line graph of the average condition state of the specified element for all bridges that were marked as having an unexpected improvement to the given element from 1995 to 2010. The second type of graph, such as Figure 5, contains 100% stacked column plots, which represent the number of bridges with the specified element in each condition state, normalized so each column is the same total height showing only the bridges that were marked as having an unexpected improvement to the given element. Green signifies condition states 1.00 to 1.99, yellow signifies 2.00 to 2.99, orange signifies 3.00 to 3.99, and red signifies 4.00 to 5.00. The third type of graph, such as Figure 7, is also normalized stacked column plots, but based on the total quantity of the specified elements across the state in each condition state. Each of these types has corresponding graphs for bridges that did not show an unexpected improvement for the given element, such as Figure 4, Figure 6, and Figure 8. Only elements chosen for quantity analysis (elements 32, 108, 302, and 107) have the quantity graphs (such as Figure 7 and Figure 8). After 4 elements were examined by quantity, it was decided to stop that analysis as the results were very similar to the previous analysis.

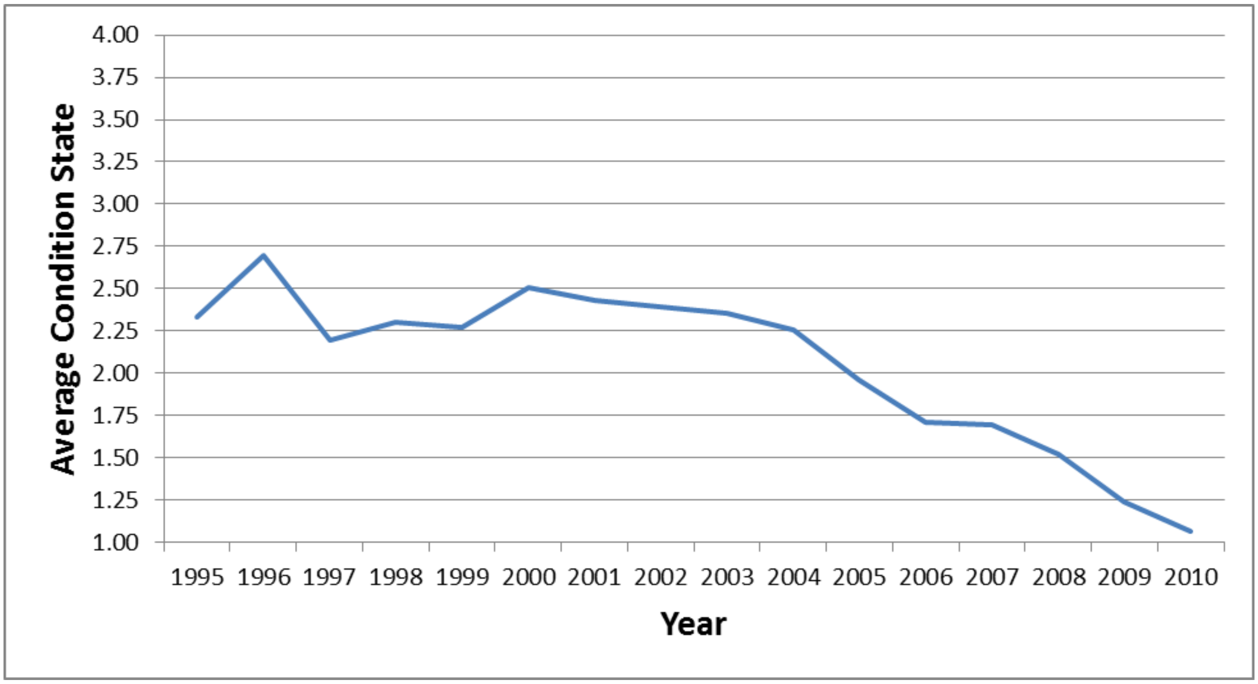

Figure 3 – Element 32 (Timber Deck - with Asphaltic Concrete (AC) Overlay) Average Condition State Trend – Improvement Noted – Reproduced from Figure B-1

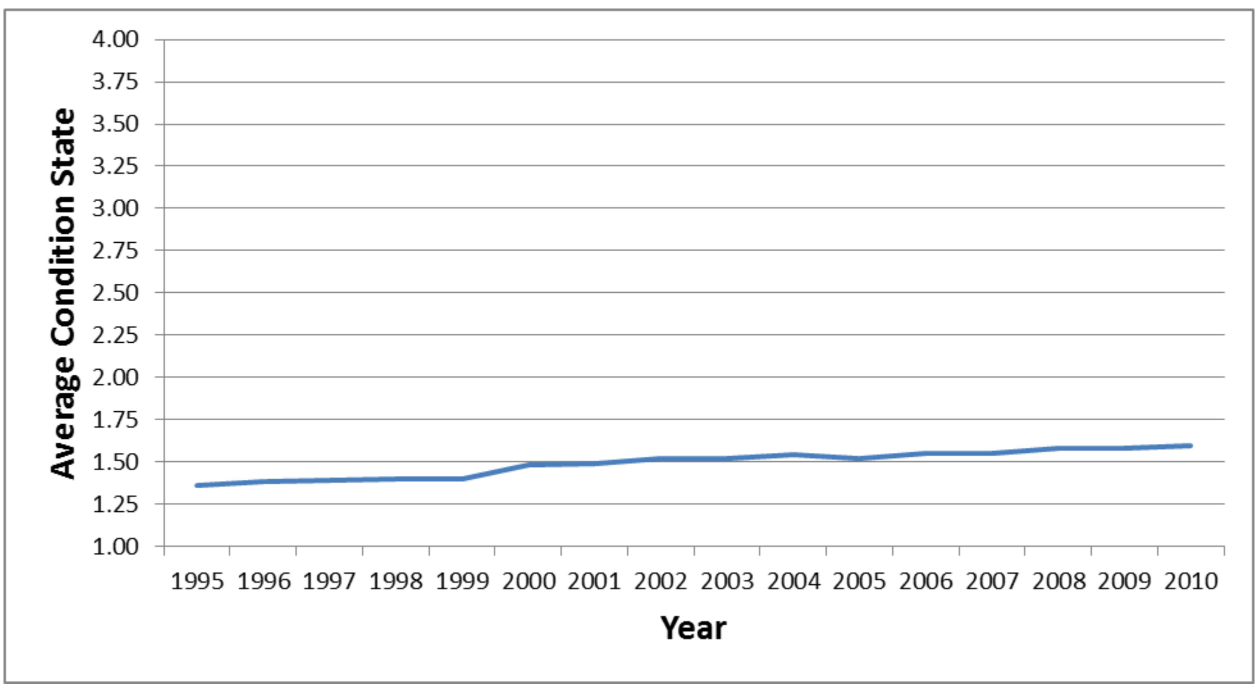

Figure 4 - Element 32 Average Condition State Trend – Improvement Not Noted – Reproduced from Figure B-2

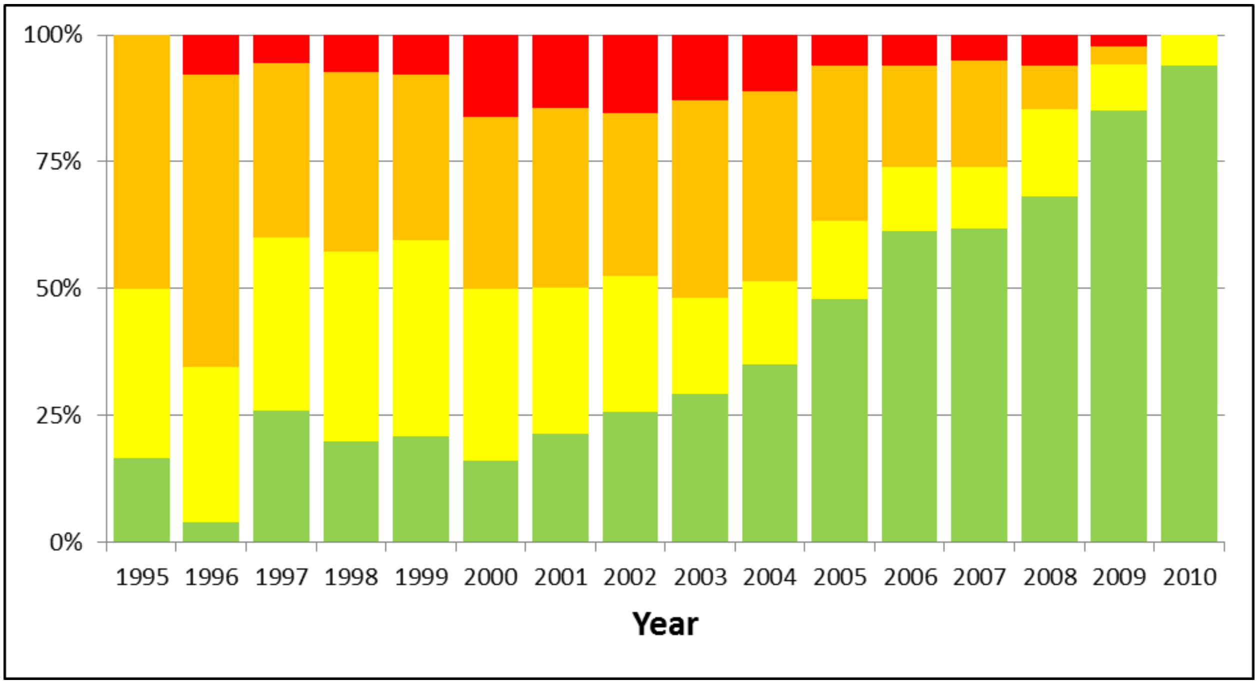

Figure 5 - Element 32 Normalized Condition State Trend – Improvement Noted – Reproduced from Figure B-3

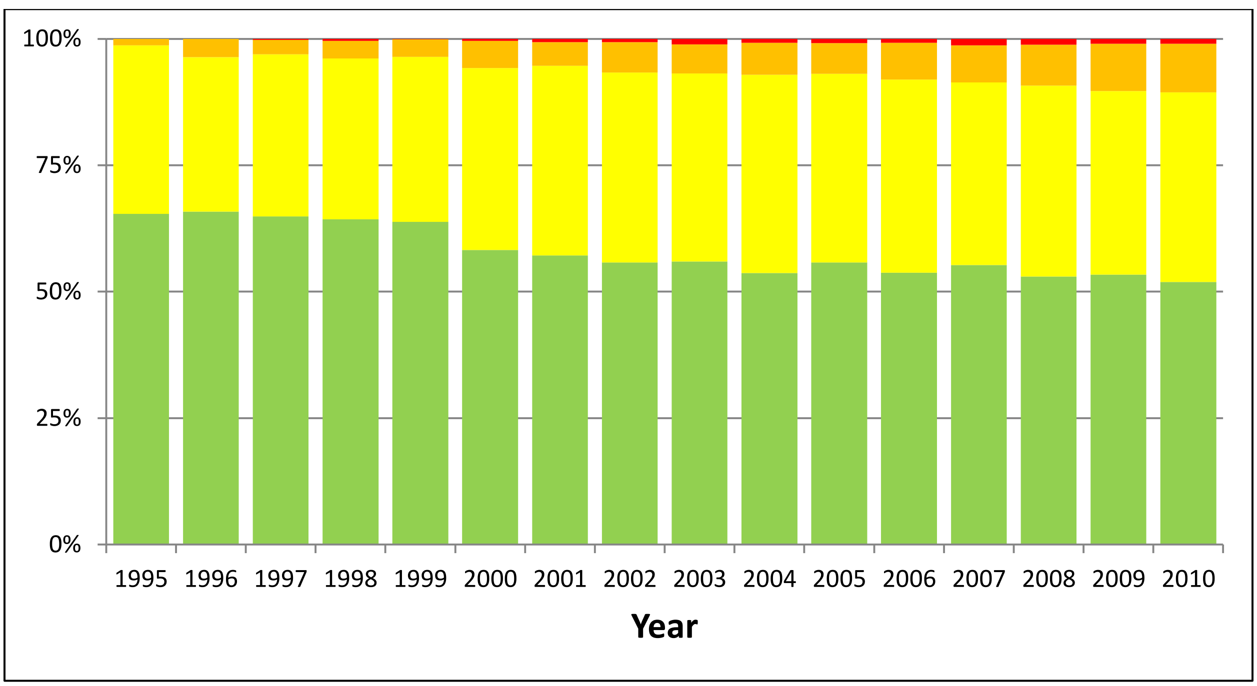

Figure 6 - Element 32 Normalized Condition State Trend – Improvement Not Noted – Reproduced from Figure B-4

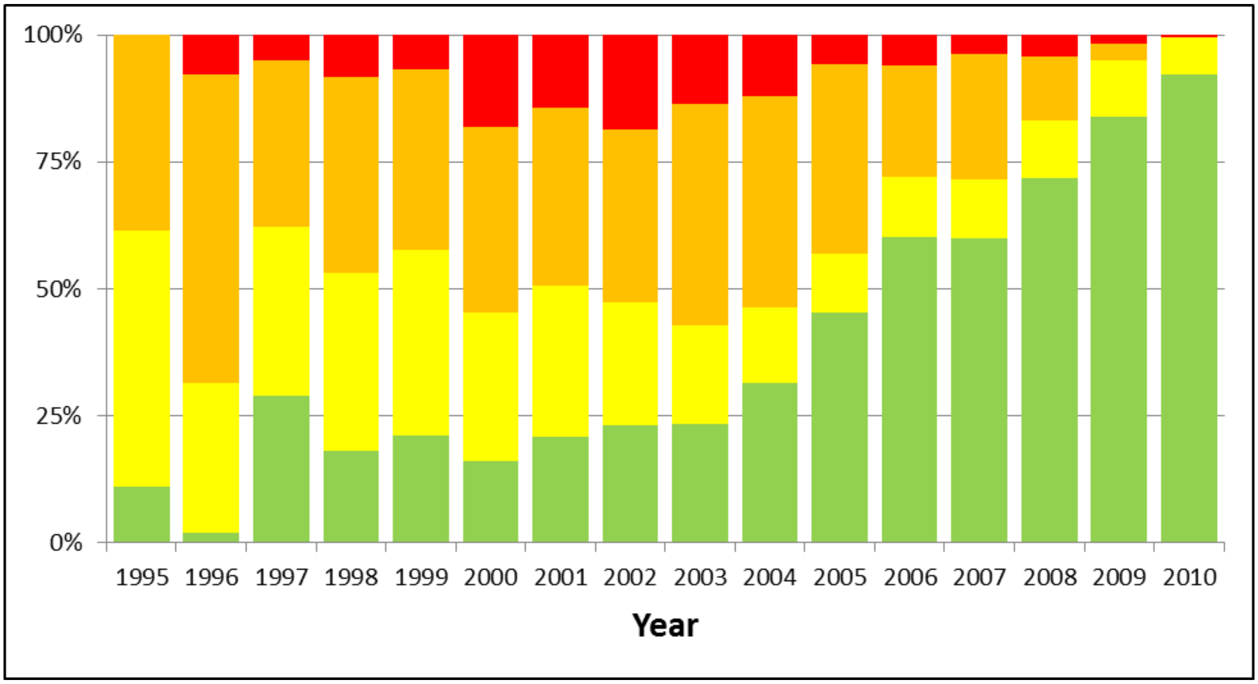

Figure 7 - Element 32 Normalized Condition State Trend – Improvement Noted (Quantity Analysis) – Reproduced from Figure B-5

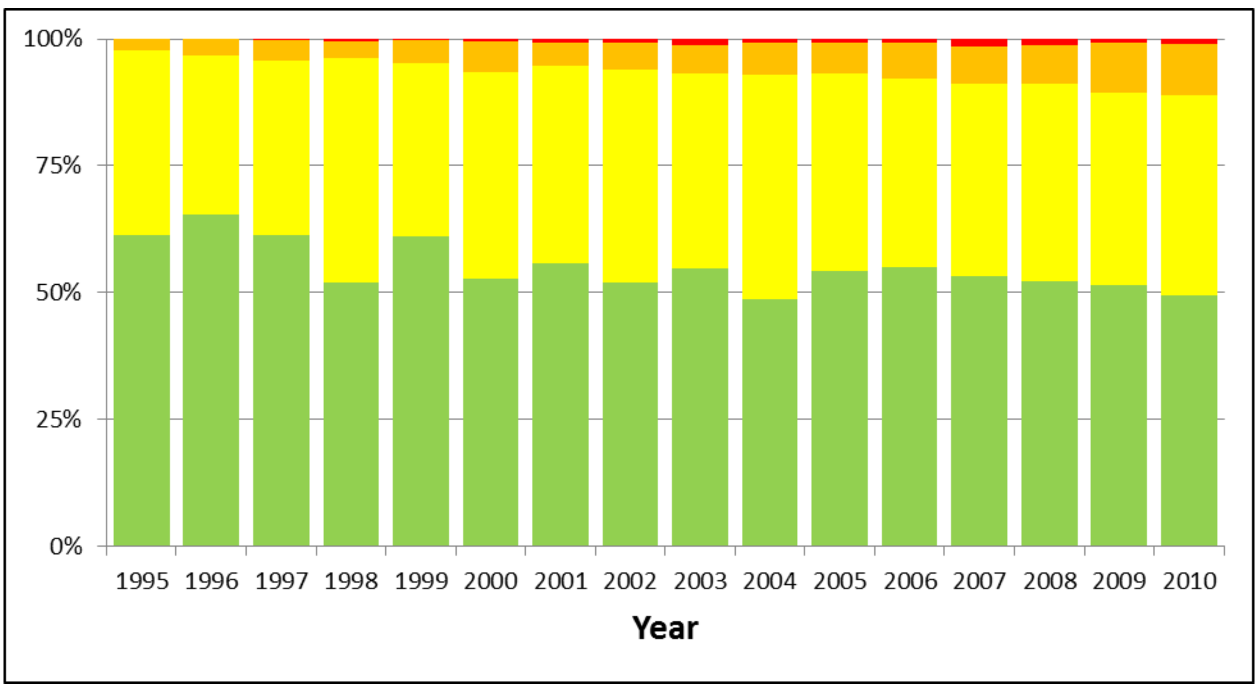

Figure 8 - Element 32 Normalized Condition State Trend – Improvement Not Noted (Quantity Analysis) – Reproduced from Figure B-6

The results of the year of improvement analysis are presented in tables such as Table 30 and Table 31 below and in their entirety in Appendix B as Table B-1 through Table B-12. The first row is the year of improvement, the second row is the number of bridges showing improvement in that year, and the last two rows are the average condition states recorded directly before and after that improvement occurred. Years with no improvements (often the early years, close to 1995) show 0.00 for before and after condition states. The full collection of tables in the appendix shows that some smart flags' and elements' condition states drop closer to 1 after improvement than others. Element 108 (Steel Open Girder with Timber Deck – Coated and Uncoated) and Smart Flag 359 (Soffit of Concrete) average around 1.55 after improvement compared to Element 302 (Compression Joint Seal) and Smart Flag 358 (Deck Cracking) which reached around 1.05 after improvement.

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Count	0	0	0	5	4	8	8	15	12	13	16	11	11	5	8	9
Before	0.00	0.00	0.00	3.00	3.13	3.63	3.49	2.94	3.00	2.97	2.89	2.85	2.60	2.85	2.79	3.08
After	0.00	0.00	0.00	1.33	1.00	1.62	1.19	1.12	1.11	1.21	1.20	1.12	1.00	1.00	1.15	1.09

Table 30 - Statewide Condition State Improvements by Year for Element 334 – Reproduced from Table B-4

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Count	0	0	0	1	5	2	3	3	1	2	0	3	2	8	9	11
Before	0.00	0.00	0.00	4.00	3.20	3.00	3.00	3.00	3.00	3.00	0.00	3.33	3.00	3.25	3.11	3.36
After	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.13	1.00	1.23

Table 31 - Statewide Condition State Improvements by Year for Smart Flag 358 – Reproduced from Table B-11

The results from the age since improvement analysis are presented in tables such as Table 32 and Table 33 below and in their entirety in Appendix B as Table B-13 through Table B-24. The first row is the age in years of the bridges containing the element being analyzed that underwent a condition state improvement of greater than 1.00. The second row is the summation of the condition states at the age shown at the top of that column. Similarly, the third row is the total count of all the bridges with inspection reports denoting a condition state improvement of greater than 1.00, at the age shown in the corresponding cell in the first row. The last row is the average condition state by year, calculated by dividing the total by the count for each age in which the count was non-zero (in order to avoid a divide-by-zero error).

Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Total	333.9	143.7	283.7	124.9	174.2	103.6	116.5	61.5	68.8	35.6	41.6	17.0	8.9	5.0	0.0	0.0
Count	213	72	164	56	101	49	71	34	40	23	24	12	7	3	0	0
Average	1.57	2.00	1.73	2.23	1.72	2.11	1.64	1.81	1.72	1.55	1.73	1.41	1.28	1.68		

Table 32 – Statewide Condition State Trend by Age since Improvement for Element 108 – Reproduced from Table B-14

Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Total	134.50	21.00	74.00	18.00	45.00	9.00	39.00	10.00	21.00	5.00	7.00	0.00	0.00	0.00	0.00	0.00
Count	96	15	59	13	36	8	30	8	15	3	5	0	0	0	0	0
Average	1.40	1.40	1.25	1.38	1.25	1.13	1.30	1.25	1.40	1.67	1.40					

Table 33 – Statewide Condition State Trend by Age since Improvement for Element 706 – Reproduced from Table B-21

The results of the age since improvement analysis are also presented in graphs such as Figure 9 and Figure 10 below and in their entirety in Appendix B as Figure B-57 through Figure B-59. These figures are graphical depictions of the Average Condition State vs. Age data from the associated tables (such as Table 32). The vertical axes were all forced to 1.00 to 3.00 (condition state value) and the horizontal axes forced to 0 to 12 (years) in order to keep the scales the same on all graphs in the set. The graphs created are straight lines between data points (with no smoothing), so elements with particularly up-and-down data show quite jagged results, such as element 240 in Figure 10.

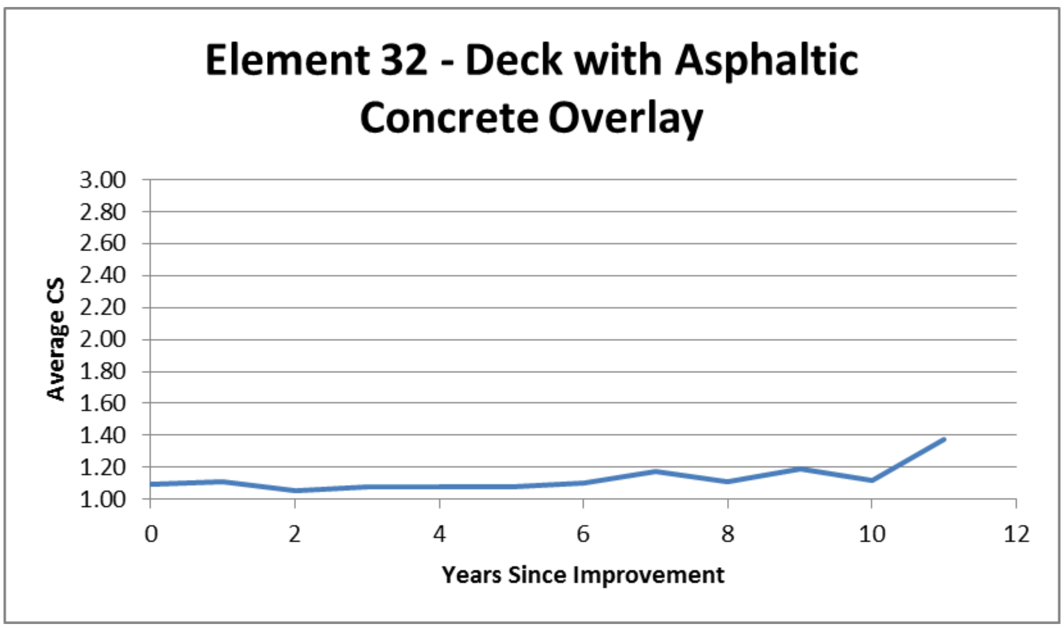

Figure 9 - Condition State Improvement Trend for Element 32 – Reproduced from Figure B-57

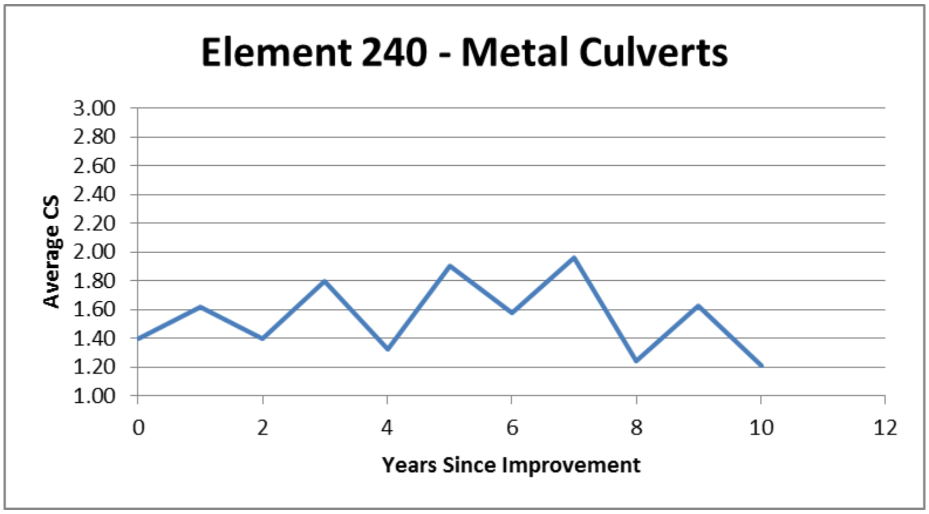

Figure 10 - Condition State Improvement Trend for Element 240 – Reproduced from Figure B-58

Potential Errors

Table 34 below shows the summary numbers for the side investigation on potential errors using the threshold of a 10%+ difference between reported quantity and reported percent * total quantity. The middle column displays the number of inspection reports in each district and total across the state that met this criterion. The right column shows the number of bridges that met this criterion to see how many of the errors occurred on the same bridges and which were unique.

District	# of Reports with Errors	# of Bridges with Errors
1	537	189
2	418	215
3	338	190
4	309	210
5	140	89
6	290	69
7	190	77
8	306	173
9	257	141
Total	2785	1353

Table 34 - Total Count of Likely >10% Erroneous Data by District

The full list of reports / bridges showing 10%+ difference (between quantity and total quantity * percent for any condition state) is provided in a separate Excel file through VDOT.

Zinc Coating Study

The results of the zinc coating study are displayed graphically in Figure 11 through Figure 19. For the quantity analysis graphs (Figure 11, Figure 12, and Figure 15), only whole number condition state values are present because there is no averaging between bridges. Note the different horizontal scales in Figure 11 and Figure 15. In Figure 11, data was grouped by two-year inspection cycles to eliminate the biannual cyclic variation in this particular analysis.

For all condition state bar graphs, green represents condition state 1.00 to 1.99, yellow is condition state 2.00 to 2.99, orange is 3.00 to 3.99, and red is 4.00 to 4.99. For the condition rating bar graphs (Figure 14), condition rating 9 is shown in purple, down through blue, green, yellow, and red to condition rating 1 as maroon, as displayed in the legend. The graphs also display the approximate percentages of bridges in 2012 that were in condition rating 7 or higher, using double-sided black arrows. This proportion in other years can be found by reading the percentage covered by the combined purple, blue, and dark green bars.

The element 107 condition state deterioration trends (data points and 6-year moving average) by age since coating for the 4 groups are shown in Figure 16. Both the yearly data points and the calculated 6-year moving averages (with each average value represented as a data point in the sixth year) are plotted. The deterioration of the superstructure condition rating is shown in similar graphs in Figure 17. Note the inversion of the y-axis, as deterioration is a decrease in condition rating but an increase in condition state. The condition state axis is held to 1.0 to 2.2 and the condition rating axis is held to 9.0 to 4.0 for consistency. The 6-year moving averages of the 4 groups are also graphed on the same plot for the condition state and condition rating analyses as Figure 18 and Figure 19, respectively, for easier comparison.

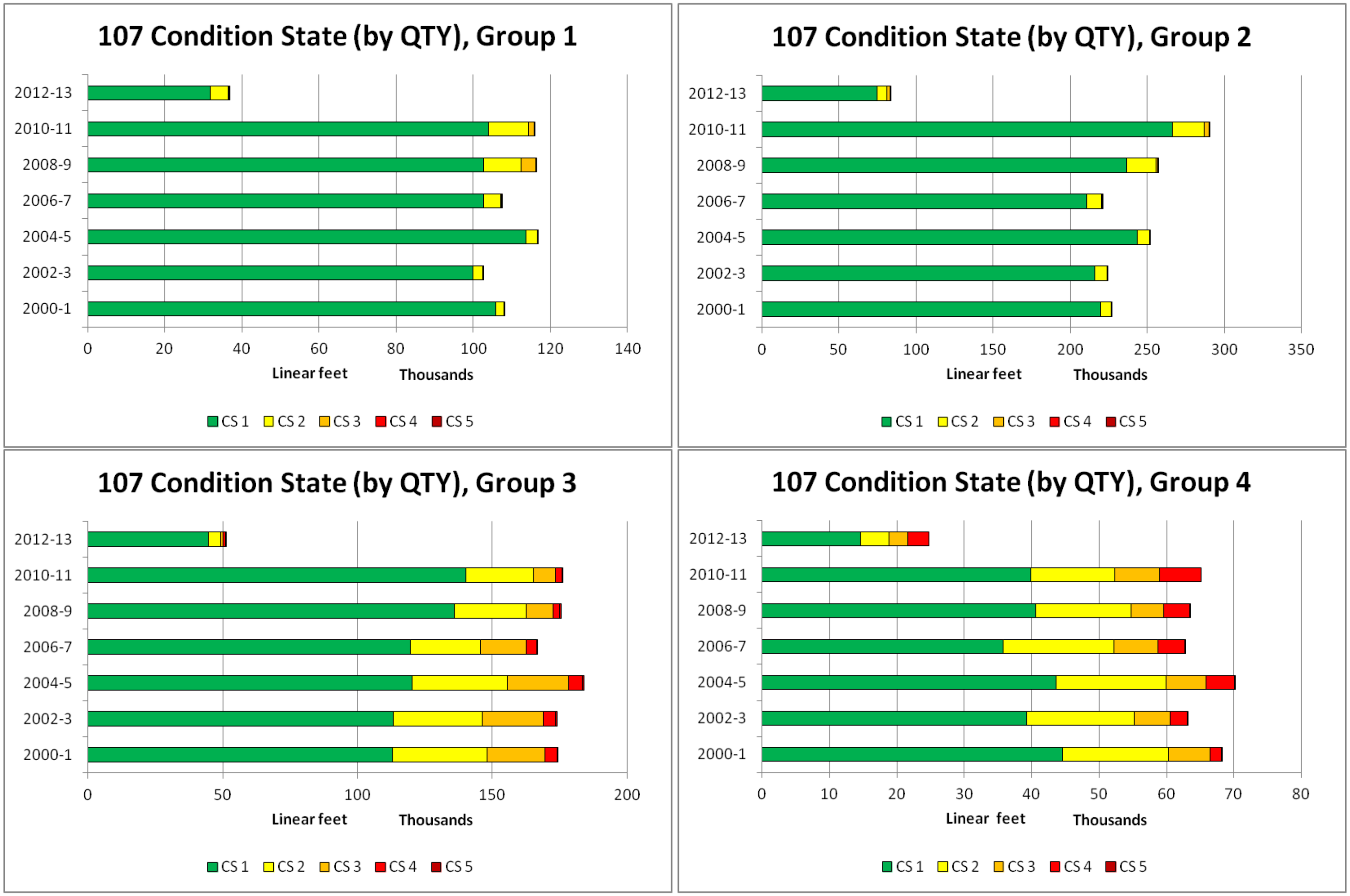

Figure 11 – Zinc Coating – Summary Graphs of Quantity in Each Condition State by Year – Two-Year Grouping

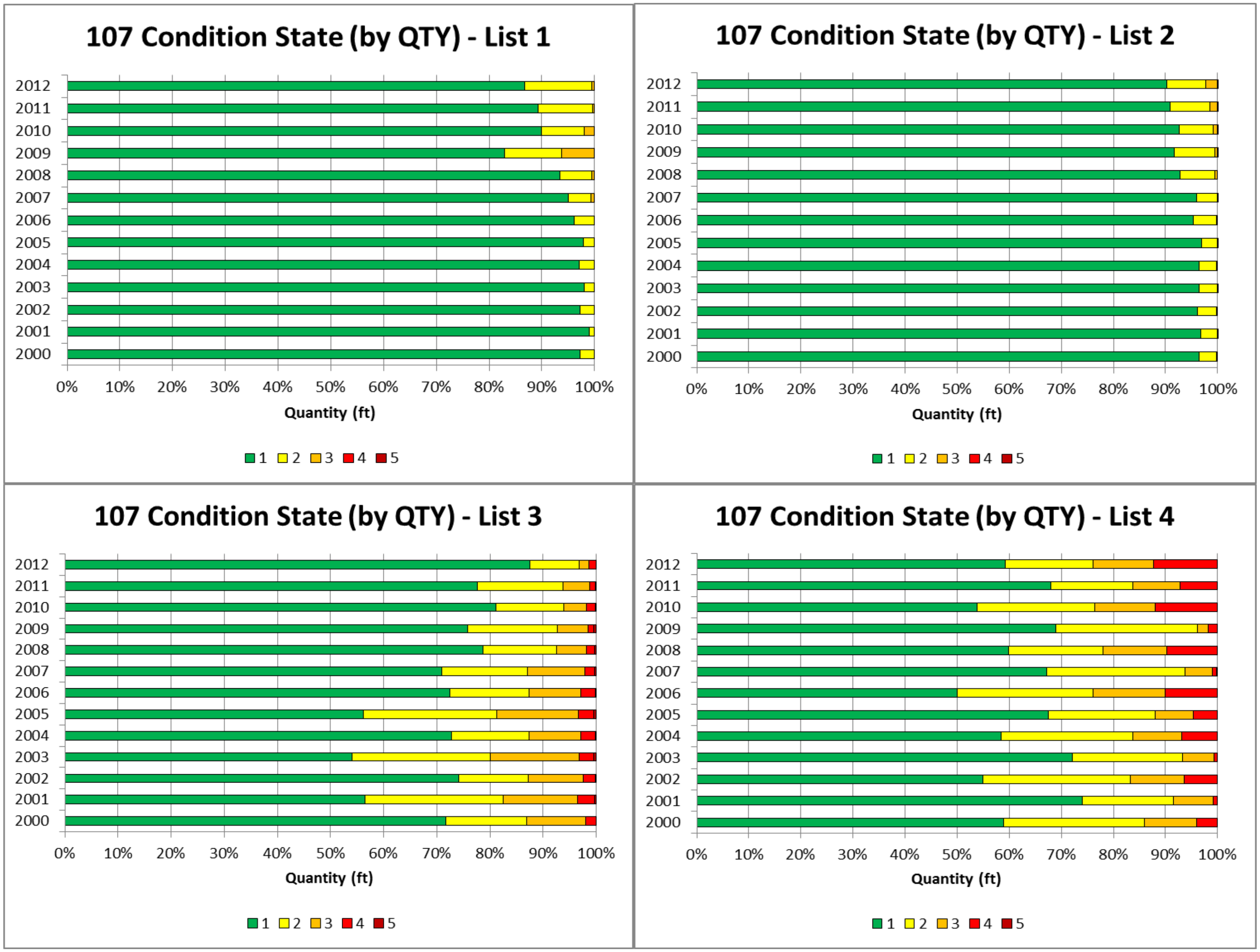

Figure 12 – Zinc Coating – Normalized Summary Graphs of Proportion of Inventory in Each Condition State Range by Year (Quantity Analysis)

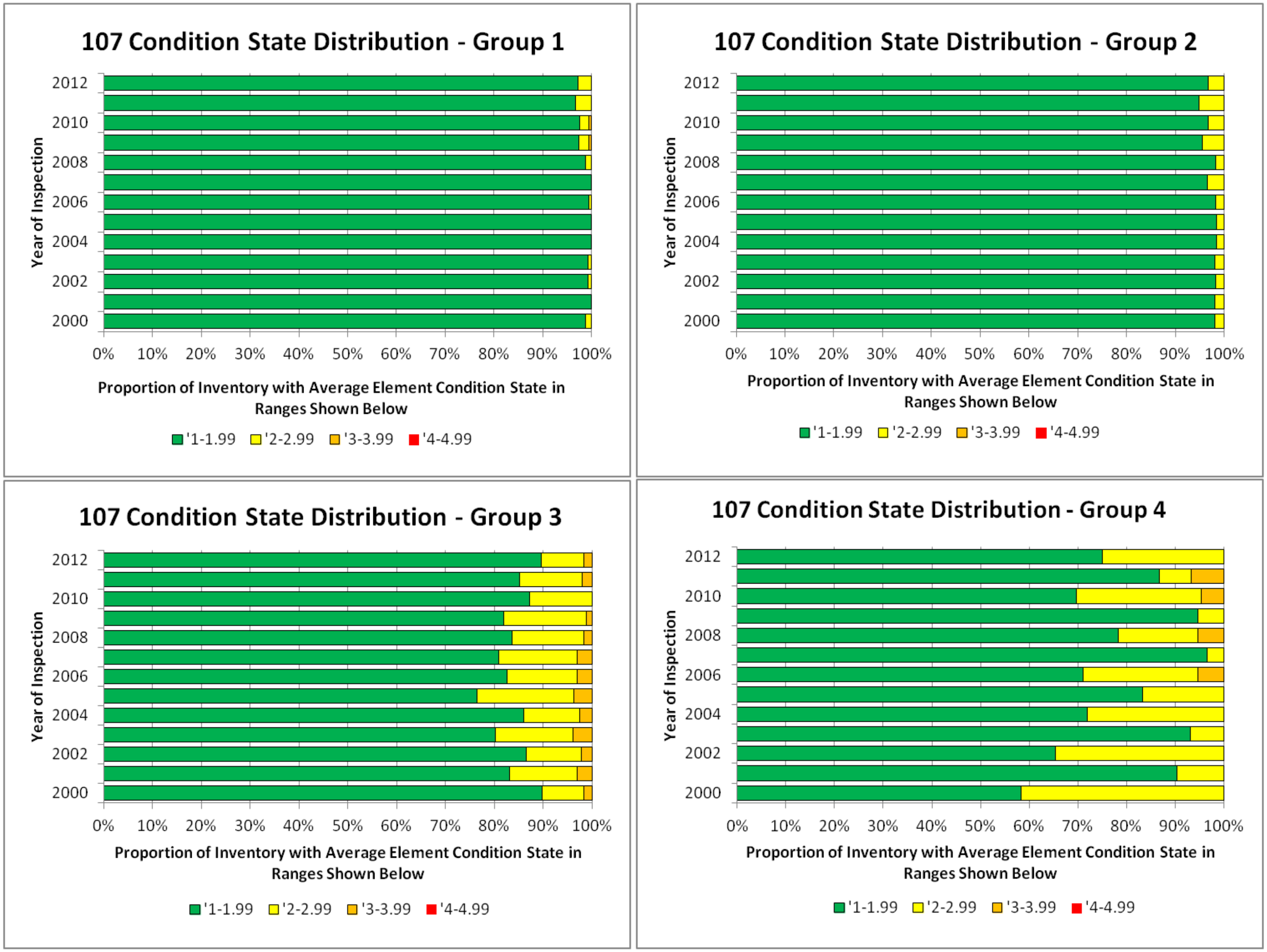

Figure 13 – Zinc Coating – Normalized Summary Graphs of Proportion of Inventory in Each Condition State Range by Year

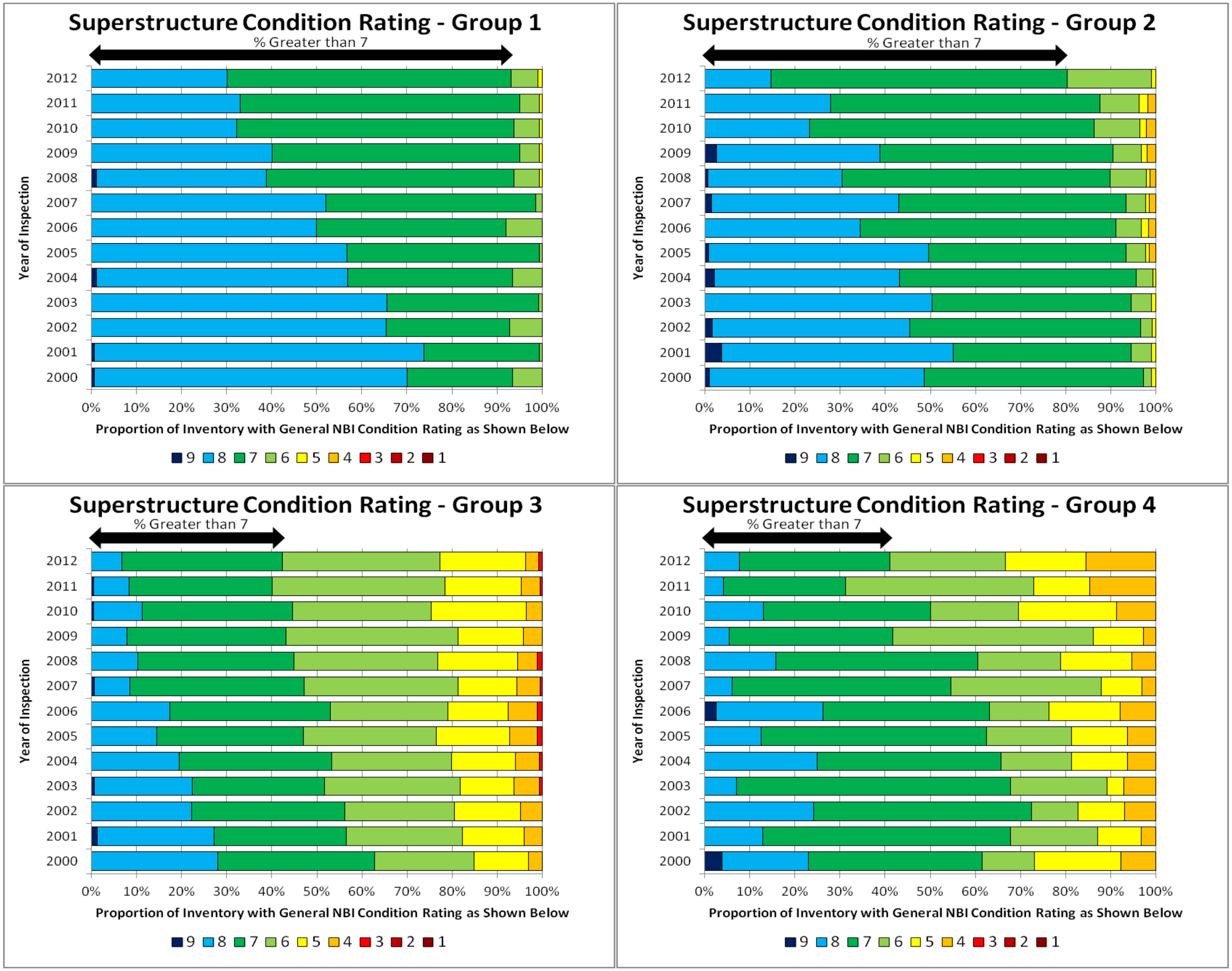

Figure 14 – Zinc Coating – Normalized Summary Graphs of Condition Rating Analysis by Year

Figure 15 – Zinc Coating – Summary Graphs of Quantity in Each Condition State by Age since Painting

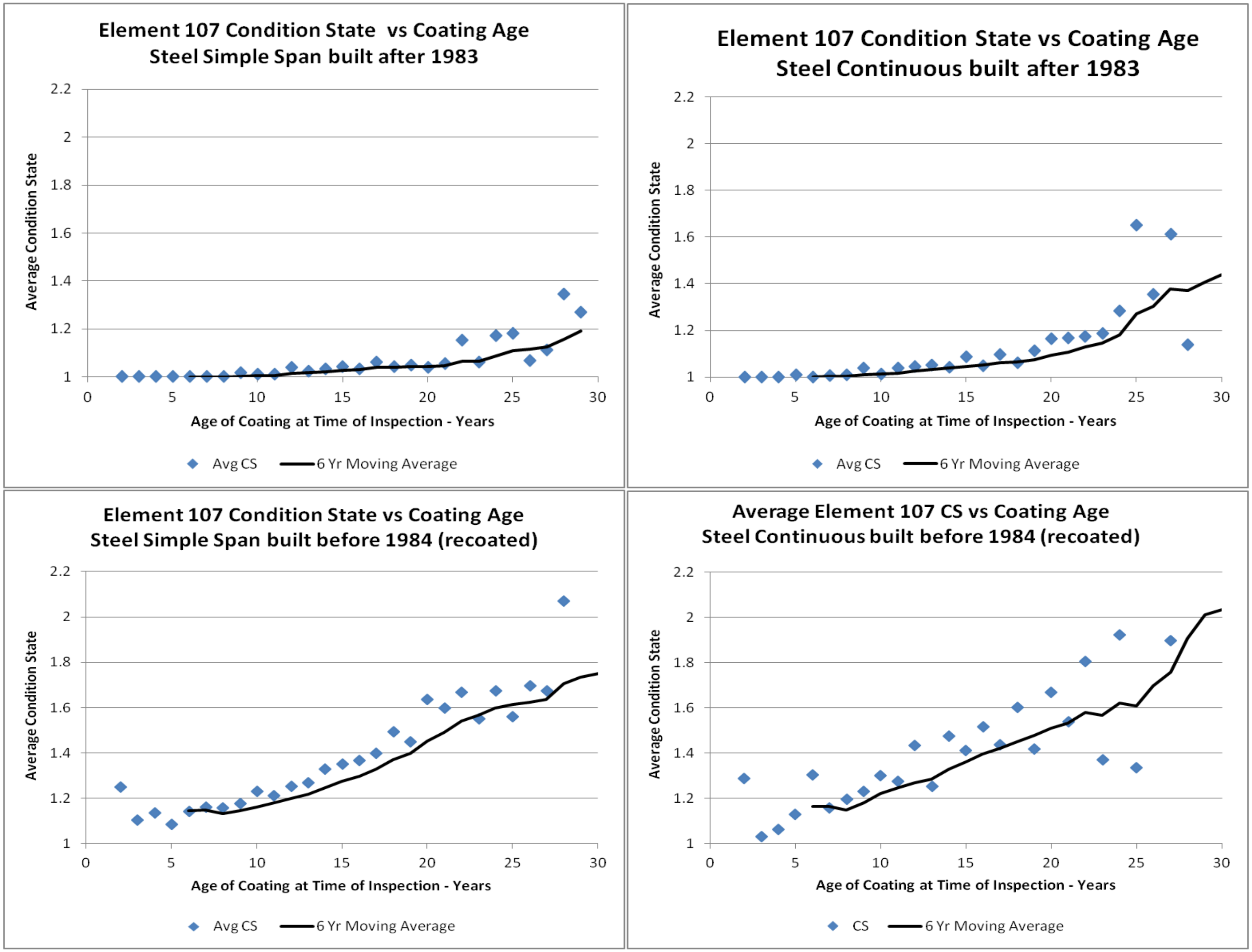

Figure 16 – Zinc Coating – Condition State Trends by Age since Painting

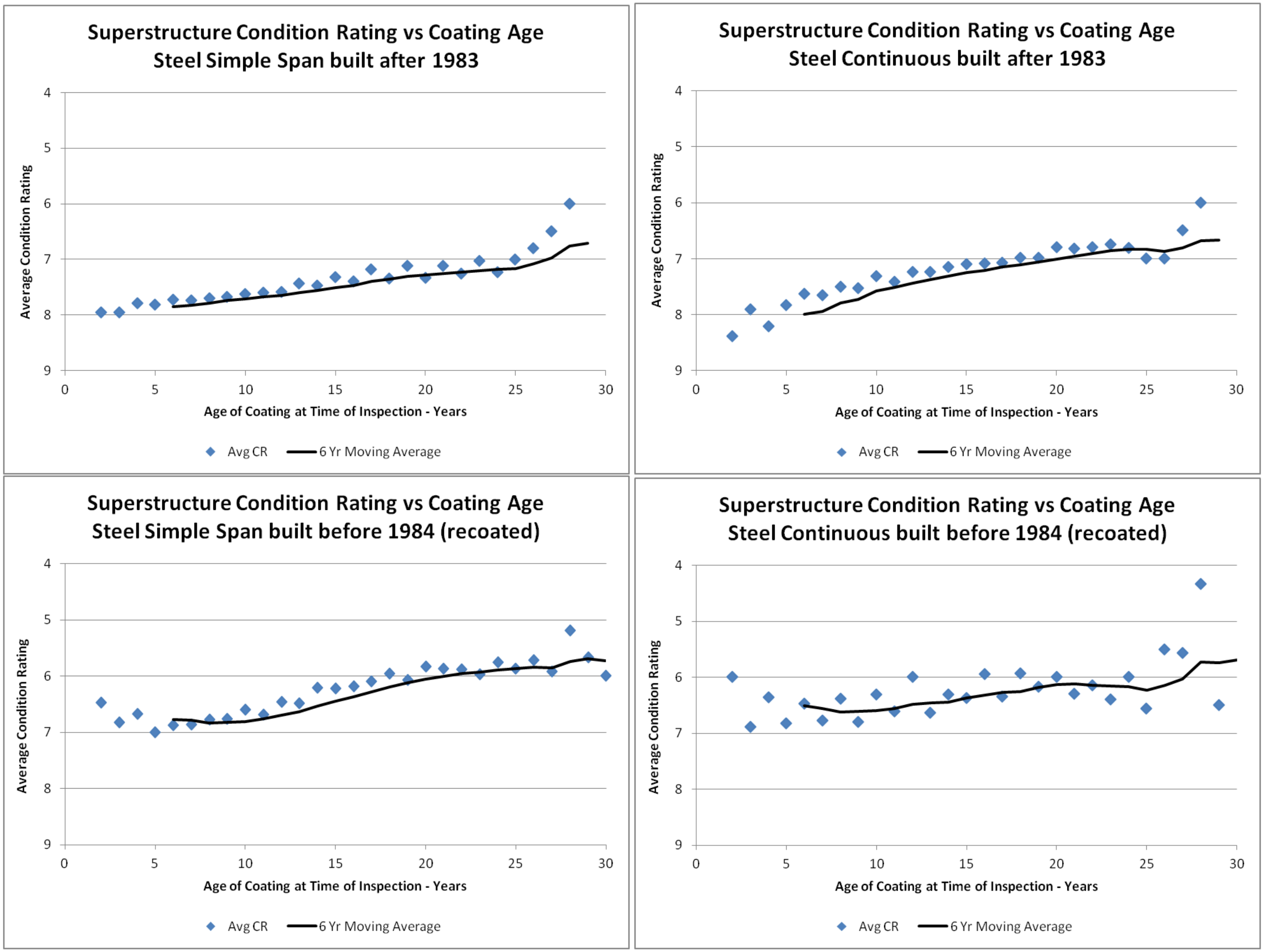

Figure 17 – Zinc Coating – Condition Rating Trends by Age since Painting

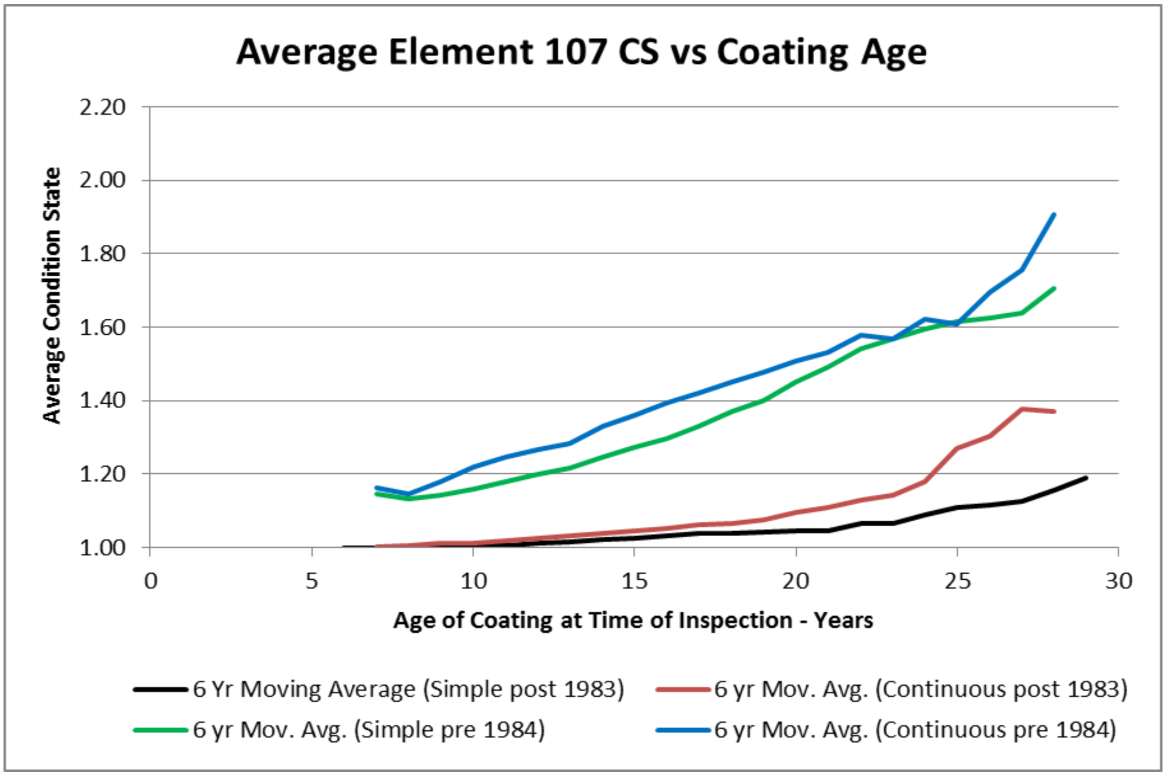

Figure 18 – Zinc Coating – Summary Trends for Condition State Deterioration

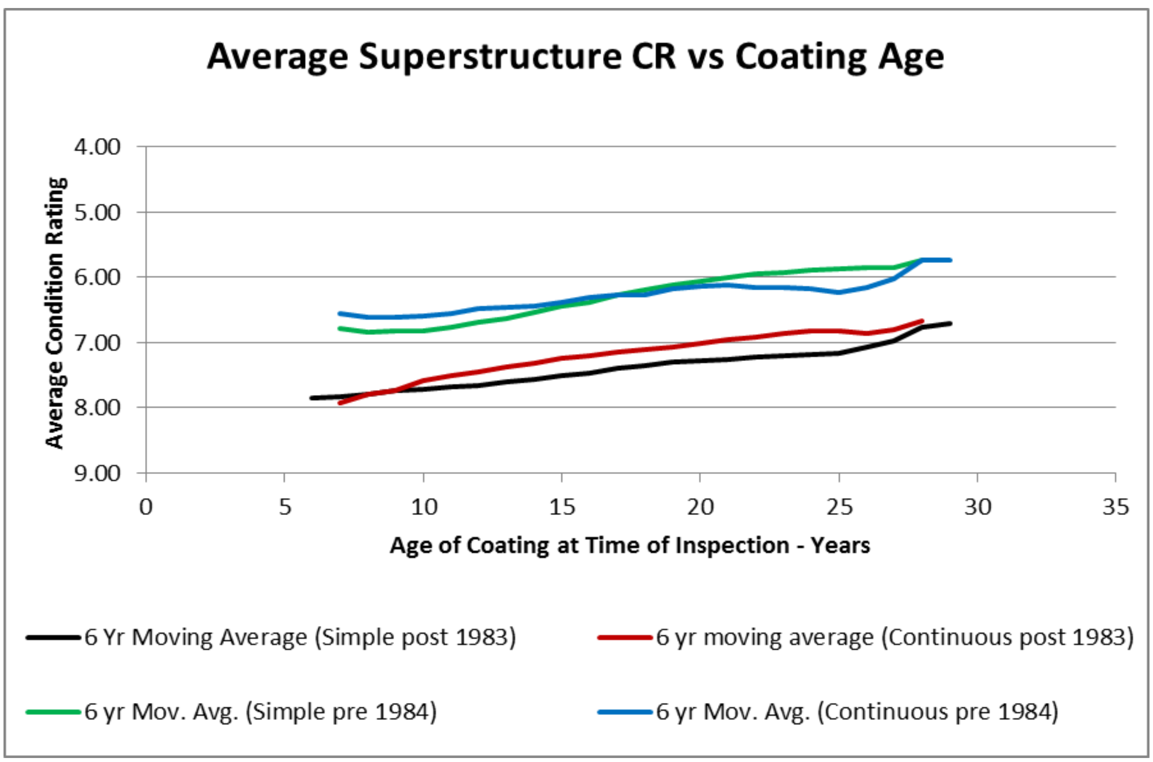

Figure 19 – Zinc Coating – Summary Trends for Condition Rating Deterioration

Table 35 shows the summary statistics for the average year the bridges in the zinc analysis were built and painted and the corresponding age of the bridge and the paint systems as of 2012. The different fields are divided by row into the bridges in each of the 4 groups.

	Average Year Bridge Was:		Average Age (in Years) of:	
Group	Built	Painted	Bridge	Paint
1	1993	1993	19	19
2	1995	1995	17	17
3	1961	1996	51	16
4	1962	1997	50	15

Table 35 - Average Year Built / Painted and Average Age of Bridge / Paint

The numbers of bridges in each group were: group 1 (326 bridges), group 2 (284 bridges), group 3 (381 bridges) and group 4 (82 bridges). Group 4 has significantly fewer bridges than the other groups and this is reflected in higher variation in the descriptive statistics. It is also noted that the number of bridges and the quantity of Element 107 decreases significantly for coating age greater than 20 years. This also is reflected in higher variability in the average condition state.

The deteriorated quantity analysis selected bridges with a non-zero quantity of element 107 in condition states 4 and / or 5 in their most recent inspection report as of September 17, 2012. This set of bridges was already filtered for the zinc study, so they are all VDOT-maintained, active, non-posted, steel beam/girder, concrete deck bridges. The number of deteriorated quantity bridges appearing in each group is as follows: 8 in group 1, 4 in group 2, 90 in group 3, and 19 in group 4, for a total of 121 bridges. The full list of these bridges is available in a separate Excel file through VDOT.

Joint Closures

The summary count data from the joint elimination study are shown in Table 36 below. The bridges that had joint quantities entirely eliminated are represented by the "ELIM" row heading. The count of bridges that had joint quantities decrease between 10% and 99% are shown in the "DECR" row. The bridges with quantity of one joint element being replaced by an equivalent quantity of another joint element are displayed as "DIFF".

Joints	District									
Summary	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Total*
ELIM	98	82	43	154	129	22	32	77	60	697
DECR	28	31	10	105	61	8	22	56	49	370
DIFF	55	61	30	105	83	7	27	49	39	456
Total	181	174	83	364	273	37	81	182	148	1523

Table 36 – Joint Closure Count Summary

The full list of bridges showing joint deterioration is provided in a separate Excel file through VDOT. Each row contains the federal bridge ID, the year the quantity decreased, and which of the three elimination options occurred on each bridge.

Priority Bridges and District Visits

The summary of the priority bridges is shown in Table 37 below. The top section of the table shows the number of bridges containing unexpected improvements to the element listed at left within the district listed at the top. These are summed both by district and by element, with the element descriptions at right. The bottom portion of the table is arranged similarly, showing bridge counts for alternate, unused classifications of four of the selected elements. Elements 107 and 108 have the bridges added back in where, based on the inspection report data, painting is the reported (and therefore “known”) improvement. Elements 301 and 302 in the bottom section use the stricter >1.00 condition state decrease criteria that the other elements use (while elements 301 and 302 in the top section use the >0.05 condition state decrease criteria).

	District Number										
Element Number	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Total*	*Element Description*
107	44	21	4	24	4	2	19	21	3	142	Steel Open Girder - Coated
108	81	64	17	15	10	2	9	19	13	230	V Steel Open Girder with Timber Deck – Coated and Uncoated
311	7	5	1	12	0	1	0	2	2	30	Moveable Bearing (Roller, sliding, etc.)
313	5	1	1	15	0	0	0	1	1	24	Fixed Bearing
301	55	88	3	349	88	30	41	13	63	730	Pourable Joint Seal
302	97	139	139	116	105	22	40	157	110	925	Compression Joint Seal
Total to Select From	289	318	165	531	207	57	109	213	192	2081	
107 w/ Paint	44	69	17	47	7	10	41	96	6	337	Steel Open Girder - Coated
108 w/ Paint	127	189	34	23	21	3	33	38	16	484	V Steel Open Girder with Timber Deck – Coated and Uncoated
301 >1	23	43	2	131	16	10	8	5	17	255	Pourable Joint Seal
302 >1	28	33	60	27	14	4	9	41	9	225	Compression Joint Seal

Table 37 - Number of Unexpected Improvements by District for Selected Element

The final list of maintenance actions (and acronyms used) was developed over the course of the study as data became available and is shown in Appendix C as Table C-25, reproduced below as Table 38. "No Maintenance Noted" refers to situations where there is no recorded work done over a period where the paper reports agree with the Pontis data showing an improvement for the given bridge and element. If there is no agreement (the paper report does not show the expected improvement), that entry is marked as "Typographical Error", which can then likely be attributed to a mistake at some stage of inspection report data entry or Excel analysis. The remaining actions refer to different types of work done (often specific to an element or category of elements) that were noted in a given inspection report as having occurred since the previous inspection report.

Code	*Corresponding Maintenance Action*
CP	Cleaned / Painted Structural Steel
SR	Superstructure Replaced
RB	Replaced Some Beams / Girders
DJ	Deck Joints Resealed
BR	Bearings Replaced
BP	Bearings Painted
AQ	Added Quantity (in CS 1)
RR	Road Repaved
NM	No Maintenance Noted
TE	Typographical Error
ND	No Data
OT	Other

Table 38 - Maintenance Action Codes and Descriptions – Reproduced from Table C-25

The final products of the district visits are shown in summary tables by element and road classification, displaying the relative percentage of number of times each maintenance action is taken on each set of bridges. These tables are presented in their entirety in Appendix C as Table C-1 through Table C-24, and a subset for element 107 is shown as Table 39 through Table 42.

Each table is divided into the 9 districts and the entire state by column. The top data row displays the count of bridges containing the desired element on the specified road classification, followed by the average and total quantity of the given element per bridge within each district. The remaining rows display the percent, in each district, of the selected bridges where the cause of improvement was due to the maintenance action coded in the leftmost column (defined in Table 38). The "Total" column shows the combined maintenance values divided into the state total count, as opposed to simply averaging the district values.

The completed inspection tables from the district visits, such as Table 15, are available in a separate Excel file through VDOT.

Total	*District*									
Element 107	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Total*
Count	6	12	4	15	5	3	8	14	3	70
Avg. Quant.	338.26	407.83	245.43	912.99	624.76	526.31	497.64	339.62	297.33	513.29
Tot. Quant.	2029.56	4893.94	981.73	13694.82	3123.80	1578.94	3981.11	4754.63	892.00	35930.52
CP	50.0%	66.7%	0.0%	40.0%	20.0%	66.7%	75.0%	71.4%	0.0%	51.4%
SR	50.0%	0.0%	25.0%	20.0%	0.0%	0.0%	0.0%	0.0%	0.0%	10.0%
RB	0.0%	0.0%	0.0%	6.7%	0.0%	0.0%	0.0%	0.0%	0.0%	1.4%
AQ	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
NM	0.0%	16.7%	75.0%	33.3%	80.0%	33.3%	25.0%	28.6%	100.0%	34.3%
TE	0.0%	16.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.9%
OT	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table 39 - District Visit Maintenance Summary – Element 107 – All Road Types – Reproduced from Table C-1

Interstate	*District*									
Element 107	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Total*
Count	1	3	0	4	3	0	5	7	0	23
Avg. Quant.	506.94	443.98	N/A	974.14	305.93	N/A	483.86	291.27	N/A	483.10
Tot. Quant.	506.94	1331.93	0.00	3896.55	917.80	0.00	2419.31	2038.89	0.00	11111.41
CP	100.0%	100.0%	N/A	25.0%	0.0%	N/A	80.0%	57.1%	N/A	56.5%
SR	0.0%	0.0%	N/A	50.0%	0.0%	N/A	0.0%	0.0%	N/A	8.7%
RB	0.0%	0.0%	N/A	0.0%	0.0%	N/A	0.0%	0.0%	N/A	0.0%
AQ	0.0%	0.0%	N/A	0.0%	0.0%	N/A	0.0%	0.0%	N/A	0.0%
NM	0.0%	0.0%	N/A	25.0%	100.0%	N/A	20.0%	42.9%	N/A	34.8%
TE	0.0%	0.0%	N/A	0.0%	0.0%	N/A	0.0%	0.0%	N/A	0.0%
OT	0.0%	0.0%	N/A	0.0%	0.0%	N/A	0.0%	0.0%	N/A	0.0%

Table 40 - District Visit Maintenance Summary – Element 107 – Interstate Roads – Reproduced from Table C-2

Primary	*District*									
Element 107	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Total*
Count	3	2	1	10	2	2	0	1	3	24
Avg. Quant.	274.38	415.21	332.00	947.72	1103.00	633.04	N/A	495.95	297.33	680.12
Tot. Quant.	823.14	830.42	332.00	9477.19	2206.00	1266.08	0.00	495.95	892.00	16322.77
CP	66.7%	100.0%	0.0%	50.0%	50.0%	50.0%	N/A	0.0%	0.0%	45.8%
SR	33.3%	0.0%	0.0%	10.0%	0.0%	0.0%	N/A	0.0%	0.0%	8.3%
RB	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	N/A	0.0%	0.0%	0.0%
AQ	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	N/A	0.0%	0.0%	0.0%
NM	0.0%	0.0%	100.0%	40.0%	50.0%	50.0%	N/A	100.0%	100.0%	45.8%
TE	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	N/A	0.0%	0.0%	0.0%
OT	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	N/A	0.0%	0.0%	0.0%

Table 41 - District Visit Maintenance Summary – Element 107 – Primary Roads – Reproduced from Table C-3

Secondary	*District*									
Element 107	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Total*
Count	2	7	3	1	0	1	3	6	0	23
Avg. Quant.	349.74	390.23	216.58	321.09	N/A	312.86	520.60	369.96	N/A	369.41
Tot. Quant.	699.48	2731.60	649.73	321.09	0.00	312.86	1561.80	2219.79	0.00	8496.34
CP	0.0%	42.9%	0.0%	0.0%	N/A	100.0%	66.7%	100.0%	N/A	52.2%
SR	100.0%	0.0%	33.3%	0.0%	N/A	0.0%	0.0%	0.0%	N/A	13.0%
RB	0.0%	0.0%	0.0%	100.0%	N/A	0.0%	0.0%	0.0%	N/A	4.3%
AQ	0.0%	0.0%	0.0%	0.0%	N/A	0.0%	0.0%	0.0%	N/A	0.0%
NM	0.0%	28.6%	66.7%	0.0%	N/A	0.0%	33.3%	0.0%	N/A	21.7%
TE	0.0%	28.6%	0.0%	0.0%	N/A	0.0%	0.0%	0.0%	N/A	8.7%
OT	0.0%	0.0%	0.0%	0.0%	N/A	0.0%	0.0%	0.0%	N/A	0.0%

Table 42 - District Visit Maintenance Summary – Element 107 – Secondary Roads – Reproduced from Table C-4

Linear Least Squares and Markov Modeling

The parameters for the LLS deterioration models are displayed in Table 43 for each of the 6 top elements in each of the 9 districts and then averaged across the state. Each line is completely described using its slope and the condition state of the bridge in 2010, which is more meaningful than the y-intercept. This intercept would have been the theoretical condition state at year 0 AD. The averages are equally weighted means of the 9 districts' values (the number of bridges per district is not taken into account here).

		District									
Element		*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Average*
107	Slope	0.0048	0.0049	0.0033	0.0044	0.0037	0.0045	0.0041	0.0042	0.0032	0.0041
	2010 CS	1.6841	1.8459	1.2790	1.8292	1.4903	1.7414	1.7100	1.7602	1.2716	1.6235
108	Slope	0.0092	0.0079	0.0060	0.0059	0.0039	0.0085	0.0061	0.0074	0.0065	0.0068
	2010 CS	3.1021	3.0124	2.2572	2.4014	1.5889	3.0651	2.5003	2.6439	2.7920	2.5959
301	Slope	-0.0046	0.0161	-0.0299	0.0227	0.0130	0.0073	0.0244	0.0179	0.0267	0.0104
	2010 CS	1.8203	1.7749	1.5566	1.8794	1.2918	2.0160	1.8706	1.8585	1.6366	1.7450
302	Slope	0.0169	0.0157	0.0104	0.0273	0.0232	0.0220	0.0348	0.0146	0.0201	0.0206
	2010 CS	1.4129	1.4857	1.4333	1.5438	1.5645	1.8874	1.8271	1.4289	1.3998	1.5537
311	Slope	0.0101	0.0048	0.0033	0.0239	0.0153	0.0085	0.0131	0.0038	0.0213	0.0116
	2010 CS	1.5250	1.5890	1.4321	1.6586	1.5773	1.6789	1.5986	1.4444	1.3938	1.5442
313	Slope	0.0032	0.0000	0.0064	0.0127	0.0126	0.0020	0.0061	0.0011	0.0117	0.0062
	2010 CS	1.3929	1.3945	1.2100	1.4923	1.5204	1.5018	1.4747	1.3827	1.2114	1.3978

Table 43 – Linear Least Squares Summary for Top Elements by District

The condition state history by age linear regression analysis produced graphs such as Figure 20 below. The data points are shown in blue for each of the years 0 to 100 where there was at least on bridge reporting a condition state. The sloping black line through the data is the trendline produced by Excel's linear least squares best fit calculations. Near that line is the equation in y = mx + b form, where "m" represents the slope of average deterioration and "b" represents the modeled condition state at 0 years of age. The complete set of these graphs can be found at the beginning of Appendix D in this report.

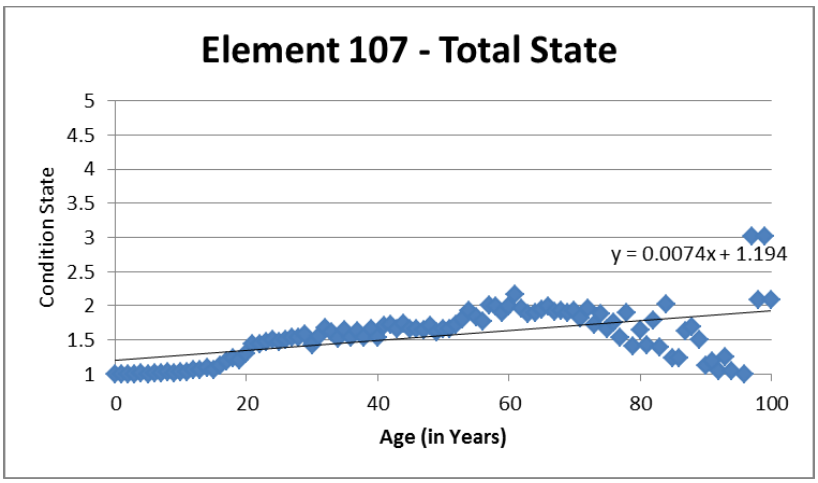

Figure 20 – Condition State History and Linear Trendline by Age – Element 107 – Total State – Reproduced from Figure D-28

The second set of graphs from the linear least squares regression analysis based on the age of bridges displays the residuals from subtracting the actual reported condition state from the condition state calculated from the linear trendline equation for the same age. These values are shown over each year of the 100 year time frame that at least one bridge reported condition state data for the given element in the given district / total state. Figure 21 below shows this set of data for the total state for element 107; the district specific graphs and those for element 108 are presented at the beginning of Appendix D in this report.

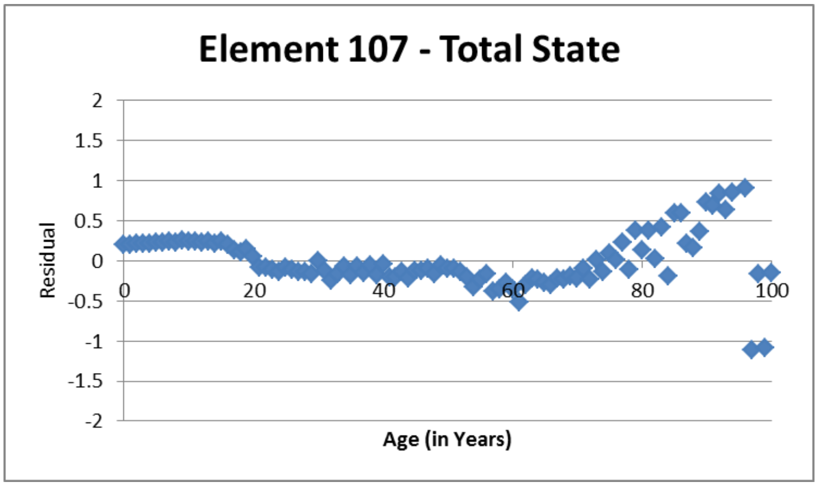

Figure 21 – Condition States Residuals (Prediction Minus Actual) by Age – Element 107 – Total State – Reproduced from Figure D-29

The numbers of bridges contributing condition state data for each district (and total state) for each age are represented in graphs such as Figure 22 below. The complete set of these graphs for element 107 and element 108 in each district are presented at the beginning of Appendix D of this report. Note that the vertical scale for each element is consistent between districts in order to better appreciate the relative number of bridges reporting for each element from different regions around the state; the "total state" graphs have necessarily higher scales.

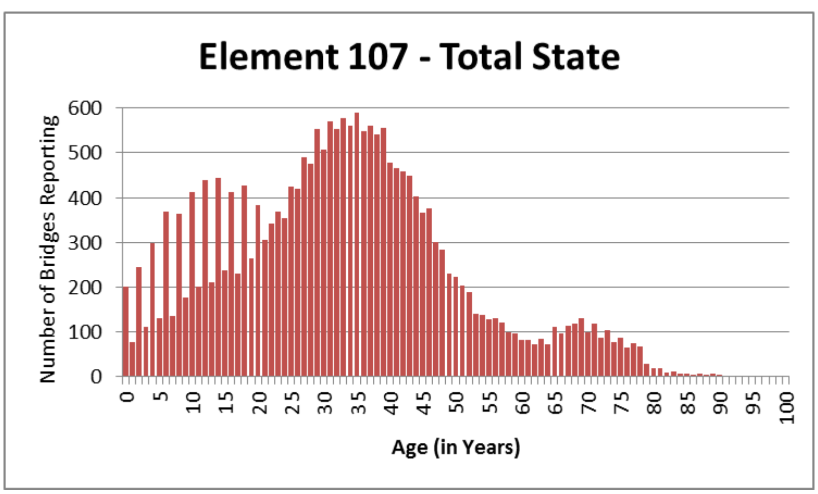

Figure 22 – Number of Bridges Reporting by Age – Element 107 – Total State – Reproduced from Figure D-30

The transition probability matrices from the Markov chain modeling are presented in their entirety in Appendix D as Table D-1 through Table D-19, 4 of which are reproduced below as Table 44 and Table 45, for element 107 in Districts 1 through 4. The left column represents the condition state the quantity of the given element is in at the beginning of the time step (a year in this report), and each column heading represents the potential condition states that element can end the year in. For this project, an element only had the option of remaining in its current condition state or deteriorating to the next worst condition state.

D1	1	2	3	4	5
1	0.990	0.010	0.000	0.000	0.000
2	0.000	0.972	0.028	0.000	0.000
3	0.000	0.000	0.976	0.024	0.000
4	0.000	0.000	0.000	0.961	0.039
5	0.000	0.000	0.000	0.000	1.000

D2	1	2	3	4	5
1	0.982	0.018	0.000	0.000	0.000
2	0.000	0.975	0.025	0.000	0.000
3	0.000	0.000	0.993	0.007	0.000
4	0.000	0.000	0.000	0.993	0.007
5	0.000	0.000	0.000	0.000	1.000

Table 44 – Markov Transition Probability Matrices – Element 107 – Districts 1 and 2 - Reproduced from Table D-1

D3	1	2	3	4	5
1	0.994	0.006	0.000	0.000	0.000
2	0.000	0.977	0.023	0.000	0.000
3	0.000	0.000	0.979	0.021	0.000
4	0.000	0.000	0.000	0.992	0.008
5	0.000	0.000	0.000	0.000	1.000

D4	1	2	3	4	5
1	0.987	0.013	0.000	0.000	0.000
2	0.000	0.972	0.028	0.000	0.000
3	0.000	0.000	0.977	0.023	0.000
4	0.000	0.000	0.000	0.985	0.015
5	0.000	0.000	0.000	0.000	1.000

Table 45 – Markov Transition Probability Matrices – Element 107 – Districts 3 and 4 - Reproduced from Table D-2

These modeled deterioration tables and corresponding actual data deterioration tables are also shown in graphical form in their entirety in Appendix D as Figure D-61 through Figure D-79, 2 of which are reproduced as Figure 23. The graphs are color coded such that, for elements 107 and 108, green represents the percentage (by quantity) of the given element in the selected district that has a condition state of 1, yellow represents 2, orange represents 3, bright red represents 4, and dark red represents the ultimate deterioration of condition state 5. For element 32, which only has 4 coded condition states, green is 1, yellow is 2, orange is 3, and dark red is 4. For element 32, which only has 3 coded condition states, green is 1, orange is 2, and dark red is 3. These slightly varying color selections are in an attempt to display similar levels of deterioration (on different elements) in the same colors.

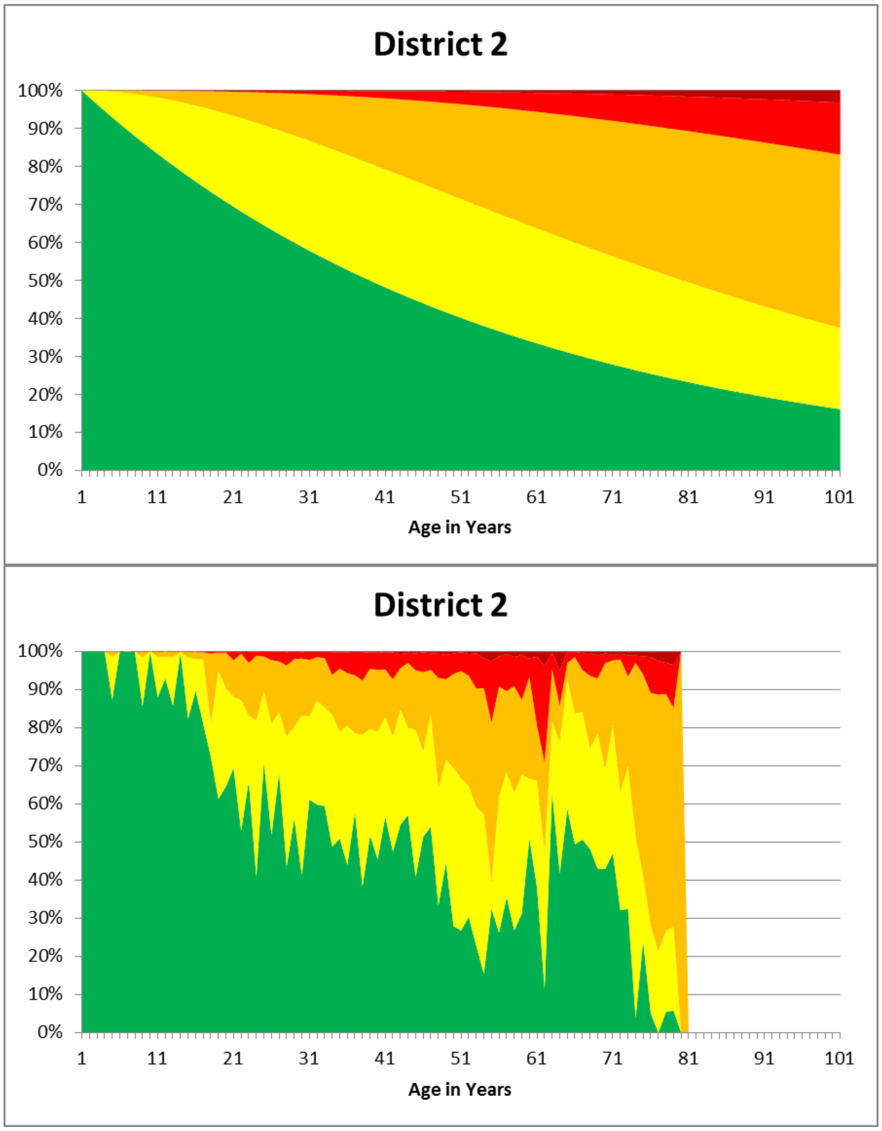

Figure 23 – Markov Chain Prediction Graphs – Element 107 – District 2 Prediction vs. Actual Graphs – Reproduced from Figure D-62

Element 108, which is a girder under a timber deck, displays a noticeably more rapid deterioration rate than element 107, which is a girder under a concrete deck. From Table D-5 and Table D-10, we can see that for the total state, element 108's chances at staying in condition states 1, 2, 3, and 4 between consecutive years are 0.990, 0.980, 0.977, and 0.986, respectively, whereas the associated element 107 values are 0.975, 0.964, 0.980, and 0.983. The result is a fairly large difference in projected deterioration over 100 years, due almost entirely to the first two transitions, as seen in the Total State graphs in Figure D-61 and Figure D-66.

It can be seen that certain elements in certain districts show particularly high levels of deterioration, such as element 302 – District 6 (in Figure D-74). For elements 107 and 108, districts 3 and 5 have slightly lower deterioration rates than the other districts and District 1 has a somewhat greater chance of deteriorating to condition state 5 over time. In general, however, consistent district-specific trends in this section of the analysis between elements were not noted.

Element 32 is shown to be less likely to deteriorate past condition state 2 once it reaches it than the other elements are. This is presented by transition probability matrices with a larger probability in the condition state 2 – 2 cell (such as in Table D-17) and with increased thickness of the yellow bands of the graphs (such as District 3 in Figure D-77).

ANALYSIS

Original Pontis Analysis by District

The data from the first several years of the Pontis database's existence are more likely prone to errors in reporting, inspection, or recording as the system had not become standardized yet and inspectors were becoming familiar with the element-level inspection techniques. Many of the graphs produced using data from the first three years (1995-1997) show seemingly random fluctuations that are inconsistent with the remaining data. These deviations can perhaps be explained by the variance in the styles of early Pontis data collection and reporting before they became more standardized by the turn of the century. Additionally, in the early years of Pontis inspection reporting, only a small percentage of the total bridge population reported data at the element level; this could also contribute to the variation of data in the early years.

As there were too many elements to analyze each one for every district, the selection process based on total number of inspection reports for each element was used to narrow down the field. After the next stage of analysis, the district summary tables by count and improvement could be created (Table 24 through Table 26), showing that the amount of unexpected improvements often did not line up with those elements that simply had more inspection data. It is thus possible that elements that were less numerous and therefore not analyzed in this report could have had many improvements and be worth additional investigation.

Due to the timing of maintenance and inspection in a given year, sometimes condition state decreases occurred in the year the maintenance action was noted, whereas sometimes they do not show up until the next inspection report. The only effect this should have on the data is analysis based on the year of improvement. For example, if a bridge was repaired in 2002 but the next inspection and associated condition state decrease wasn't until 2004, this analysis would show the improvement occurring in 2004.

However, sometimes a bridge was inspected, repaired, and then re-inspected in the same year. While the methods of this investigation take this possibility into account and display the median condition state for that year, the result is a condition state decrease split between the true before and after values. As an example of how this might alter the apparent data for a bridge, say an element was in condition state 2.50 in February 2002 and was repaired to condition state 1.00 in June 2002, and was reported as such in September 2002. The resulting condition state cell for 2002 would display 1.75 and not decrease to 1.00 until the following inspection, say 2004. This bridge would thus not show up as having an "unexpected improvement" given the >1.00 criteria, even though the repair ultimately caused a 1.5 condition state decrease. This example illustrates a rare occurrence, but demonstrates how the analysis process could contain specific loopholes.

All of the line and normalized column graphs show the expected general deterioration occurring in the bridges that did not show a condition state improvement of greater than 1. The line graphs (such as Figure 4) have a positive slope, denoting the condition increasing. If the criterion for improvement was made more lenient, such as a >0.5 condition state decrease, it is likely that the bridges without improvement would show more dramatic worsening. This is because as the criteria is brought closer to any non-zero condition state decrease it becomes increasingly likely that the bridges remaining in the "no improvement noted" category would be comprised entirely of bridges that only deteriorate. Any change to make the criterion closer to 0 increases the chances of inspector variance showing up (as a form of "no maintenance noted" in this report). It is also much more likely for two inspectors to report the same condition state with a difference of 0.1 condition state than 1.0 condition state.

Similarly, the line and normalized column graphs representing the bridges that did show an improvement (such as Figure 3) based on the criteria in this report depict a general decrease in condition state. These graphs show data from all of these bridges for the entire 15 year time frame, meaning bridges that were improved in 2008 still had their deteriorated condition state mixed into the 2006 average. This ultimately means these graphs show that bridges whose average condition states were shown to dramatically decrease show a large improvement in general over the entire time frame. The analysis tracking condition state change as a function of age since improvement was undertaken to attempt to account for the noise in these graphs and provide more meaningful trends.

The quantity analysis of the condition state trend portion of this report yielded graphs very similar to the analysis that weighted each bridge equally (compare Figure 6 and Figure 8). Slight differences occur due to bridges having different quantities of elements across the state, but these differences were not significant enough across even a single district to merit quantity analysis for more than 4 elements. The first few years were more likely to have variation between the two analyses because there were fewer bridges reporting, so chances were higher that the standard deviation of bridge size would be large enough to produce a visible graphical difference.

The deck and slab elements, of which element 32 was chosen for the quantity analysis, have quantity units in the Pontis Element Definition Manual listed as “EACH”. However, the total quantity listed is still the square footage of the bridge, so the only difference the “EACH” makes is that the inspector has to pick a single condition state to represent the entire bridge deck (it becomes more similar to the NBI inspections in this way). As the process of analyzing the quantity in this report multiplies the total quantity by the percent in each condition state, the resulting quantity analysis graphs yield similar results for both the deck and non-deck elements. Similarly, as the Markov transition analysis was performed using the probability that a certain quantity of each element would deteriorate in a given year, the results for element 32 are only affected by the "EACH" unit in that the Pontis data shows that bridges stay in condition state 1 for several years and then suddenly become entirely in condition state 2.

The condition state trends by age since improvement tables (Table B-13 through Table B-24) show that there are many more data points at lower ages than higher ages (years 1 and 2 compared to, say, 10 year old data). This is because consistent data, from which element improvement was derived, only starts around year 1998, meaning most improvements aren't noted until the 2000s. Each combination of consecutive improvement – inspection years will yield 1 year old data, while 10 year old data, for example, only comes from the case of a 2000 improvement with a 2010 inspection (or a rare 1999-2009, 1998-2008, 1997-2007 pairing).

The algorithm to calculate the year of improvement (for the age since improvement analysis) has several assumptions that have important bearing on the results obtained. In instances in which there was no pair of consecutive years with a condition state decrease of greater than 1.00, the bridge was ignored for this analysis (these bridges still showed up under the previous criteria of a >1.00 condition state decrease from the maximum condition state to the 2010 condition state). In instances in which there were multiple years between the previous inspection and the one in which the lower condition state was noted (such as with a two year inspection cycle), the improvement was recorded as occurring in the first year the lower condition state was reported. In rare instances where multiple condition state drops greater than

1.00 were recorded, the algorithm reports the improvement year as the first (earliest) of such decreases.

The graphs following the average condition state of the improved bridges based on the number of years since improvement did not often show the desired trend. Figure 9 shows that element 32 deteriorated as expected as the bridges containing that element aged since the occurrence of the improvement noted in this analysis. Most of the elements produced graphs such as element 323 in Figure 10, however, where the condition state does not show any discernible trend at all, jumping up and down equally as the age increases. It would be expected that after the single year of condition state decrease corresponding to the improvement noted the bridges would then deteriorate normally until the next intervention.

A potential source of error was that there was no check if there was another improvement (of any condition state decrease) after the initial decrease. This could cause slight variations in the data, but averaged across the state it should not have stopped the bridges from showing increased deterioration with age. Also with these graphs, only years in which there were 5 or more bridges reporting were displayed, which mainly affected the number of years to display per element in Figure B-57 through Figure B-59.

Bridges are often inspected every other year, so data from those bridges follow a biannual trend. This is especially true after important structural elements, such as the girders, are improved because the bridge is no longer in an advanced deterioration state and it can be monitored less frequently. This manifests itself in the data if the set of bridges inspected on even years happens to have a different average condition state than those inspected on odd years. The biannual trend shows up in several parts of this analysis, such as the yearly normalized column graphs (as in Figure B-17), the average condition state trends by age since improvement (as in

Figure B-58), the zinc coating analysis (see group 4 in Figure 13 and Figure 14) and in the Markov modeling process (much higher quantity in even years in Table 21, especially right after improvement).

Potential Errors

As can be seen from Table 34, the number of potential errors varies significantly by district, following the general trends of the number of bridges in each district. Out of 22581 total bridges in the database, 1353 were noted to have potential quantity recording errors at some point in their Pontis inspection history; this is 6.0% of the total bridges. It can be seen that about half of the potential errors occur on additional reports from the same set of bridges (1353 / 2785 = 48.6%).

Zinc Coating Study

The graphs from the zinc coating study (Figure 11 through Figure 19) show trends for element 107 (or the superstructure) on all bridges meeting the zinc coating criteria, regardless of whether significant improvements were shown or not. This means that the deterioration trends shown should be indicative of the actual average worsening of condition of the beams from 1995 to 2010.

Figure 15 shows the relative amount of data (by quantity) being graphed in each year of age since painting. The biannual trend is quite visible and prompted every two years of data to be graphed together in the similar Figure 11. The data trails off after about 20 years because the zinc coating system began to be used in 1983 (age 29 years as of the analysis), and took several years to catch on. There is also not as much data for the lower years for several of the groups due to Pontis data collection starting in 1995. For example, bridges painted in 1993 can only have data starting at 2 years; those painted in 1992 can only have data starting at 3 years, etc. The result is a bell shape, best seen in the bridges built after 1983 (groups 1 and 2 of Figure 15).

The condition state analysis graphs by quantity and by bridge, as seen in Figure 12 and Figure 13, respectively, follow the same general trends, but the quantity analysis contains a slightly higher percentage of the bar graphs denoting worse condition states. An example helps to illustrate the difference. If a bridge has 100 linear feet of element 107, and 25 feet are in condition state 2 while 75 feet are in condition state 1, the quantity bar graph for that bridge will be 25% yellow (and 75% green), but the overall bridge will average to 1.25 and stay 100% green for the by-bridge bar graph. This difference was consistent between the vast majority of the quantity graphs and the by-bridge graphs. For this reason, the quantity analysis was not included in the after-paint analysis.

The average condition states versus age of paint graphs (by group in Figure 16 and summarized in Figure 18) yield consistent results between similar bridges (groups 1 and 2, and groups 3 and 4). The initial condition state was close to 1 for groups 1 and 2, with a gradual increase in condition state (deterioration) over time. It appears that the condition state remains close to 1 for approximately 10 years, and then begins to show a gradual worsening of condition for the next 10 years. The rate of deterioration seems to accelerate after 20 years, with this trend slightly more significant in the continuous bridges. For groups 3 and 4 (the recoated bridges), the average condition state after recoating is about 1.2 and there is a gradual and immediate deterioration trend which remains fairly constant over the next 25 years.

The trends for superstructure condition rating for these bridges are presented by group in Figure 17 and are summarized in Figure 19. These trends are similar to those described for the condition state analysis but with less variability. This is likely because the condition rating is determined by the condition of many elements other than just the girders. These other elements may have been improved separately from the girders or merely display different deterioration rates. The condition rating trends for simple and continuous span bridges show no significant difference between the two, and recoated bridges have generally worse condition ratings than shop coated bridges for the same age of coating.

Joint Closures

The joint closure summary in Table 36 shows that the proportion of joint eliminations where the action is total elimination is 45.8%, the proportion where it is a decrease in quantity is 24.3%, and the proportion where one joint element is replaced with equivalent quantity of a different joint element is 29.9%. The table illustrates that there was a wide variation by district in the number of joint modifications this investigation discovered, from 81 in District 7 to 364 in District 4.

Priority Bridges and District Visits

The criteria for what an "unexpected improvement" was had great bearing on the population of bridges chosen for analysis with or without improvement. Bridges that had a >1.00 condition state decrease between two consecutive years but then deteriorated back up to a total of less than 1.00 condition state of the max did not get selected. On the other hand, bridges that, for whatever reason, showed multiple smaller improvements (none of which were singly more than 1.00) that totaled an improvement of more than 1.00 did get selected. The >0.05 condition state decrease as a more lenient criterion for the two joint elements (301 and 302) likely increased their sensitivity to inspector variance (as a form of “no maintenance noted” in this report) over the other elements. That modified criterion was only used in the selection of priority bridges for the district visits so it only affected the population of bridges in that sub-study.

The list of which bridges have a >1.00 decrease from max to current condition state was produced by the computer, but the manual process of selecting the years of improvement from those bridges sometimes revealed multiple condition state drops. When there were multiple significant improvements (more than a 0.50 condition state decrease between two consecutive inspection reports) on the same bridge, each improvement was listed as a separate row in this analysis in order to maximize the data from the same population of inspection reports. In instances where the quantity of the element changed on a given bridge, the most recently entered quantity was used in the final tables in Appendix C.

The process for selecting priority bridges to investigate for the district visit sub-study meant the results are representative, and not complete. Forty bridges was the cutoff chosen to keep the workload reasonable for the inspection personnel finding and returning the reports, and allowing the trips to take place in a single work day even in the farther away districts. When there were 10 or fewer bridges for an element in a district, all of those bridges were able to be selected, while a random number generator was used in cases with more than that. The result is that almost all of the bearing elements (311 and 313) were included, a moderate portion of the beam elements (107 and 108) was included, and only a small, but hopefully characteristic, selection of the joint elements (301 and 302) was able to be included. Using the cutoff criteria from this report, the statewide selected / available bridge ratios for the three element groups are 46 / 54 (85.2%) for bearings, 165 / 372 (44.4%) for beams, and 218 / 1655 (13.2%) for joints.

Part of the preparation process for the beam elements (107 and 108) was to remove those bridges where the unexpected improvement was shown to correlate to repainting noted in a separate "year repainted" field in the inspection reports (referenced from the InspEvnt PDI table). However, it can be seen from Table C-1 and Table C-5 that 51.4% and 10.5% of the bridges with elements 107 and 108, respectively, still had painting as the maintenance causing improvement as discovered from the "work done" section in the inspection reports. This means that the "year repainted" field was likely overlooked in the inspection process of these bridges.

"No maintenance noted" showed up consistently as around a third of the improvements in the different elements, between 24.2% for element 108 and 42.1% for element 313. A main possibility for why these show up so frequently is merely inspector variation, where two inspection reports show similar or identical notes (similar level of deterioration), but one will give a condition state of 3.6 and the next will give a condition state of 2.4, for example. These differences were often noted between a private consultant and a state inspector but occasionally the difference would even be between two inspection reports from the same inspector. When the notes are significantly different, it is likely that some maintenance action occurred but was not marked in the "work done" section (or anywhere else on the report), and the type of work could therefore not be classified for this report.

From Appendix C, it can be seen that District 4, the Richmond district, has a much higher quantity of elements 107 and 108 (beam elements) per bridge than the other districts. This indicates there were longer / wider bridges in the Richmond district, or that they had a denser arrangement of beams per bridge.

The tables in Appendix C created by separating the different roadway classifications show information both on the relative proportion of each element improved on each type of road and the maintenance actions taken on each. Element 107 is evenly split between the three classifications, while element 108 only appears on bridges carrying secondary roads (and a single primary road); this confirms that timber decks are rarely used on major roads. Element 302 is more or less evenly split between the three classifications, while element 301 has more than 60% on secondary roads, with similar overall counts; this leads to the deduction that the pourable joint seals are improved (and used) less on major roads than the compression joint seals are. For the bearing elements (311 and 313), the highest levels of superstructure replacement came on secondary roads.

Linear Least Squares and Markov Chain Modeling

The results of the LLS regression analysis (presented in Table 43) show general deterioration trends of 6 elements in the form of condition state slope predictions and the average condition states of those elements in 2010, separated by district. Of the 3 element groups, averaged across the state, the bearing elements (311 and 313) have the lowest 2010 condition state at around 1.42. This was followed by the joint elements (301 and 302) next with a 2010 condition state around 1.65. The beam elements' 2010 condition state averaged around 2.10, with element 108 (beam under timber deck) almost a full condition state worse than element 107 (beam under concrete deck) at 2.60 vs. 1.62, respectively. Additionally, element 108 deteriorated 1.66 times as fast as element 107. Both beam statistics indicate that the timber decks do not protect the beams as well as concrete decks do.

A reason why it may be difficult to apply linear regression to condition state deterioration is that the language of the condition state definitions do not yield even spacing. For example, the physical difference between elements in condition states 1 and 2 will not be the same as between condition states 2 and 3 and they may take a different amount of time to deteriorate, even though both are a decrease of 1.00. Also, the physical deterioration itself is likely nonlinear, with more advanced deterioration (pitting, corrosion, etc.) occurring only after the coating / paint systems weaken.

The LLS condition state deterioration slopes are fairly low on average, as 0.01 means that it takes 100 years with no improvements for the element to deteriorate 1 condition state. A possible explanation for why this is so low is that bridges built after 1995 only have data beginning at their year of construction, usually at pristine condition states, so the data could be skewed to give a set containing these bridges an unrepresentatively low deterioration average. The degree of this skew would be based on the proportion of bridges in a certain district (for a given element) that were recently built; more new bridges likely means more skew. This would result in slopes that are lower than the true deterioration level, in a few extreme cases even looking as though the bridge average condition states are improving (see element 301 in districts 1 and 3). Bridges improving less than the 1.00 "unexpected improvement" criteria were included in the data for average regression, so they could also lessen the slope from the true deterioration.

For the linear least square condition state deterioration trends based on age of bridge for element 107 (such as Figure D-28), it can be seen that bridges often wait 15-20 years before element 107 deterioration begins. At that time, the condition state decreases at a moderate rate until it reaches about 2.00 around 75 years of age, at which point the data generally stops following any discernible trends. The residual graphs (such as Figure D-29) show the same trends as functions of how far below the modeled trendlines the actual data are (by subtracting them at each year). As the trendlines are forced to be linear while the actual deterioration follows the above trends, the residuals are generally positive to start, then go slightly negative, then become more variable (positively and negatively) at older ages.

The graphs showing the number of bridges reporting element 107 by age (such as Figure D-30) show that there is a steep drop-off of bridges reporting after about 45 years, and again around 75 years, so the condition states from the upper years are more prone to variation. Additionally, as the Pontis data was not collected until 1995 (up until 2010 for this report), we do not know the condition state histories of bridges outside of that timeframe, we merely have a window of information. For example, a bridge built in 1998 gives us 1-12 year data while a bridge built in 1950 gives us 45-60 year data. This means we do not have more than 15 years of data for any bridge, and there me be some error introduced by following different bridges' condition states as age increases.

Element 108 (a beam under a timber deck) shows a somewhat different trend. Deterioration appears to occur more immediately (as seen in Figure D-58), with the condition state increasing to 2.5 over the first twenty years and then staying there until the data becomes sporadic after about 80 years, when there were fewer bridges reporting. On that note, it is interesting that in the graphs of the number of bridges reporting element 108, such as Figure D-60, there was a giant spike in the population of bridges reporting element 108 in the seventy to eighty year range, indicating a large number of new timber deck bridges being constructed in the early- to mid-1930s. This is possibly because this was the era of President Franklin Delano Roosevelt's New Deal, which created many construction projects; several of these were bridges in rural Virginia where they would be likely to have been built with timber decks. Additionally, VDOT may have picked up existing bridges into their NBI database at this time; if they did not have information on bridge construction they may have entered the year they acquired each bridge as the year of its construction.

Due to the transition constraints the Markov modeling was performed under, all Markov graphs (Figure D-61 through Figure D-79) show steady deterioration between condition states, with each condition state boundary having a distinct deterioration percent depending on the given district and element. Due to the nature of the transition probability matrix multiplication, the boundary from condition state 1 to 2 (green to yellow) must start at its steepest and decrease asymptotically while the other boundaries will change from increasing to decreasing slope at some age. For example, in the modeled plot for element 108 in District 7 (bottom left graph in Figure D-69), the inflection point for condition state 2 to 3 (yellow to orange) occurs at around 30 years and the inflection point for condition state 3 to 4 (orange to bright red) occurs at around 60 years.

It should be noted that element 32 (Table D-16 through Table D-19 and Figure D-76 through Figure D-79) never deteriorates past condition state 3 and element 302 (Table D-11 through Table D-15 and Figure D-71 through Figure D-75) never deteriorates past condition state 4. On the other hand, elements 107 (Table D-1 through Table D-5 and Figure D-61 through Figure D-65) and 108 (Table D-6 through Table D-10 and Figure D-66 through Figure D-70) deteriorate to condition state 5. This is because in the element definitions in the Pontis Element Data Collection Manual, only 3 condition states are coded for element 32 and 4 condition states coded for element 302 (VDOT, 2007). Thus, it is important to keep in mind that the lowest coded condition state per element represents the maximum state of deterioration: condition state 3 in element 32 is analogous to condition state 4 in element 302 and condition state 5 in elements 107 or 108; these are all colored dark red to indicate similarly advanced levels of deterioration.

Element 32 (Timber deck – with asphaltic concrete (AC) overlay) only has 6 districts reporting for the Markov section of the analysis. This is because in the original element selection by count (see Table 24 through Table 26), element 32 did not appear in the top 20 elements for districts 4, 6, and 9 and did not undergo quantity analysis in those districts.

The first step of the Markov modeling in this investigation was to limit the data selection to those bridges with the desired elements showing an unexpected improvement as per the criterion of a >1.00 condition state decrease from max to current. Similarly, the first step of the LLS regression across an entire district was to create an average deterioration slope / intercept based on those bridges without an "unexpected improvement". As in many of the previous sections of this report, the results are affected by the bridges that do or do not meet this criterion. If the threshold for improvement is decreased, more bridges with maintenance actions (that are unrepresentative of the desired natural deterioration) would likely be omitted. However, there would also be an increased chance of "improvements" being inspector variance (as a form of "no maintenance noted" in this report) as the criterion is brought closer to any condition state decrease at all.

One of the main limitations of the Markov chain modeling in this report (due to available data) is the inherent assumption that bridges were not improved from the time of construction until 1995. Due to the lack of Pontis inspection report data before 1995, it would be impossible to know if a bridge had deteriorated naturally over the course of its life until 1995, or had just been recently repaired in 1994 at age 50 years, say. The result of this is an unknown proportion of the data that could cause the transition probability matrices to have skewed deterioration rates. As the matrices created from this analysis could include bridges that were improved but not noted, the true natural deterioration rates are likely slightly greater than those presented in this report. The relationships between the deteriorations in various elements shown in this report may or may not stay the same if these unknown improvements were omitted, depending on which bridges they occurred on and when.

It is also useful to remember the Markov modeling in this report used the quantity data for the desired elements as opposed to averaging the deterioration equally for each bridge. This will provide greater weight to the deterioration of elements on bridges with a larger quantity of the elements selected. As discussed earlier in the Analysis section, element 32 which has a recorded quantity unit of “each” still provides square footage data, and as this is used in the analysis, more weight is given to larger bridges for that element as well.

From the 100 year graphs showing the Markov model vs. the actual condition state data (such as Figure D-61), one can compare the relative accuracy of the models between districts and elements. Each graph set has some disparity due to the fact that 100 years of real world variation has been modeled using a single transition matrix (multiplied out over 100 years). This means that those graphs of real world data that more closely follow steady condition state deterioration will be more closely modeled by the Markov chains that Excel optimized.

CONCLUSIONS

Through numerous data mining investigations of Pontis and NBI data, exploratory analysis was shown to be useful in providing information that was not obvious before this project.

The first study, characterizing the performance of coatings on girders under Virginia bridges, was successful. Deterioration trends were found by analyzing the Pontis and NBI data that were not observable from the raw data. Overall, the zinc-based coating system seems to be performing well. The condition states and ratings for coatings on older bridges, which have been repainted, deteriorate more quickly than those on newer bridges with shop coating. A significant difference was not observed in the performance of simple span and continuous span bridges.

The second study of quantitatively looking at which VDOT maintenance practices are being undertaken and how they are recorded through investigating the district reports was partially successful. The current information regarding maintenance actions appears to be insufficient for the ultimate questions VDOT is asking relating to maintenance cost effectiveness. Still, much has been and can be learned from analysis of the actions that have been recorded.

Several side studies arose over the course of this project and they also provided useful statistics. Condition state trends were plotted for bridges that did and did not undergo a significant improvement. Summary tables and complete ID lists were created for bridges with potential reporting errors, bridges with joint elements that were eliminated, and those with beam sections in advanced deterioration condition were also produced. Several linear least squares algorithms (macros) were created in Visual Basic for Applications to predict deterioration of 6 selected elements. Markov transition probability matrices and associated deterioration graphs for a 100-year horizon were created for 4 elements.

Significant variations in results and perceived conclusions can arise from slight variations in the raw data. As such, if more studies are conducted with the intent of extracting meaningful information, stricter inspector standards should be implemented.

RECOMMENDATIONS

The >1.00 decrease from max to current condition state criterion for “unexpected improvement” affected the cut-offs for much of the analysis in this project, deciding which set different bridge condition state trends were graphed in, which priority bridges were selected for district visits, and excluding “improved” bridges from both modeling methods. Future research could modify this criterion, by element if desired, to include a different population of bridges as those having an improvement (similar to how the joint improvement criterion was decreased for the district visit study in this project).

Selection of elements for analysis in this report was based on the number of bridges they appeared on and the number of improvements noted. Various parts of the project could be performed on additional elements of interest based on criticality to bridge performance, anticipated maintenance / deterioration, or other criteria by a future researcher.

The Pontis analysis methods used in this report on VDOT data could be modified and used in other states that use Pontis depending on what their specific areas of maintenance interest are. For additional states, many of the investigations from this report would have corollaries in their NBI data if similar trends were desired. The methods from the NBI part of the zinc coating study in this project could also be directly applied to the NBI data in any state.

If stricter inspector criteria for the rating of condition states were implemented, inspector variance (as a form of “no maintenance noted” in the district visit section of this report) would likely be reduced. This project could merely conclude that if the quantities and notes were the same but the condition state was different, there would likely be a difference of inspector opinion as the reason for disparity. It may be useful, therefore, to conduct an additional investigation on inspector variance. A supplementary study could, through closer analysis of inspection report data and interviews with inspectors, explore the extent of the variability, the causes of differences in opinions, and propose ways to mitigate that error. Relatedly, it would be useful to ensure that painting gets noted in the "year repainted" field on the inspector reports. That way, the field could be more meaningfully felt to represent the entire population of bridges that were repainted.

It would be useful to institute a uniform state-wide database for storing information on maintenance actions in Virginia. This way, it would be much easier to perform investigations on the effectiveness of various actions, and computer resources could more readily be used in the analysis of maintenance on many additional elements. This system would likely by similar to the proposed National Bridge Maintenance Database (Hearn, Thompson, Mystkowski, & Hyman, 2010) described in the Review of the Literature earlier in this report.

Following this report, it is suggested that more streamlined methods be developed to run the analyses that are deemed most useful to VDOT. This way, as more data is produced and becomes available to researchers, the tables and graphs can be updated so analysis can continue with minimal additional human interaction. More sophisticated statistical methods, perhaps using more advanced software packages than Microsoft Excel, can also be applied to this data as additional desired results are precisely defined in projects continuing this work.

The project advisory group expressed interest in exploring the feasibility of defining sub-elements for girder ends below joints as a way of better capturing coating performance for VDOT's steel painted bridges. This arose from a discussion of their personal experiences investigating beam deterioration.

Trends of element 107 beam deterioration under various cases of joint elimination could be found by filtering the bridges from the zinc coating study by the results of the joint elimination study. Other similar studies for potential correlation could be completed by analyzing modifications (quantity reduction, replacement, etc.) of other elements, or performing lookups on various bridge traffic or environmental categories, and filtering the zinc coating element 107 condition state and rating data by the resulting bridge IDs.

As with any computation-based research, the analysis will become quicker as computer hardware and software resources improve. This progress allows for more complex data manipulation and expanded interconnectivity of Excel cells to streamline any raw data addition / modification. Additionally, as time progresses and more data is collected in the Pontis system, the methods presented in this report will return more representative data with more years of recorded condition state trends on elements with and without improvements noted. This will also refine the accuracy of the LLS and Markov prediction models this project developed.

Average element value Linear Least Squares regression analysis by district could be performed on additional elements by running the macro on the data in the desired elements' worksheets in the district-specific Excel files available through VDOT. District 1 contains the macros: "LLS_Predict_Lite" for most elements and "LLS_Predict_Lite_107_or_108" for elements 107 and 108. For the same set of files, running the individual bridge LLS macro ("LLS_Predict") would result in a separate regression analysis being performed on each bridge's unique condition state history. Lastly, the LLS analysis by age of bridge could be run on elements other than 107 and 108.

The comparison of the element-level deterioration (LLS and Markov chain) models developed in this project to existing regression analyses and Markov chain transition probability matrices is left to another investigation.

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APPENDICES

APPENDIX A - ELEMENT CODES AND DESCRIPTIONS

Derived from the Pontis Element Data Collection Manual (VDOT, 2007)

Code	Element Description
012	Concrete Deck - Bare - with Uncoated Reinforcement
013	Concrete Deck - with AC Overlay - without Membrane
014	Concrete Deck - with AC Overlay - with Membrane
018	Concrete Deck - Thin Overlay (less than 1”) - no AC Overlay
022	Concrete Deck - Rigid Overlay (greater than 1”) - no AC Overlay
026	Concrete Deck - Bare - with Coated Reinforcement
027	Concrete Deck - with Cathodic Protection
028	Steel Deck - Open Grid
029	Steel Deck - Concrete Filled Grid
030	Metal Deck - Corrugated/Orthotropic, Etc
031	Timber Deck
032	Timber Deck - with asphaltic concrete (AC) Overlay
038	Concrete Slab - Bare - with Uncoated Reinforcement
039	Concrete Slab - with AC Overlay - without Membrane
040	Concrete Slab - with AC Overlay - with Membrane
044	Concrete Slab - Thin Overlay (less than 1”) - no AC Overlay
048	Concrete Slab - Rigid Overlay (greater than 1”) - no AC Overlay
052	Concrete Slab - Bare - with Coated Reinforcement
053	Concrete Slab - with Cathodic Protection
054	Timber Slab
055	Timber Slab - with asphaltic concrete (AC) Overlay
092	V Reinforced Concrete Sidewalk
094	V Timber Sidewalk
098	V Steel Sidewalk, Open Grid - Coated
101	Steel Closed Web/Box Girder - Uncoated
102	Steel Closed Web/Box Girder - Coated
104	P/S Concrete Voided and Unvoided Closed Web/Box Girder
105	Reinforced Concrete Voided and Unvoided Closed Web/Box Girder
106	Steel Open Girder - Uncoated
107	Steel Open Girder - Coated
108	V Steel Open Girder with Timber Deck – Coated and Uncoated
109	P/S Concrete Open Girder
110	Reinforced Concrete Open Girder
111	Timber Open Girder
112	Steel Stringer - Uncoated
113	Steel Stringer - Coated
115	P/S Concrete Stringer
116	Reinforced Concrete Stringer
117	Timber Stringer
120	Steel Bottom Chord of Through Truss - Uncoated
121	Steel Bottom Chord of Through Truss - Coated
125	Steel Through Truss excluding bottom chord - Uncoated

126	Steel Through Truss excluding bottom chord - Coated
130	Steel Deck Truss - Uncoated
131	Steel Deck Truss - Coated
135	Timber Truss or Arch
140	Steel Arch - Uncoated
141	Steel Arch - Coated
143	P/S Concrete Arch
144	Reinforced Concrete Arch
145	Other Material Arch
146	Steel Cable - Uncoated (not embedded in concrete)
147	Steel Cable (not embedded in concrete) - Coated
151	Steel Floor Beam - Uncoated
152	Steel Floor Beam - Coated
154	P/S Concrete Floor Beam
155	Reinforced Concrete Floor Beam
156	Timber Floor Beam
160	Steel Pin and/or Pin & Hanger Assembly - Uncoated
161	Steel Pin and/or Pin & Hanger Assembly - Coated
201	Steel Column or Pile Extension - Uncoated
202	Steel Column or Pile Extension - Coated
204	P/S Concrete Column or Pile Extension
205	Reinforced Concrete Column or Pile Extension
206	Timber Column or Pile Extension
210	Reinforced Concrete Pier Wall
211	Other Material Pier Wall
215	Reinforced Concrete Abutment
216	Timber Abutment
217	Other Material Abutment
220	Reinforced Concrete Submerged Pile Cap/Footing
225	Steel Submerged Pile
226	P/S Concrete Submerged Pile
227	Reinforced Concrete Submerged Pile
228	Timber Submerged Pile
230	Steel Pier Cap - Uncoated
231	Steel Pier Cap - Coated
233	P/S Concrete Pier Cap
234	Reinforced Concrete Pier Cap
235	Timber Pier Cap
240	Metal Culvert
241	Concrete Culvert
242	Timber Culvert
243	Other Culvert
285	V Slope - Protected

286	V Slope - Unprotected
295	V Reinforced Concrete Wingwalls
296	V Timber Wingwalls
297	V Other Material Wingwalls
298	Smart Flag – Culvert Endwall/Headwall
298	V Smart Flag - Culvert Endwall/Headwall
299	V Smart Flag - Culvert Wingwall
300	Strip Seal Expansion Joint
301	Pourable Joint Seal
302	Compression Joint Seal
303	Assembly Joint/Seal
304	Open Expansion Joint
310	Elastomeric Bearing
311	Moveable Bearing (Roller, sliding, etc.)
312	Enclosed/Concealed Bearing or Bearing System
313	Fixed Bearing
314	Pot Bearing
315	Disk Bearing
320	Prestressed Concrete Approach Slab
321	Reinforced Concrete Approach Slab
330	Metal Bridge Railing - Uncoated
331	Reinforced Concrete Bridge Railing
332	Timber Bridge Railing
334	Metal Bridge Railing - Coated
356	Smart Flag - Steel Fatigue
357	Smart Flag - Pack Rust
358	Smart Flag - Deck Cracking
359	Smart Flag - Soffit of Conc
360	Smart Flag - Settlement
361	Smart Flag - Scour -
362	Smart Flag - Traffic Impact Damage
363	Smart Flag - Section Loss
444	V Mechanically Stabilized Earth - Abutment
701	V Smart Flag - Utilities
702	V Smart Flag - Drains
703	V Smart Flag - Lighting
704	V Smart Flag - Roadway Over Culverts
706	V Smart Flag - Soffit of Overhang of Conc
707	V Smart Flag - Soffit of Conc
708	V Smart Flag – Debris in Channel -
709	V Smart Flag – Replacement -
710	V Smart Flag – Deck Replacement
738	Concrete Slab - Covered with Fill

APPENDIX B - CONDITION STATE TRENDS

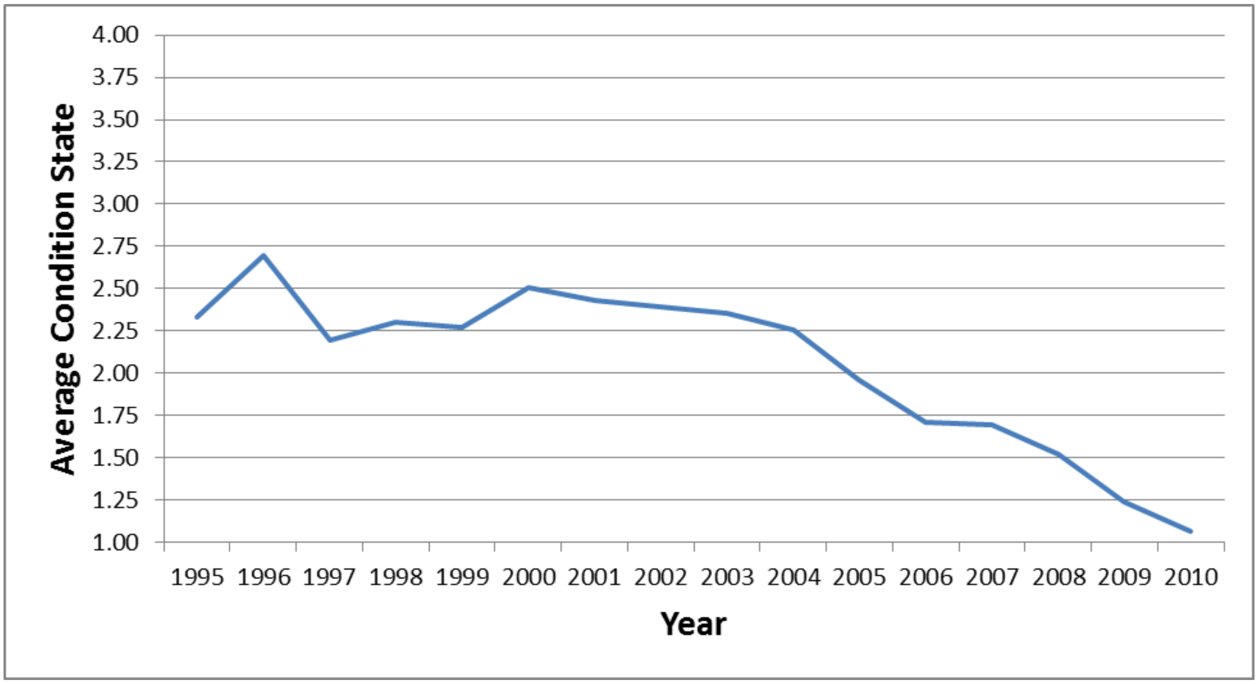

Figure B-1 - Element 32 (Timber Deck - with Asphaltic Concrete (AC) Overlay) Average Condition State Trend – Improvement Noted

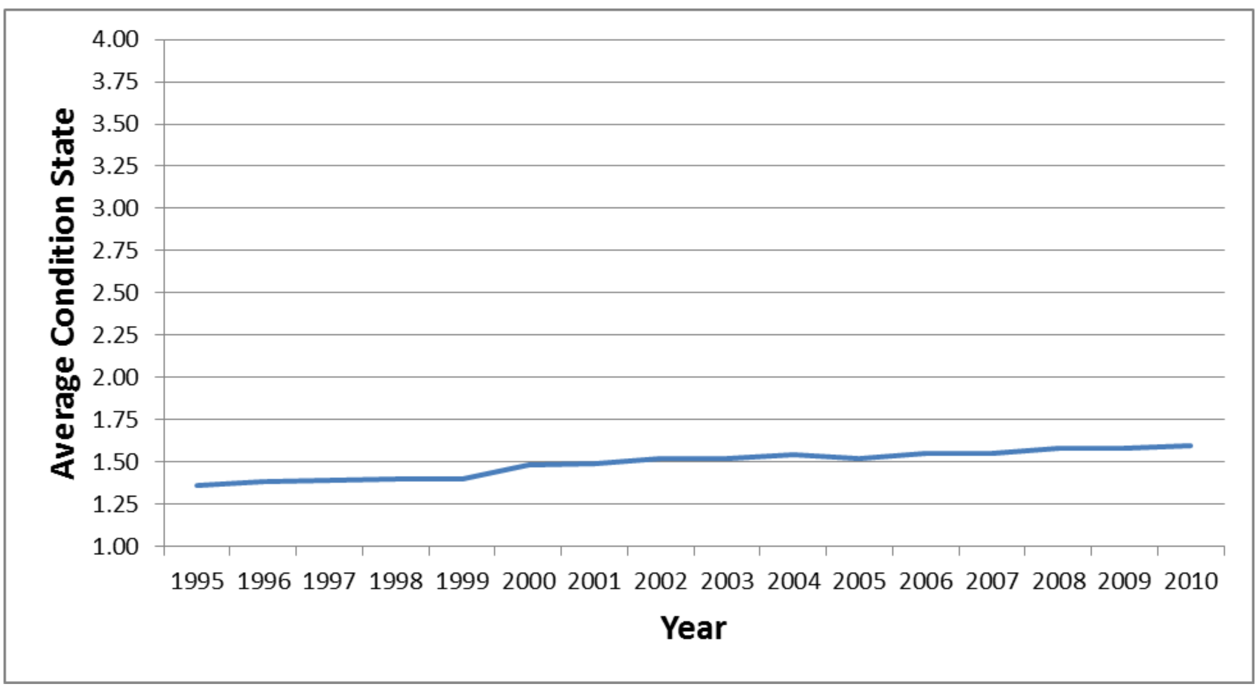

Figure B-2 - Element 32 Average Condition State Trend – Improvement Not Noted

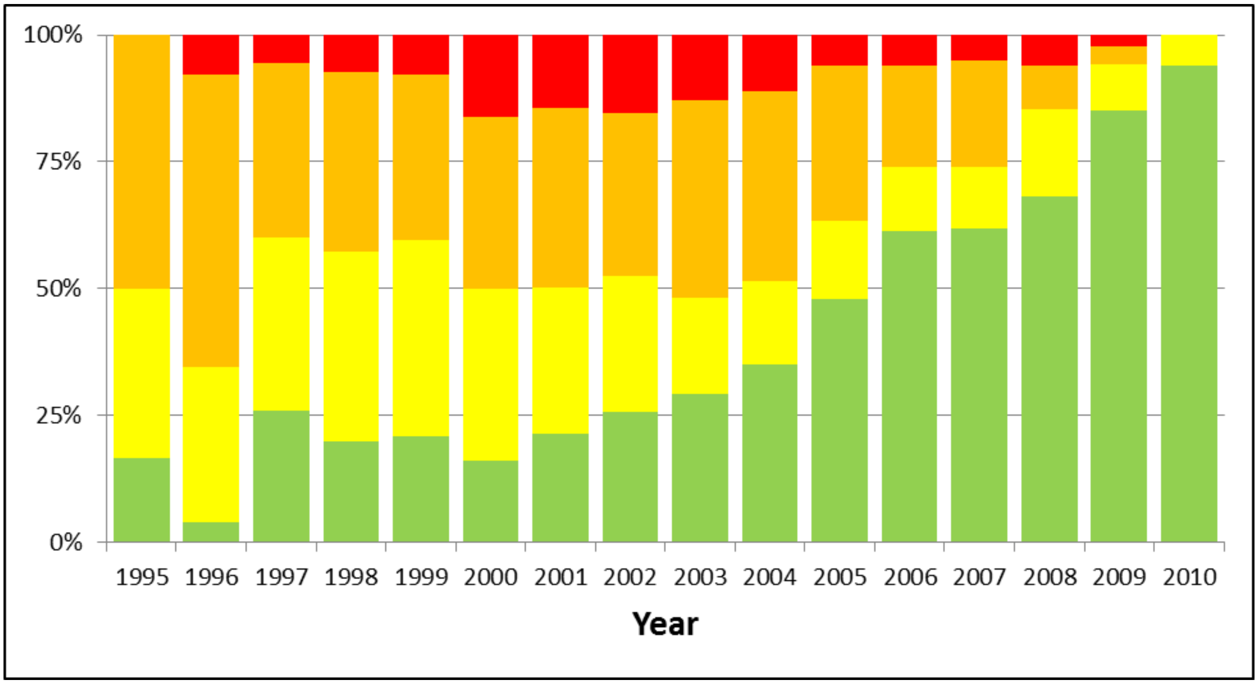

Figure B-3 - Element 32 Normalized Condition State Trend – Improvement Noted

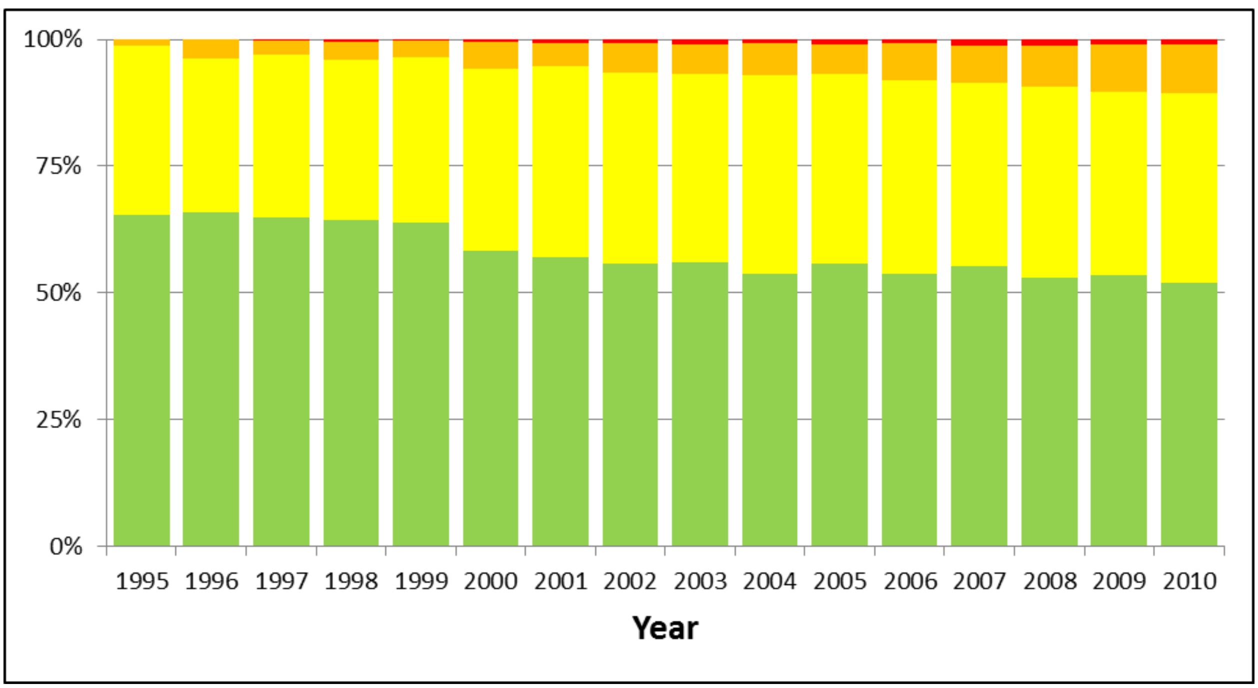

Figure B-4 – Element 32 Normalized Condition State Trend – Improvement Not Noted

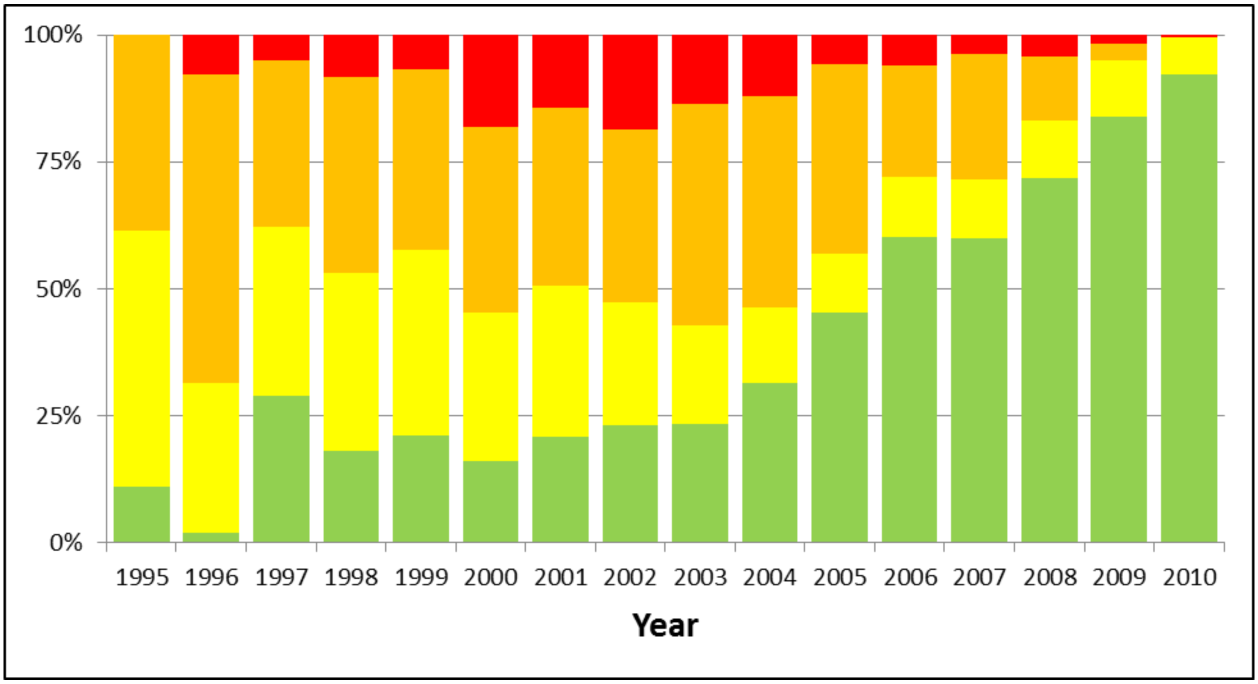

Figure B-5 – Element 32 Normalized Condition State Trend – Improvement Noted (Quantity Analysis)

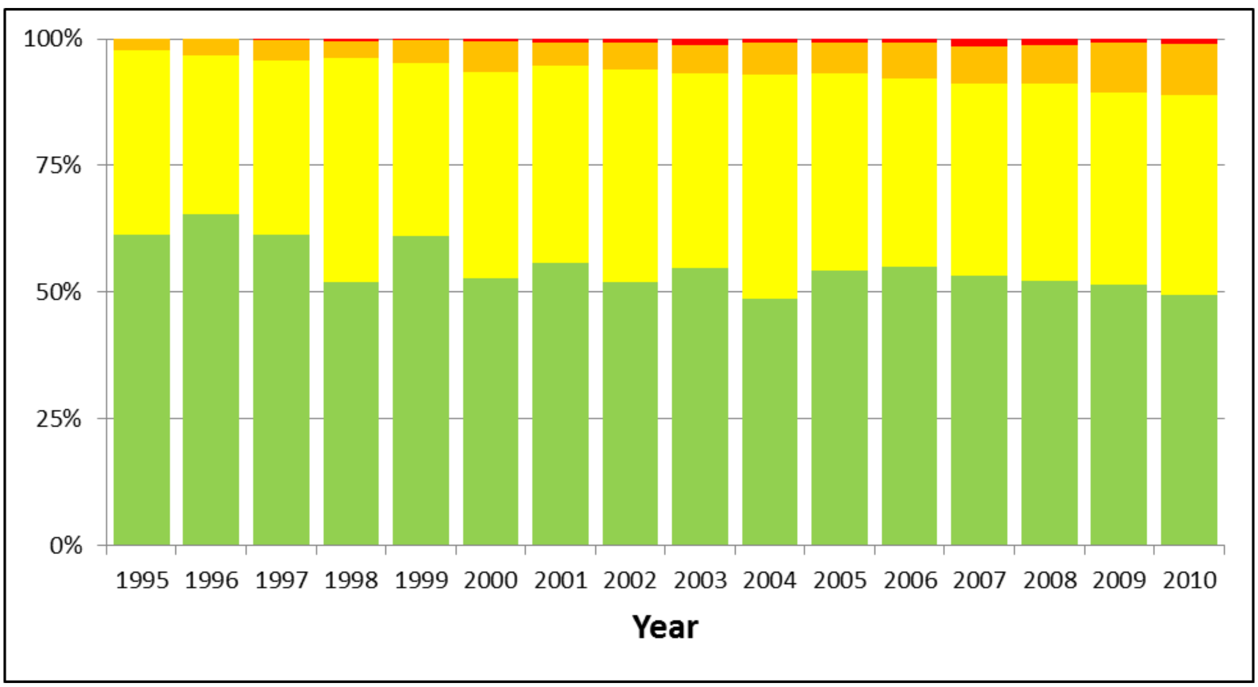

Figure B-6 – Element 32 Normalized Condition State Trend – Improvement Not Noted (Quantity Analysis)

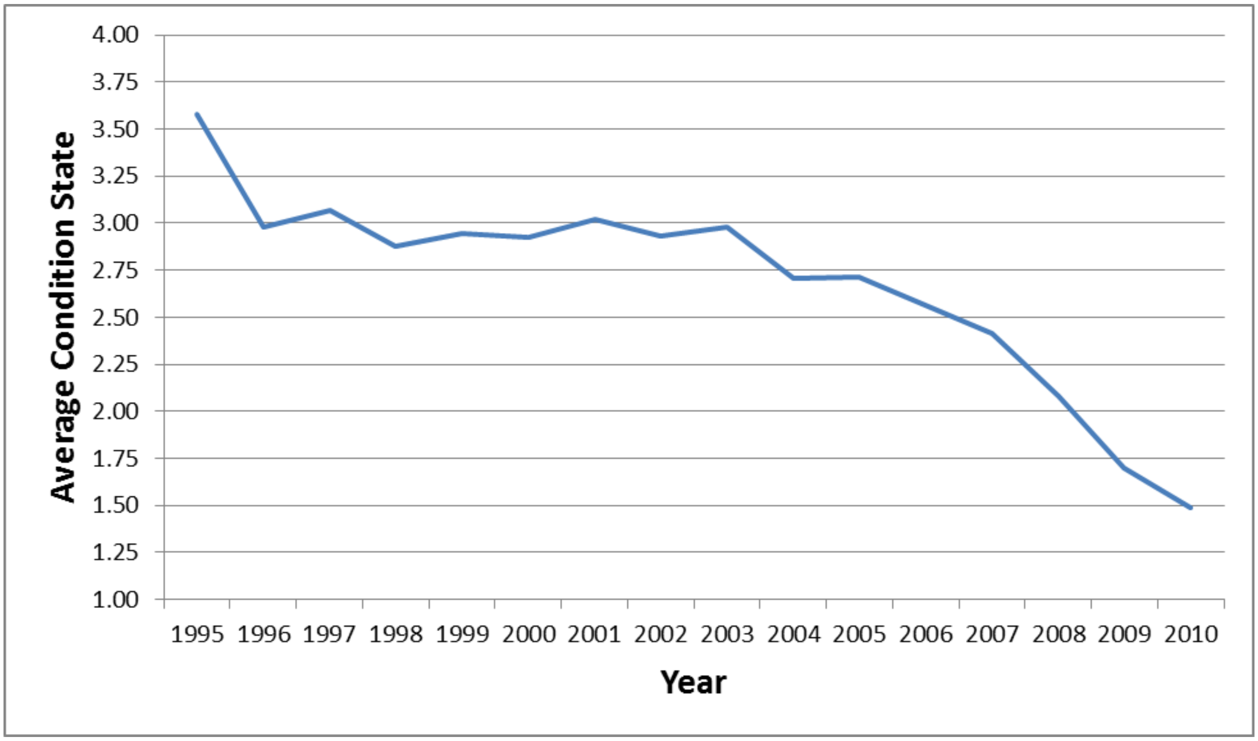

Figure B-7 – Element 108 (Steel Open Girder with Timber Deck – Coated and Uncoated) Average Condition State Trend – Improvement Noted

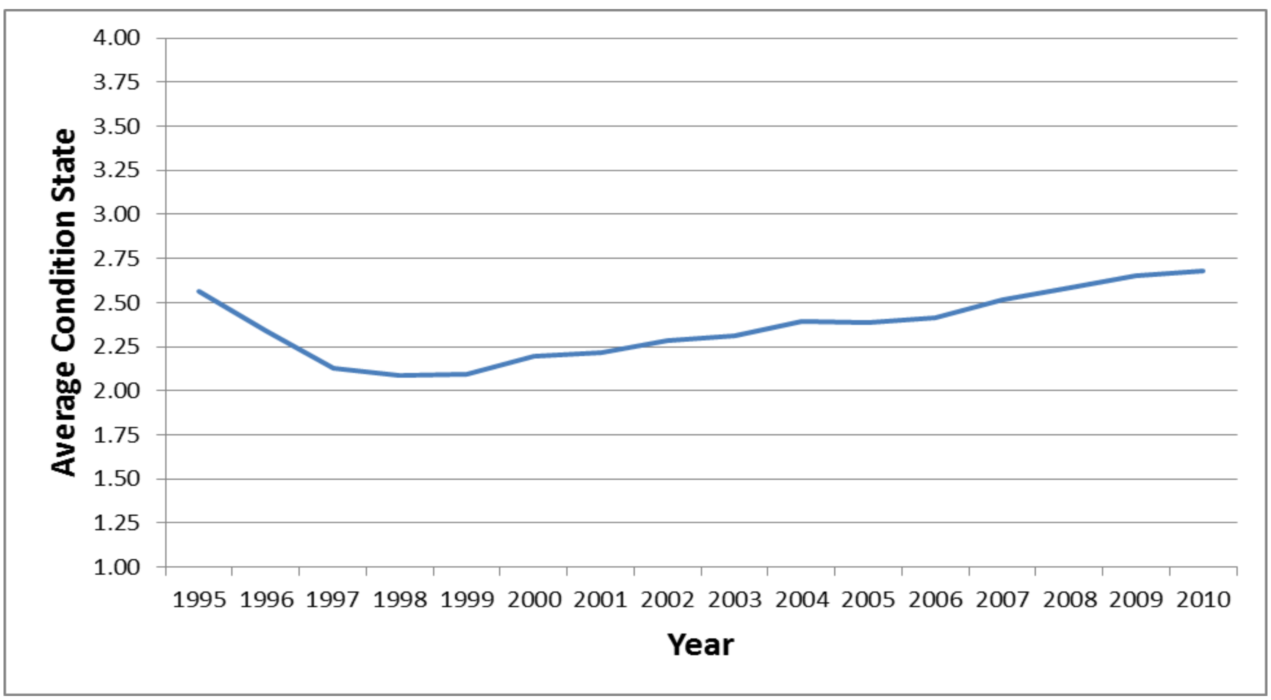

Figure B-8 – Element 108 Average Condition State Trend – Improvement Noted

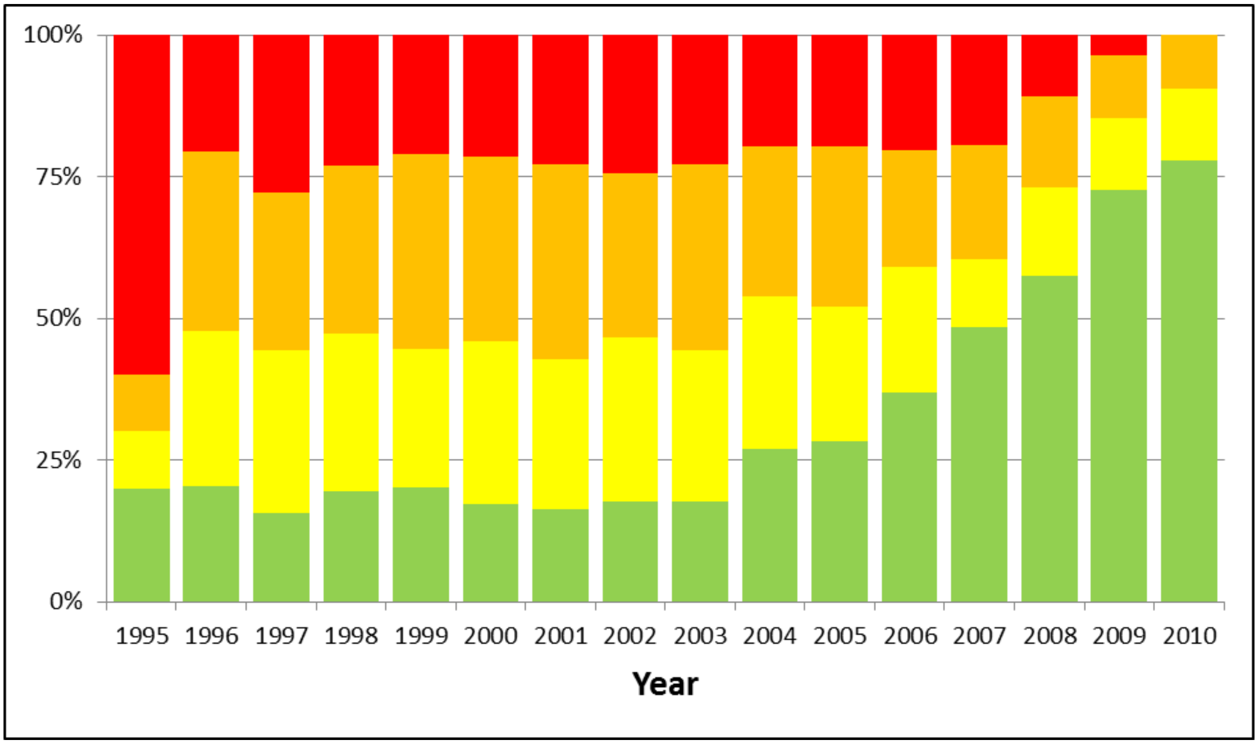

Figure B-9 – Element 108 Normalized Condition State Trend – Improvement Noted

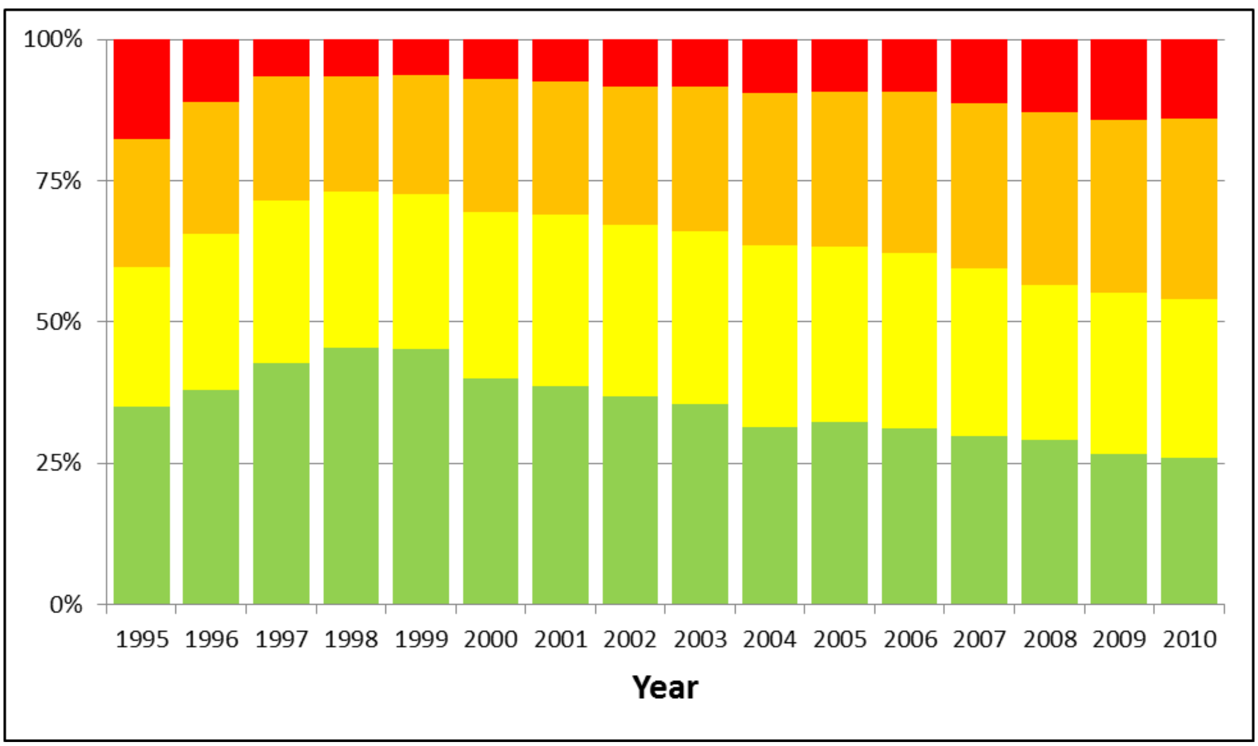

Figure B-10 – Element 108 Normalized Condition State Trend – Improvement Not Noted

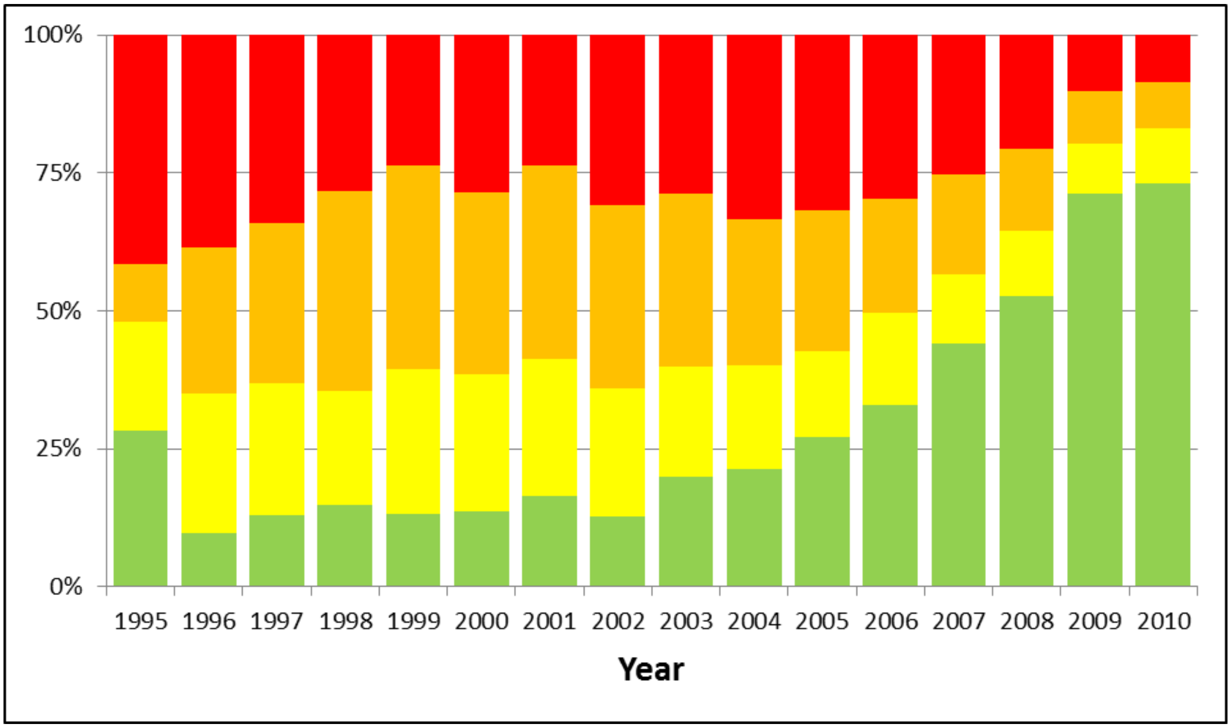

Figure B-11 – Element 108 Normalized Condition State Trend – Improvement Noted (Quantity Analysis)

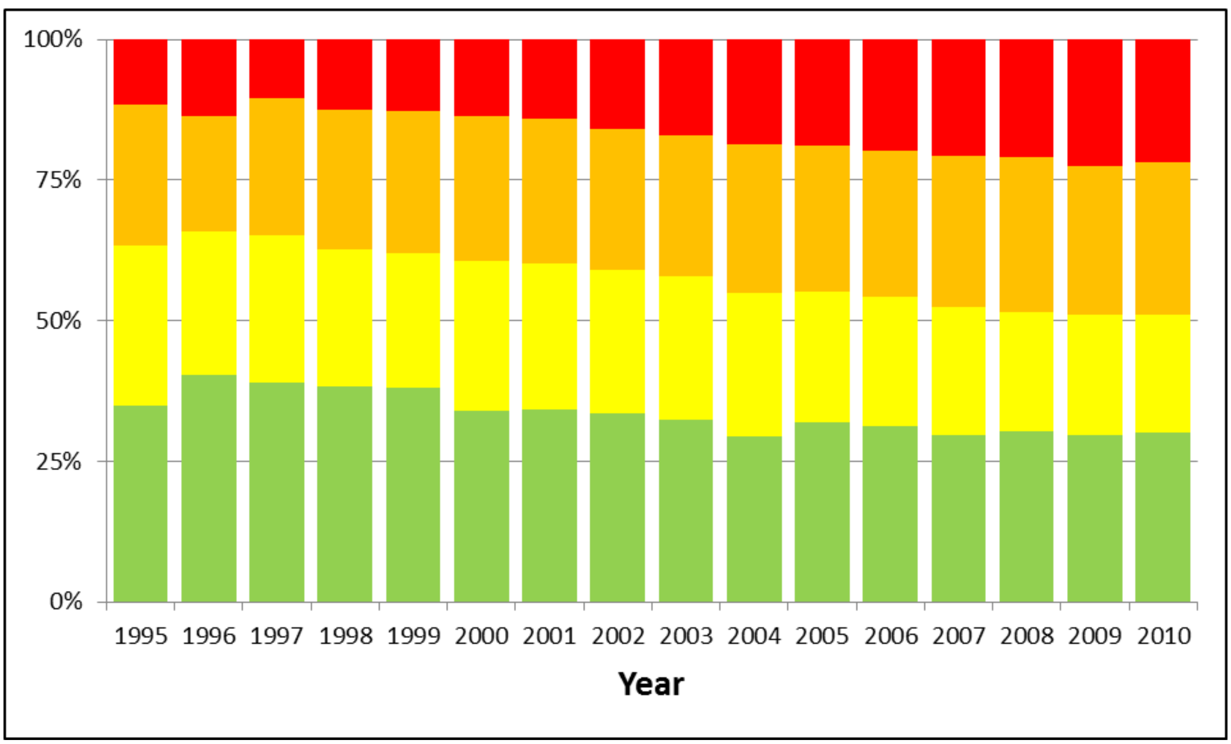

Figure B-12 – Element 108 Normalized Condition State Trend – Improvement Not Noted (Quantity Analysis)

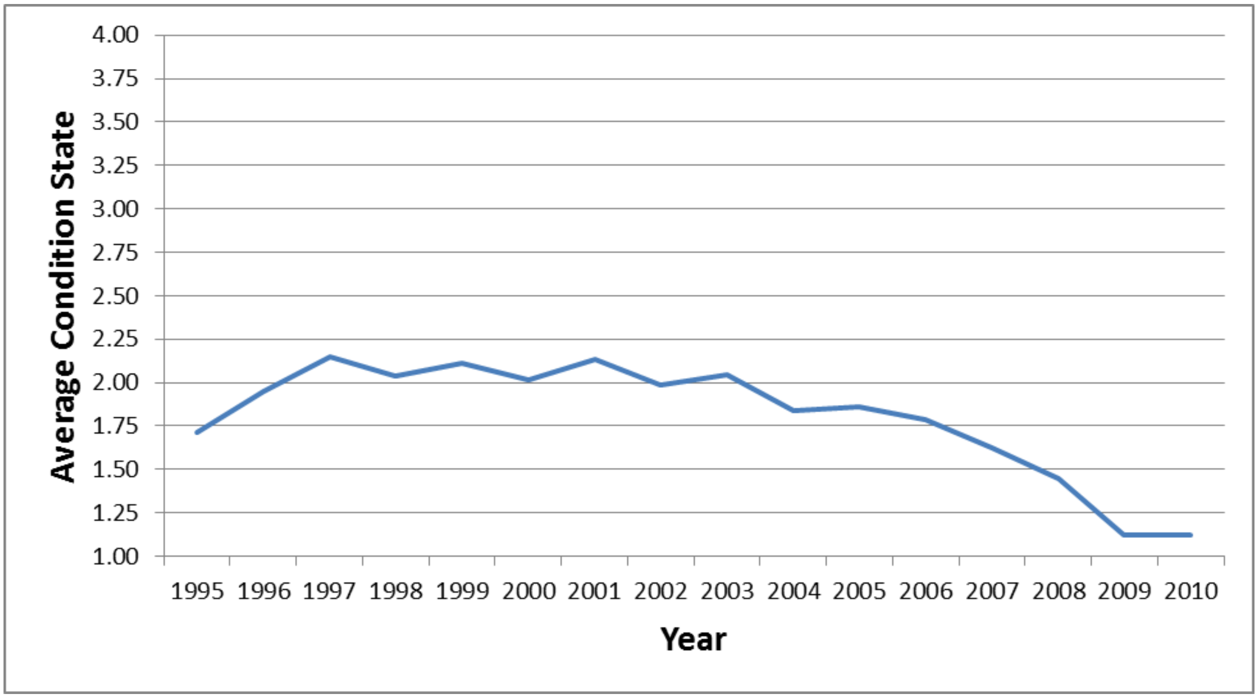

Figure B-13 – Element 302 (Compression Joint Seal) Average Condition State Trend – Improvement Noted

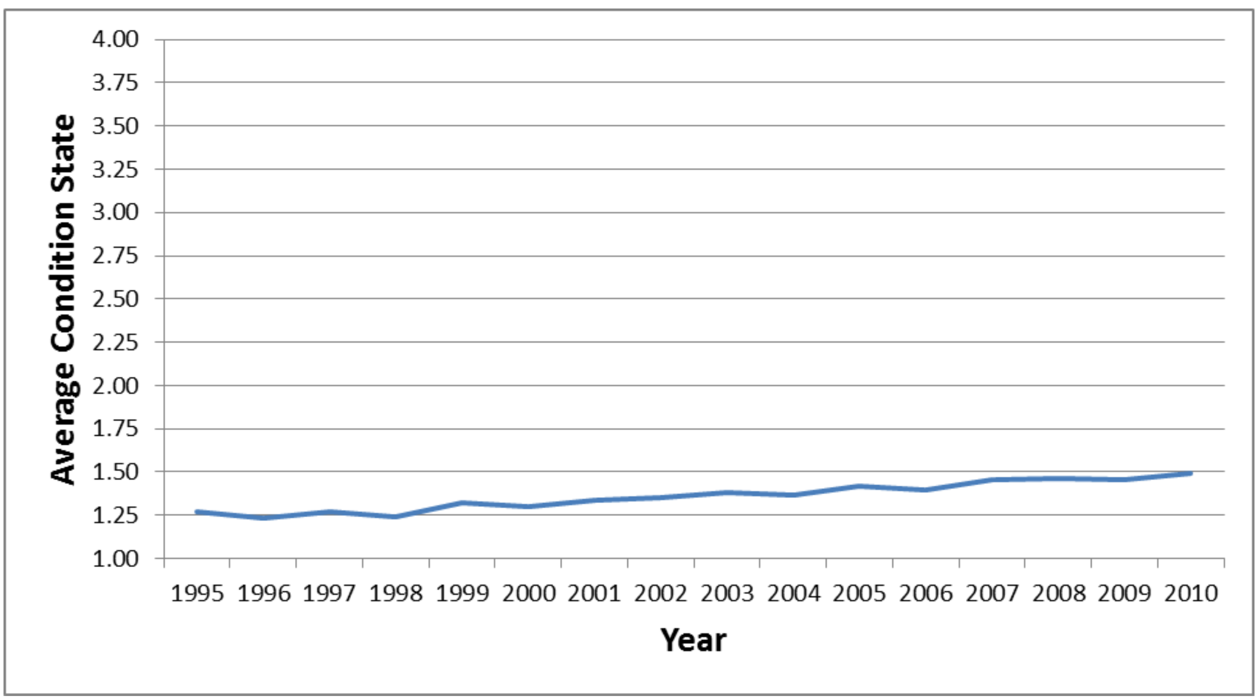

Figure B-14 – Element 302 Average Condition State Trend – Improvement Not Noted

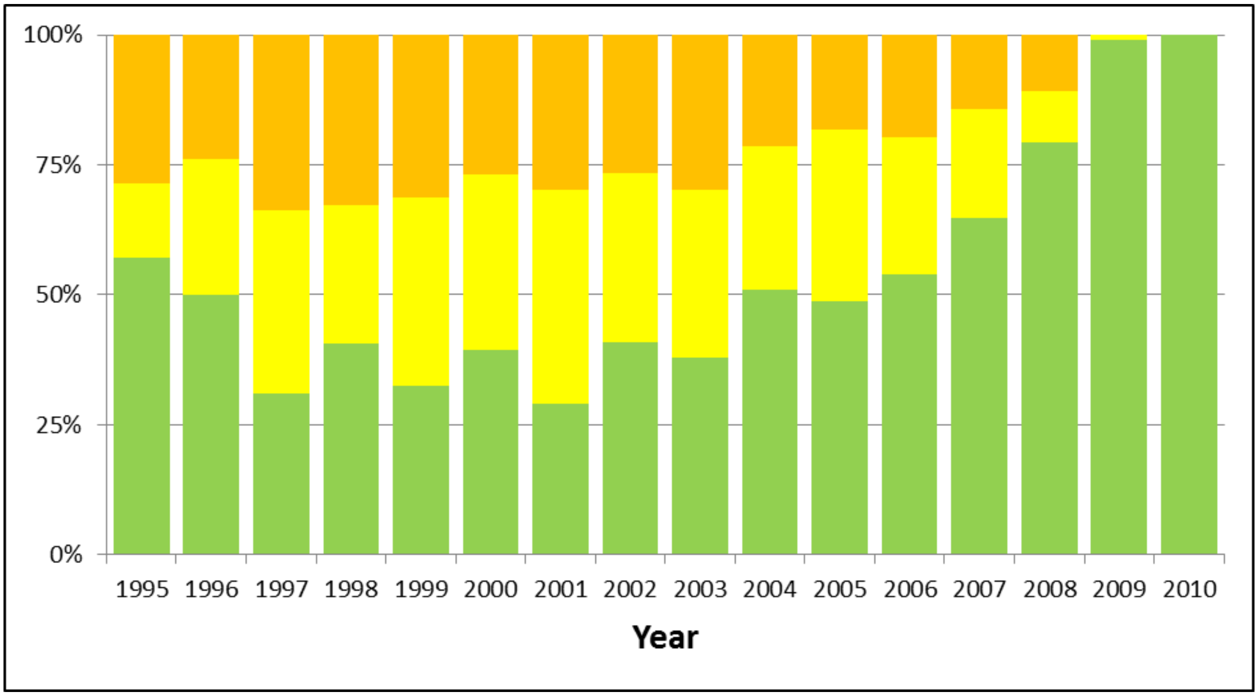

Figure B-15 – Element 302 Normalized Condition State Trend – Improvement Noted

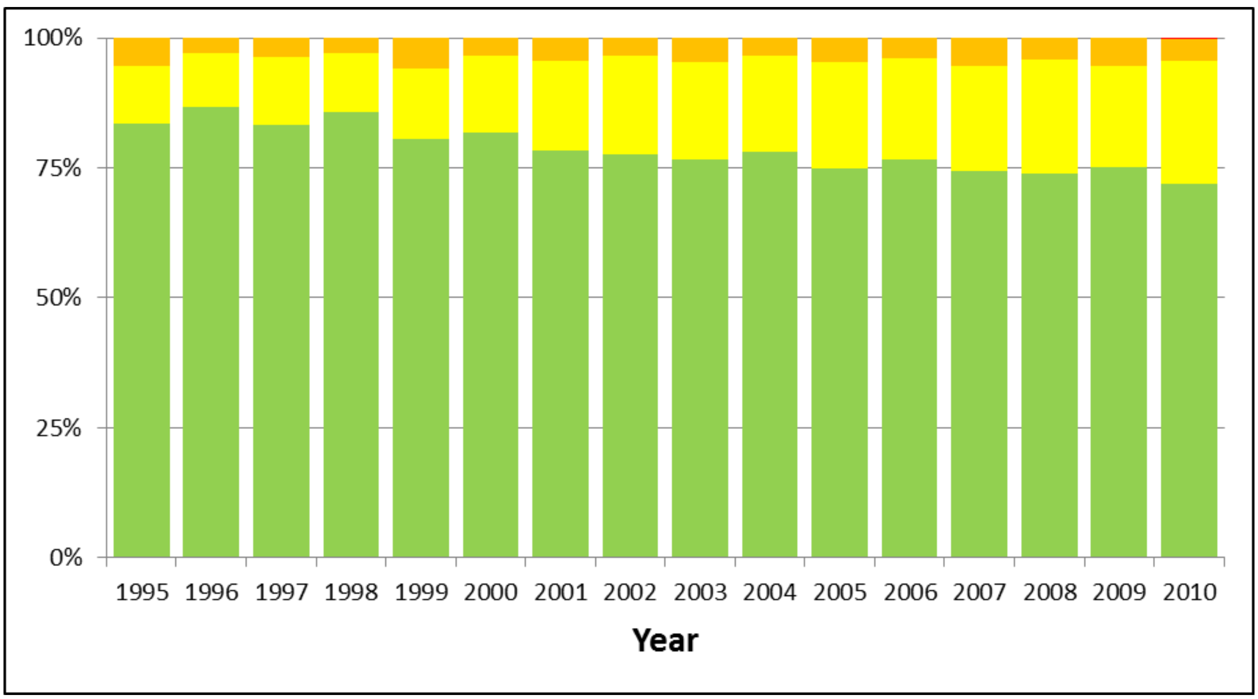

Figure B-16 – Element 302 Normalized Condition State Trend – Improvement Not Noted

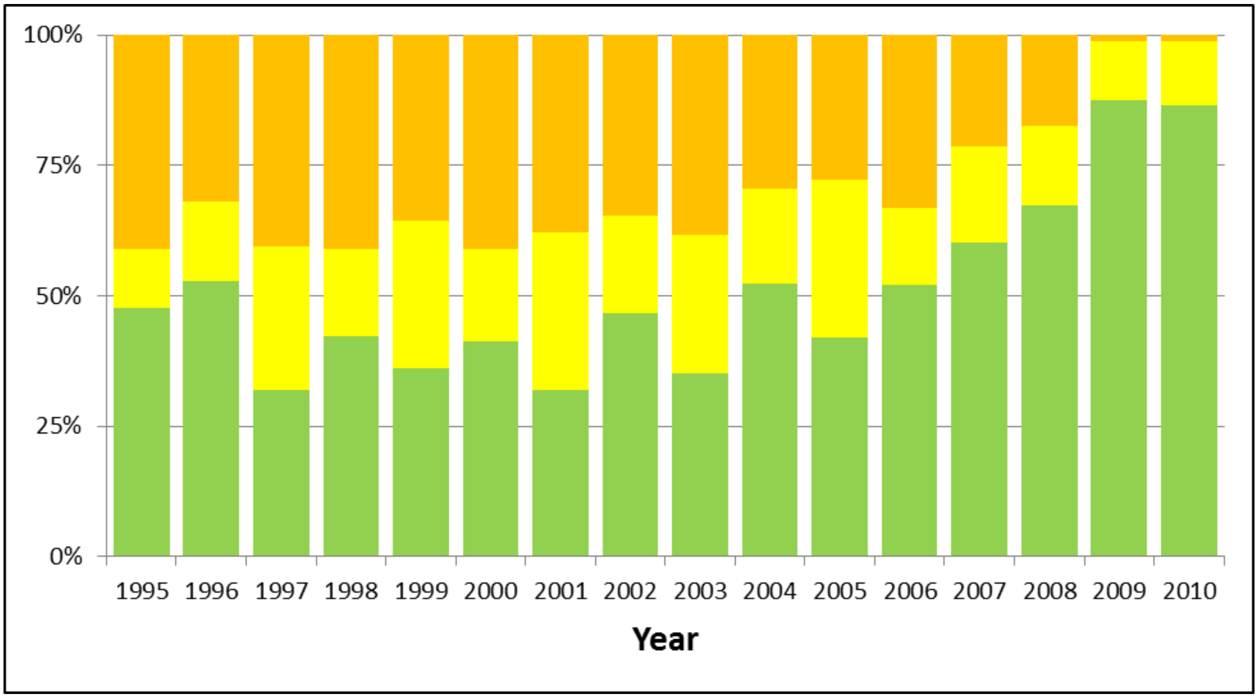

Figure B-17 – Element 302 Normalized Condition State Trend – Improvement Noted (Quantity Analysis)

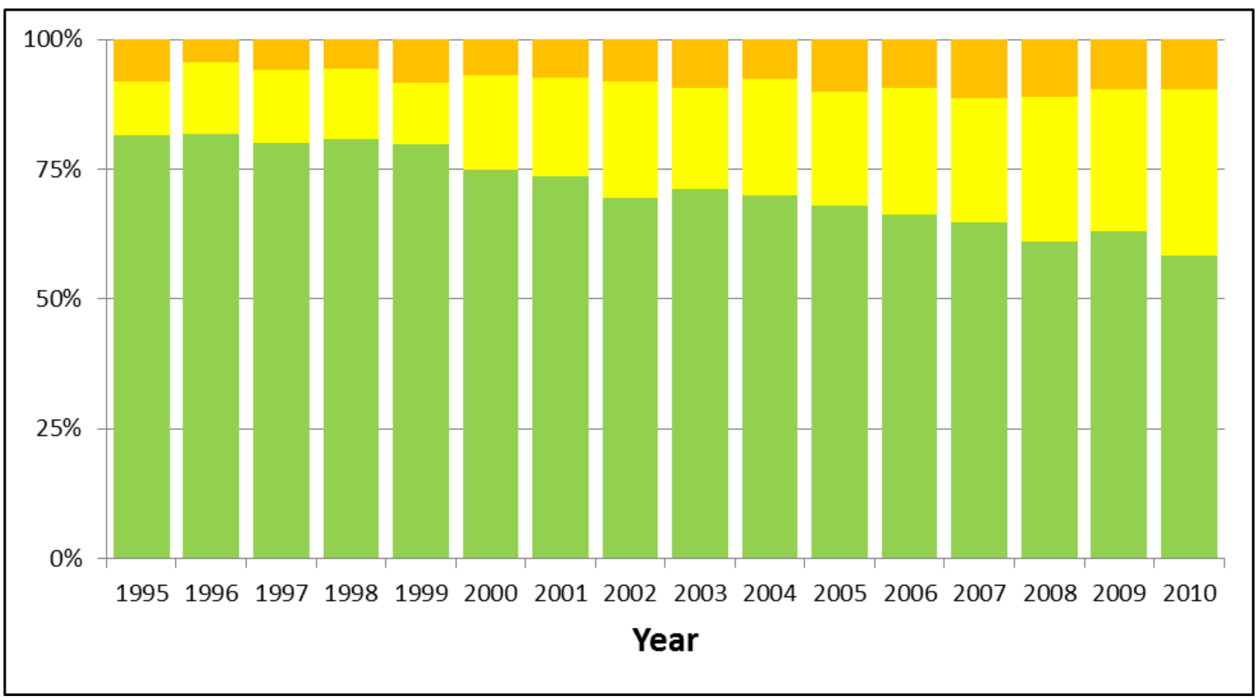

Figure B-18 – Element 302 Normalized Condition State Trend – Improvement Not Noted (Quantity Analysis)

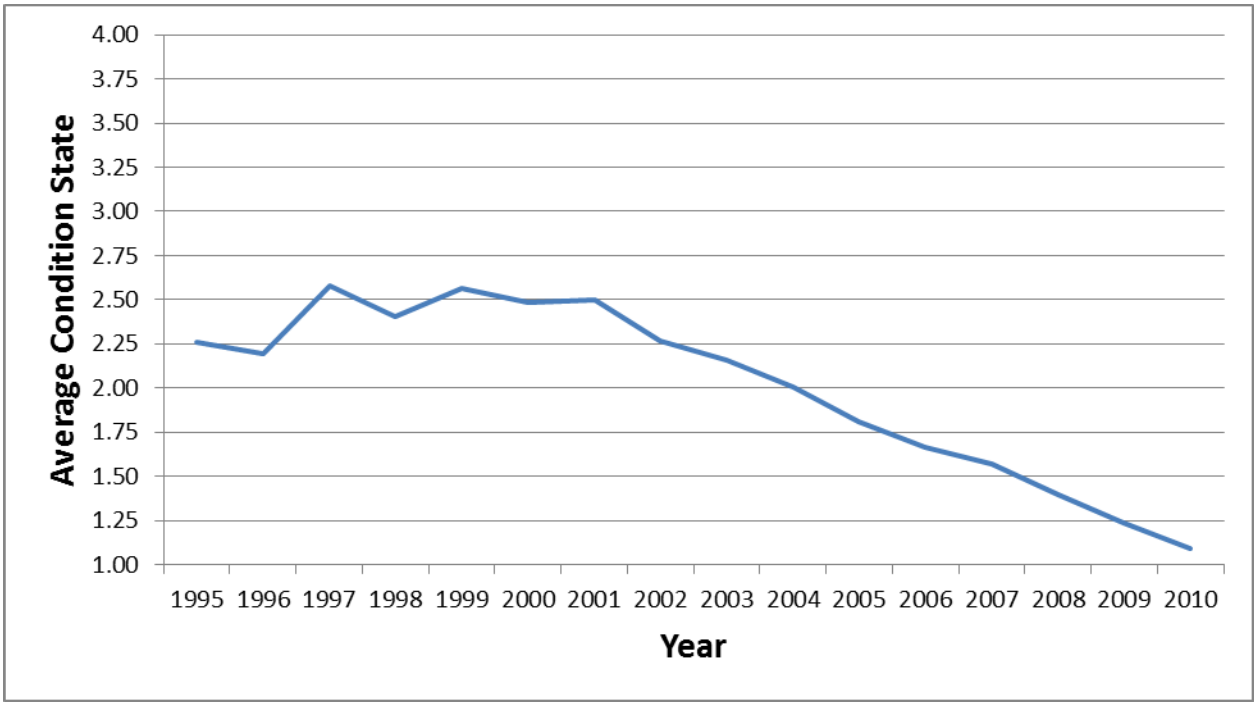

Figure B-19 – Element 334 (Metal Bridge Railing – Coating) Average Condition State Trend – Improvement Noted

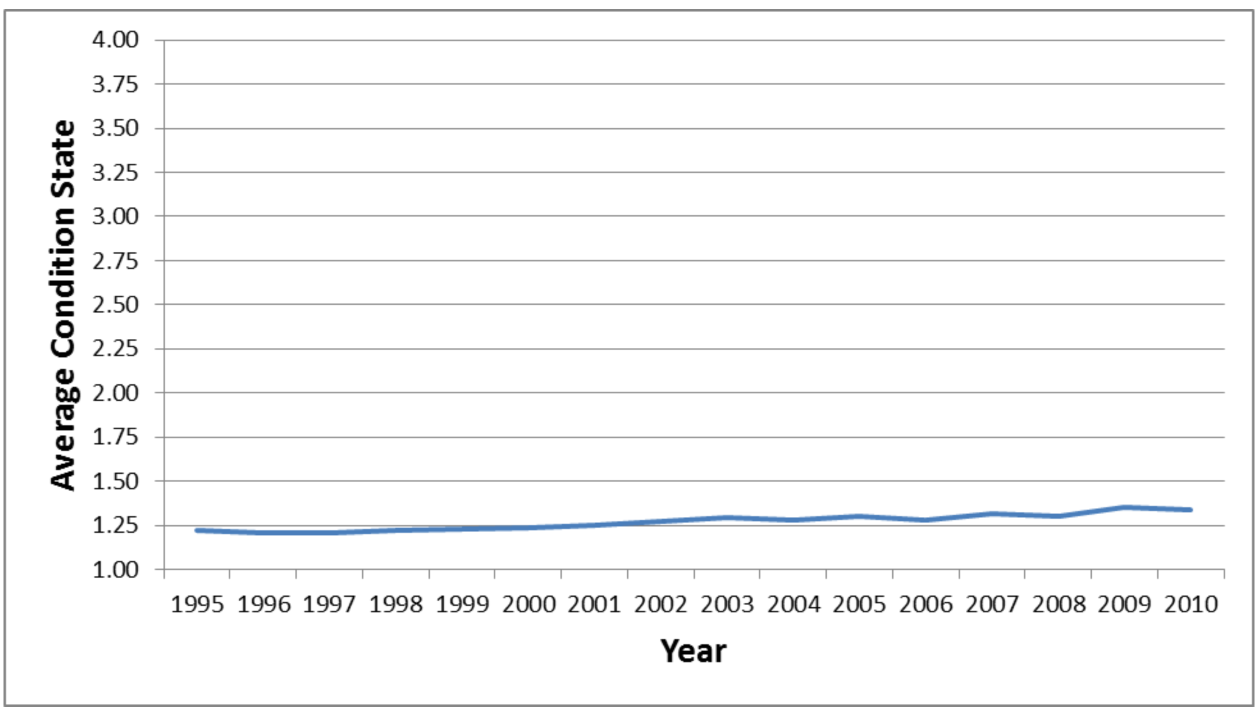

Figure B-20 – Element 334 Average Condition State Trend – Improvement Not Noted

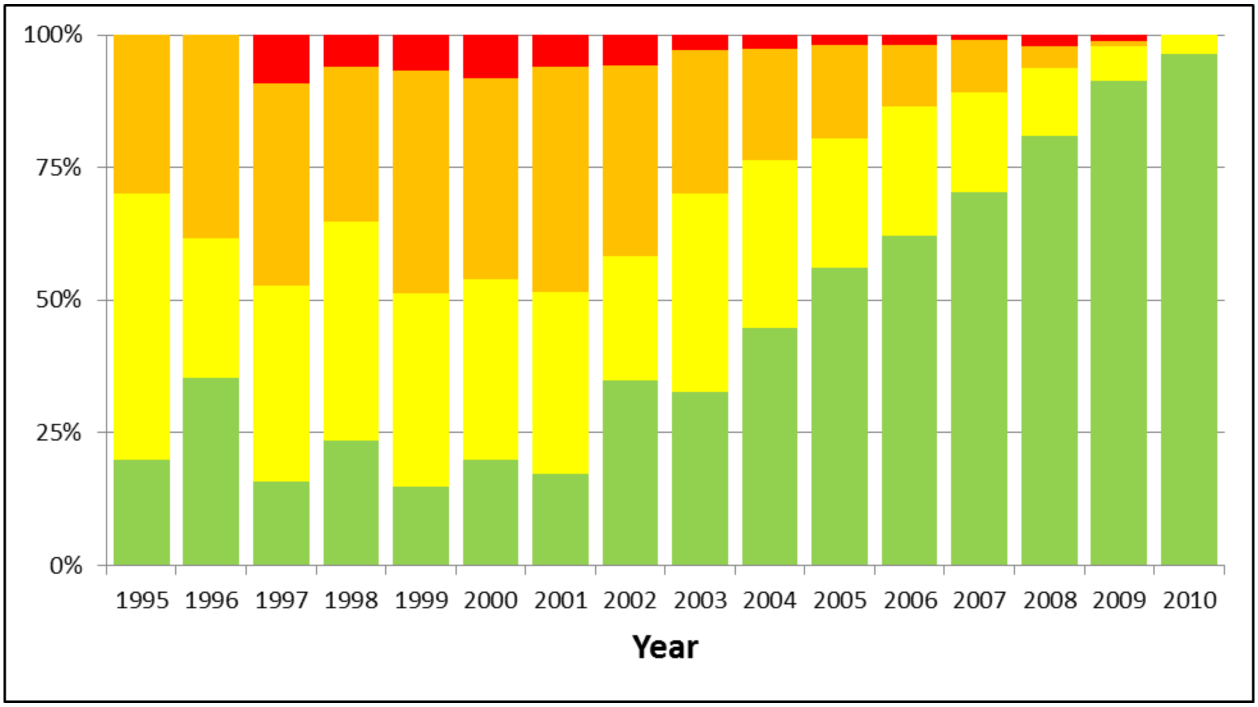

Figure B-21 – Element 334 Normalized Condition State Trend – Improvement Noted

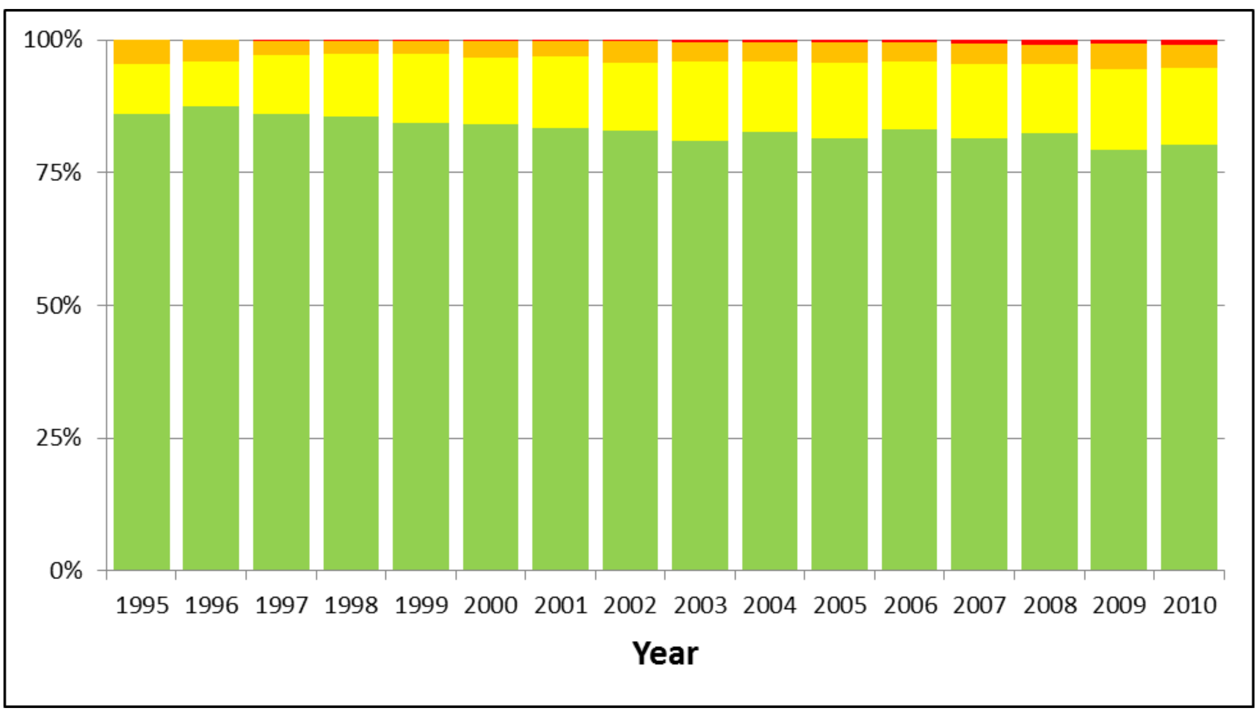

Figure B-22 – Element 334 Normalized Condition State Trend – Improvement Not Noted

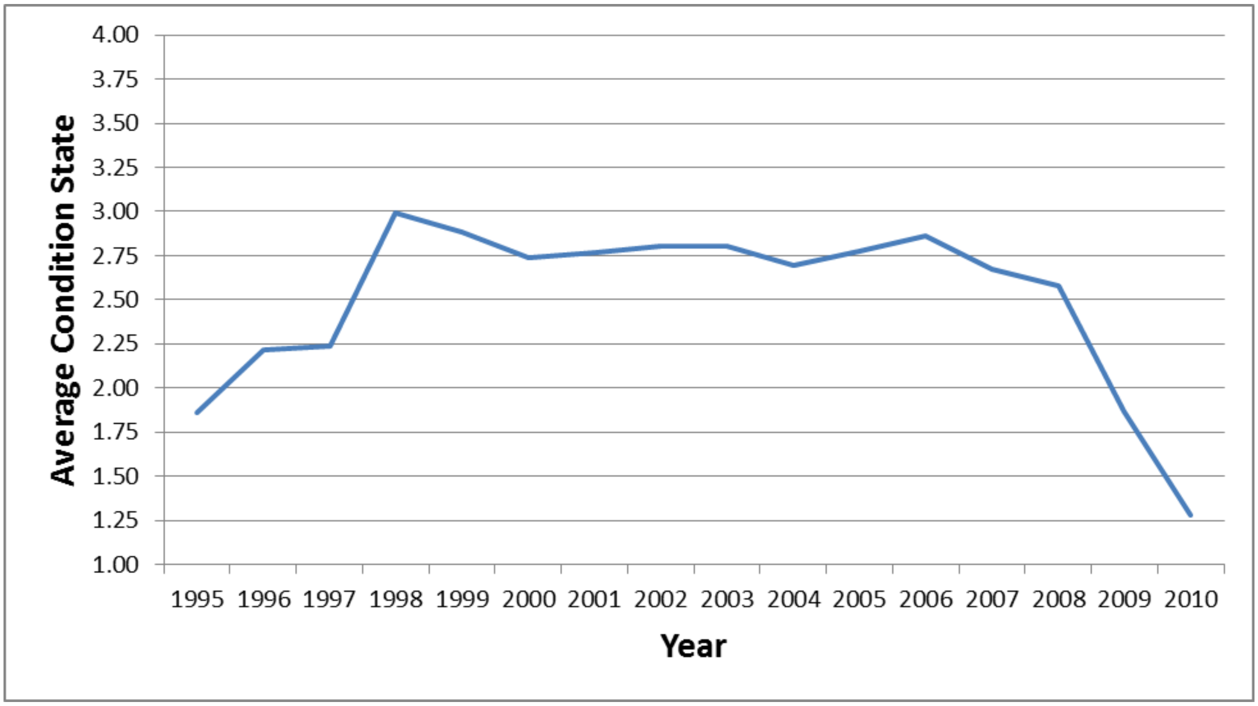

Figure B-23 – Element 240 (Metal Culvert) Average Condition State Trend – Improvement Noted

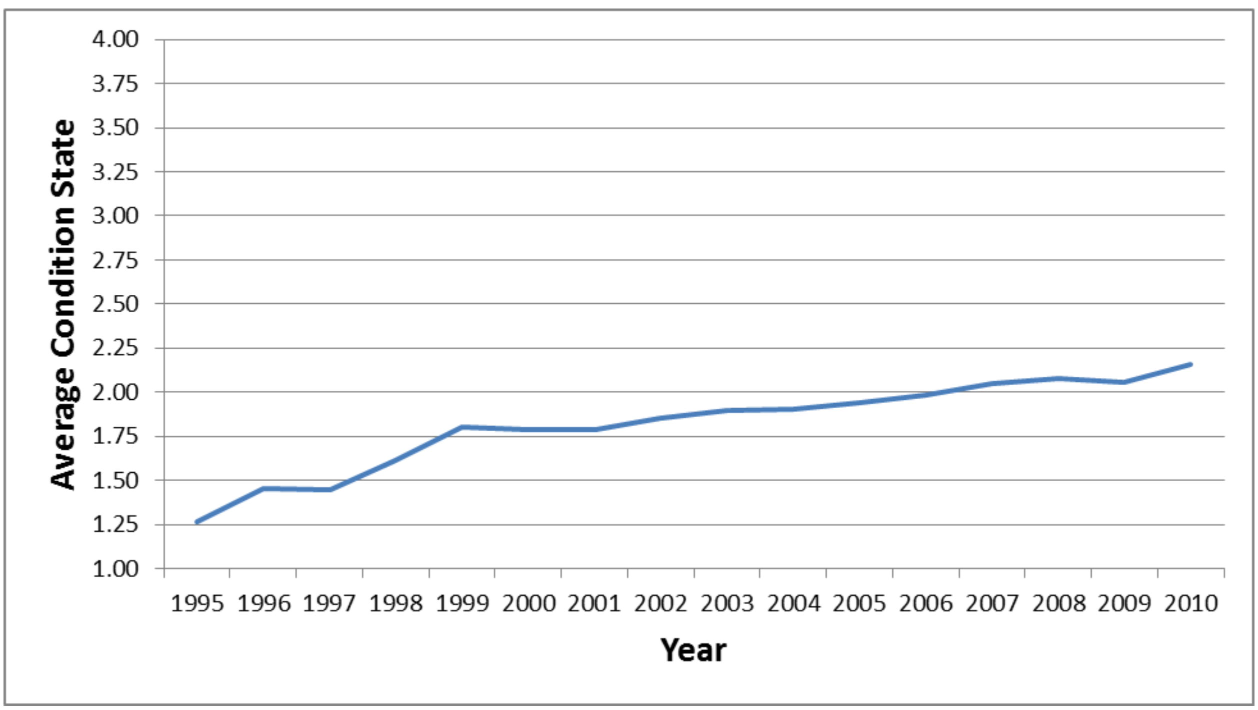

Figure B-24 – Element 240 Average Condition State Trend – Improvement Not Noted

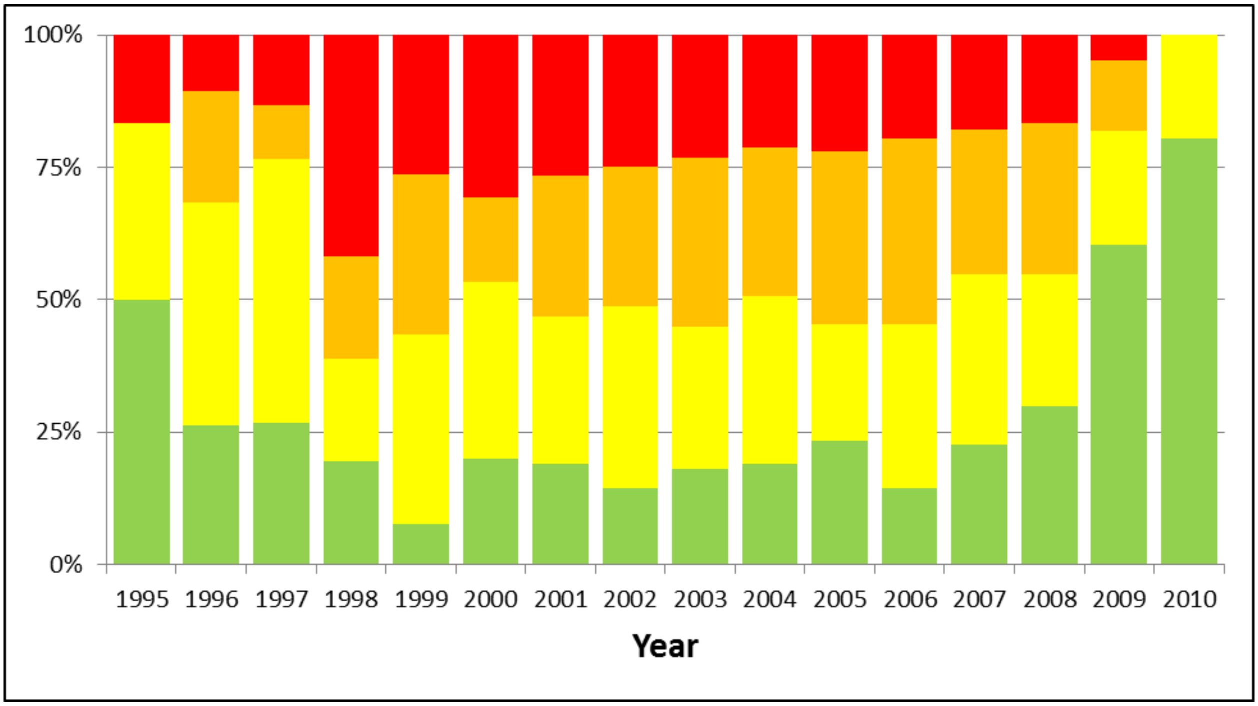

Figure B-25 – Element 240 Normalized Condition State Trend – Improvement Noted

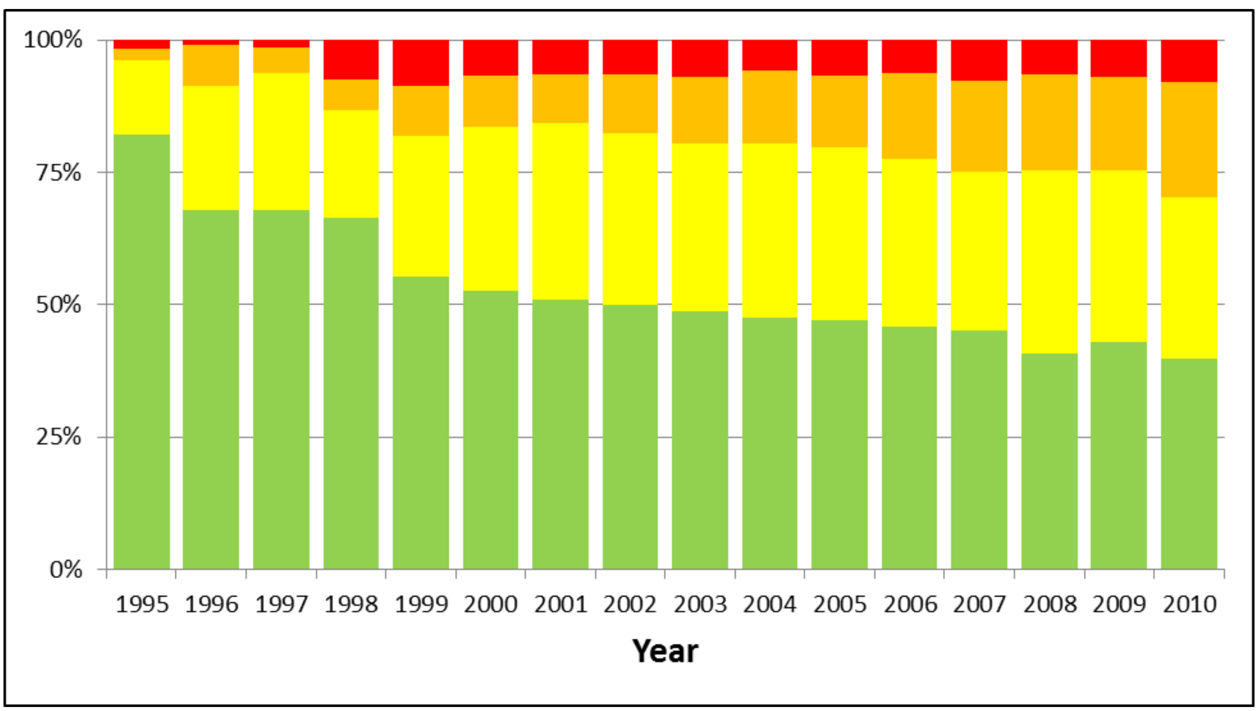

Figure B-26 – Element 240 Normalized Condition State Trend – Improvement Not Noted

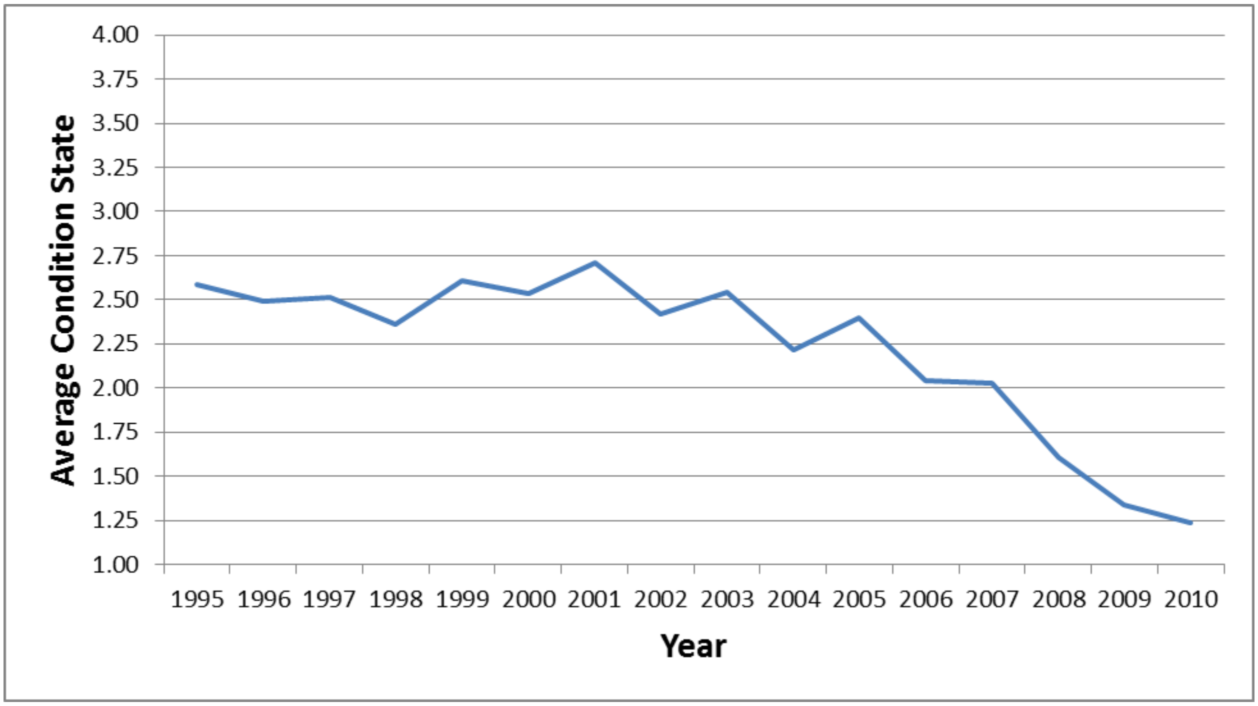

Figure B-27 – Element 107 (Steel Open Girder - Coated) Average Condition State Trend – Improvement Noted

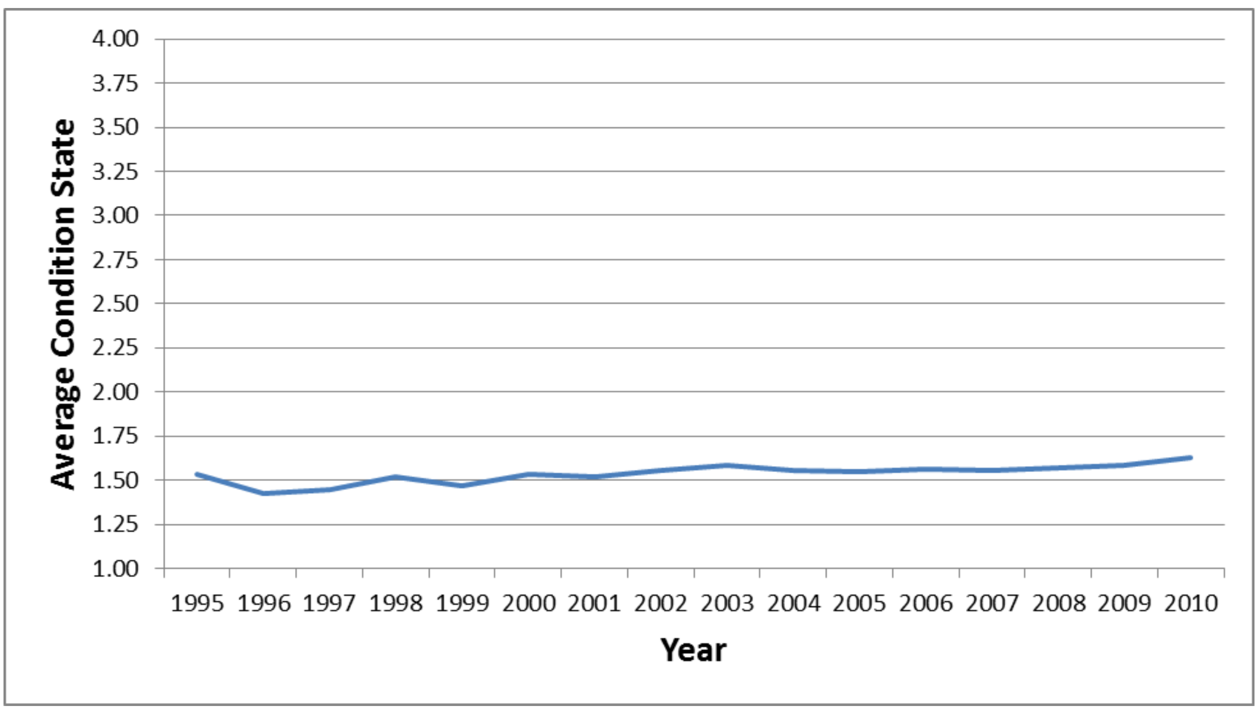

Figure B-28 – Element 107 Average Condition State Trend – Improvement Not Noted

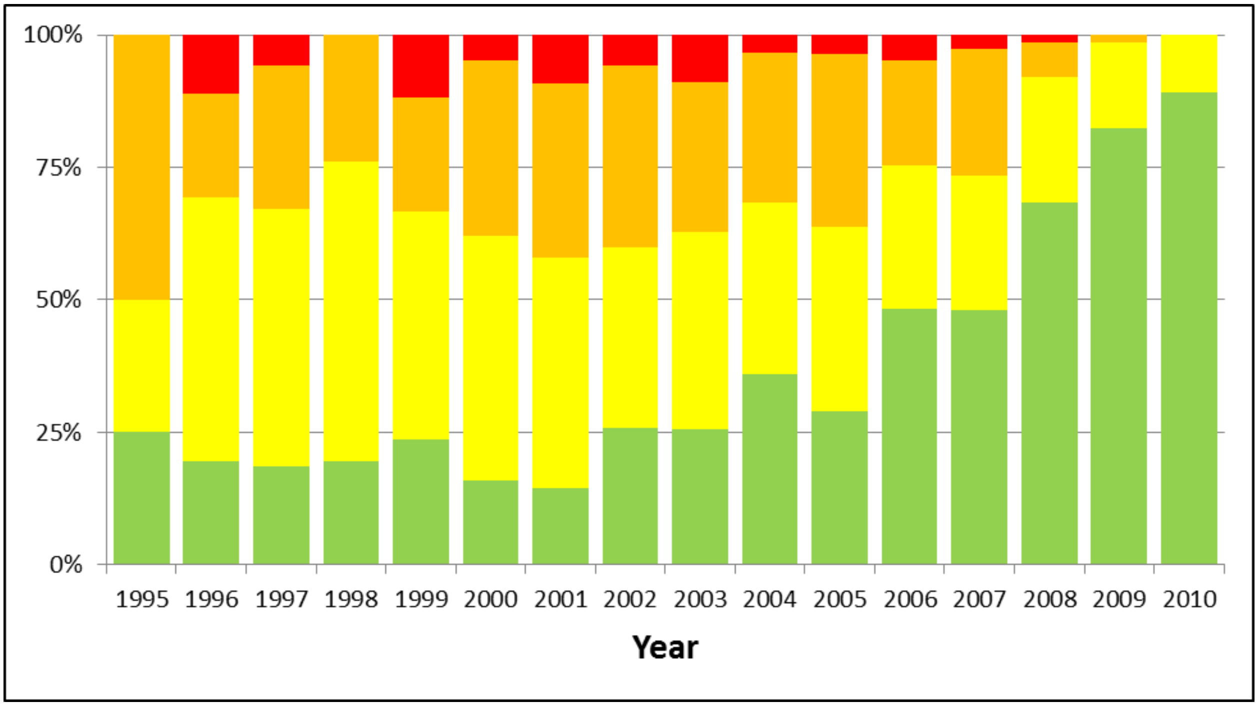

Figure B-29 – Element 107 Normalized Condition State Trend – Improvement Noted

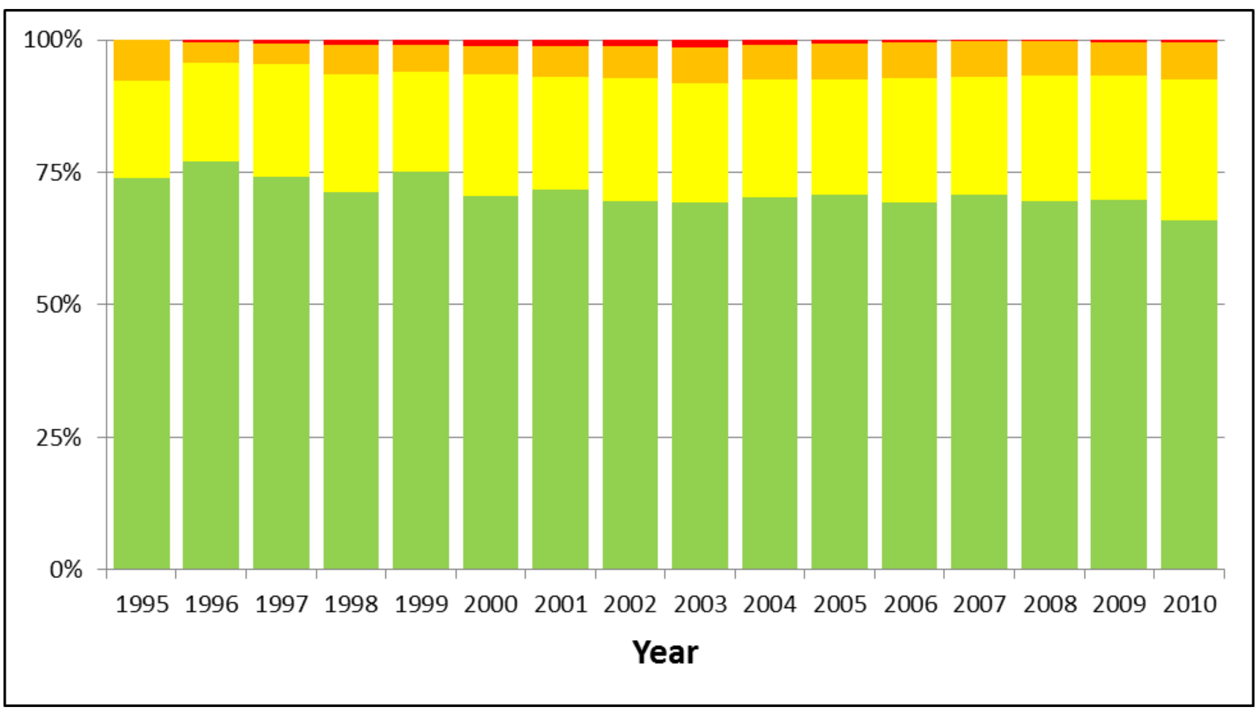

Figure B-30 – Element 107 Normalized Condition State Trend – Improvement Not Noted

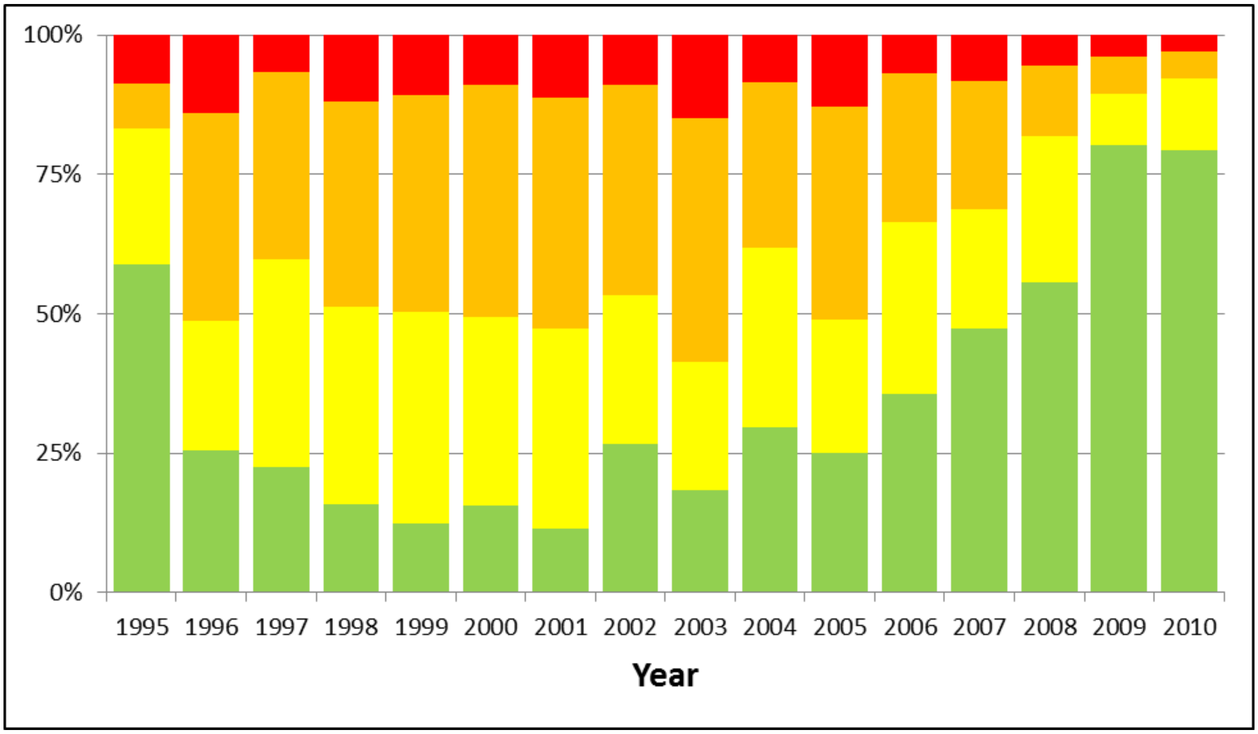

Figure B-31 – Element 107 Normalized Condition State Trend – Improvement Noted (Quantity Analysis)

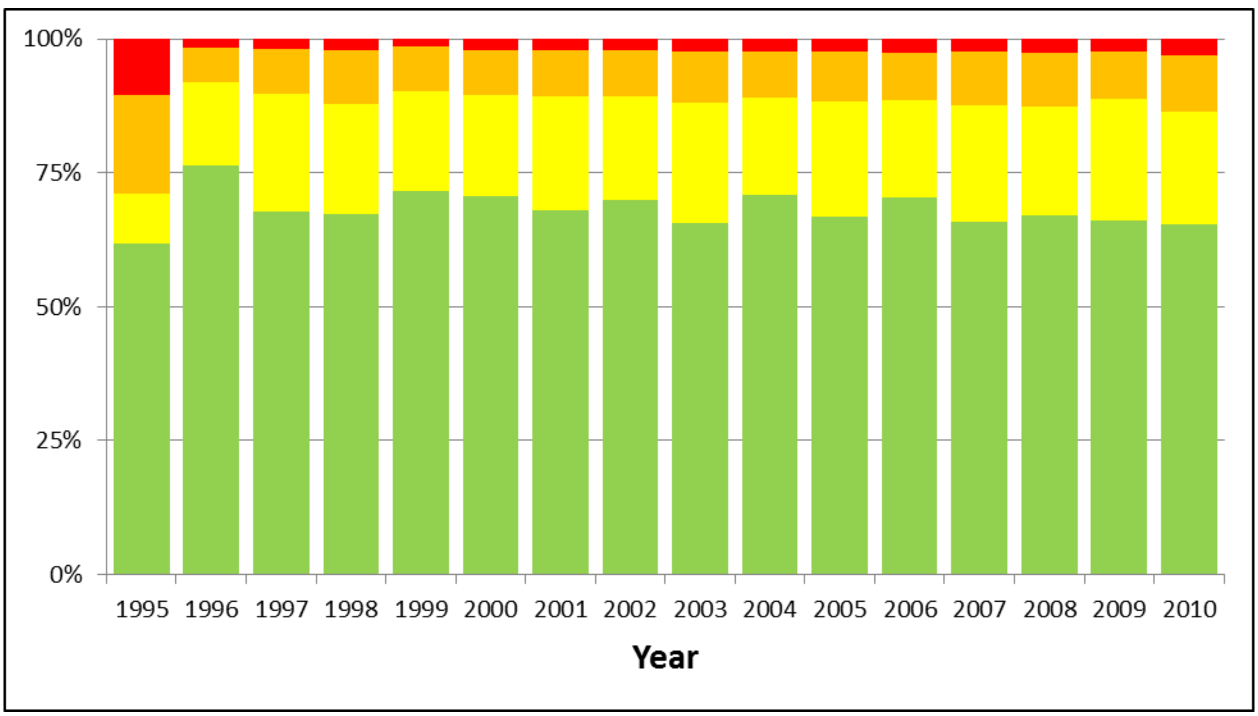

Figure B-32 – Element 107 Normalized Condition State Trend – Improvement Not Noted (Quantity Analysis)

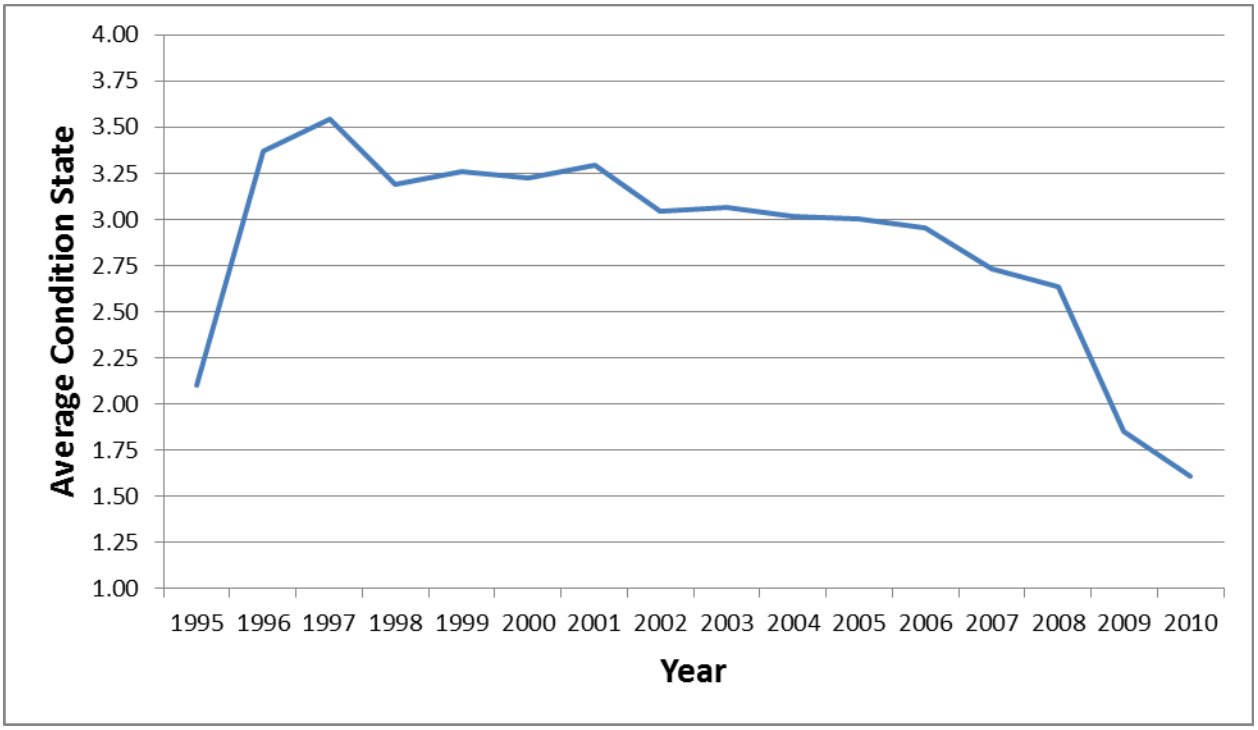

Figure B-33 – Smart Flag 359 (Soffit of Concrete) Average Condition State Trend – Improvement Noted

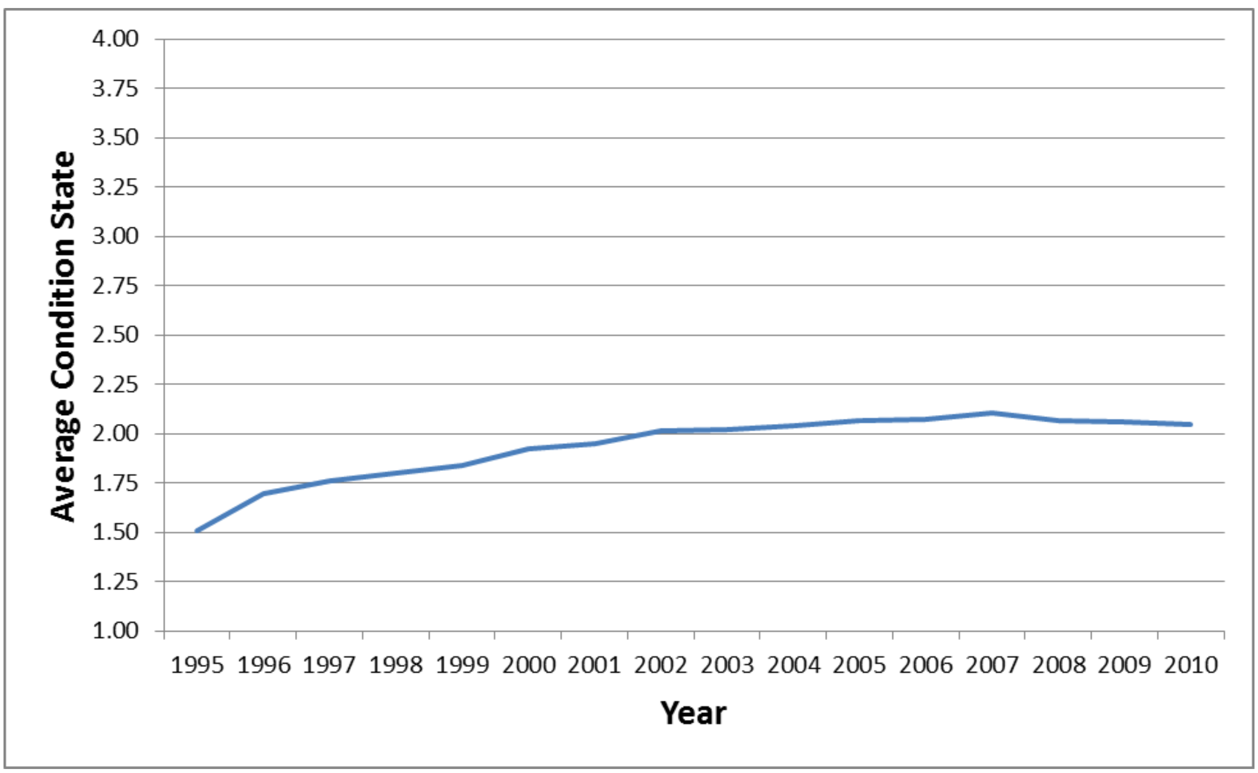

Figure B-34 – Smart Flag 359 Average Condition State Trend – Improvement Not Noted

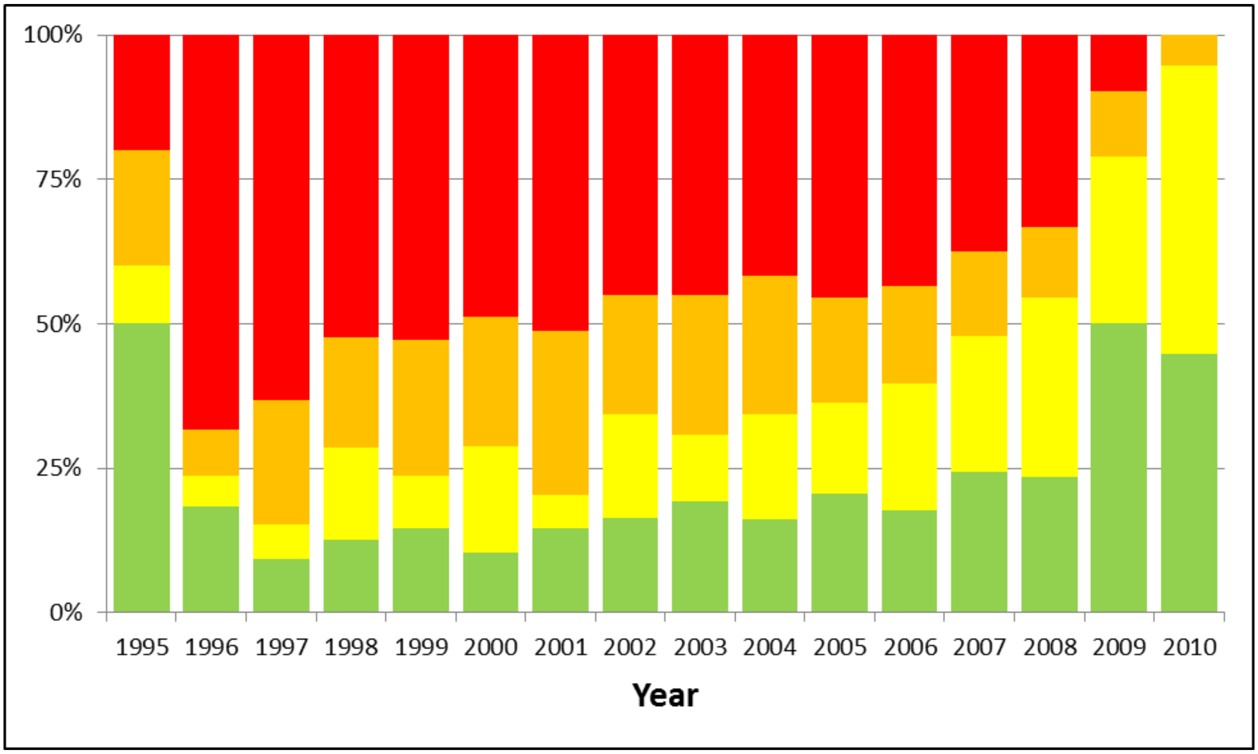

Figure B-35 – Smart Flag 359 Normalized Condition State Trend – Improvement Noted

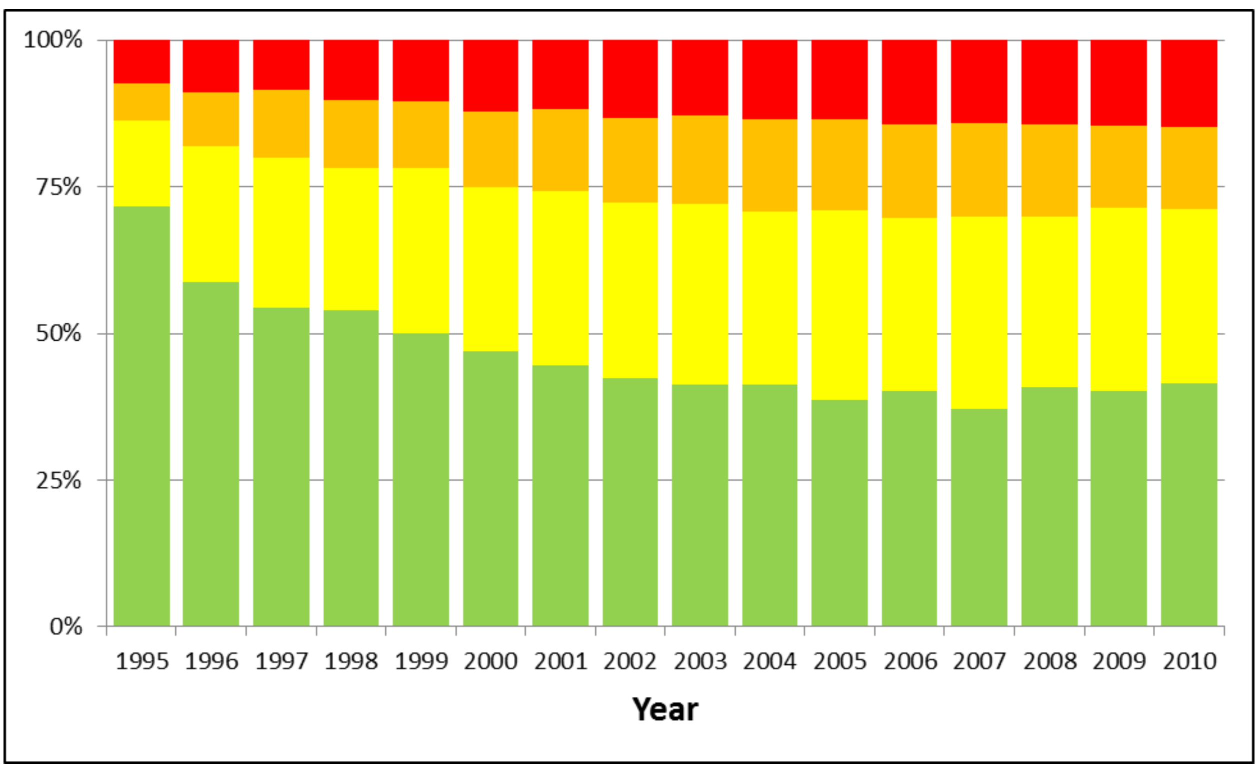

Figure B-36 – Smart Flag 359 Normalized Condition State Trend – Improvement Not Noted

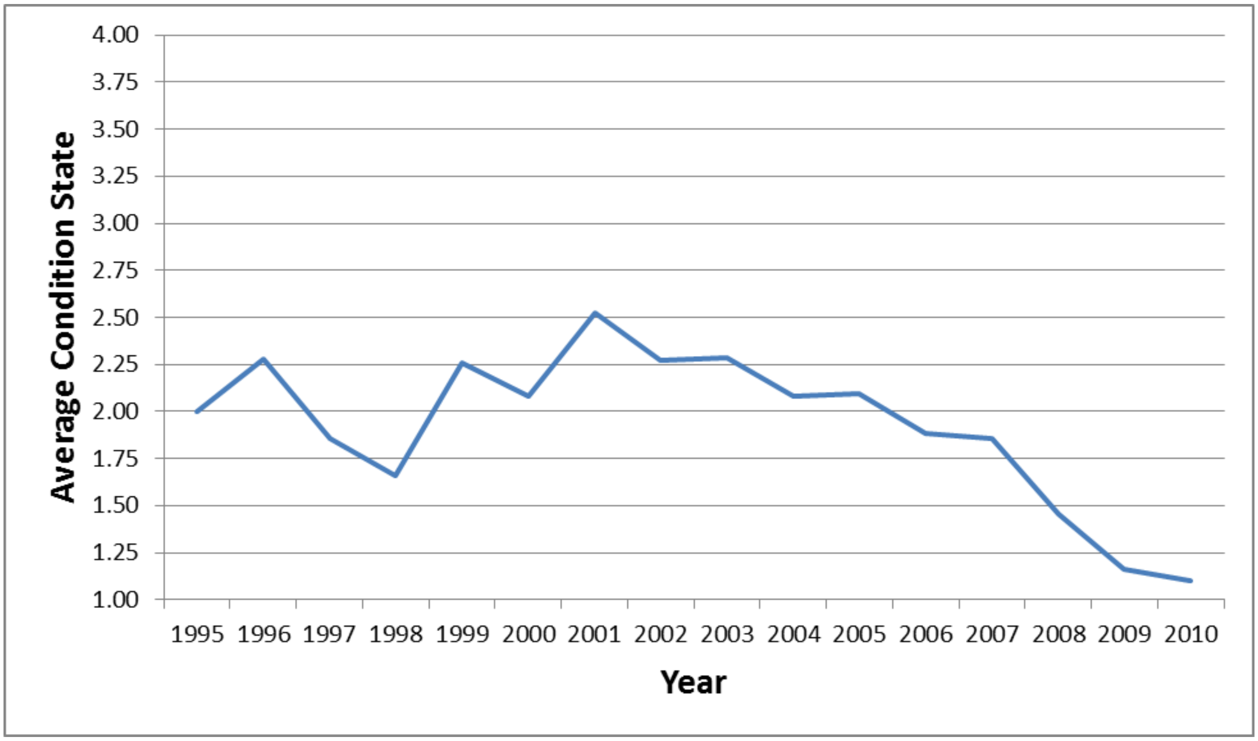

Figure B-37 – Smart Flag 702 (Drains) Average Condition State Trend – Improvement Noted

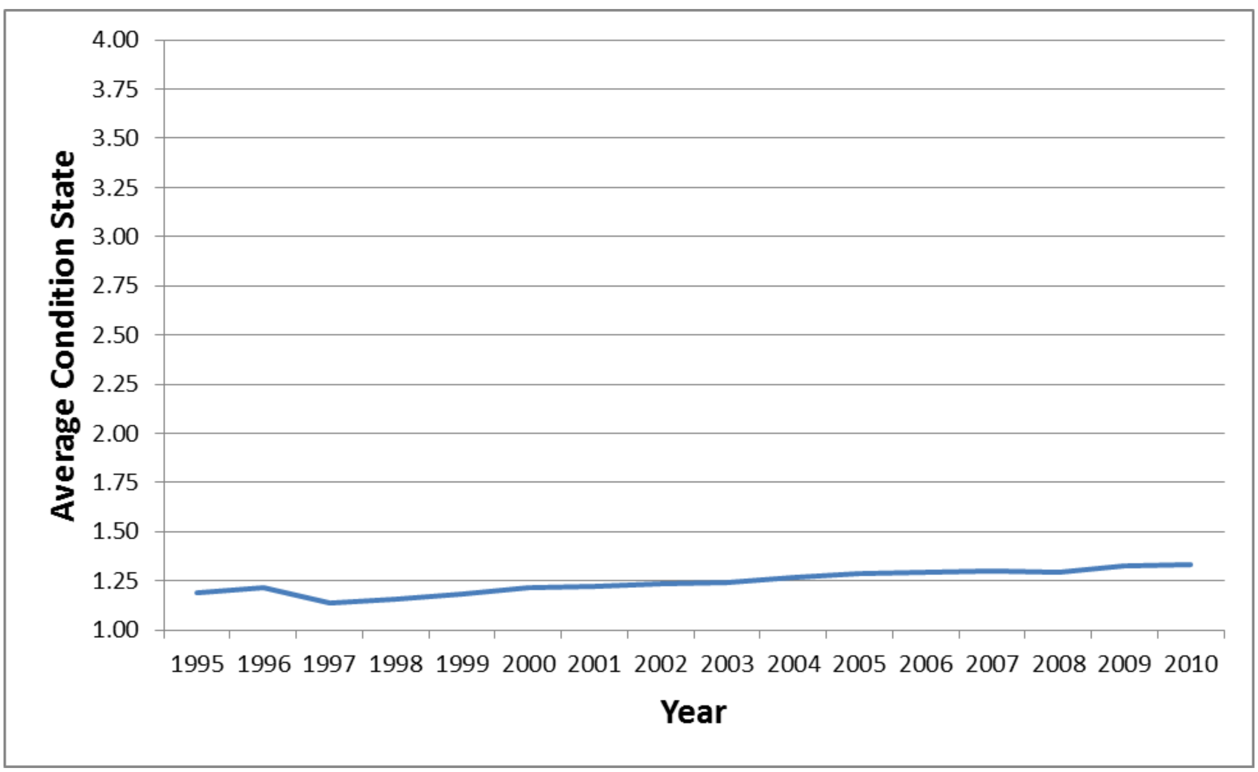

Figure B-38 – Smart Flag 702 Average Condition State Trend – Improvement Not Noted

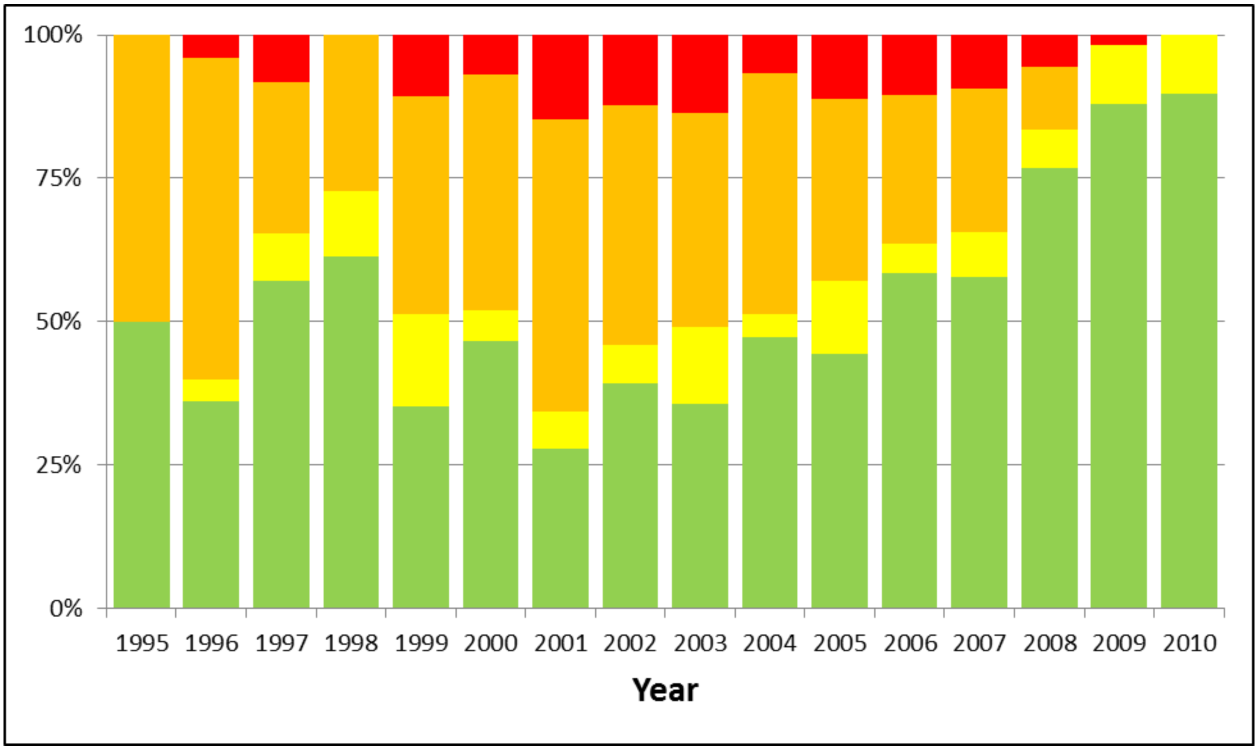

Figure B-39 – Smart Flag 702 Normalized Condition State Trend – Improvement Noted

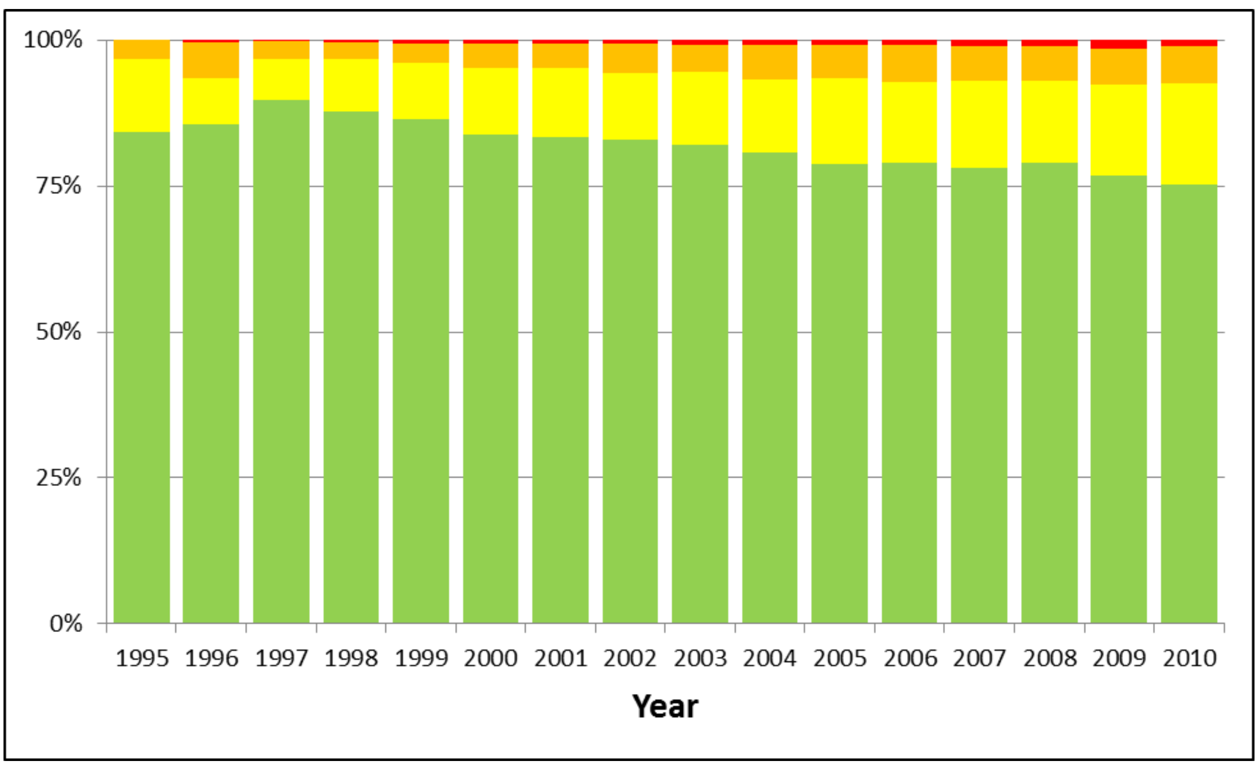

Figure B-40 – Smart Flag 702 Normalized Condition State Trend – Improvement Not Noted

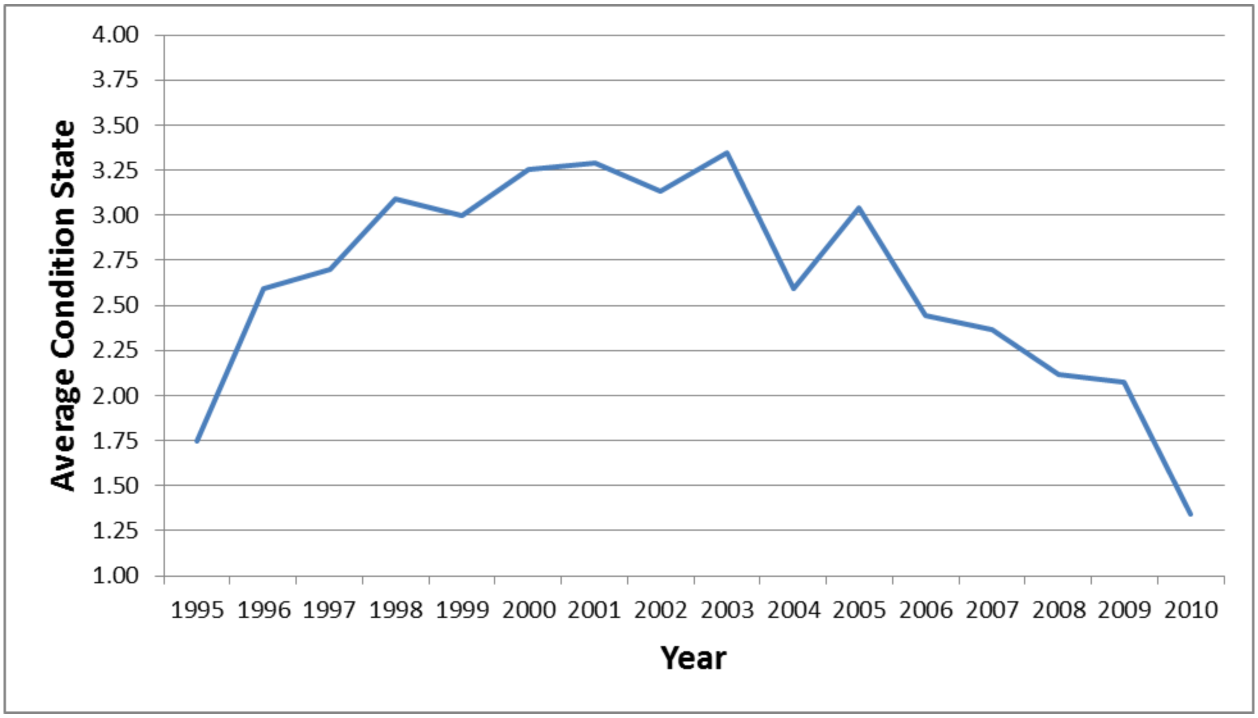

Figure B-41 – Smart Flag 706 (Soffit of Overhang of Concrete) Average Condition State Trend – Improvement Noted

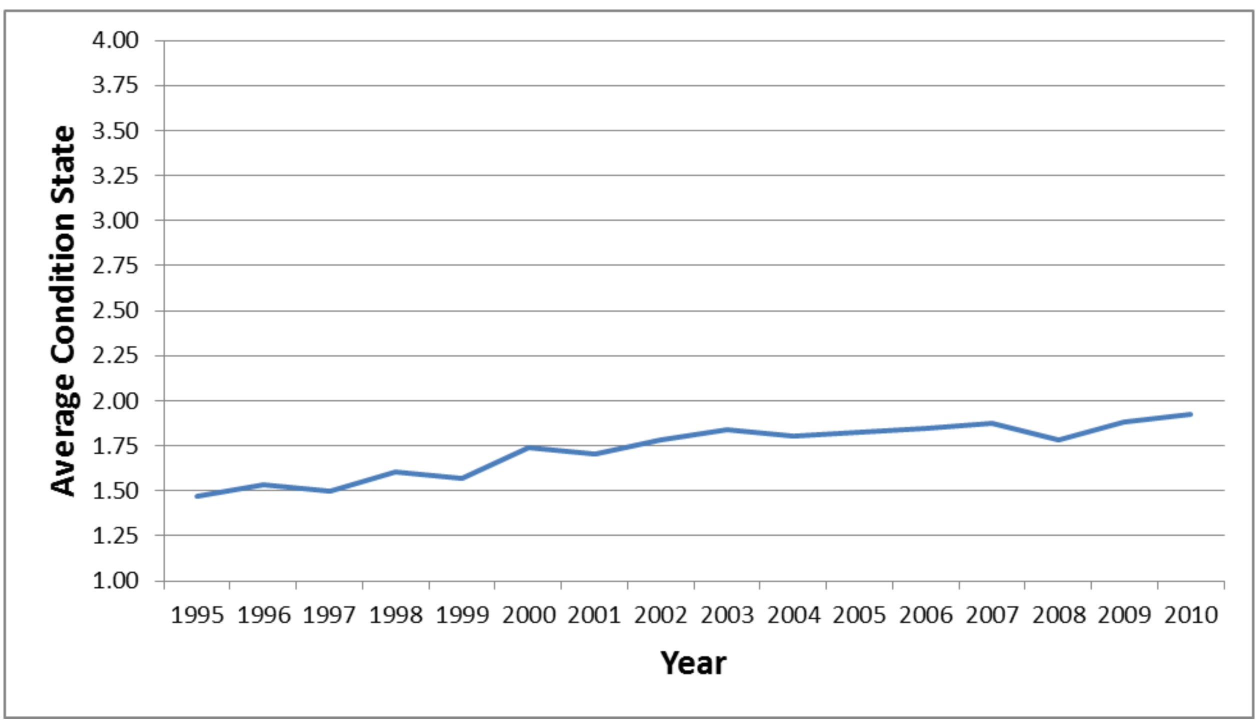

Figure B-42 – Smart Flag 706 () Average Condition State Trend – Improvement Not Noted

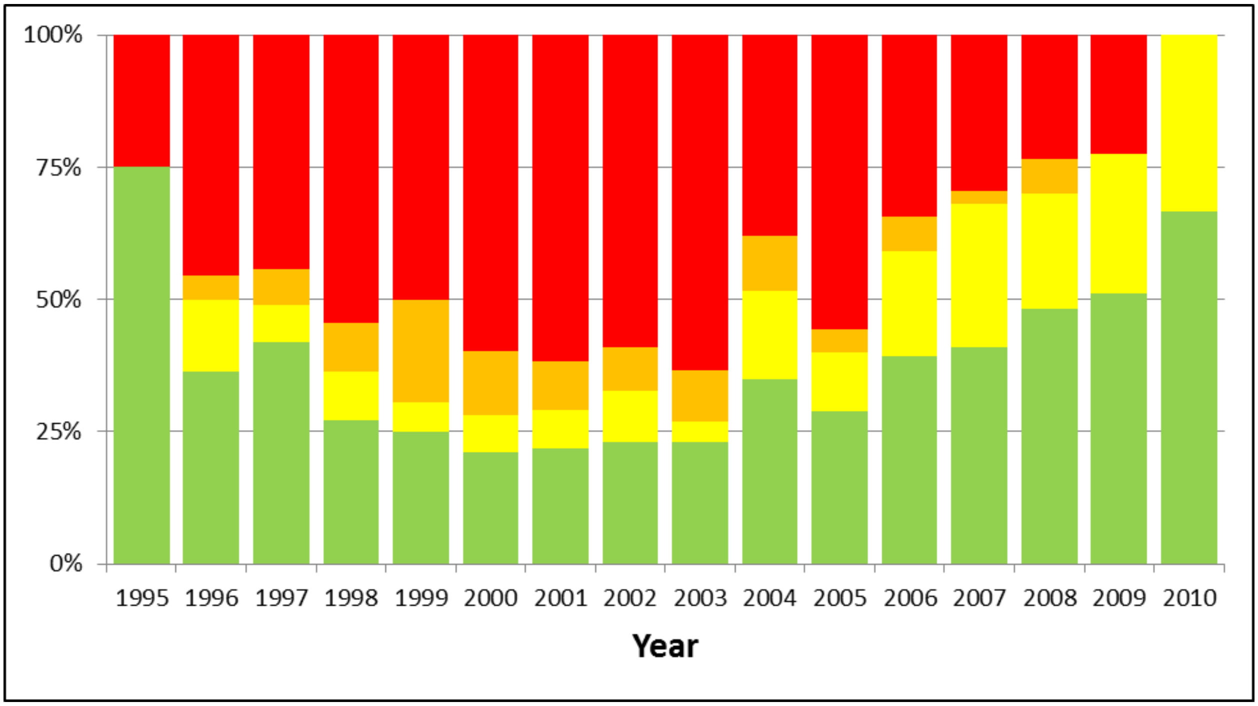

Figure B-43 – Smart Flag 706 Normalized Condition State Trend – Improvement Noted

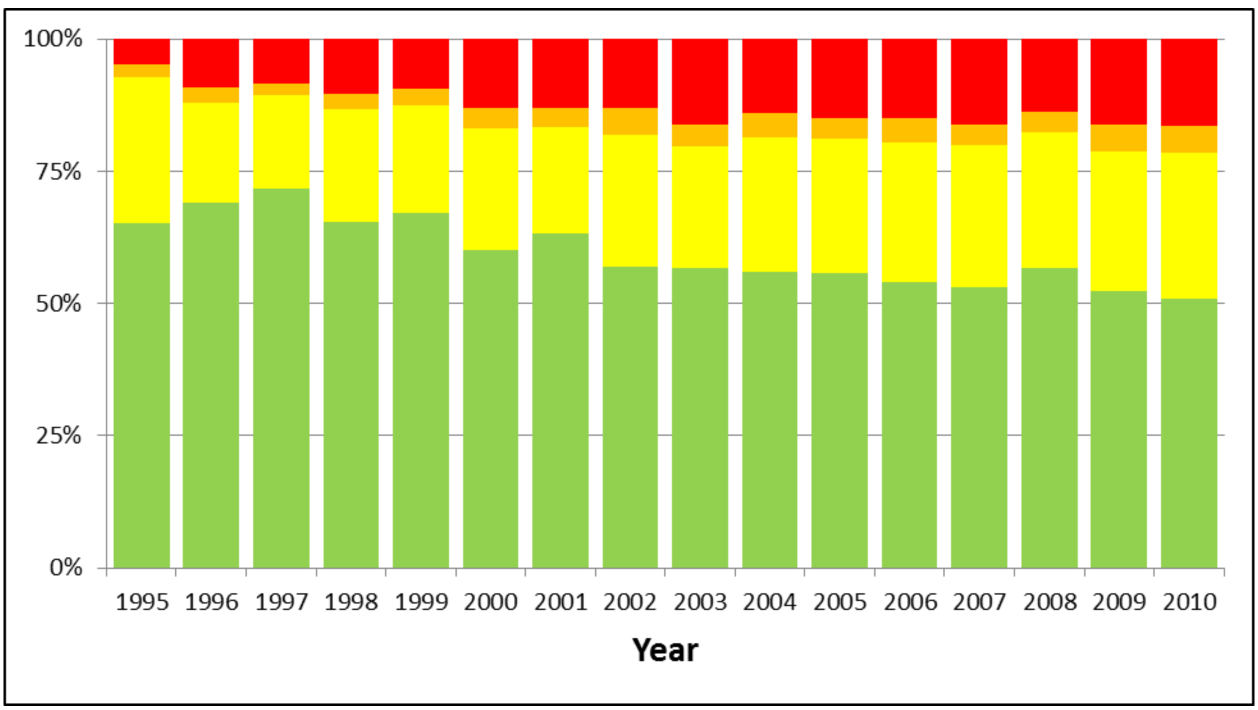

Figure B-44 – Smart Flag 706 Normalized Condition State Trend – Improvement Not Noted

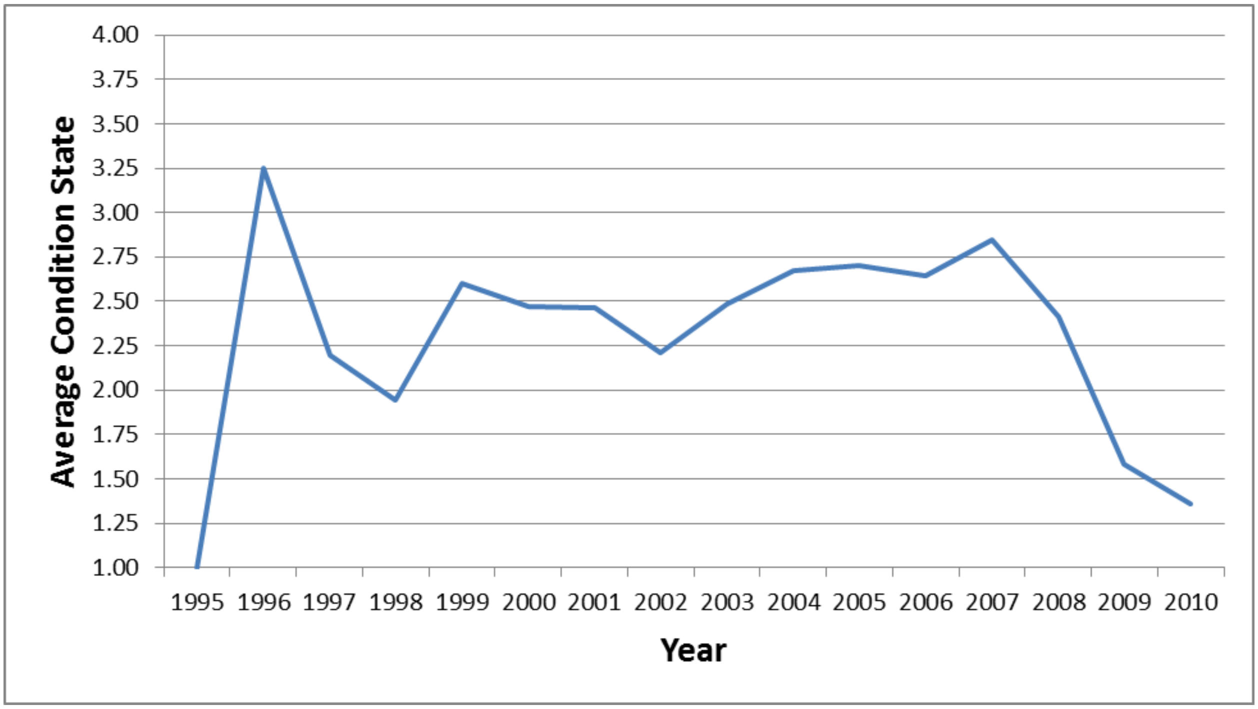

Figure B-45 – Smart Flag 363 (Section Loss) Average Condition State Trend – Improvement Noted

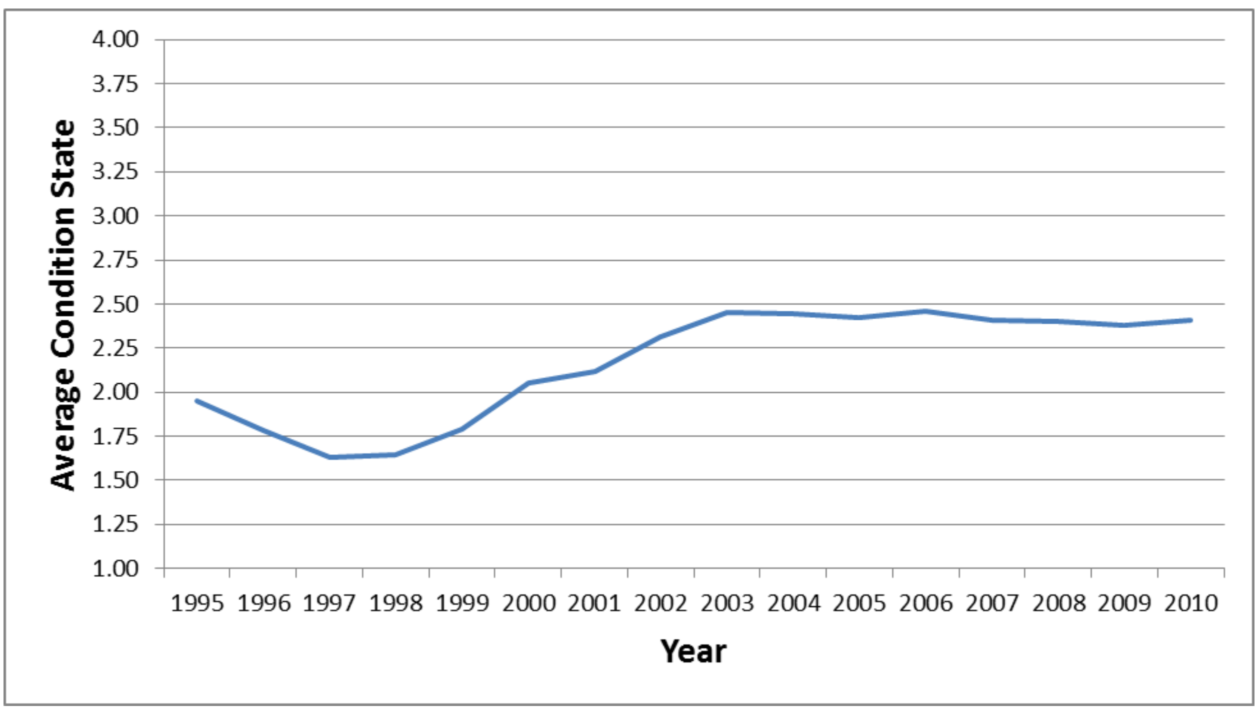

Figure B-46 – Smart Flag 363 Average Condition State Trend – Improvement Not Noted

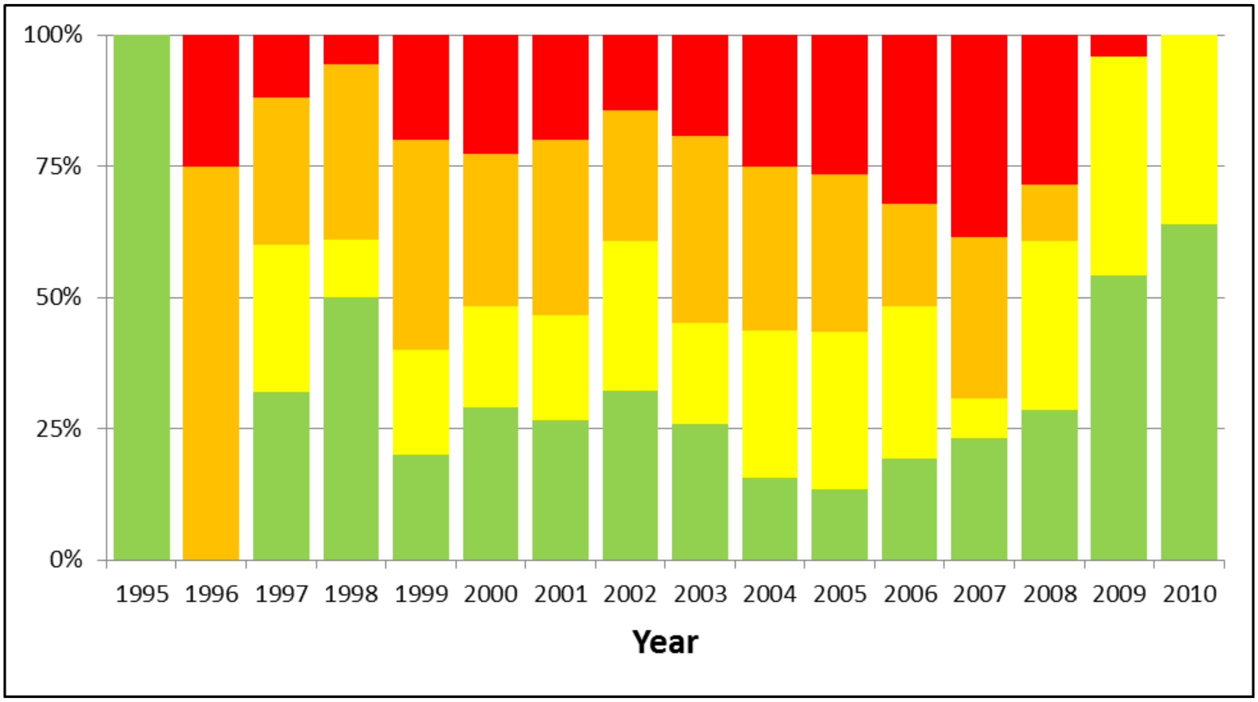

Figure B-47 – Smart Flag 363 Normalized Condition State Trend – Improvement Noted

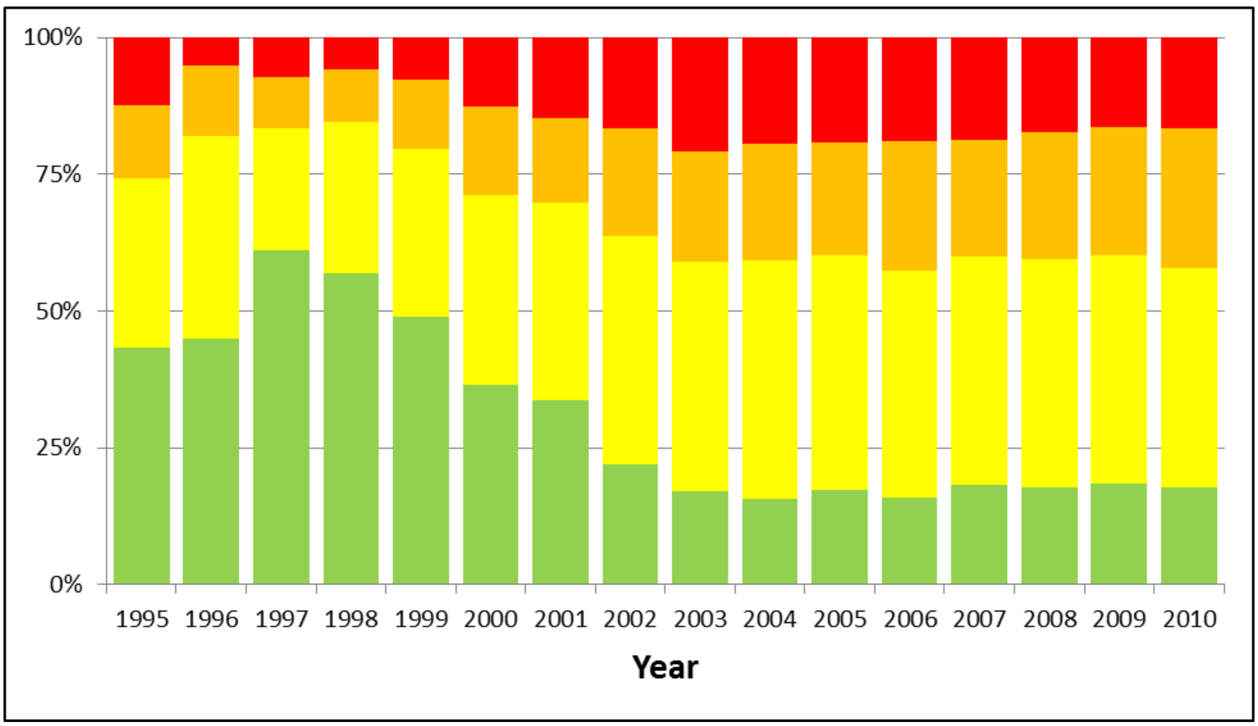

Figure B-48 – Smart Flag 363 Normalized Condition State Trend – Improvement Not Noted

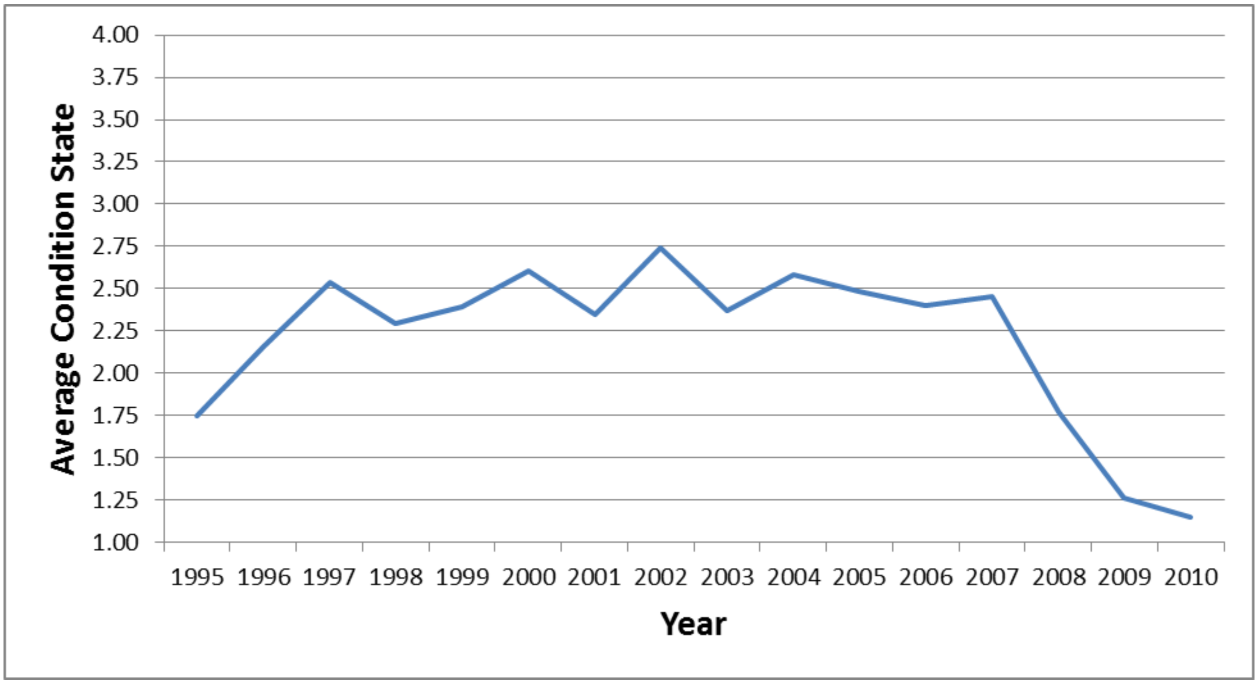

Figure B-49 – Smart Flag 358 (Deck Cracking) Average Condition State Trend – Improvement Noted

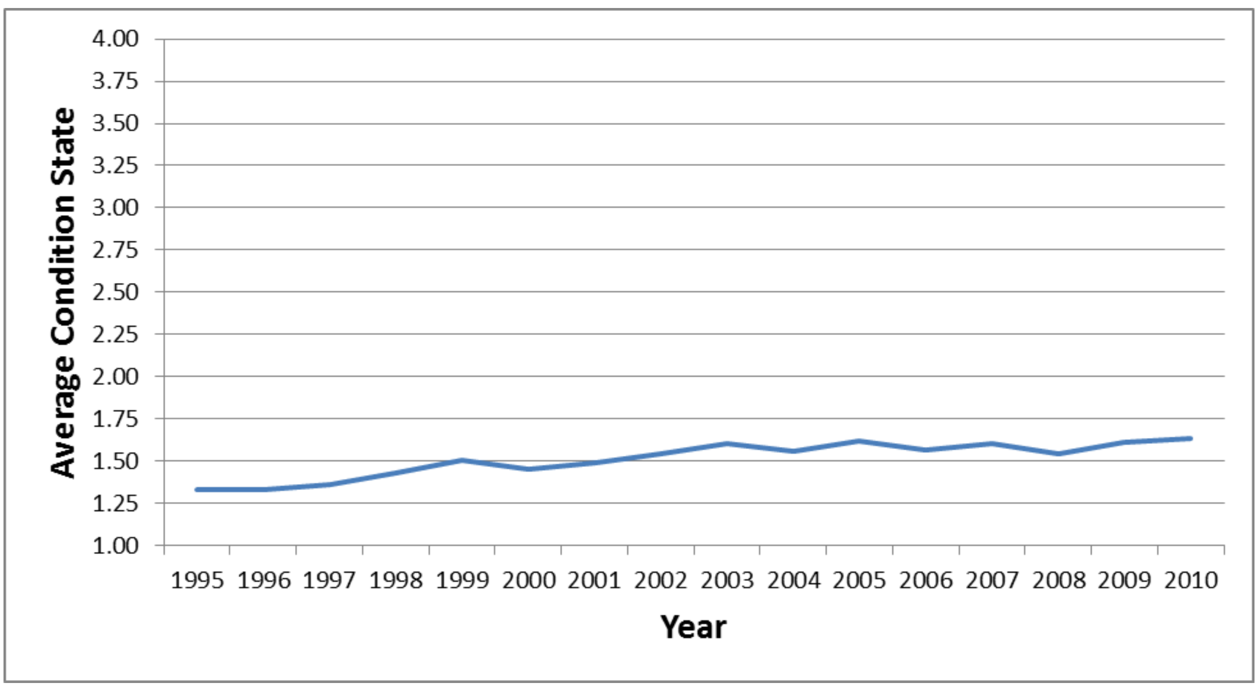

Figure B-50 – Smart Flag 358 Average Condition State Trend – Improvement Not Noted

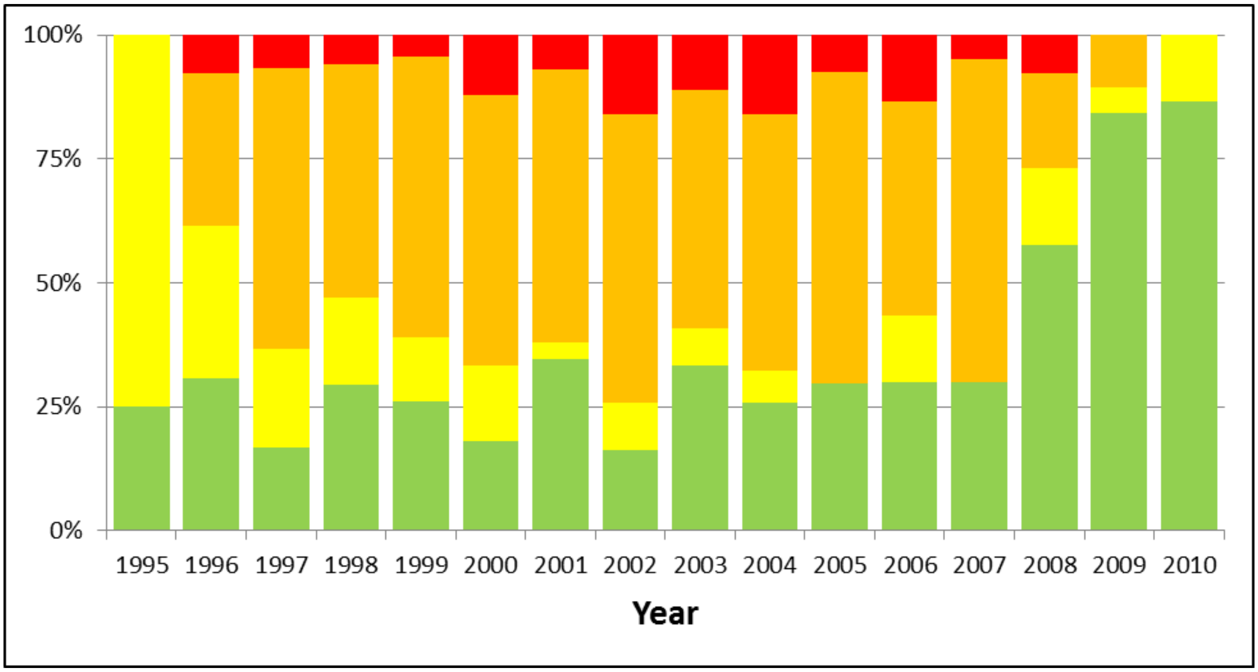

Figure B-51 – Smart Flag 358 Normalized Condition State Trend – Improvement Noted

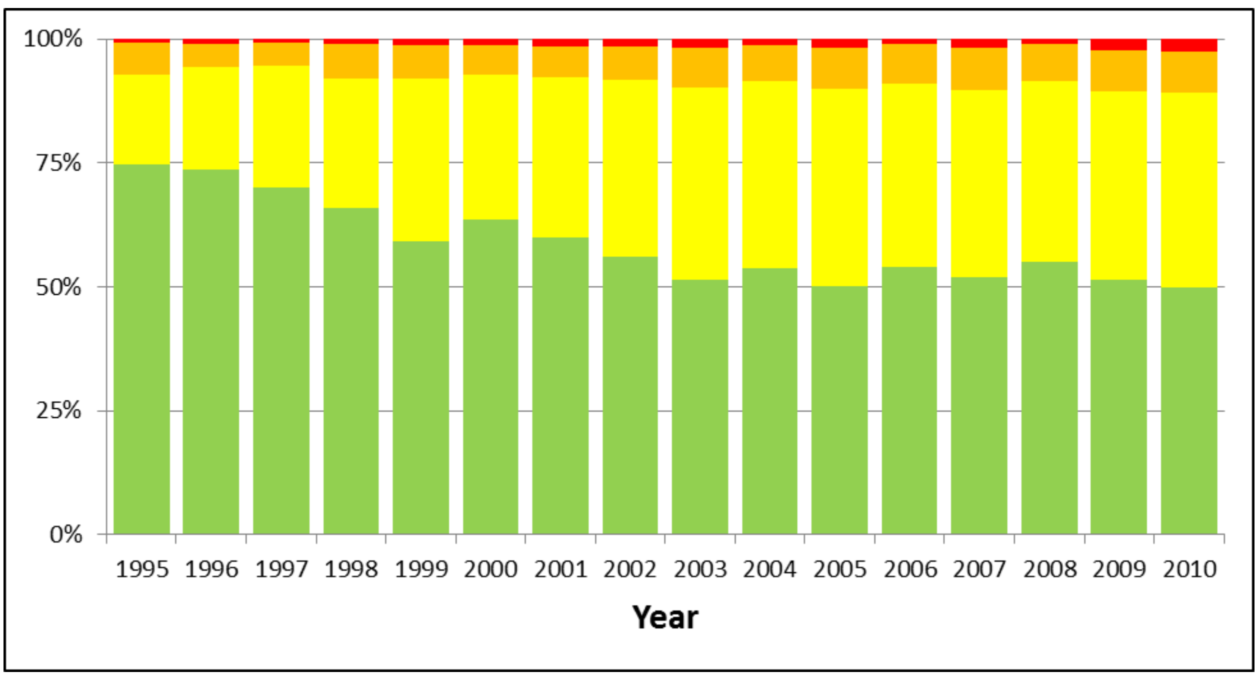

Figure B-52 – Smart Flag 358 Normalized Condition State Trend – Improvement Not Noted

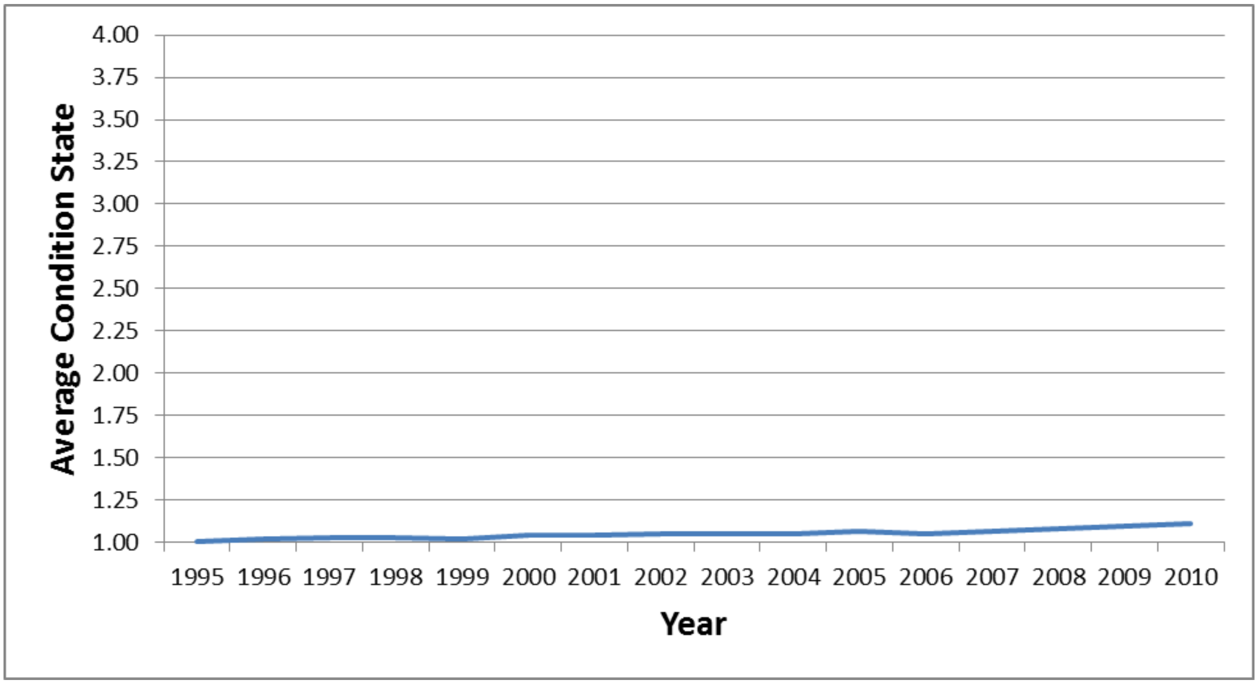

Figure B-53 – Smart Flag 704 (Roadway Over Culverts) Average Condition State Trend – Improvement Noted

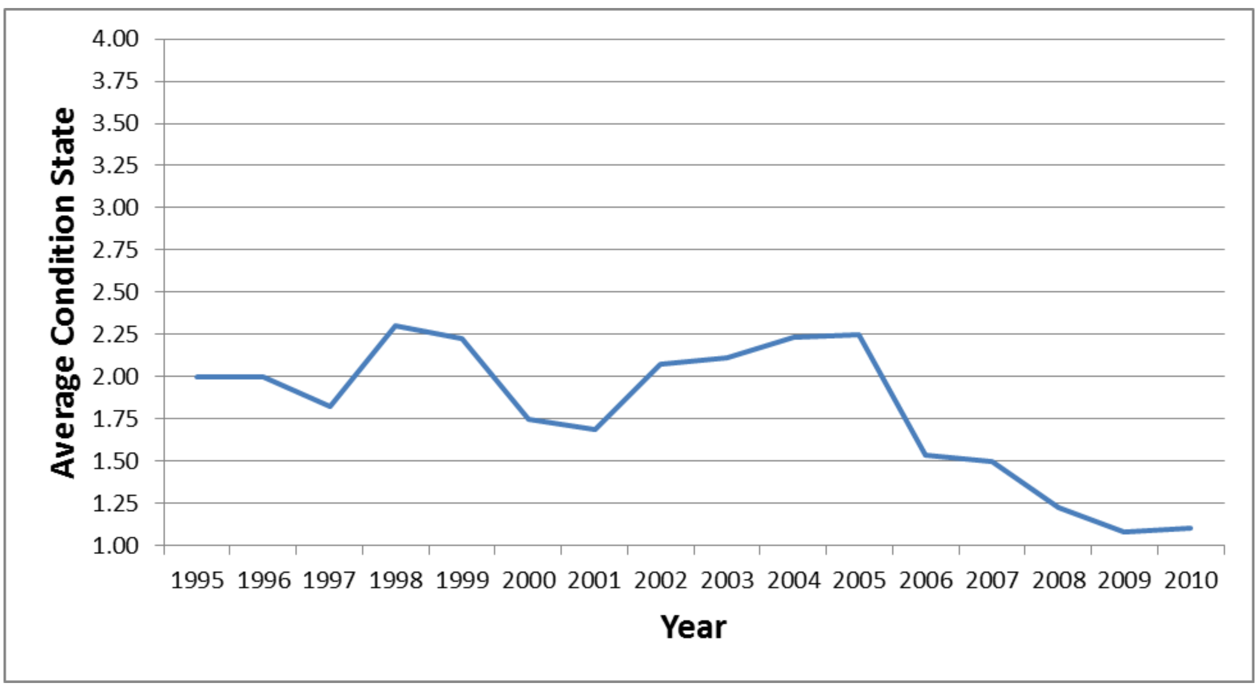

Figure B-54 – Smart Flag 704 Average Condition State Trend – Improvement Not Noted

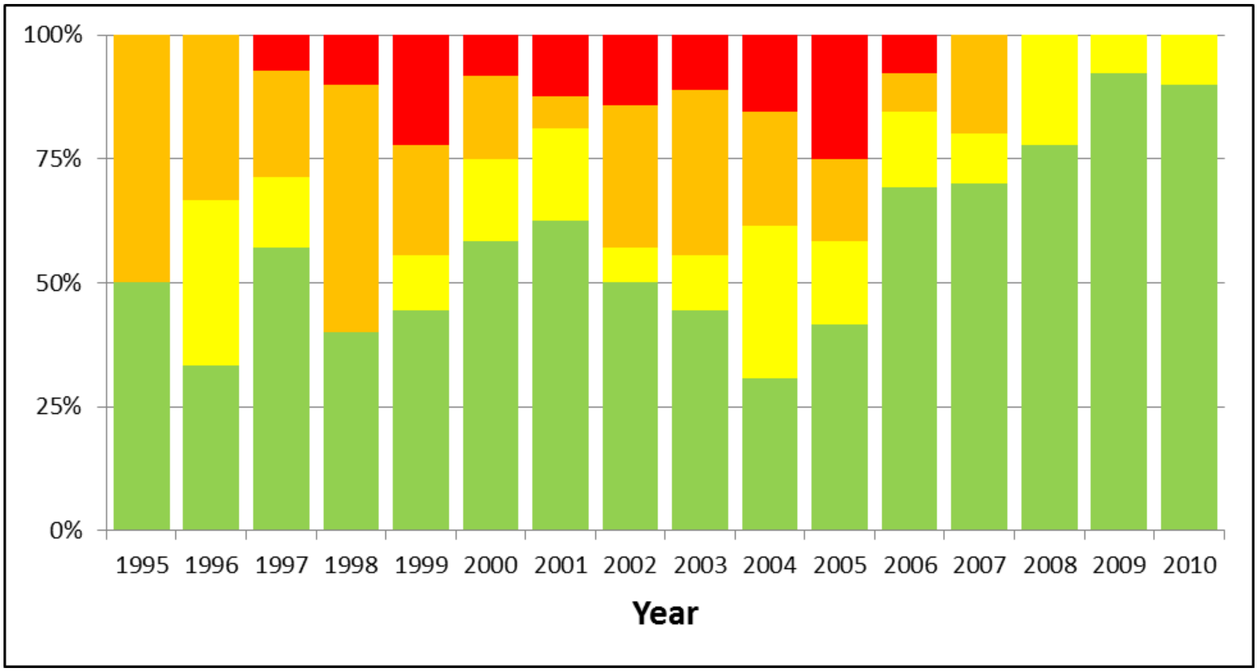

Figure B-55 – Smart Flag 704 Normalized Condition State Trend – Improvement Noted

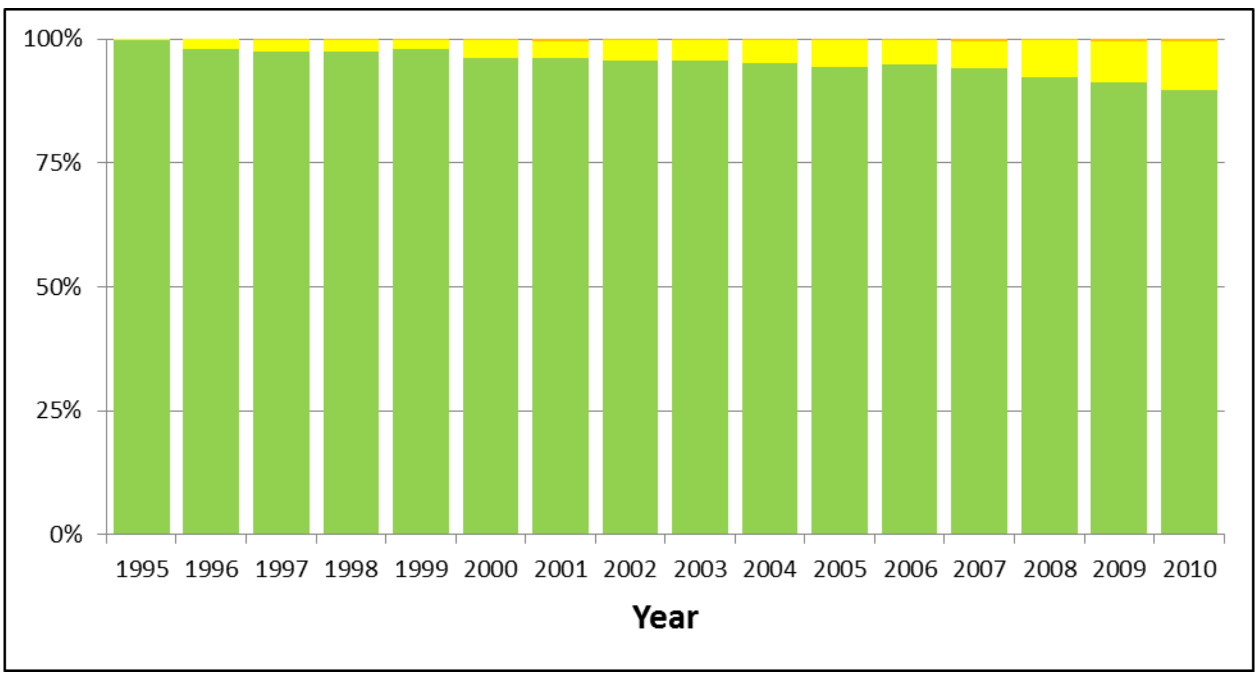

Figure B-56 - Smart Flag 704 Normalized Condition State Trend – Improvement Not Noted

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Count	0	0	1	1	14	14	13	20	12	16	32	19	14	17	14	15
Before	0.00	0.00	3.00	4.00	3.25	3.14	3.19	3.35	3.25	3.34	3.18	3.16	3.43	3.29	3.36	3.40
After	0.00	0.00	1.00	1.00	1.07	1.07	1.08	1.23	1.00	1.38	1.09	1.05	1.00	1.06	1.07	1.00

Table B-1 - Statewide Condition State Improvements by Year for Element 32

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Count	0	0	5	7	11	15	8	8	10	20	14	17	26	33	26	13
Before	0.00	0.00	3.71	4.39	3.79	3.93	4.49	4.01	4.20	3.74	3.64	3.34	3.59	3.66	3.94	3.93
After	0.00	0.00	1.45	1.93	1.49	1.75	1.41	1.20	1.42	1.77	1.71	1.28	1.25	1.69	1.67	1.75

Table B-2 - Statewide Condition State Improvements by Year for Element 108

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Count	0	0	0	1	7	8	7	22	17	16	16	11	24	27	36	15
Before	0.00	0.00	0.00	3.00	2.75	2.94	2.82	2.71	2.81	2.81	2.86	2.76	2.67	2.55	2.63	2.84
After	0.00	0.00	0.00	1.00	1.07	1.06	1.01	1.02	1.02	1.13	1.08	1.00	1.05	1.06	1.08	1.17

Table B-3 - Statewide Condition State Improvements by Year for Element 302

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Count	0	0	0	5	4	8	8	15	12	13	16	11	11	5	8	9
Before	0.00	0.00	0.00	3.00	3.13	3.63	3.49	2.94	3.00	2.97	2.89	2.85	2.60	2.85	2.79	3.08
After	0.00	0.00	0.00	1.33	1.00	1.62	1.19	1.12	1.11	1.21	1.20	1.12	1.00	1.00	1.15	1.09

Table B-4 - Statewide Condition State Improvements by Year for Element 334

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Count	0	0	1	0	3	7	5	4	3	7	7	5	5	10	33	26
Before	0.00	0.00	3.00	0.00	2.88	3.81	3.08	3.19	3.26	3.37	3.33	3.66	3.47	3.33	3.27	3.13
After	0.00	0.00	1.00	0.00	1.50	1.32	1.00	1.38	1.67	1.30	1.41	1.27	1.56	1.69	1.49	1.27

Table B-5 - Statewide Condition State Improvements by Year for Element 240

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Count	0	0	1	2	5	5	3	15	9	7	6	8	20	17	20	12
Before	0.00	0.00	3.00	3.43	3.20	2.86	2.49	2.78	3.23	3.60	2.59	2.80	3.05	3.10	2.88	2.42
After	0.00	0.00	1.46	1.26	1.22	1.31	1.04	1.19	1.44	1.65	1.18	1.08	1.44	1.32	1.19	1.20

Table B-6 - Statewide Condition State Improvements by Year for Element 107

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Count	0	0	0	1	8	21	6	13	13	6	9	10	12	21	34	29
Before	0.00	0.00	0.00	4.00	3.88	4.24	4.17	4.00	3.85	4.00	3.67	4.10	3.83	3.95	3.88	3.95
After	0.00	0.00	0.00	2.00	1.25	1.79	1.50	1.23	1.31	1.67	1.33	1.63	1.71	1.74	1.50	1.67

Table B-7 - Statewide Condition State Improvements by Year for Smart Flag 359

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Count	0	0	0	3	2	4	3	8	7	13	4	11	9	17	14	9
Before	0.00	0.00	0.00	3.33	3.00	3.00	3.00	3.00	3.14	3.23	3.00	3.00	3.33	3.24	3.29	3.33
After	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	1.14	1.08	1.00	1.00	1.22	1.06	1.07	1.33

Table B-8 - Statewide Condition State Improvements by Year for Smart Flag 702

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Count	0	0	0	0	0	6	6	6	5	14	4	4	12	12	8	19
Before	0.00	0.00	0.00	0.00	0.00	3.83	3.83	4.33	3.80	4.00	3.50	4.00	4.00	4.25	4.00	4.32
After	0.00	0.00	0.00	0.00	0.00	1.58	1.17	1.17	1.00	1.43	1.25	1.50	1.67	1.67	1.19	1.34

Table B-9 - Statewide Condition State Improvements by Year for Smart Flag 706

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Count	0	0	0	0	0	2	2	6	1	3	1	0	2	6	9	7
Before	0.00	0.00	0.00	0.00	0.00	3.50	3.50	3.50	4.00	4.00	3.00	0.00	4.00	3.67	3.67	3.43
After	0.00	0.00	0.00	0.00	0.00	1.50	1.00	1.33	1.00	2.00	1.00	0.00	1.50	1.75	1.56	1.29

Table B-10 - Statewide Condition State Improvements by Year for Smart Flag 363

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Count	0	0	0	1	5	2	3	3	1	2	0	3	2	8	9	11
Before	0.00	0.00	0.00	4.00	3.20	3.00	3.00	3.00	3.00	3.00	0.00	3.33	3.00	3.25	3.11	3.36
After	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.13	1.00	1.23

Table B-11 - Statewide Condition State Improvements by Year for Smart Flag 358

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Count	0	0	0	0	1	5	0	1	1	2	2	4	3	0	3	1
Before	0.00	0.00	0.00	0.00	3.00	3.10	0.00	3.00	4.00	3.50	3.00	3.50	3.67	0.00	3.33	3.00
After	0.00	0.00	0.00	0.00	1.00	1.20	0.00	1.00	2.00	1.50	1.00	1.00	1.00	0.00	1.00	1.00

Table B-12 - Statewide Condition State Improvements by Year for Smart Flag 704

Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Total	221.50	61.00	163.00	55.00	138.00	47.50	84.00	36.50	62.00	19.00	29.00	11.00	2.00	1.00	0.00	0.00
Count	202	55	154	51	128	44	76	31	56	16	26	8	1	1	0	0
Average	1.10	1.11	1.06	1.08	1.08	1.08	1.11	1.18	1.11	1.19	1.12	1.38	2.00	1.00		

Table B-13 - Statewide Condition State Trend by Age since Improvement for Element 32

Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Total	333.9	143.7	283.7	124.9	174.2	103.6	116.5	61.5	68.8	35.6	41.6	17.0	8.9	5.0	0.0	0.0
Count	213	72	164	56	101	49	71	34	40	23	24	12	7	3	0	0
Average	1.57	2.00	1.73	2.23	1.72	2.11	1.64	1.81	1.72	1.55	1.73	1.41	1.28	1.68		

Table B-14 - Statewide Condition State Trend by Age since Improvement for Element 108

Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Total	220.64	16.02	141.19	12.36	96.86	15.01	63.90	7.05	36.07	4.32	11.64	0.00	1.00	0.00	0.00	0.00
Count	207	13	134	10	89	11	56	6	30	4	10	0	1	0	0	0
Average	1.07	1.23	1.05	1.24	1.09	1.36	1.14	1.18	1.20	1.08	1.16		1.00			

Table B-15 - Statewide Condition State Trend by Age since Improvement for Element 302

Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Total	145.49	51.65	121.14	45.58	103.83	38.77	66.33	28.95	37.84	18.05	14.75	2.42	4.00	0.00	0.00	0.00
Count	125	40	101	38	86	31	55	23	33	14	13	2	3	0	0	0
Average	1.16	1.29	1.20	1.20	1.21	1.25	1.21	1.26	1.15	1.29	1.13		1.33			

Table B-16 - Statewide Condition State Trend by Age since Improvement for Element 334

Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Total	162.22	19.40	48.80	10.79	48.88	11.43	25.18	5.88	19.94	4.88	6.06	0.00	1.00	0.00	0.00	0.00
Count	116	12	35	6	37	6	16	3	16	3	5	0	1	0	0	0
Average	1.40	1.62	1.39	1.80	1.32	1.90	1.57	1.96	1.25	1.63	1.21		1.00			

Table B-17 - Statewide Condition State Trend by Age since Improvement for Element 240

Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Total	167.44	26.29	112.14	21.77	70.79	12.22	49.63	11.21	31.55	5.19	12.42	2.55	3.27	0.00	0.00	0.00
Count	130	16	85	11	55	8	36	8	22	5	8	2	3	0	0	0
Average	1.29	1.64	1.32	1.98	1.29	1.53	1.38	1.40	1.43	1.04	1.55	1.27	1.09			

Table B-18 - Statewide Condition State Trend by Age since Improvement for Element 107

Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Total	286.17	42.00	161.00	34.00	108.00	31.00	94.00	25.00	66.00	16.00	42.00	5.00	1.00	0.00	0.00	0.00
Count	183	27	108	18	70	16	58	13	38	7	23	3	1	0	0	0
Average	1.56	1.56	1.49	1.89	1.54	1.94	1.62	1.92	1.74	2.29	1.83	1.67	1.00			

Table B-19 - Statewide Condition State Trend by Age since Improvement for Smart Flag 359

Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Total	113.00	25.00	77.00	17.00	50.00	12.00	33.00	6.00	17.00	4.00	7.00	0.00	3.00	0.00	0.00	0.00
Count	104	23	70	16	49	12	33	6	17	4	7	0	3	0	0	0
Average	1.09	1.09	1.10	1.06	1.02	1.00	1.00	1.00	1.00	1.00	1.00		1.00			

Table B-20 - Statewide Condition State Trend by Age since Improvement for Smart Flag 702

Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Total	134.50	21.00	74.00	18.00	45.00	9.00	39.00	10.00	21.00	5.00	7.00	0.00	0.00	0.00	0.00	0.00
Count	96	15	59	13	36	8	30	8	15	3	5	0	0	0	0	0
Average	1.40	1.40	1.25	1.38	1.25	1.13	1.30	1.25	1.40	1.67	1.40					

Table B-21 - Statewide Condition State Trend by Age since Improvement for Smart Flag 706

Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Total	57.50	25.00	26.00	14.00	13.00	4.00	9.00	3.00	6.00	2.00	2.00	0.00	0.00	0.00	0.00	0.00
Count	39	17	18	7	9	3	6	2	5	1	1	0	0	0	0	0
Average	1.47	1.47	1.44	2.00	1.44	1.33	1.50	1.50	1.20	2.00	2.00					

Table B-22 - Statewide Condition State Trend by Age since Improvement for Smart Flag 363

Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Total	53.50	5.00	29.00	0.00	19.00	3.00	14.00	3.00	10.00	3.00	6.00	2.00	0.00	0.00	0.00	0.00
Count	50	3	25	0	16	1	12	1	8	1	5	1	0	0	0	0
Average	1.07	1.67	1.16		1.19	3.00	1.17	3.00	1.25	3.00	1.20	2.00				

Table B-23 - Statewide Condition State Trend by Age since Improvement for Smart Flag 358

Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Total	26.00	9.00	11.00	9.00	12.00	5.00	4.00	0.00	4.00	0.00	3.00	0.00	0.00	0.00	0.00	0.00
Count	23	8	10	6	11	3	4	0	4	0	3	0	0	0	0	0
Average	1.13	1.13	1.10	1.50	1.09	1.67	1.00		1.00		1.00					

Table B-24 - Statewide Condition State Trend by Age since Improvement for Smart Flag 704

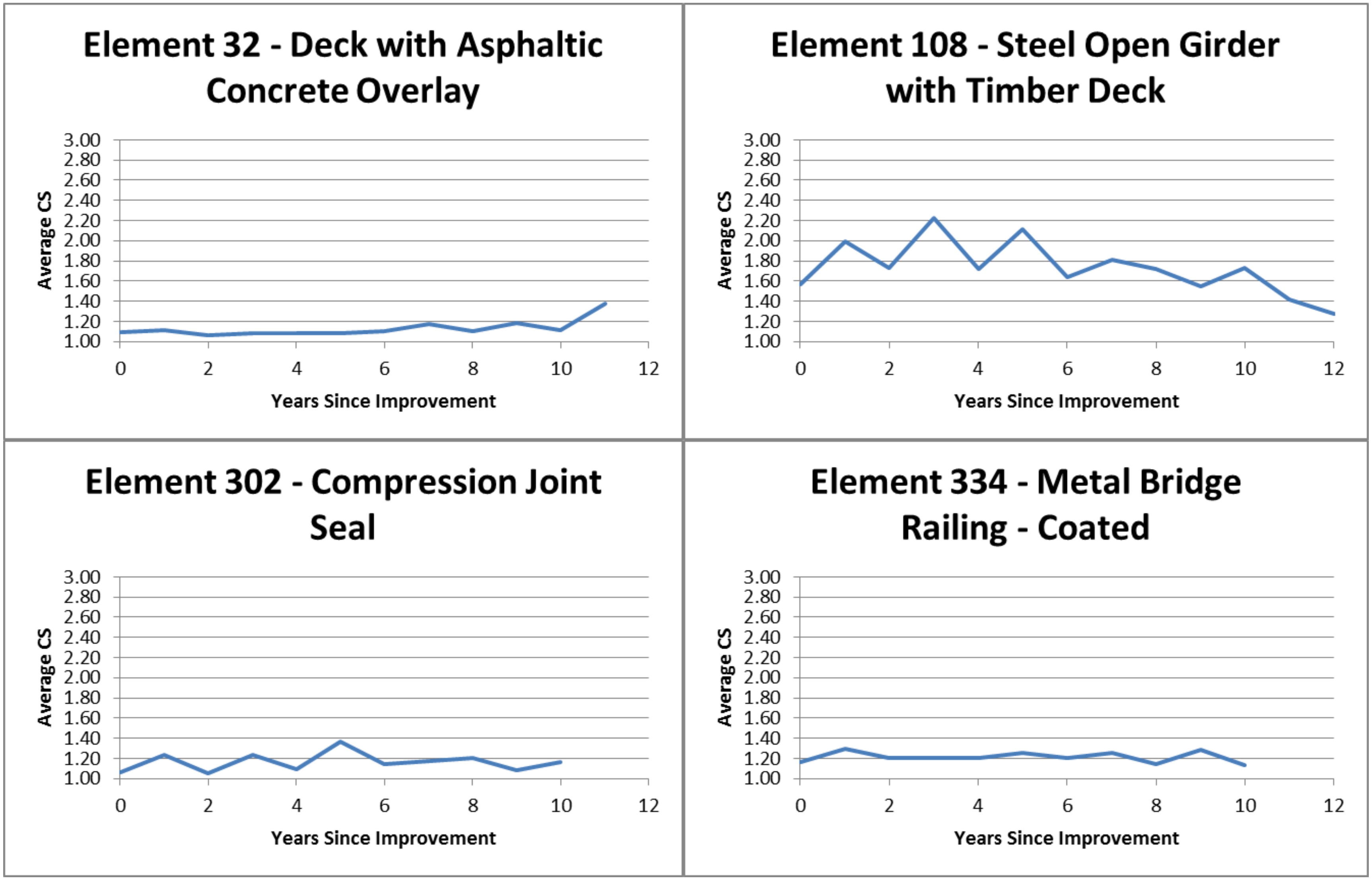

Figure B-57 - Statewide Condition State Trend Lines by Age since Improvement for Elements 32, 108, 302, and 334

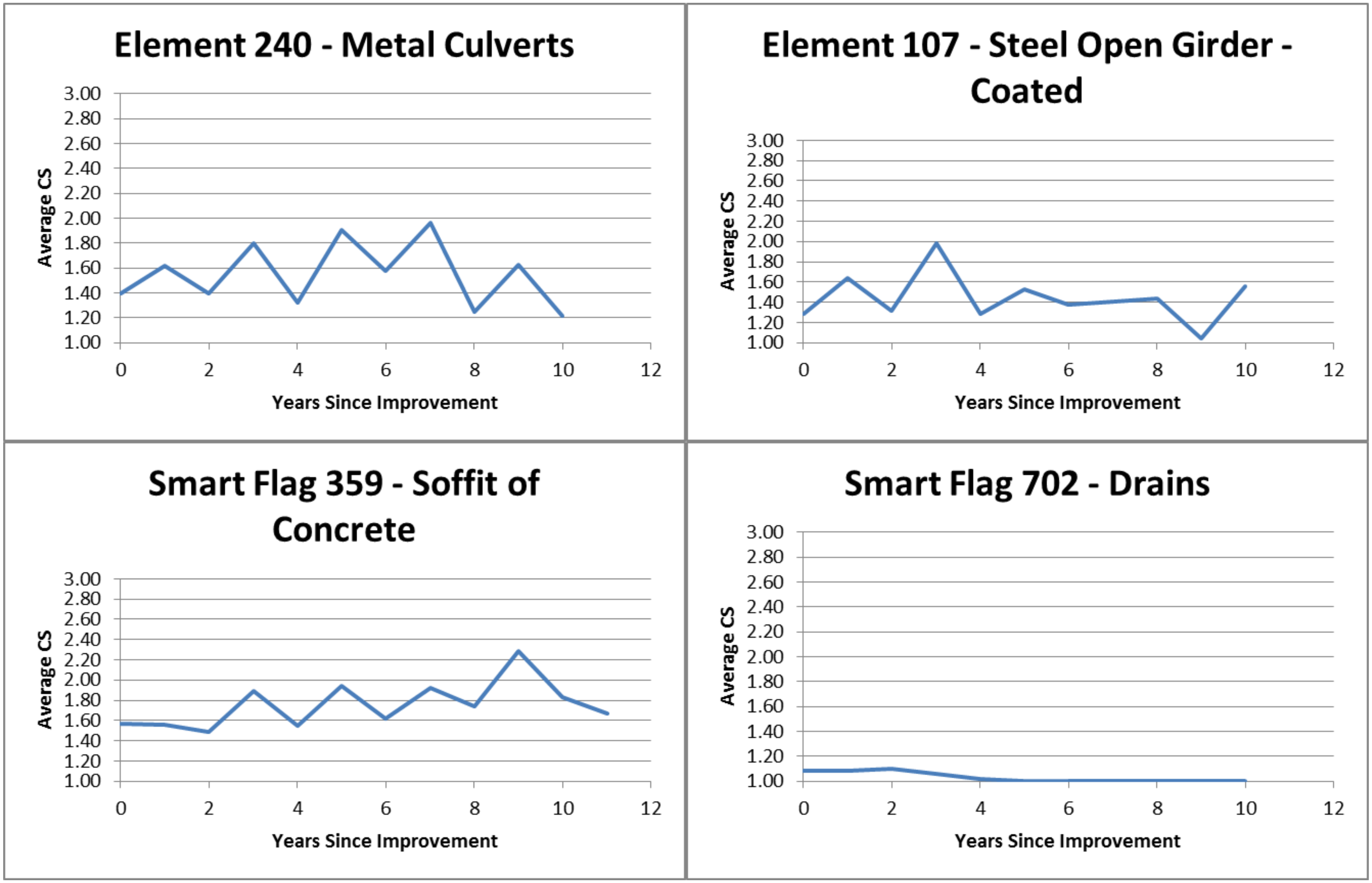

Figure B-58 - Statewide Condition State Trend Lines by Age since Improvement for Elements 240 and 107 and Smart Flags 359 and 702

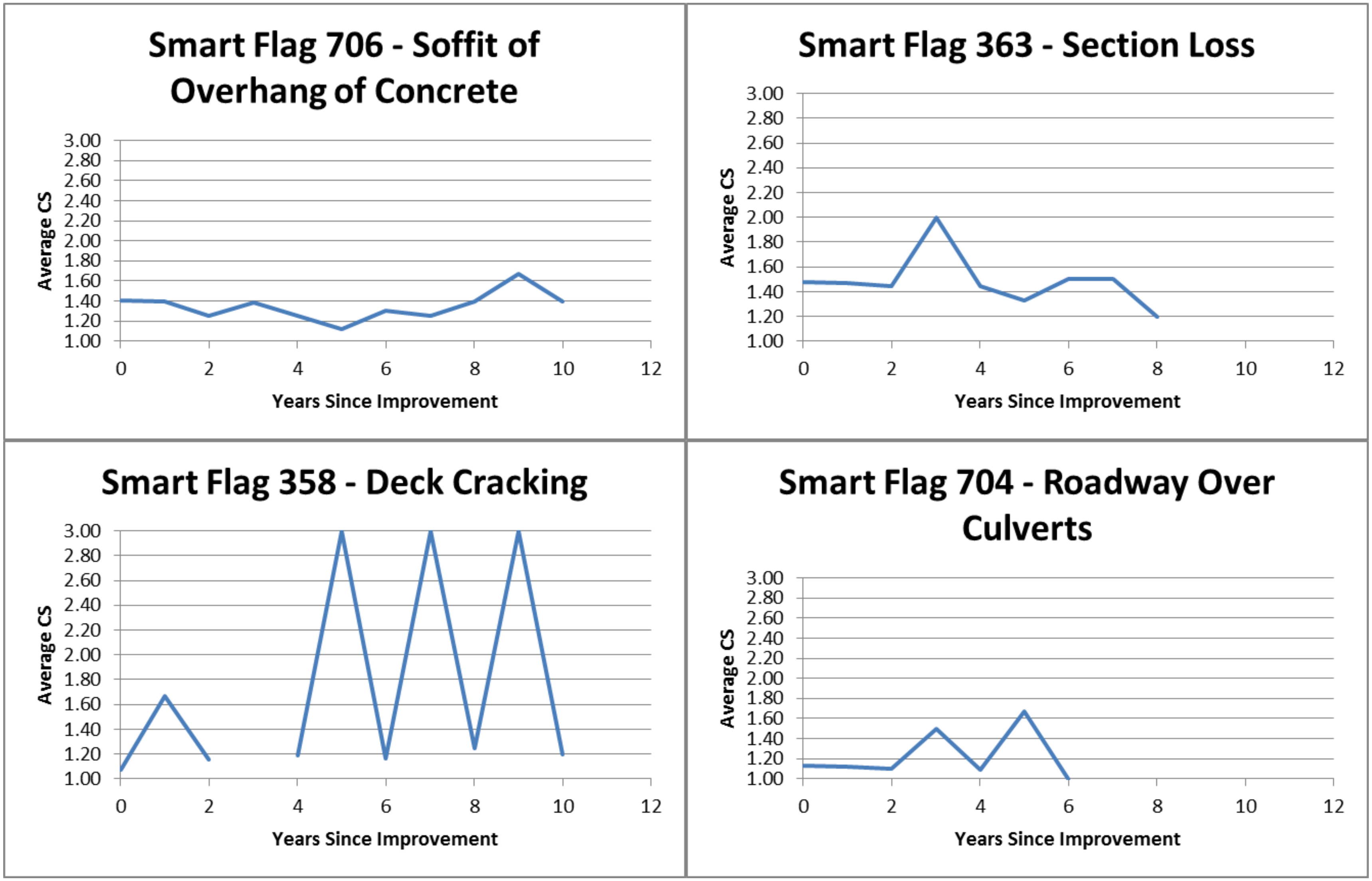

Figure B-59 - Statewide Condition State Trend Lines by Age since Improvement for Smart Flags 706, 363, 358, and 704

APPENDIX C – DISTRICT VISIT RESULTS

Total	*District*									
Element 107	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Total*
Count	6	12	4	15	5	3	8	14	3	70
Avg. Quant.	338.26	407.83	245.43	912.99	624.76	526.31	497.64	339.62	297.33	513.29
Tot. Quant.	2029.56	4893.94	981.73	13694.82	3123.80	1578.94	3981.11	4754.63	892.00	35930.52
CP	50.0%	66.7%	0.0%	40.0%	20.0%	66.7%	75.0%	71.4%	0.0%	51.4%
SR	50.0%	0.0%	25.0%	20.0%	0.0%	0.0%	0.0%	0.0%	0.0%	10.0%
RB	0.0%	0.0%	0.0%	6.7%	0.0%	0.0%	0.0%	0.0%	0.0%	1.4%
AQ	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
NM	0.0%	16.7%	75.0%	33.3%	80.0%	33.3%	25.0%	28.6%	100.0%	34.3%
TE	0.0%	16.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.9%
OT	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table C-1 – District Visit Maintenance Summary – Element 107 – All Road Classifications

Interstate	*District*									
Element 107	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Total*
Count	1	3	0	4	3	0	5	7	0	23
Avg. Quant.	506.94	443.98	N/A	974.14	305.93	N/A	483.86	291.27	N/A	483.10
Tot. Quant.	506.94	1331.93	0.00	3896.55	917.80	0.00	2419.31	2038.89	0.00	11111.41
CP	100.0%	100.0%	N/A	25.0%	0.0%	N/A	80.0%	57.1%	N/A	56.5%
SR	0.0%	0.0%	N/A	50.0%	0.0%	N/A	0.0%	0.0%	N/A	8.7%
RB	0.0%	0.0%	N/A	0.0%	0.0%	N/A	0.0%	0.0%	N/A	0.0%
AQ	0.0%	0.0%	N/A	0.0%	0.0%	N/A	0.0%	0.0%	N/A	0.0%
NM	0.0%	0.0%	N/A	25.0%	100.0%	N/A	20.0%	42.9%	N/A	34.8%
TE	0.0%	0.0%	N/A	0.0%	0.0%	N/A	0.0%	0.0%	N/A	0.0%
OT	0.0%	0.0%	N/A	0.0%	0.0%	N/A	0.0%	0.0%	N/A	0.0%

Table C-2 – District Visit Maintenance Summary – Element 107 – Interstate Roads

Primary	District									
Element 107	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Total*
Count	3	2	1	10	2	2	0	1	3	24
Avg. Quant.	274.38	415.21	332.00	947.72	1103.00	633.04	N/A	495.95	297.33	680.12
Tot. Quant.	823.14	830.42	332.00	9477.19	2206.00	1266.08	0.00	495.95	892.00	16322.77
CP	66.7%	100.0%	0.0%	50.0%	50.0%	50.0%	N/A	0.0%	0.0%	45.8%
SR	33.3%	0.0%	0.0%	10.0%	0.0%	0.0%	N/A	0.0%	0.0%	8.3%
RB	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	N/A	0.0%	0.0%	0.0%
AQ	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	N/A	0.0%	0.0%	0.0%
NM	0.0%	0.0%	100.0%	40.0%	50.0%	50.0%	N/A	100.0%	100.0%	45.8%
TE	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	N/A	0.0%	0.0%	0.0%
OT	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	N/A	0.0%	0.0%	0.0%

Table C-3 – District Visit Maintenance Summary – Element 107 – Primary Roads

Secondary	District									
Element 107	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Total*
Count	2	7	3	1	0	1	3	6	0	23
Avg. Quant.	349.74	390.23	216.58	321.09	N/A	312.86	520.60	369.96	N/A	369.41
Tot. Quant.	699.48	2731.60	649.73	321.09	0.00	312.86	1561.80	2219.79	0.00	8496.34
CP	0.0%	42.9%	0.0%	0.0%	N/A	100.0%	66.7%	100.0%	N/A	52.2%
SR	100.0%	0.0%	33.3%	0.0%	N/A	0.0%	0.0%	0.0%	N/A	13.0%
RB	0.0%	0.0%	0.0%	100.0%	N/A	0.0%	0.0%	0.0%	N/A	4.3%
AQ	0.0%	0.0%	0.0%	0.0%	N/A	0.0%	0.0%	0.0%	N/A	0.0%
NM	0.0%	28.6%	66.7%	0.0%	N/A	0.0%	33.3%	0.0%	N/A	21.7%
TE	0.0%	28.6%	0.0%	0.0%	N/A	0.0%	0.0%	0.0%	N/A	8.7%
OT	0.0%	0.0%	0.0%	0.0%	N/A	0.0%	0.0%	0.0%	N/A	0.0%

Table C-4 – District Visit Maintenance Summary – Element 107 – Secondary Roads

Total	*District*									
Element 108	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Total*
Count	10	13	17	11	10	3	6	14	11	95
Avg. Quant.	93.91	136.66	111.17	188.70	117.87	63.67	126.70	104.50	64.50	115.62
Tot. Quant.	939.06	1776.58	1889.85	2075.74	1178.72	191.00	760.21	1463.07	709.49	10983.72
CP	0.0%	0.0%	0.0%	9.1%	0.0%	0.0%	33.3%	42.9%	9.1%	10.5%
SR	60.0%	84.6%	70.6%	36.4%	50.0%	0.0%	50.0%	42.9%	18.2%	51.6%
RB	0.0%	0.0%	0.0%	18.2%	10.0%	0.0%	0.0%	0.0%	9.1%	4.2%
AQ	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	7.1%	9.1%	2.1%
NM	20.0%	15.4%	23.5%	27.3%	40.0%	33.3%	16.7%	7.1%	45.5%	24.2%
TE	20.0%	0.0%	5.9%	9.1%	0.0%	66.7%	0.0%	0.0%	9.1%	7.4%
OT	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table C-5 – District Visit Maintenance Summary – Element 108 – All Road Classifications

Interstate	*District*									
Element 108	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Total*
Count	0	0	0	0	0	0	0	0	0	0
Avg. Quant.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Tot. Quant.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CP	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SR	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
RB	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
AQ	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
NM	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
TE	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
OT	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Table C-6 – District Visit Maintenance Summary – Element 108 – Interstate Roads

Primary	District									
Element 108	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Total*
Count	0	0	0	0	0	0	0	0	1	1
Avg. Quant.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.00	0.00
Tot. Quant.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CP	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.0%	0.0%
SR	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.0%	0.0%
RB	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100.0%	100.0%
AQ	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.0%	0.0%
NM	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.0%	0.0%
TE	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.0%	0.0%
OT	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.0%	0.0%

Table C-7 – District Visit Maintenance Summary – Element 108 – Primary Roads

Secondary	District									
Element 108	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Total*
Count	10	13	17	11	10	3	6	14	11	95
Avg. Quant.	93.91	136.66	111.17	188.70	117.87	63.67	126.70	104.50	57.35	114.79
Tot. Quant.	939.06	1776.58	1889.85	2075.74	1178.72	191.00	760.21	1463.07	630.86	10905.09
CP	0.0%	0.0%	0.0%	9.1%	0.0%	0.0%	33.3%	42.9%	9.1%	10.5%
SR	60.0%	84.6%	70.6%	36.4%	50.0%	0.0%	50.0%	42.9%	18.2%	51.6%
RB	0.0%	0.0%	0.0%	18.2%	10.0%	0.0%	0.0%	0.0%	0.0%	3.2%
AQ	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	7.1%	9.1%	2.1%
NM	20.0%	15.4%	23.5%	27.3%	40.0%	33.3%	16.7%	7.1%	45.5%	24.2%
TE	20.0%	0.0%	5.9%	9.1%	0.0%	66.7%	0.0%	0.0%	9.1%	7.4%
OT	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table C-8 – District Visit Maintenance Summary – Element 108 – Secondary Roads

Total	District									
Element 301	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Total*
Count	10	12	3	12	14	23	11	6	11	102
Avg. Quant.	31.25	28.93	51.73	61.64	44.89	60.87	43.10	17.73	51.52	46.37
Tot. Quant.	312.51	347.14	155.19	739.67	628.46	1400.08	474.12	106.35	566.69	4730.22
DJ	70.0%	41.7%	66.7%	33.3%	42.9%	60.9%	72.7%	50.0%	27.3%	51.0%
AQ	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SR	0.0%	0.0%	0.0%	25.0%	7.1%	0.0%	0.0%	0.0%	0.0%	3.9%
RR	0.0%	0.0%	0.0%	0.0%	0.0%	4.3%	0.0%	0.0%	0.0%	1.0%
NM	20.0%	50.0%	33.3%	41.7%	50.0%	30.4%	27.3%	50.0%	54.5%	39.2%
TE	10.0%	8.3%	0.0%	0.0%	0.0%	4.3%	0.0%	0.0%	9.1%	3.9%
OT	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	9.1%	1.0%

Table C-9 – District Visit Maintenance Summary – Element 301 – All Road Classifications

Interstate	*District*									
Element 301	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Total*
Count	2	0	0	3	3	3	0	0	1	12
Avg. Quant.	37.89	N/A	N/A	58.53	31.36	98.09	N/A	N/A	119.93	63.30
Tot. Quant.	75.78	0.00	0.00	175.60	94.08	294.26	0.00	0.00	119.93	759.64
DJ	100.0%	N/A	N/A	33.3%	33.3%	33.3%	N/A	N/A	0.0%	41.7%
AQ	0.0%	N/A	N/A	0.0%	0.0%	0.0%	N/A	N/A	0.0%	0.0%
SR	0.0%	N/A	N/A	0.0%	0.0%	0.0%	N/A	N/A	0.0%	0.0%
RR	0.0%	N/A	N/A	0.0%	0.0%	33.3%	N/A	N/A	0.0%	8.3%
NM	0.0%	N/A	N/A	66.7%	66.7%	33.3%	N/A	N/A	100.0%	50.0%
TE	0.0%	N/A	N/A	0.0%	0.0%	0.0%	N/A	N/A	0.0%	0.0%
OT	0.0%	N/A	N/A	0.0%	0.0%	0.0%	N/A	N/A	0.0%	0.0%

Table C-10 – District Visit Maintenance Summary – Element 301 – Interstate Roads

Primary	*District*									
Element 301	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Total*
Count	0	0	1	6	4	5	1	1	8	26
Avg. Quant.	N/A	N/A	0.00	29.27	23.52	58.85	0.00	0.00	14.99	29.22
Tot. Quant.	75.78	0.00	0.00	175.60	94.08	294.26	0.00	0.00	119.93	759.64
DJ	N/A	N/A	100.0%	33.3%	50.0%	20.0%	0.0%	0.0%	37.5%	34.6%
AQ	N/A	N/A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SR	N/A	N/A	0.0%	33.3%	25.0%	0.0%	0.0%	0.0%	0.0%	11.5%
RR	N/A	N/A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
NM	N/A	N/A	0.0%	33.3%	25.0%	80.0%	100.0%	100.0%	50.0%	50.0%
TE	N/A	N/A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
OT	N/A	N/A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	12.5%	3.8%

Table C-11 – District Visit Maintenance Summary – Element 301 – Primary Roads

Secondary	*District*									
Element 301	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Total*
Count	8	12	2	3	7	15	10	5	2	64
Avg. Quant.	9.47	0.00	0.00	58.53	13.44	19.62	0.00	0.00	59.96	11.87
Tot. Quant.	75.78	0.00	0.00	175.60	94.08	294.26	0.00	0.00	119.93	759.64
DJ	62.5%	41.7%	50.0%	33.3%	42.9%	80.0%	80.0%	60.0%	0.0%	59.4%
AQ	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SR	0.0%	0.0%	0.0%	33.3%	0.0%	0.0%	0.0%	0.0%	0.0%	1.6%
RR	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
NM	25.0%	50.0%	50.0%	33.3%	57.1%	13.3%	20.0%	40.0%	50.0%	32.8%
TE	12.5%	8.3%	0.0%	0.0%	0.0%	6.7%	0.0%	0.0%	50.0%	6.3%
OT	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table C-12 – District Visit Maintenance Summary – Element 301 – Secondary Roads

Total	*District*									
Element 302	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Total*
Count	9	12	14	9	15	18	8	18	13	116
Avg. Quant.	74.18	47.95	57.19	39.79	64.54	45.63	60.83	48.44	72.85	56.01
Tot. Quant.	667.65	575.43	800.68	358.07	968.15	821.29	486.60	871.83	947.08	6496.79
DJ	44.4%	75.0%	92.9%	11.1%	53.3%	27.8%	50.0%	77.8%	15.4%	51.7%
AQ	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	5.6%	0.0%	0.9%
SR	11.1%	0.0%	0.0%	22.2%	0.0%	0.0%	0.0%	0.0%	0.0%	2.6%
RR	11.1%	0.0%	0.0%	0.0%	0.0%	5.6%	0.0%	5.6%	0.0%	2.6%
NM	33.3%	25.0%	7.1%	66.7%	46.7%	66.7%	25.0%	11.1%	76.9%	39.7%
TE	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	12.5%	0.0%	7.7%	1.7%
OT	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	12.5%	0.0%	0.0%	0.9%

Table C-13 – District Visit Maintenance Summary – Element 302 – All Road Classifications

Interstate	*District*									
Element 302	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Total*
Count	1	1	0	5	9	2	2	10	4	34
Avg. Quant.	66.00	73.07	N/A	39.20	75.28	63.10	69.24	49.75	109.79	65.11
Tot. Quant.	66.00	73.07	0.00	195.98	677.51	126.20	138.48	497.48	439.17	2213.89
DJ	100.0%	0.0%	N/A	20.0%	33.3%	50.0%	50.0%	80.0%	25.0%	47.1%
AQ	0.0%	0.0%	N/A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
SR	0.0%	0.0%	N/A	40.0%	0.0%	0.0%	0.0%	0.0%	0.0%	5.9%
RR	0.0%	0.0%	N/A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
NM	0.0%	100.0%	N/A	40.0%	66.7%	50.0%	0.0%	20.0%	75.0%	44.1%
TE	0.0%	0.0%	N/A	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
OT	0.0%	0.0%	N/A	0.0%	0.0%	0.0%	50.0%	0.0%	0.0%	2.9%

Table C-14 – District Visit Maintenance Summary – Element 302 – Interstate Roads

Primary	District									
Element 302	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Total*
Count	4	5	6	2	3	12	5	0	6	43
Avg. Quant.	95.94	48.20	89.84	52.99	57.03	43.02	62.25	N/A	38.43	58.12
Tot. Quant.	383.75	241.01	539.06	105.98	171.08	516.30	311.23	0.00	230.57	2498.97
DJ	25.0%	100.0%	83.3%	0.0%	66.7%	33.3%	60.0%	N/A	16.7%	48.8%
AQ	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	N/A	0.0%	0.0%
SR	25.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	N/A	0.0%	2.3%
RR	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	N/A	0.0%	0.0%
NM	50.0%	0.0%	16.7%	100.0%	33.3%	66.7%	40.0%	N/A	83.3%	48.8%
TE	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	N/A	0.0%	0.0%
OT	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	N/A	0.0%	0.0%

Table C-15 – District Visit Maintenance Summary – Element 302 – Primary Roads

Secondary	District									
Element 302	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Total*
Count	4	6	8	2	3	4	1	8	3	39
Avg. Quant.	54.48	43.56	32.70	28.06	39.85	44.70	36.89	46.79	92.45	45.74
Tot. Quant.	217.90	261.35	261.61	56.11	119.56	178.79	36.89	374.36	277.35	1783.93
DJ	50.0%	66.7%	100.0%	0.0%	100.0%	0.0%	0.0%	75.0%	0.0%	59.0%
AQ	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	12.5%	0.0%	2.6%
SR	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
RR	25.0%	0.0%	0.0%	0.0%	0.0%	25.0%	0.0%	12.5%	0.0%	7.7%
NM	25.0%	33.3%	0.0%	100.0%	0.0%	75.0%	0.0%	0.0%	66.7%	25.6%
TE	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	33.3%	5.1%
OT	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

Table C-16 – District Visit Maintenance Summary – Element 302 – Secondary Roads

Total	*District*									
Element 311	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Total*
Count	7	5	1	9	0	1	0	2	2	27
Avg. Quant.	24.54	15.20	15.00	19.32	N/A	70.00	N/A	70.00	15.40	25.09
Tot. Quant.	171.79	76.00	15.00	173.84	0.00	70.00	0.00	140.00	30.80	677.43
BR	14.3%	0.0%	100.0%	11.1%	N/A	0.0%	N/A	50.0%	50.0%	18.5%
BP	0.0%	40.0%	0.0%	22.2%	N/A	0.0%	N/A	50.0%	0.0%	18.5%
SR	71.4%	0.0%	0.0%	11.1%	N/A	0.0%	N/A	0.0%	0.0%	22.2%
AQ	0.0%	0.0%	0.0%	0.0%	N/A	0.0%	N/A	0.0%	0.0%	0.0%
NM	0.0%	40.0%	0.0%	55.6%	N/A	100.0%	N/A	0.0%	50.0%	33.3%
TE	0.0%	0.0%	0.0%	0.0%	N/A	0.0%	N/A	0.0%	0.0%	0.0%
OT	14.3%	20.0%	0.0%	0.0%	N/A	0.0%	N/A	0.0%	0.0%	7.4%

Table C-17 – District Visit Maintenance Summary – Element 311 – All Road Classifications

Interstate	*District*									
Element 311	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Total*
Count	0	2	0	4	0	1	0	2	0	9
Avg. Quant.	N/A	14.50	N/A	23.03	N/A	70.00	N/A	70.00	N/A	36.79
Tot. Quant.	0.00	29.00	0.00	92.11	0.00	70.00	0.00	140.00	0.00	331.11
BR	N/A	0.0%	N/A	0.0%	N/A	0.0%	N/A	50.0%	N/A	11.1%
BP	N/A	0.0%	N/A	25.0%	N/A	0.0%	N/A	50.0%	N/A	22.2%
SR	N/A	0.0%	N/A	25.0%	N/A	0.0%	N/A	0.0%	N/A	11.1%
AQ	N/A	0.0%	N/A	0.0%	N/A	0.0%	N/A	0.0%	N/A	0.0%
NM	N/A	50.0%	N/A	50.0%	N/A	100.0%	N/A	0.0%	N/A	44.4%
TE	N/A	0.0%	N/A	0.0%	N/A	0.0%	N/A	0.0%	N/A	0.0%
OT	N/A	50.0%	N/A	0.0%	N/A	0.0%	N/A	0.0%	N/A	11.1%

Table C-18 – District Visit Maintenance Summary – Element 311 – Interstate Roads

Primary	District									
Element 311	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Total*
Count	5	1	1	4	0	0	0	0	1	12
Avg. Quant.	25.49	15.00	15.00	16.43	N/A	N/A	N/A	N/A	28.80	21.00
Tot. Quant.	127.46	15.00	15.00	65.73	0.00	0.00	0.00	0.00	28.80	251.99
BR	20.0%	0.0%	100.0%	25.0%	N/A	N/A	N/A	N/A	0.0%	25.0%
BP	0.0%	100.0%	0.0%	25.0%	N/A	N/A	N/A	N/A	0.0%	16.7%
SR	60.0%	0.0%	0.0%	0.0%	N/A	N/A	N/A	N/A	0.0%	25.0%
AQ	0.0%	0.0%	0.0%	0.0%	N/A	N/A	N/A	N/A	0.0%	0.0%
NM	0.0%	0.0%	0.0%	50.0%	N/A	N/A	N/A	N/A	100.0%	25.0%
TE	0.0%	0.0%	0.0%	0.0%	N/A	N/A	N/A	N/A	0.0%	0.0%
OT	20.0%	0.0%	0.0%	0.0%	N/A	N/A	N/A	N/A	0.0%	8.3%

Table C-19 – District Visit Maintenance Summary – Element 311 – Primary Roads

Secondary	District									
Element 311	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Total*
Count	2	2	0	1	0	0	0	0	1	6
Avg. Quant.	22.17	16.00	N/A	16.00	N/A	N/A	N/A	N/A	2.00	15.72
Tot. Quant.	44.33	32.00	0.00	16.00	0.00	0.00	0.00	0.00	2.00	94.33
BR	0.0%	0.0%	N/A	0.0%	N/A	N/A	N/A	N/A	100.0%	16.7%
BP	0.0%	50.0%	N/A	0.0%	N/A	N/A	N/A	N/A	0.0%	16.7%
SR	100.0%	0.0%	N/A	0.0%	N/A	N/A	N/A	N/A	0.0%	33.3%
AQ	0.0%	0.0%	N/A	0.0%	N/A	N/A	N/A	N/A	0.0%	0.0%
NM	0.0%	50.0%	N/A	100.0%	N/A	N/A	N/A	N/A	0.0%	33.3%
TE	0.0%	0.0%	N/A	0.0%	N/A	N/A	N/A	N/A	0.0%	0.0%
OT	0.0%	0.0%	N/A	0.0%	N/A	N/A	N/A	N/A	0.0%	0.0%

Table C-20 – District Visit Maintenance Summary – Element 311 – Secondary Roads

Total	*District*									
Element 313	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Total*
Count	5	1	1	9	0	0	0	1	2	19
Avg. Quant.	18.94	8.00	24.00	20.64	N/A	N/A	N/A	18.00	21.00	19.60
Tot. Quant.	94.70	8.00	24.00	185.78	0.00	0.00	0.00	18.00	42.00	372.48
BR	20.0%	0.0%	100.0%	11.1%	N/A	N/A	N/A	0.0%	0.0%	15.8%
BP	0.0%	0.0%	0.0%	33.3%	N/A	N/A	N/A	100.0%	50.0%	26.3%
SR	40.0%	0.0%	0.0%	11.1%	N/A	N/A	N/A	0.0%	0.0%	15.8%
AQ	0.0%	0.0%	0.0%	0.0%	N/A	N/A	N/A	0.0%	0.0%	0.0%
NM	40.0%	100.0%	0.0%	44.4%	N/A	N/A	N/A	0.0%	50.0%	42.1%
TE	0.0%	0.0%	0.0%	0.0%	N/A	N/A	N/A	0.0%	0.0%	0.0%
OT	0.0%	0.0%	0.0%	0.0%	N/A	N/A	N/A	0.0%	0.0%	0.0%

Table C-21 – District Visit Maintenance Summary – Element 313 – All Road Classifications

Interstate	*District*									
Element 313	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Total*
Count	0	0	0	2	0	0	0	1	2	5
Avg. Quant.	N/A	N/A	N/A	29.56	N/A	N/A	N/A	18.00	21.00	23.82
Tot. Quant.	0.00	0.00	0.00	59.11	0.00	0.00	0.00	18.00	42.00	119.11
BR	N/A	N/A	N/A	0.0%	N/A	N/A	N/A	0.0%	0.0%	0.0%
BP	N/A	N/A	N/A	50.0%	N/A	N/A	N/A	100.0%	50.0%	60.0%
SR	N/A	N/A	N/A	0.0%	N/A	N/A	N/A	0.0%	0.0%	0.0%
AQ	N/A	N/A	N/A	0.0%	N/A	N/A	N/A	0.0%	0.0%	0.0%
NM	N/A	N/A	N/A	50.0%	N/A	N/A	N/A	0.0%	50.0%	40.0%
TE	N/A	N/A	N/A	0.0%	N/A	N/A	N/A	0.0%	0.0%	0.0%
OT	N/A	N/A	N/A	0.0%	N/A	N/A	N/A	0.0%	0.0%	0.0%

Table C-22 – District Visit Maintenance Summary – Element 313 – Interstate Roads

Primary	District									
Element 313	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Total*
Count	4	0	0	4	0	0	0	0	0	8
Avg. Quant.	19.93	N/A	N/A	20.75	N/A	N/A	N/A	N/A	N/A	20.34
Tot. Quant.	79.70	0.00	0.00	83.00	0.00	0.00	0.00	0.00	0.00	162.70
BR	25.0%	N/A	N/A	0.0%	N/A	N/A	N/A	N/A	N/A	12.5%
BP	0.0%	N/A	N/A	50.0%	N/A	N/A	N/A	N/A	N/A	25.0%
SR	50.0%	N/A	N/A	0.0%	N/A	N/A	N/A	N/A	N/A	25.0%
AQ	0.0%	N/A	N/A	0.0%	N/A	N/A	N/A	N/A	N/A	0.0%
NM	25.0%	N/A	N/A	50.0%	N/A	N/A	N/A	N/A	N/A	37.5%
TE	0.0%	N/A	N/A	0.0%	N/A	N/A	N/A	N/A	N/A	0.0%
OT	0.0%	N/A	N/A	0.0%	N/A	N/A	N/A	N/A	N/A	0.0%

Table C-23 – District Visit Maintenance Summary – Element 313 – Primary Roads

Secondary	District									
Element 313	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*Total*
Count	1	1	1	3	0	0	0	0	0	6
Avg. Quant.	15.00	8.00	24.00	14.56	N/A	N/A	N/A	N/A	N/A	15.11
Tot. Quant.	15.00	8.00	24.00	43.67	0.00	0.00	0.00	0.00	0.00	90.67
BR	0.0%	0.0%	100.0%	33.3%	N/A	N/A	N/A	N/A	N/A	33.3%
BP	0.0%	0.0%	0.0%	0.0%	N/A	N/A	N/A	N/A	N/A	0.0%
SR	0.0%	0.0%	0.0%	33.3%	N/A	N/A	N/A	N/A	N/A	16.7%
AQ	0.0%	0.0%	0.0%	0.0%	N/A	N/A	N/A	N/A	N/A	0.0%
NM	100.0%	100.0%	0.0%	33.3%	N/A	N/A	N/A	N/A	N/A	50.0%
TE	0.0%	0.0%	0.0%	0.0%	N/A	N/A	N/A	N/A	N/A	0.0%
OT	0.0%	0.0%	0.0%	0.0%	N/A	N/A	N/A	N/A	N/A	0.0%

Table C-24 - District Visit Maintenance Summary – Element 313 – Secondary Roads

Code	*Corresponding Maintenance Action*
CP	Cleaned / Painted Structural Steel
SR	Superstructure Replaced
RB	Replaced Some Beams / Girders
DJ	Deck Joints Resealed
BR	Bearings Replaced
BP	Bearings Painted
AQ	Added Quantity (in CS 1)
RR	Road Repaved
NM	No Maintenance Noted
TE	Typographical Error
ND	No Data
OT	Other

Table C-25 - Maintenance Action Codes and Descriptions

Code	*Corresponding Road Description*	*Road Classification*
1	Rural - Principal Arterial - Interstate	Interstate
2	Rural - Principal Arterial - Other	Primary
6	Rural - Minor Arterial	Primary
7	Rural - Major Collector	Secondary
8	Rural - Minor Collector	Secondary
9	Rural – Local	Secondary
11	Urban - Principal Arterial - Interstate	Interstate
12	Urban - Principal Arterial - Freeway / Expressway	Primary
14	Urban - Other Principal Arterial	Primary
16	Urban - Minor Arterial	Primary
17	Urban - Collector	Secondary
19	Urban – Local	Secondary

Table C-26 - Road Type Codes, Descriptions, and Classifications

APPENDIX D – FULL LLS AND MARKOV CHAIN RESULTS

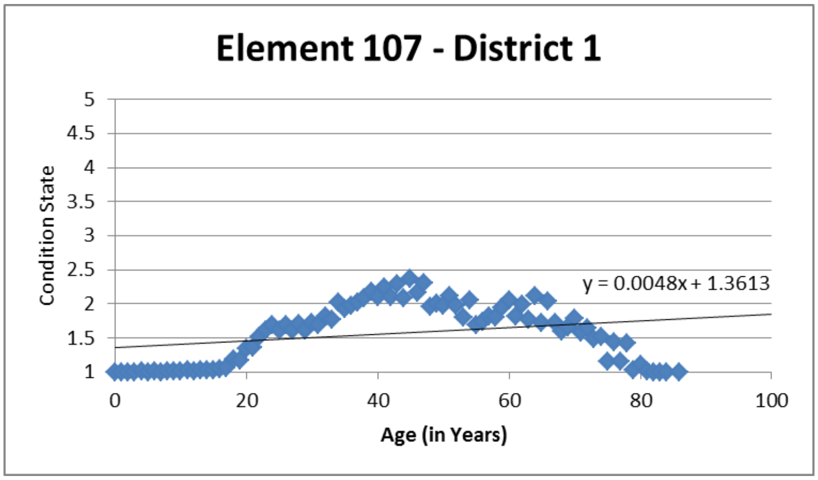

Figure D-1 – Condition State History and Linear Trendline by Age – Element 107 – District 1

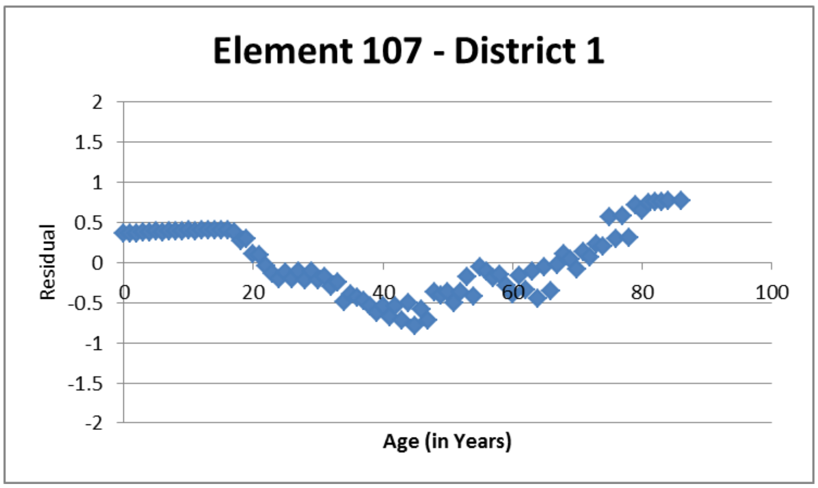

Figure D-2 – Condition States Residuals (Prediction Minus Actual) by Age – Element 107 – District 1

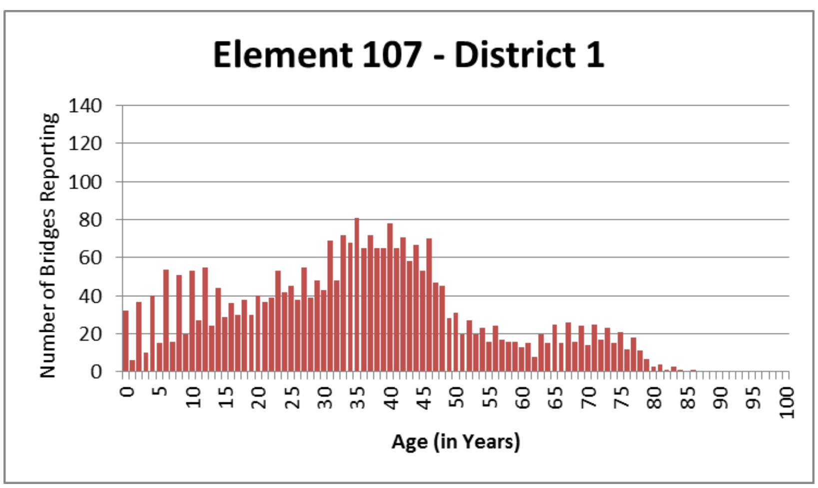

Figure D-3 – Number of Bridges Reporting by Age – Element 107 – District 1

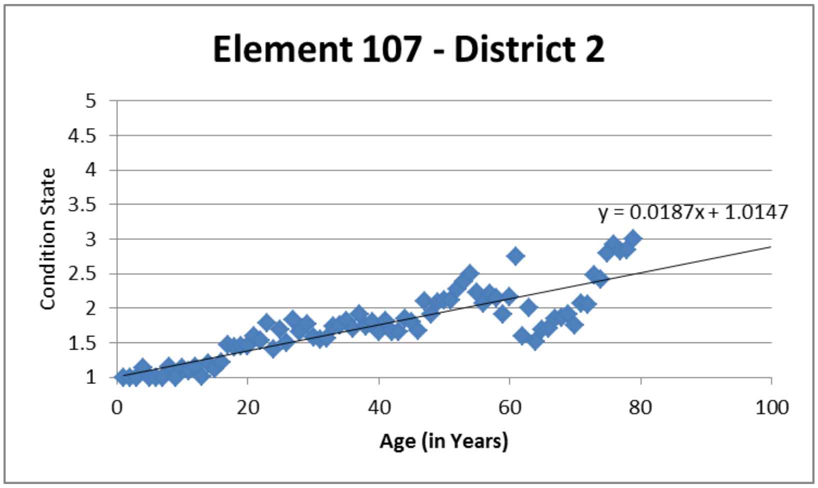

Figure D-4 – Condition State History and Linear Trendline by Age – Element 107 – District 2

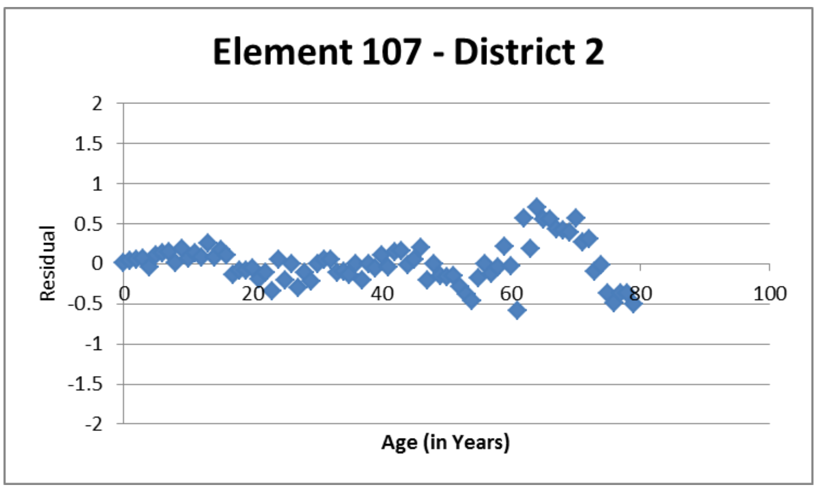

Figure D-5 – Condition States Residuals (Prediction Minus Actual) by Age – Element 107 – District 2

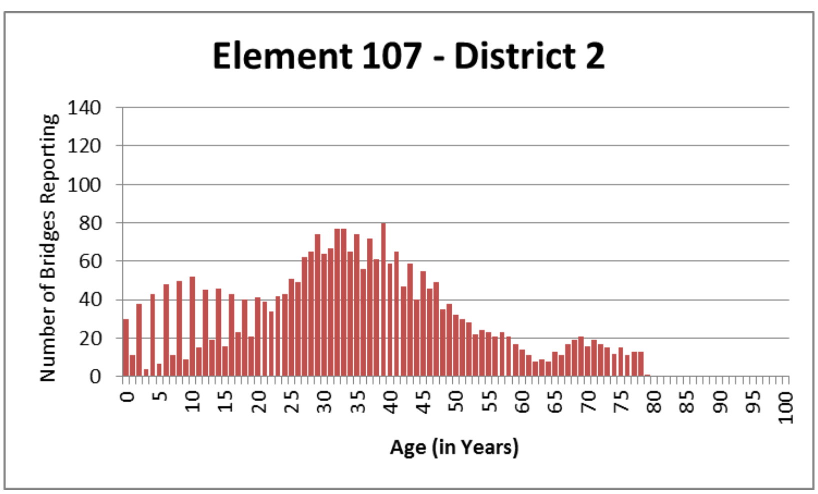

Figure D-6 – Number of Bridges Reporting by Age – Element 107 – District 2

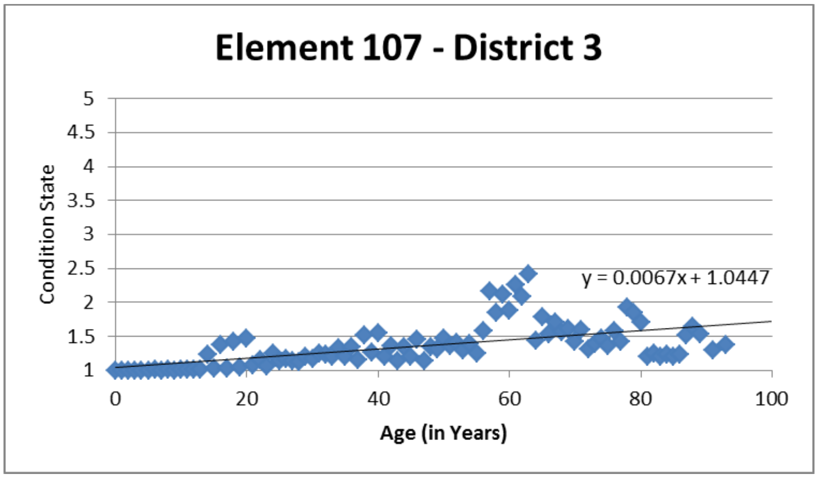

Figure D-7 – Condition State History and Linear Trendline by Age – Element 107 – District 3

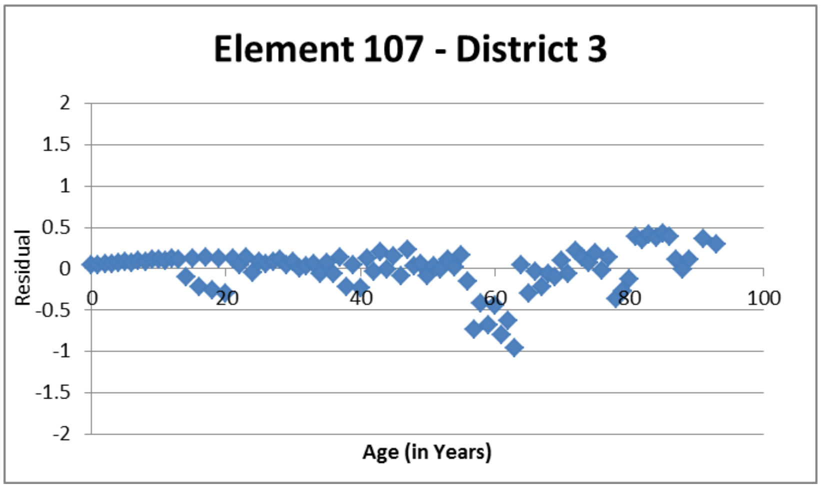

Figure D-8 – Condition States Residuals (Prediction Minus Actual) by Age – Element 107 – District 3

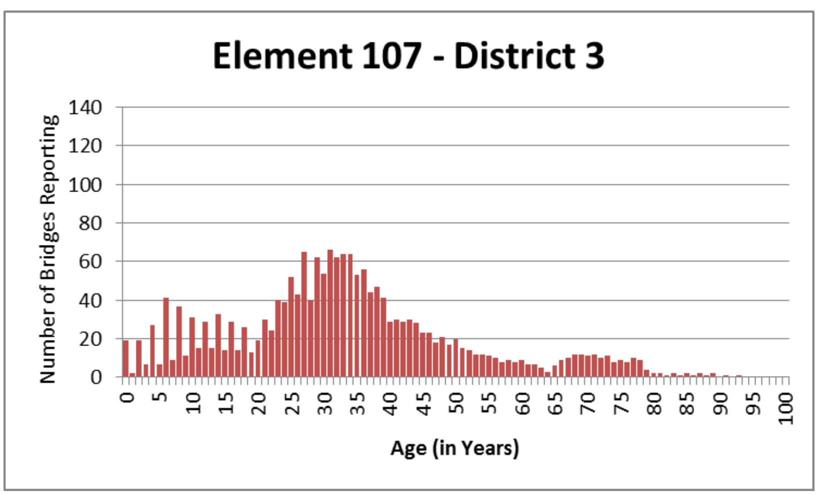

Figure D-9 – Number of Bridges Reporting by Age – Element 107 – District 3

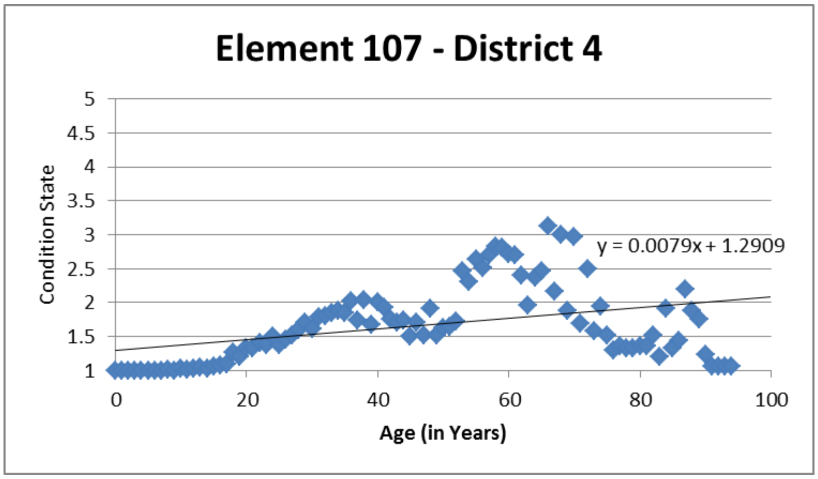

Figure D-10 – Condition State History and Linear Trendline by Age – Element 107 – District 4

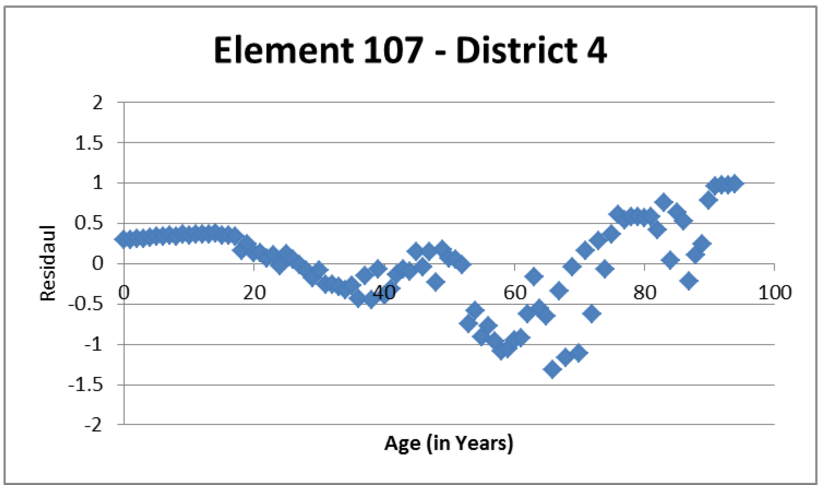

Figure D-11 – Condition States Residuals (Prediction Minus Actual) by Age – Element 107 – District 4

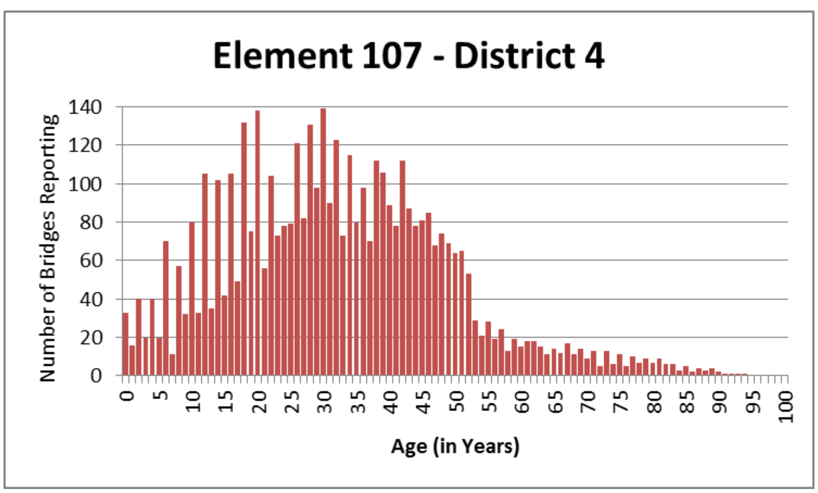

Figure D-12 – Number of Bridges Reporting by Age – Element 107 – District 4

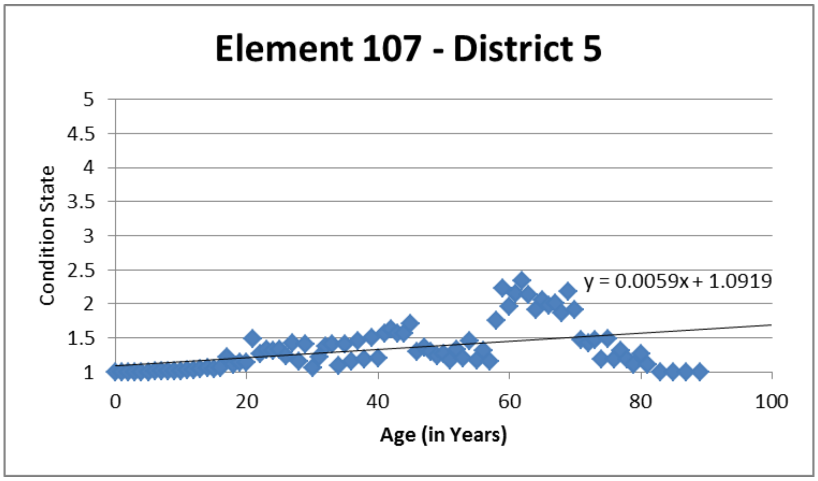

Figure D-13 – Condition State History and Linear Trendline by Age – Element 107 – District 5

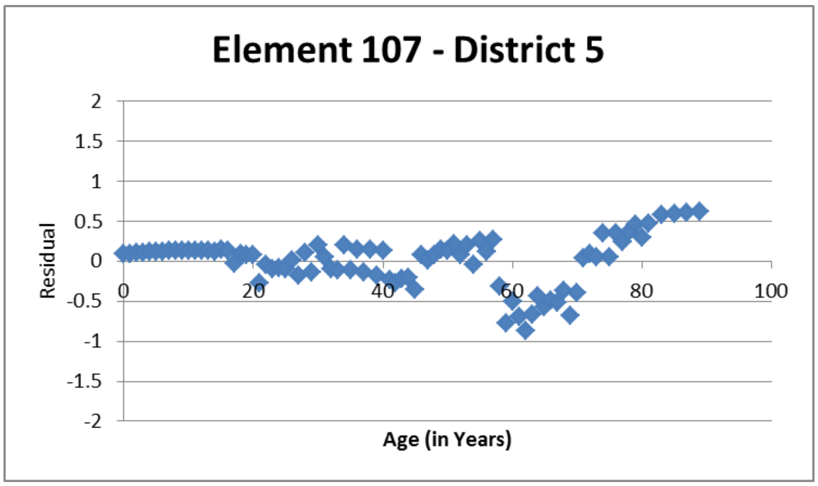

Figure D-14 – Condition States Residuals (Prediction Minus Actual) by Age – Element 107 – District 5

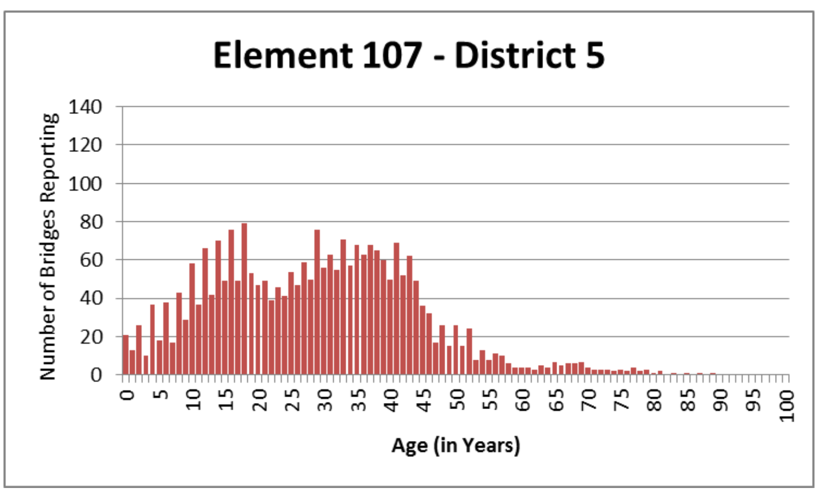

Figure D-15 – Number of Bridges Reporting by Age – Element 107 – District 5

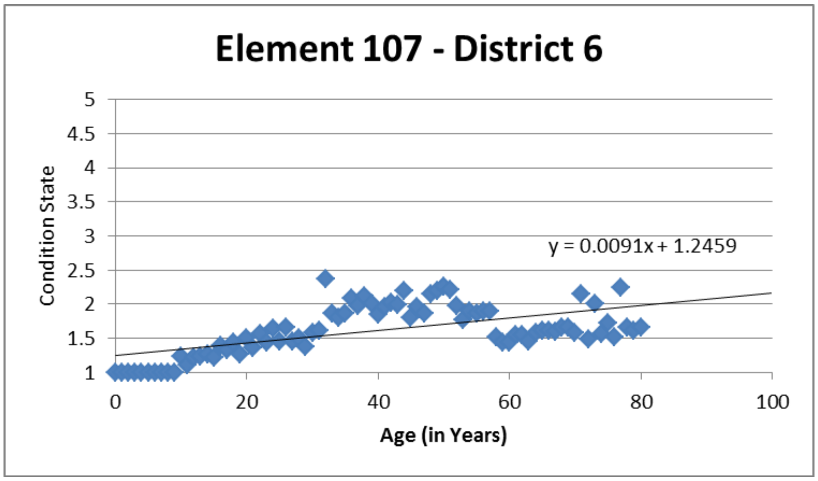

Figure D-16 – Condition State History and Linear Trendline by Age – Element 107 – District 6

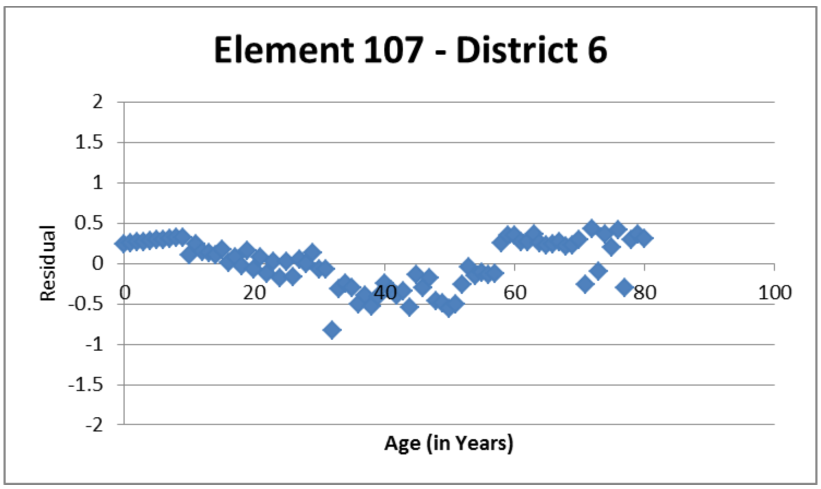

Figure D-17 – Condition States Residuals (Prediction Minus Actual) by Age – Element 107 – District 6

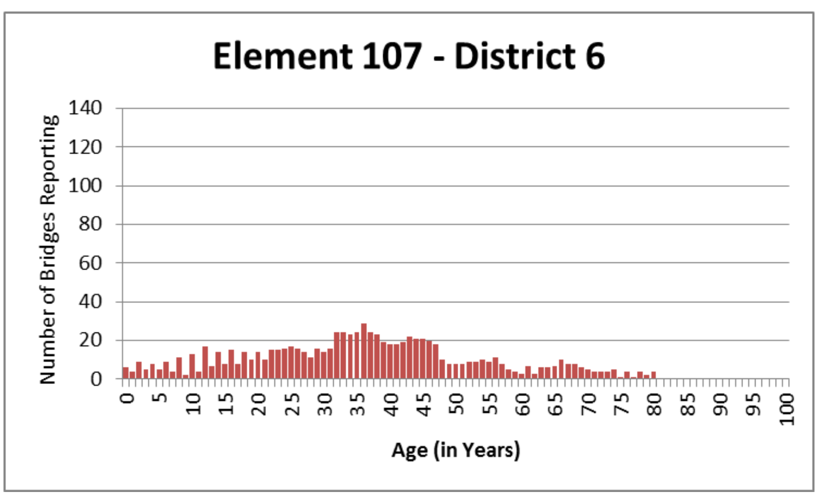

Figure D-18 – Number of Bridges Reporting by Age – Element 107 – District 6

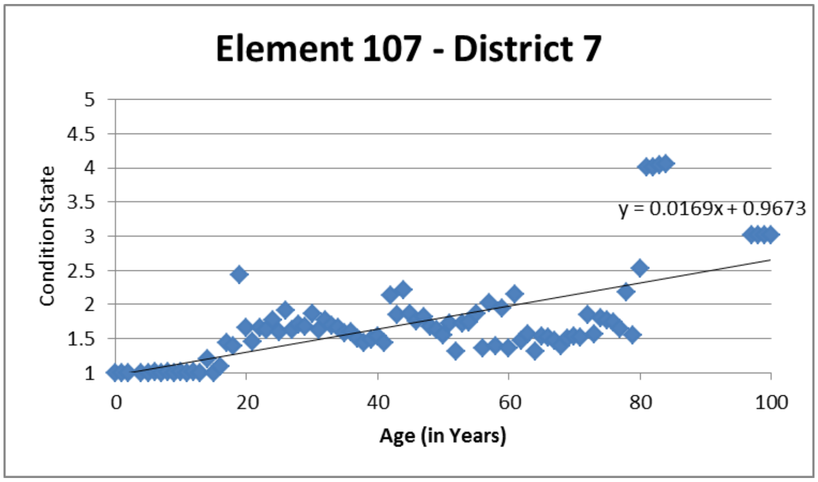

Figure D-19 – Condition State History and Linear Trendline by Age – Element 107 – District 7

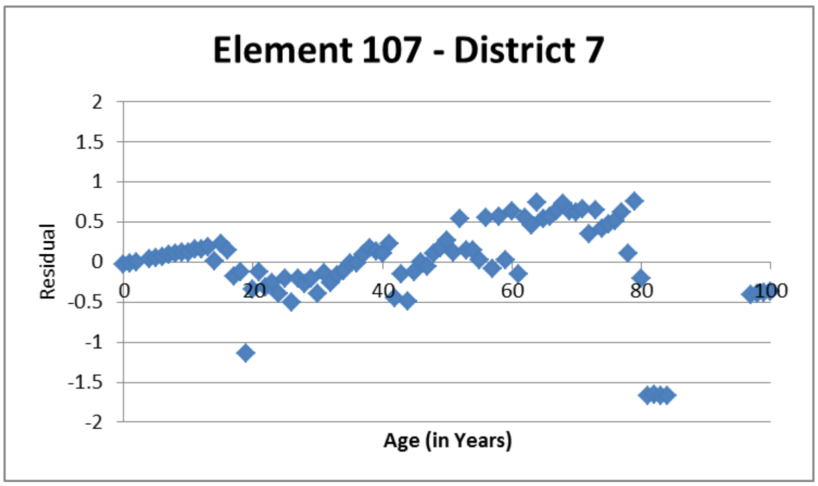

Figure D-20 – Condition States Residuals (Prediction Minus Actual) by Age – Element 107 – District 7

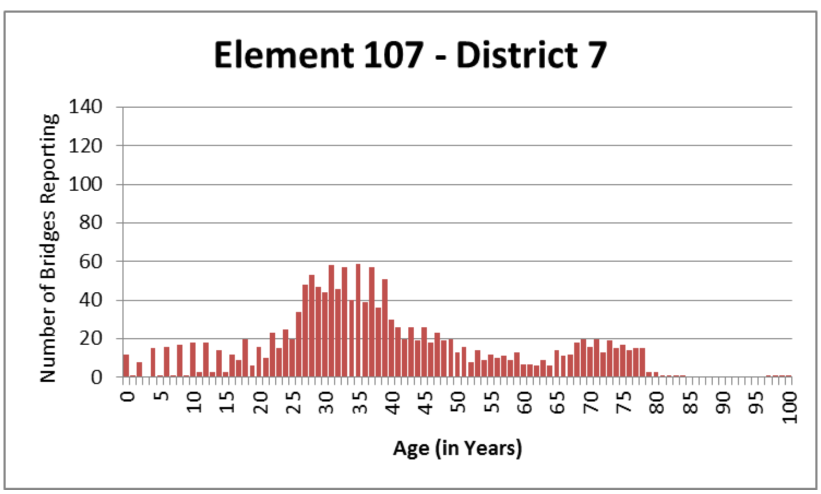

Figure D-21 – Number of Bridges Reporting by Age – Element 107 – District 7

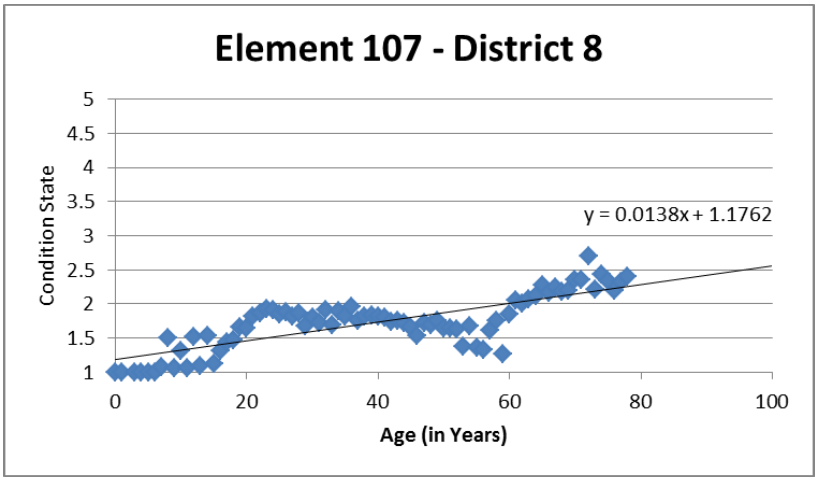

Figure D-22 – Condition State History and Linear Trendline by Age – Element 107 – District 8

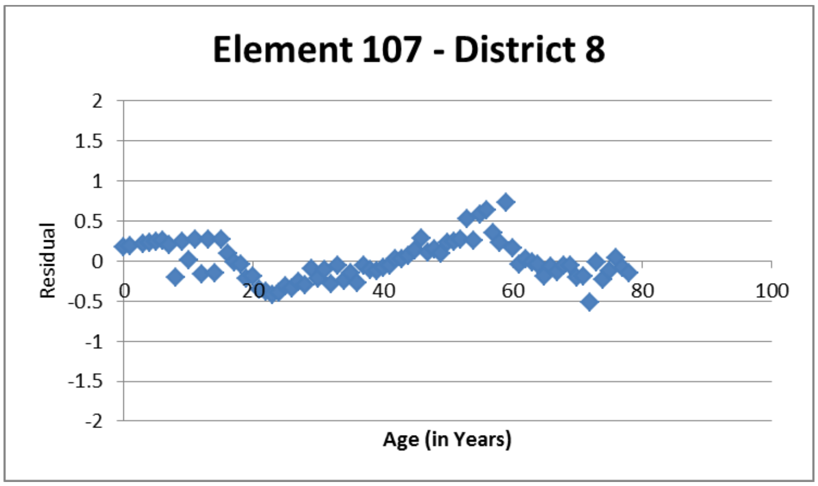

Figure D-23 – Condition States Residuals (Prediction Minus Actual) by Age – Element 107 – District 8

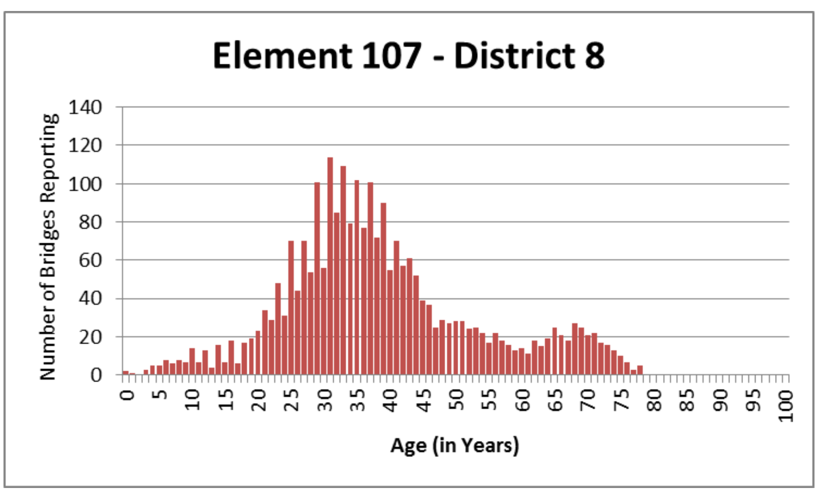

Figure D-24 – Number of Bridges Reporting by Age – Element 107 – District 8

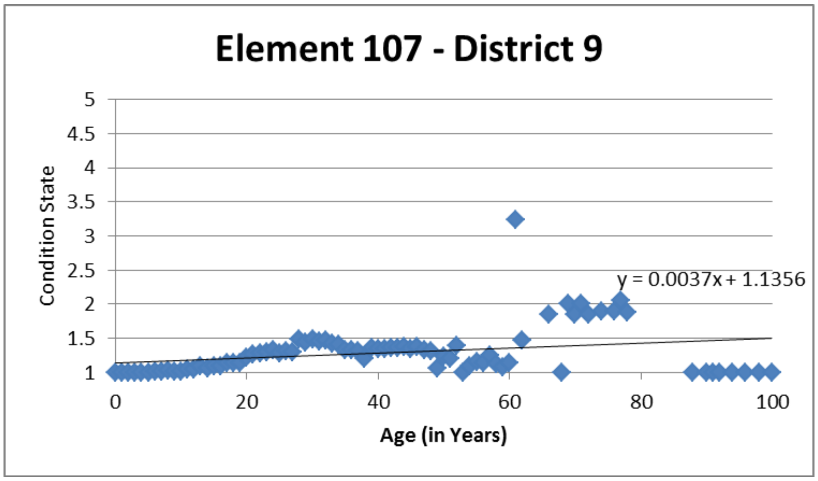

Figure D-25 – Condition State History and Linear Trendline by Age – Element 107 – District 9

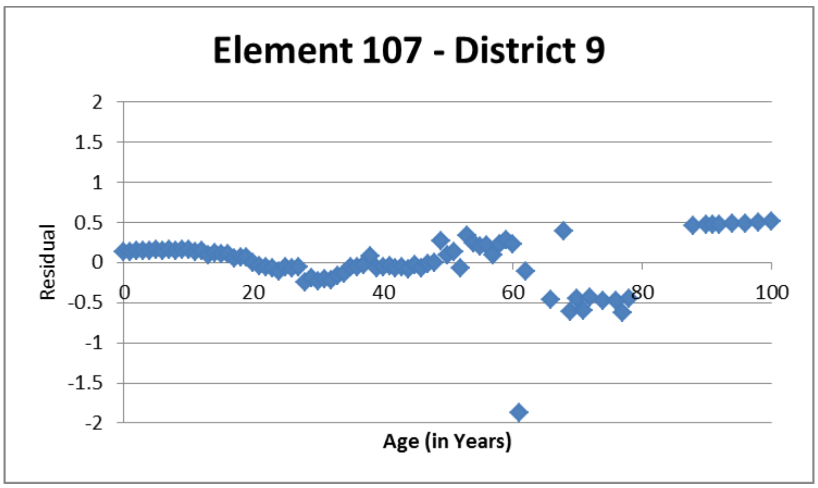

Figure D-26 – Condition States Residuals (Prediction Minus Actual) by Age – Element 107 – District 9

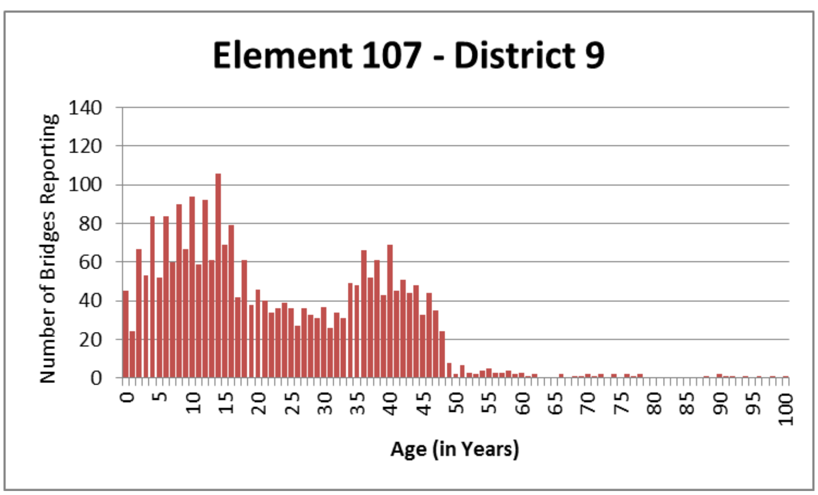

Figure D-27 – Number of Bridges Reporting by Age – Element 107 – District 9

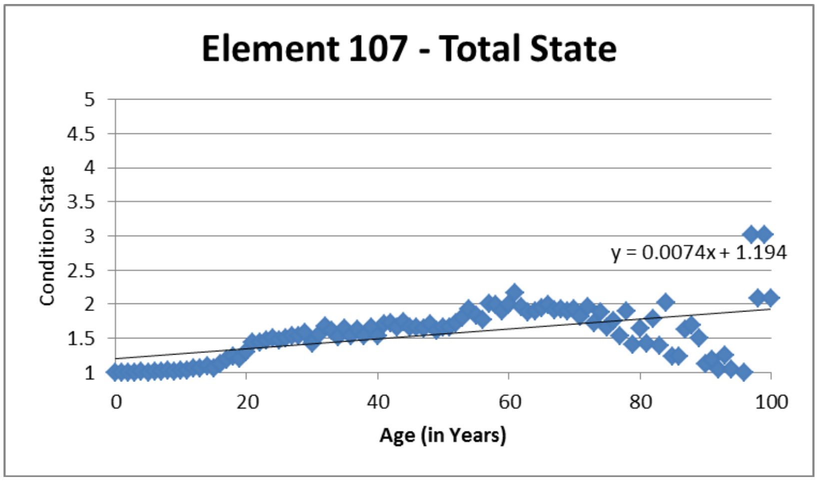

Figure D-28 – Condition State History and Linear Trendline by Age – Element 107 – Total State

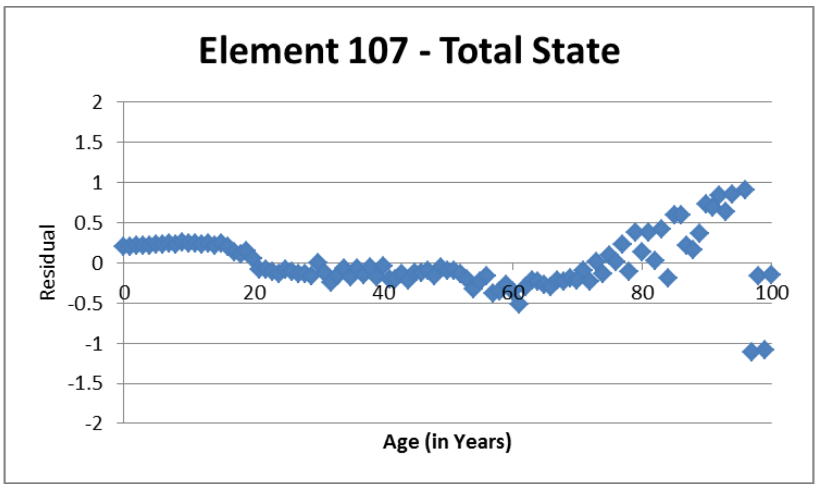

Figure D-29 – Condition States Residuals (Prediction Minus Actual) by Age – Element 107 – Total State

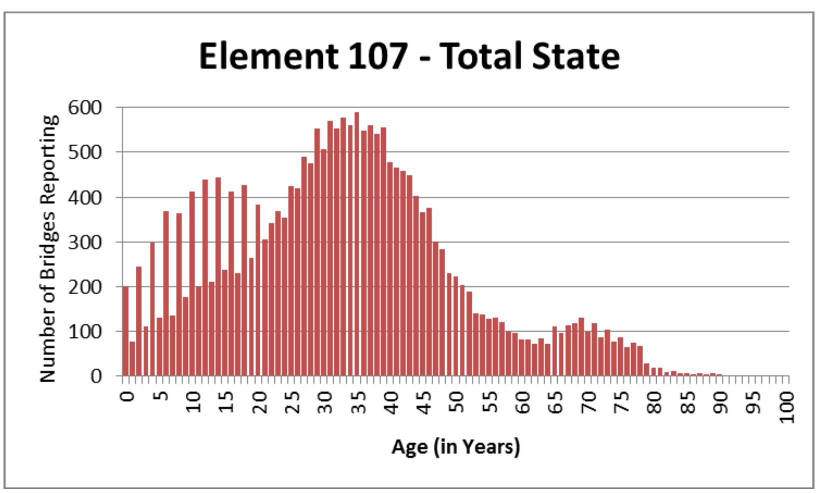

Figure D-30 – Number of Bridges Reporting by Age – Element 107 – Total State

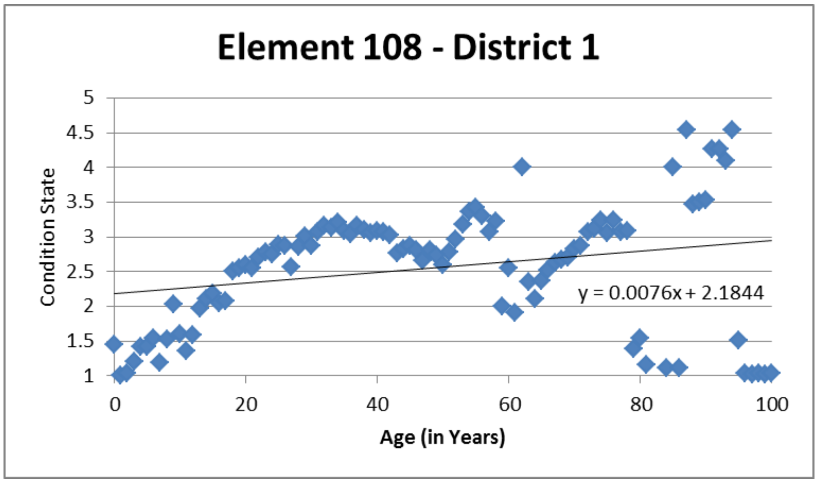

Figure D-31 – Condition State History and Linear Trendline by Age – Element 108 – District 1

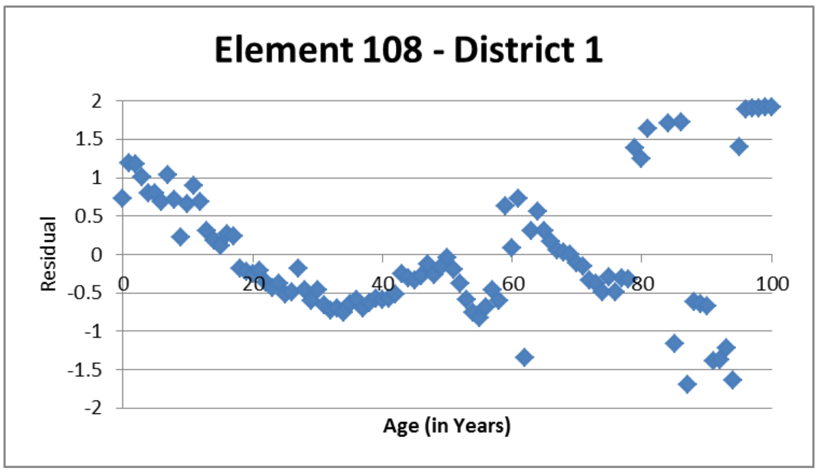

Figure D-32 – Condition States Residuals (Prediction Minus Actual) by Age – Element 108 – District 1

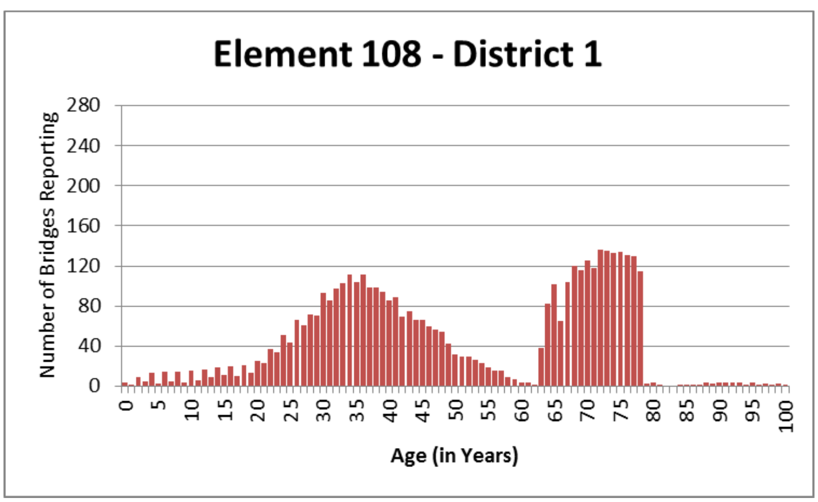

Figure D-33 – Number of Bridges Reporting by Age – Element 108 – District 1

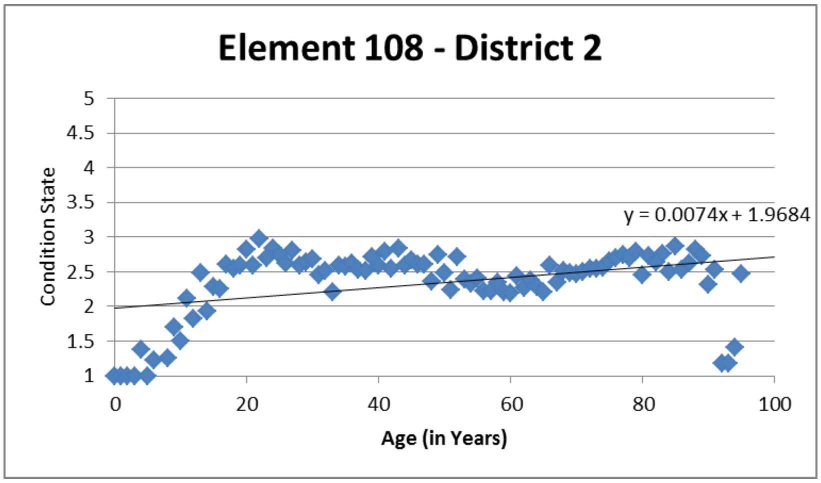

Figure D-34 – Condition State History and Linear Trendline by Age – Element 108 – District 2

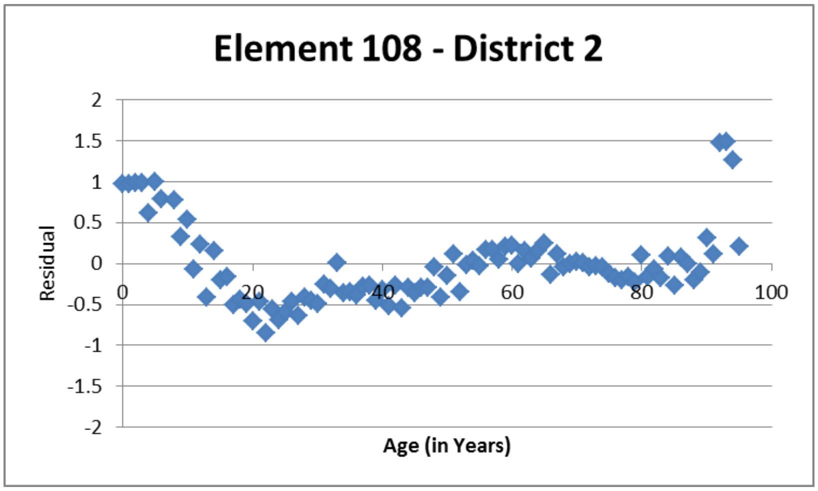

Figure D-35 – Condition States Residuals (Prediction Minus Actual) by Age – Element 108 – District 2

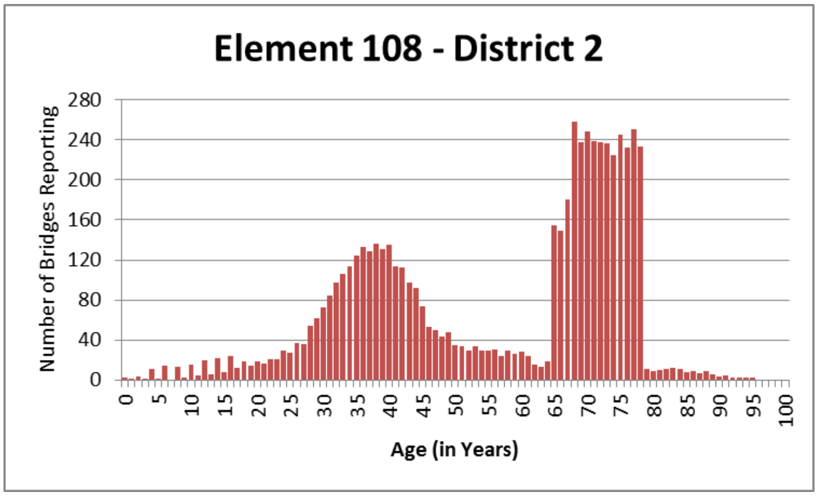

Figure D-36 – Number of Bridges Reporting by Age – Element 108 – District 2

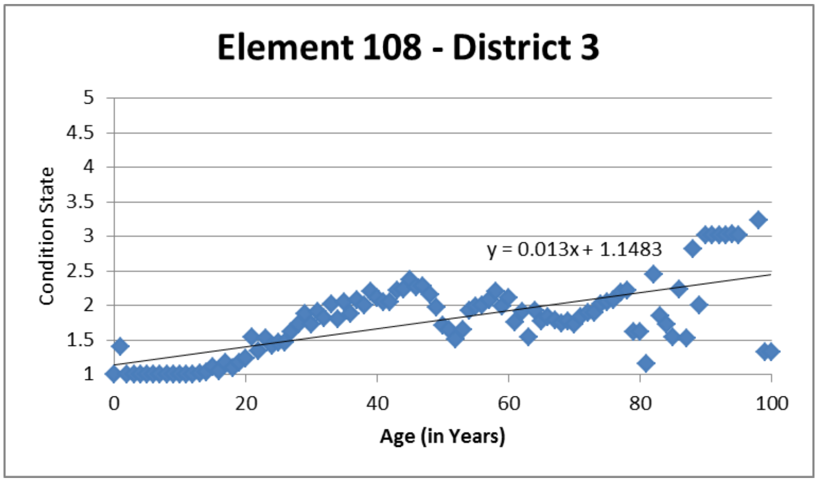

Figure D-37 – Condition State History and Linear Trendline by Age – Element 108 – District 3

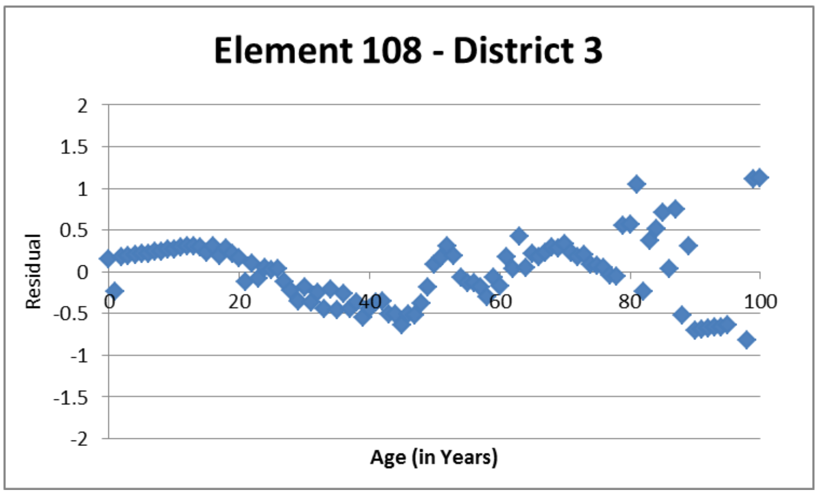

Figure D-38 – Condition States Residuals (Prediction Minus Actual) by Age – Element 108 – District 3

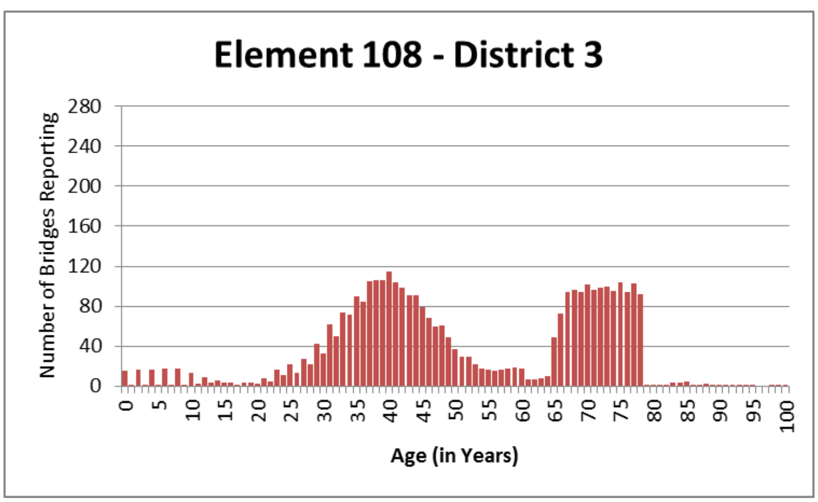

Figure D-39 – Number of Bridges Reporting by Age – Element 108 – District 3

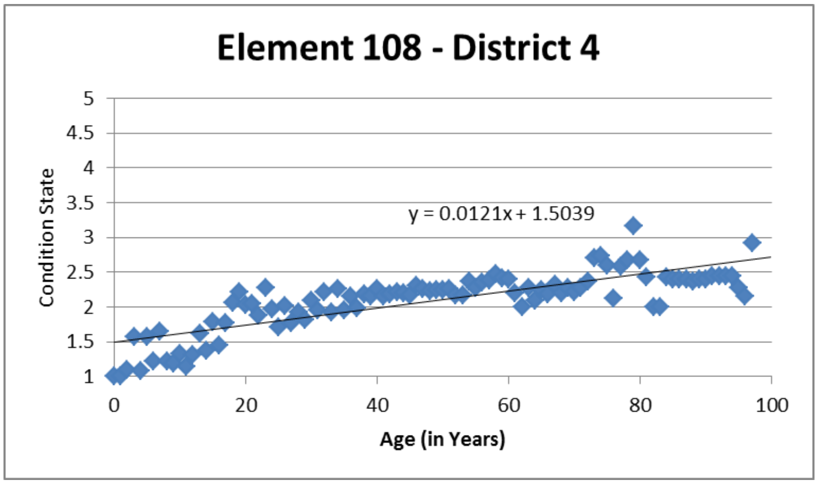

Figure D-40 – Condition State History and Linear Trendline by Age – Element 108 – District 4

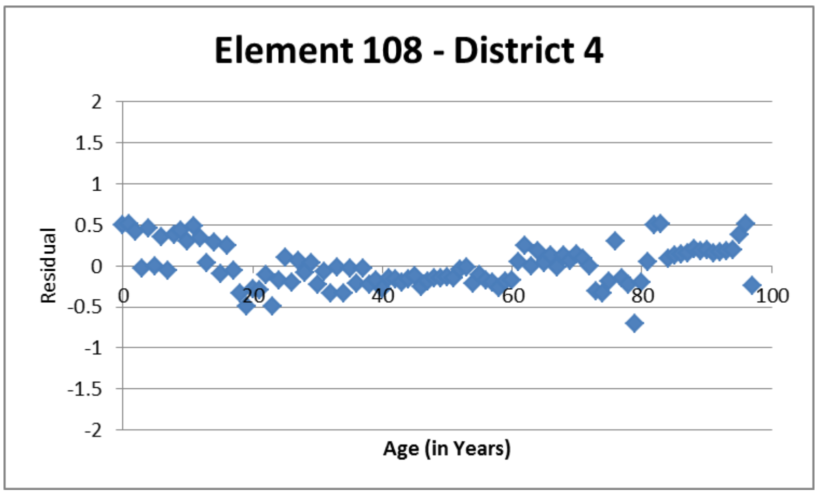

Figure D-41 – Condition States Residuals (Prediction Minus Actual) by Age – Element 108 – District 4

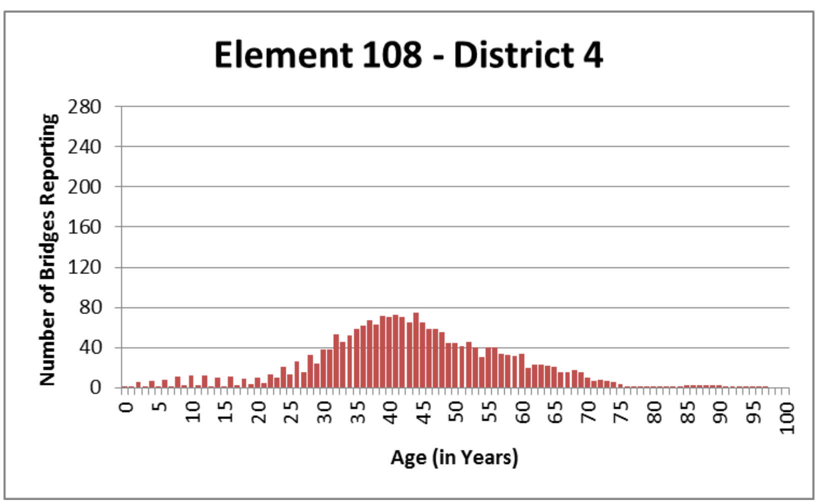

Figure D-42 – Number of Bridges Reporting by Age – Element 108 – District 4

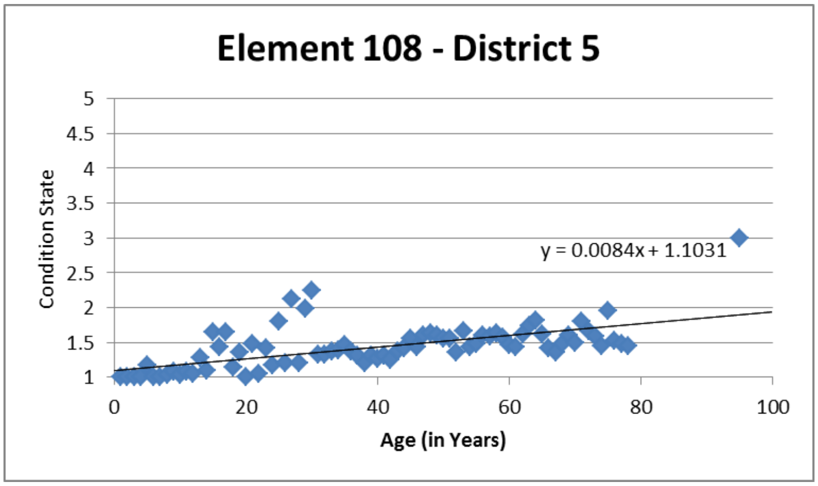

Figure D-43 – Condition State History and Linear Trendline by Age – Element 108 – District 5

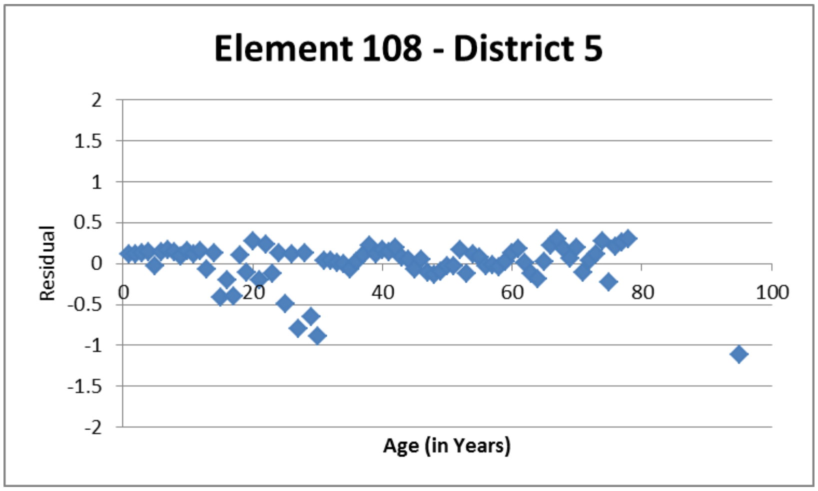

Figure D-44 – Condition States Residuals (Prediction Minus Actual) by Age – Element 108 – District 5

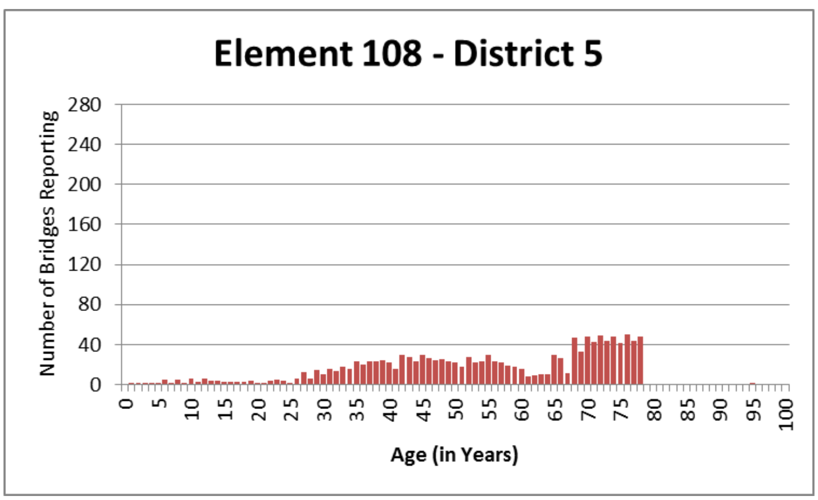

Figure D-45 – Number of Bridges Reporting by Age – Element 108 – District 5

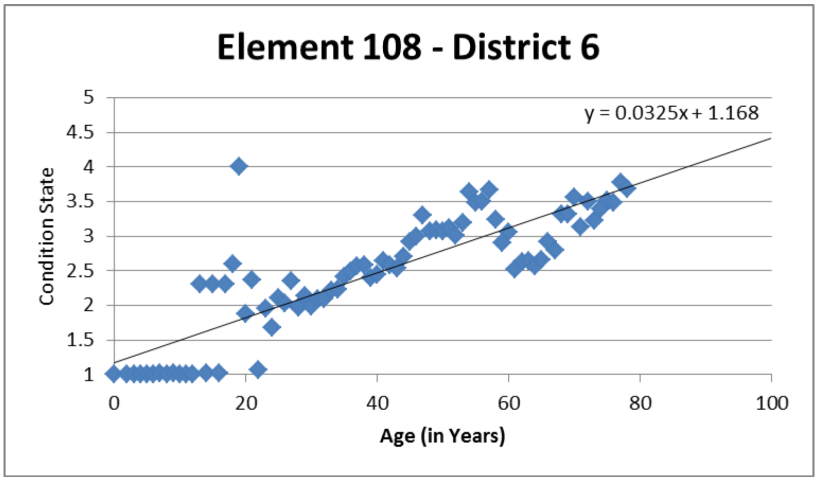

Figure D-46 – Condition State History and Linear Trendline by Age – Element 108 – District 6

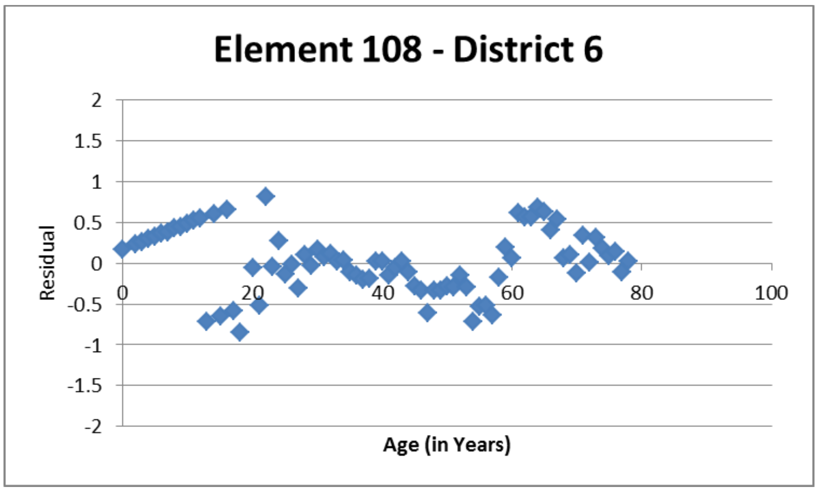

Figure D-47 – Condition States Residuals (Prediction Minus Actual) by Age – Element 108 – District 6

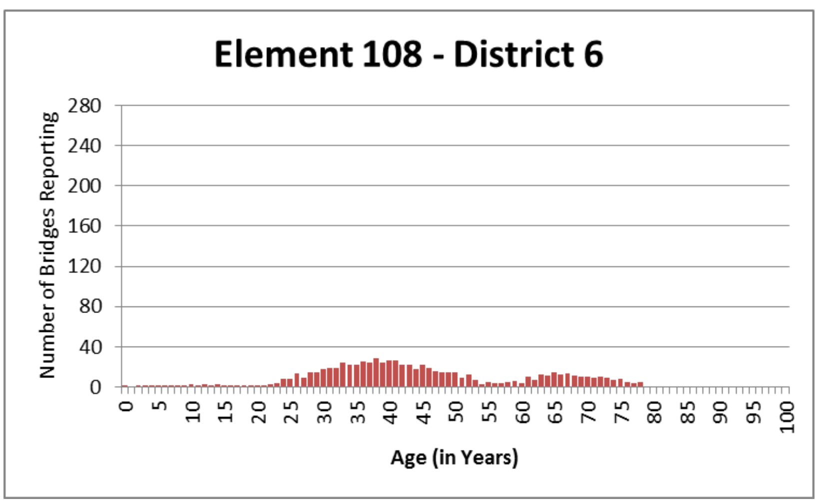

Figure D-48 – Number of Bridges Reporting by Age – Element 108 – District 6

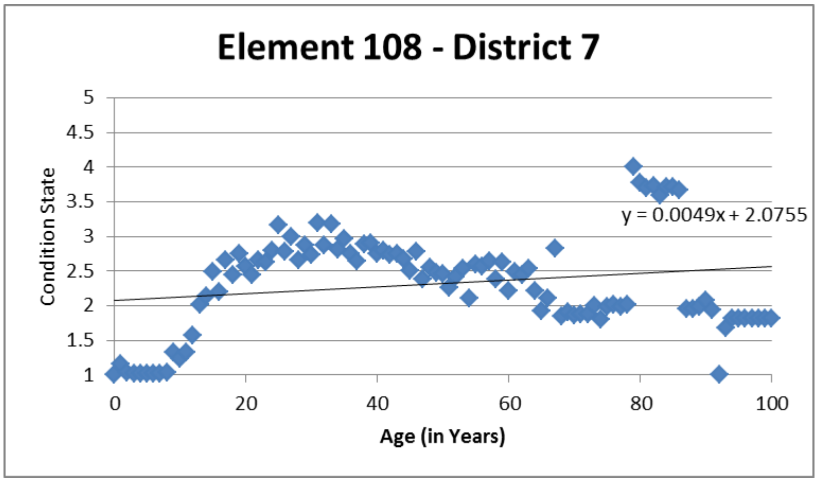

Figure D-49 – Condition State History and Linear Trendline by Age – Element 108 – District 7

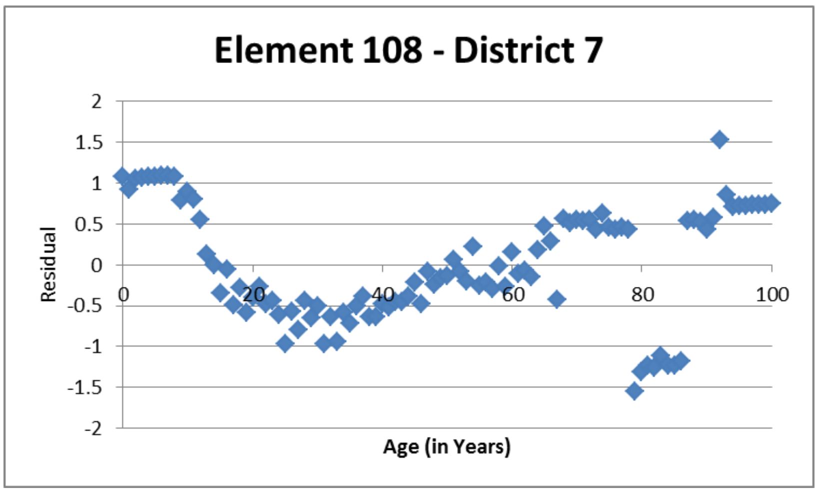

Figure D-50 – Condition States Residuals (Prediction Minus Actual) by Age – Element 108 – District 7

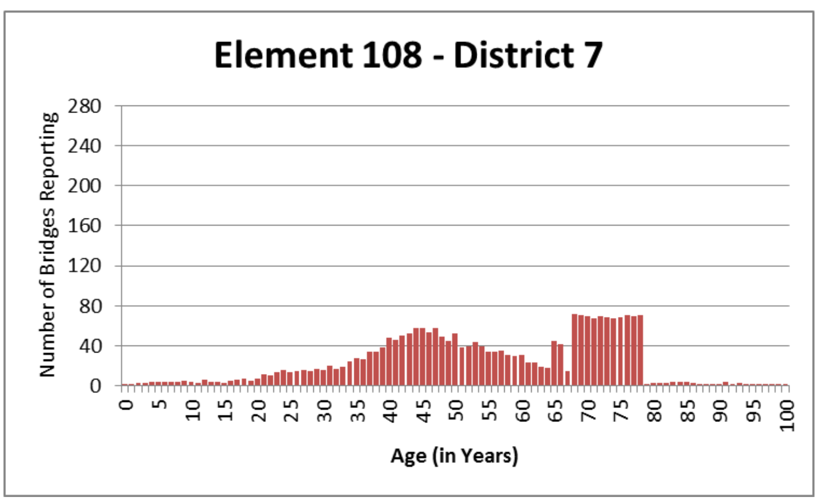

Figure D-51 – Number of Bridges Reporting by Age – Element 108 – District 7

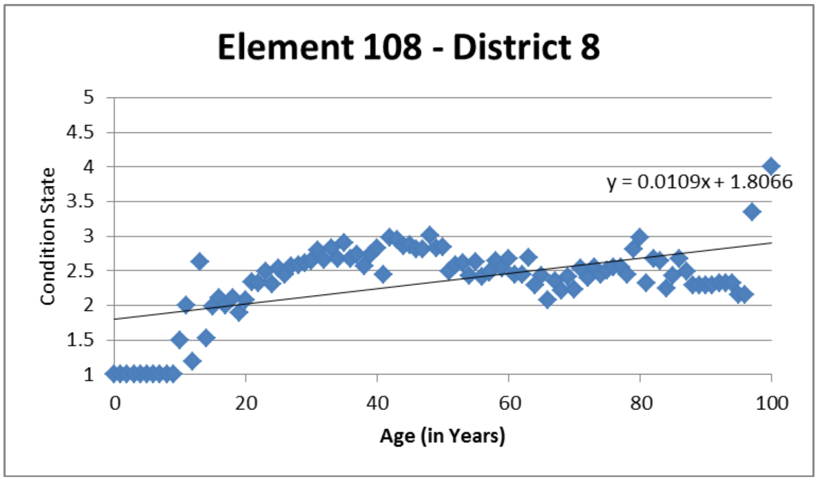

Figure D-52 – Condition State History and Linear Trendline by Age – Element 108 – District 8

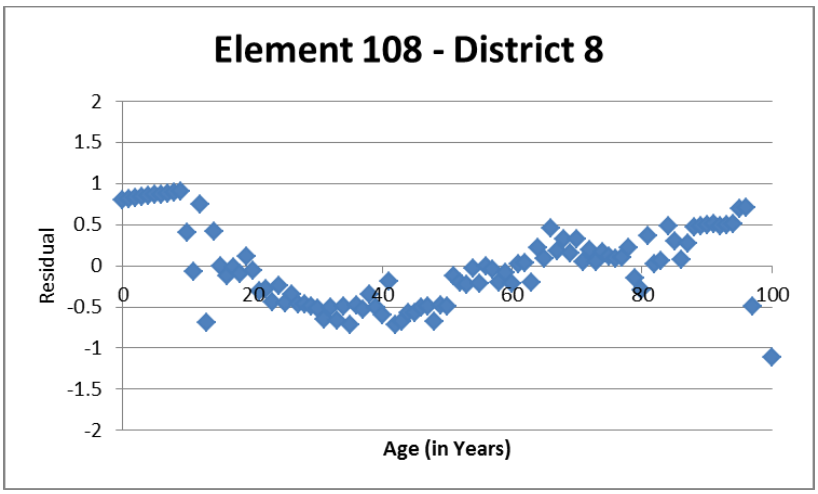

Figure D-53 – Condition States Residuals (Prediction Minus Actual) by Age – Element 108 – District 8

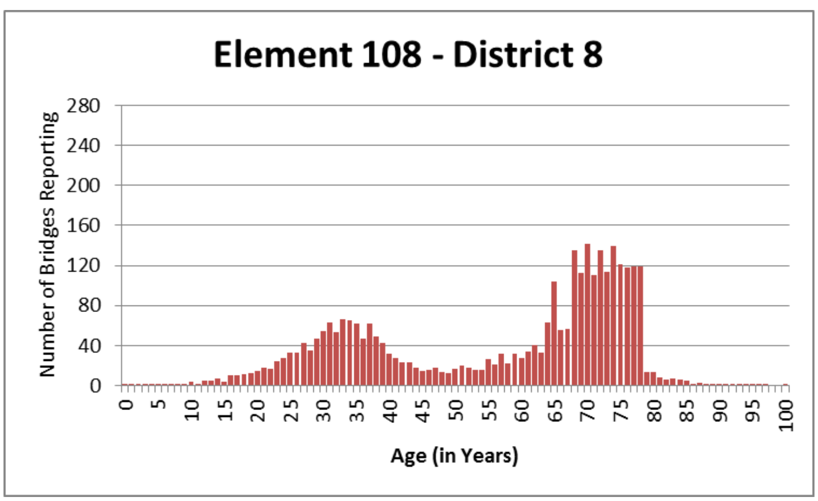

Figure D-54 – Number of Bridges Reporting by Age – Element 108 – District 8

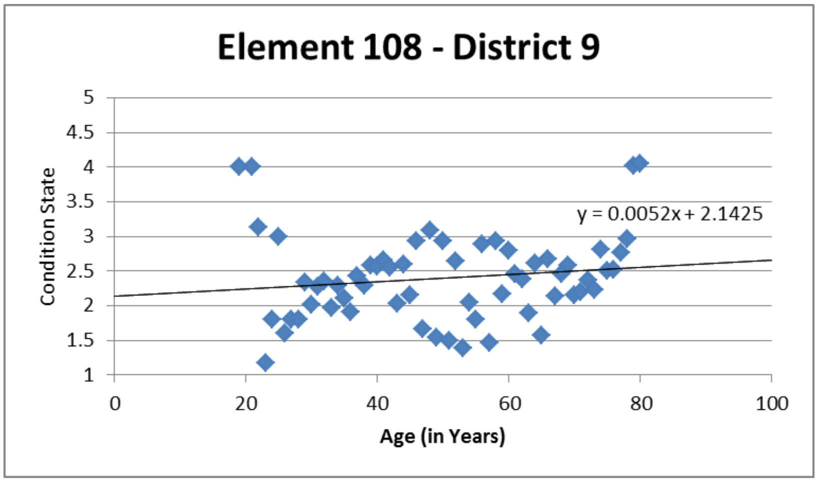

Figure D-55 – Condition State History and Linear Trendline by Age – Element 108 – District 9

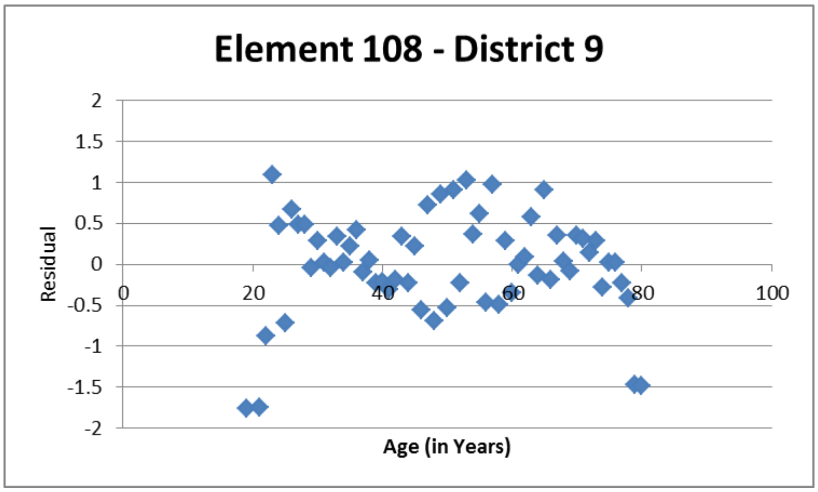

Figure D-56 – Condition States Residuals (Prediction Minus Actual) by Age – Element 108 – District 9

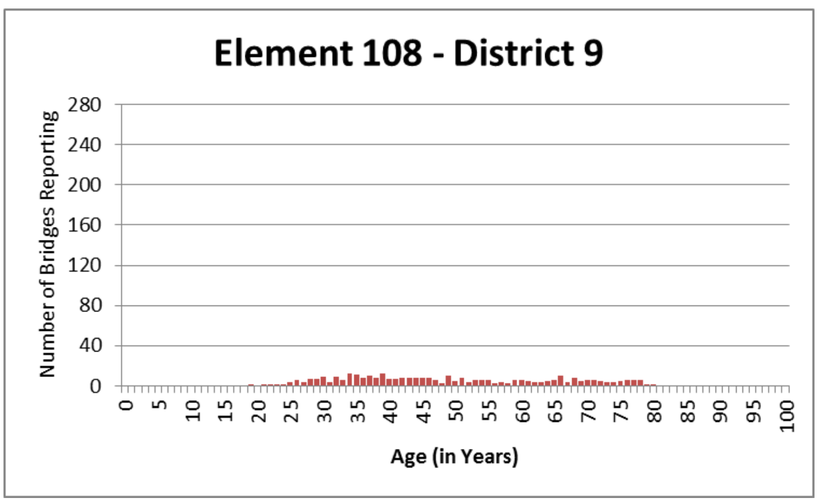

Figure D-57 – Number of Bridges Reporting by Age – Element 108 – District 9

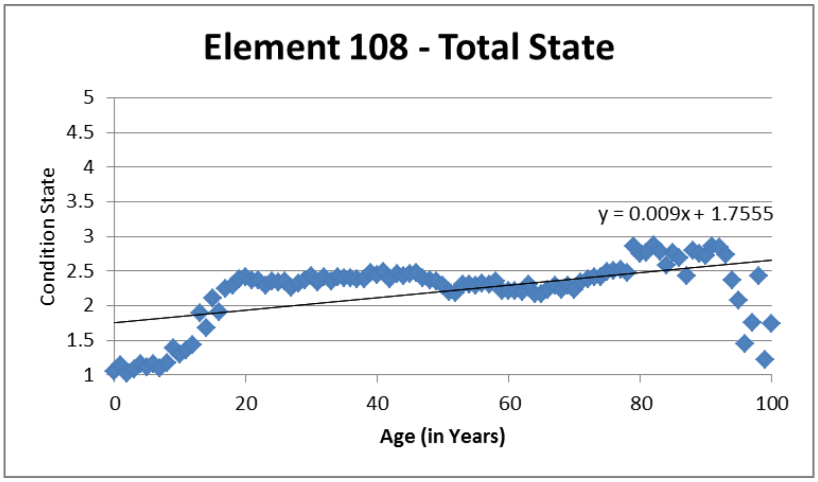

Figure D-58 – Condition State History and Linear Trendline by Age – Element 108 – Total State

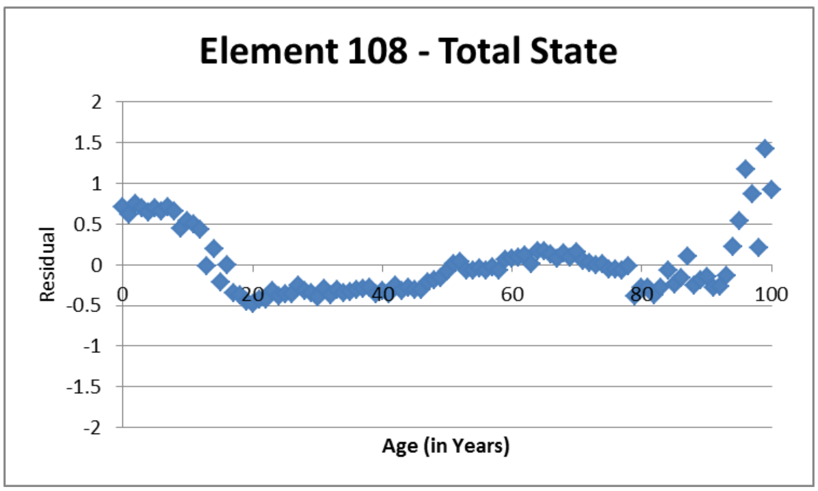

Figure D-59 – Condition States Residuals (Prediction Minus Actual) by Age – Element 108 – Total State

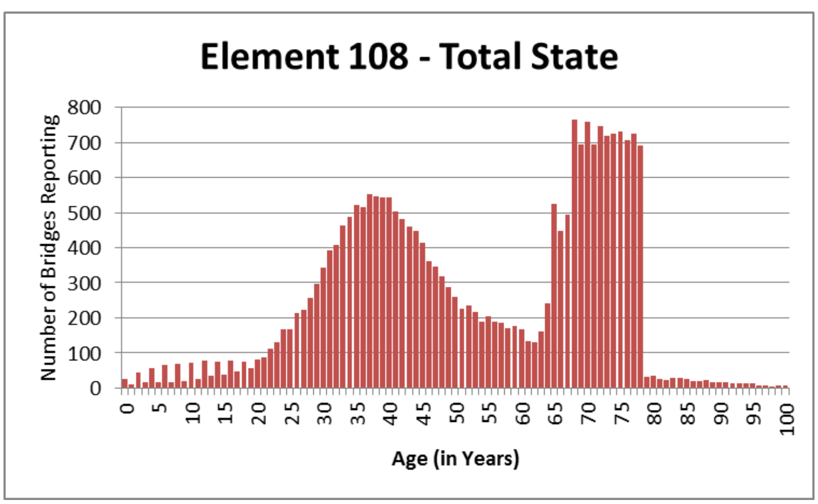

Figure D-60 – Number of Bridges Reporting by Age – Element 108 – Total State

D1	1	2	3	4	5
1	0.990	0.010	0.000	0.000	0.000
2	0.000	0.972	0.028	0.000	0.000
3	0.000	0.000	0.976	0.024	0.000
4	0.000	0.000	0.000	0.961	0.039
5	0.000	0.000	0.000	0.000	1.000

D2	1	2	3	4	5
1	0.982	0.018	0.000	0.000	0.000
2	0.000	0.975	0.025	0.000	0.000
3	0.000	0.000	0.993	0.007	0.000
4	0.000	0.000	0.000	0.993	0.007
5	0.000	0.000	0.000	0.000	1.000

Table D-1 – Markov Transition Probability Matrices – Element 107 – Districts 1 and 2

D3	1	2	3	4	5
1	0.994	0.006	0.000	0.000	0.000
2	0.000	0.977	0.023	0.000	0.000
3	0.000	0.000	0.979	0.021	0.000
4	0.000	0.000	0.000	0.992	0.008
5	0.000	0.000	0.000	0.000	1.000

D4	1	2	3	4	5
1	0.987	0.013	0.000	0.000	0.000
2	0.000	0.972	0.028	0.000	0.000
3	0.000	0.000	0.977	0.023	0.000
4	0.000	0.000	0.000	0.985	0.015
5	0.000	0.000	0.000	0.000	1.000

Table D-2 – Markov Transition Probability Matrices – Element 107 – Districts 3 and 4

D5	1	2	3	4	5
1	0.994	0.006	0.000	0.000	0.000
2	0.000	0.976	0.024	0.000	0.000
3	0.000	0.000	0.970	0.030	0.000
4	0.000	0.000	0.000	0.990	0.010
5	0.000	0.000	0.000	0.000	1.000

D6	1	2	3	4	5
1	0.987	0.013	0.000	0.000	0.000
2	0.000	0.973	0.027	0.000	0.000
3	0.000	0.000	0.982	0.018	0.000
4	0.000	0.000	0.000	0.982	0.018
5	0.000	0.000	0.000	0.000	1.000

Table D-3 – Markov Transition Probability Matrices – Element 107 – Districts 5 and 6

D7	1	2	3	4	5
1	0.986	0.014	0.000	0.000	0.000
2	0.000	0.978	0.022	0.000	0.000
3	0.000	0.000	0.961	0.039	0.000
4	0.000	0.000	0.000	1.000	0.000
5	0.000	0.000	0.000	0.000	1.000

D8	1	2	3	4	5
1	0.976	0.024	0.000	0.000	0.000
2	0.000	0.987	0.013	0.000	0.000
3	0.000	0.000	0.989	0.011	0.000
4	0.000	0.000	0.000	0.982	0.018
5	0.000	0.000	0.000	0.000	1.000

Table D-4 – Markov Transition Probability Matrices – Element 107 - District 7 and 8

D9	1	2	3	4	5
1	0.992	0.008	0.000	0.000	0.000
2	0.000	0.996	0.004	0.000	0.000
3	0.000	0.000	0.987	0.013	0.000
4	0.000	0.000	0.000	0.997	0.003
5	0.000	0.000	0.000	0.000	1.000

Total	1	2	3	4	5
1	0.990	0.010	0.000	0.000	0.000
2	0.000	0.980	0.020	0.000	0.000
3	0.000	0.000	0.977	0.023	0.000
4	0.000	0.000	0.000	0.986	0.014
5	0.000	0.000	0.000	0.000	1.000

Table D-5 – Markov Transition Probability Matrices – Element 107 – District 9 and Total State

D1	1	2	3	4	5
1	0.970	0.030	0.000	0.000	0.000
2	0.000	0.953	0.047	0.000	0.000
3	0.000	0.000	0.960	0.040	0.000
4	0.000	0.000	0.000	0.967	0.033
5	0.000	0.000	0.000	0.000	1.000

D2	1	2	3	4	5
1	0.973	0.027	0.000	0.000	0.000
2	0.000	0.919	0.081	0.000	0.000
3	0.000	0.000	0.984	0.016	0.000
4	0.000	0.000	0.000	0.983	0.017
5	0.000	0.000	0.000	0.000	1.000

Table D-6 – Markov Transition Probability Matrices – Element 108 – Districts 1 and 2

D3	1	2	3	4	5
1	0.986	0.014	0.000	0.000	0.000
2	0.000	0.977	0.023	0.000	0.000
3	0.000	0.000	0.990	0.010	0.000
4	0.000	0.000	0.000	0.987	0.013
5	0.000	0.000	0.000	0.000	1.000

D4	1	2	3	4	5
1	0.965	0.035	0.000	0.000	0.000
2	0.000	0.986	0.014	0.000	0.000
3	0.000	0.000	0.989	0.011	0.000
4	0.000	0.000	0.000	0.989	0.011
5	0.000	0.000	0.000	0.000	1.000

Table D-7 – Markov Transition Probability Matrices – Element 108 – Districts 3 and 4

D5	1	2	3	4	5
1	0.991	0.009	0.000	0.000	0.000
2	0.000	0.987	0.013	0.000	0.000
3	0.000	0.000	0.976	0.024	0.000
4	0.000	0.000	0.000	0.991	0.009
5	0.000	0.000	0.000	0.000	1.000

D6	1	2	3	4	5
1	0.968	0.032	0.000	0.000	0.000
2	0.000	0.948	0.052	0.000	0.000
3	0.000	0.000	0.955	0.045	0.000
4	0.000	0.000	0.000	0.995	0.005
5	0.000	0.000	0.000	0.000	1.000

Table D-8 – Markov Transition Probability Matrices – Element 108 – Districts 5 and 6

D7	1	2	3	4	5
1	0.971	0.029	0.000	0.000	0.000
2	0.000	0.935	0.065	0.000	0.000
3	0.000	0.000	0.971	0.029	0.000
4	0.000	0.000	0.000	0.990	0.010
5	0.000	0.000	0.000	0.000	1.000

D8	1	2	3	4	5
1	0.956	0.044	0.000	0.000	0.000
2	0.000	0.973	0.027	0.000	0.000
3	0.000	0.000	0.986	0.014	0.000
4	0.000	0.000	0.000	0.982	0.018
5	0.000	0.000	0.000	0.000	1.000

Table D-9 – Markov Transition Probability Matrices – Element 108 – Districts 7 and 8

D9	1	2	3	4	5
1	0.976	0.024	0.000	0.000	0.000
2	0.000	0.964	0.036	0.000	0.000
3	0.000	0.000	0.971	0.029	0.000
4	0.000	0.000	0.000	0.989	0.011
5	0.000	0.000	0.000	0.000	1.000

Total	1	2	3	4	5
1	0.975	0.025	0.000	0.000	0.000
2	0.000	0.964	0.036	0.000	0.000
3	0.000	0.000	0.980	0.020	0.000
4	0.000	0.000	0.000	0.983	0.017
5	0.000	0.000	0.000	0.000	1.000

Table D-10 – Markov Transition Probability Matrices – Element 108 – District 9 and Total State

D1	1	2	3	4	5
1	0.993	0.007	0.000	0.000	0.000
2	0.000	0.994	0.006	0.000	0.000
3	0.000	0.000	1.000	0.000	0.000
4	0.000	0.000	0.000	0.000	1.000
5	0.000	0.000	0.000	0.000	0.000

D2	1	2	3	4	5
1	0.987	0.013	0.000	0.000	0.000
2	0.000	0.996	0.004	0.000	0.000
3	0.000	0.000	1.000	0.000	0.000
4	0.000	0.000	0.000	0.000	1.000
5	0.000	0.000	0.000	0.000	0.000

Table D-11 – Markov Transition Probability Matrices – Element 302 – Districts 1 and 2

D3	1	2	3	4	5
1	0.988	0.012	0.000	0.000	0.000
2	0.000	0.975	0.025	0.000	0.000
3	0.000	0.000	1.000	0.000	0.000
4	0.000	0.000	0.000	0.000	1.000
5	0.000	0.000	0.000	0.000	0.000

D4	1	2	3	4	5
1	0.994	0.006	0.000	0.000	0.000
2	0.000	0.980	0.020	0.000	0.000
3	0.000	0.000	1.000	0.000	0.000
4	0.000	0.000	0.000	0.000	1.000
5	0.000	0.000	0.000	0.000	0.000

Table D-12 – Markov Transition Probability Matrices – Element 302 – Districts 3 and 4

D5	1	2	3	4	5
1	0.994	0.006	0.000	0.000	0.000
2	0.000	0.976	0.024	0.000	0.000
3	0.000	0.000	1.000	0.000	0.000
4	0.000	0.000	0.000	0.000	1.000
5	0.000	0.000	0.000	0.000	0.000

D6	1	2	3	4	5
1	0.982	0.018	0.000	0.000	0.000
2	0.000	0.951	0.049	0.000	0.000
3	0.000	0.000	1.000	0.000	0.000
4	0.000	0.000	0.000	0.000	1.000
5	0.000	0.000	0.000	0.000	0.000

Table D-13 – Markov Transition Probability Matrices – Element 302 – Districts 5 and 6

D7	1	2	3	4	5
1	0.988	0.012	0.000	0.000	0.000
2	0.000	0.997	0.003	0.000	0.000
3	0.000	0.000	1.000	0.000	0.000
4	0.000	0.000	0.000	0.000	1.000
5	0.000	0.000	0.000	0.000	0.000

D8	1	2	3	4	5
1	0.992	0.008	0.000	0.000	0.000
2	0.000	0.996	0.004	0.000	0.000
3	0.000	0.000	1.000	0.000	0.000
4	0.000	0.000	0.000	0.000	1.000
5	0.000	0.000	0.000	0.000	0.000

Table D-14 – Markov Transition Probability Matrices – Element 302 – Districts 7 and 8

D9	1	2	3	4	5
1	0.994	0.006	0.000	0.000	0.000
2	0.000	0.985	0.015	0.000	0.000
3	0.000	0.000	1.000	0.000	0.000
4	0.000	0.000	0.000	0.000	1.000
5	0.000	0.000	0.000	0.000	0.000

Total	1	2	3	4	5
1	0.990	0.010	0.000	0.000	0.000
2	0.000	0.986	0.014	0.000	0.000
3	0.000	0.000	1.000	0.000	0.000
4	0.000	0.000	0.000	0.000	1.000
5	0.000	0.000	0.000	0.000	0.000

Table D-15 – Markov Transition Probability Matrices – Element 302 – District 9 and Total State

D1	1	2	3	4	5
1	0.988	0.012	0.000	0.000	0.000
2	0.000	0.988	0.012	0.000	0.000
3	0.000	0.000	0.987	0.013	0.000
4	0.000	0.000	0.000	1.000	0.000
5	0.000	0.000	0.000	0.000	0.000

D2	1	2	3	4	5
1	0.992	0.008	0.000	0.000	0.000
2	0.000	0.992	0.008	0.000	0.000
3	0.000	0.000	0.989	0.011	0.000
4	0.000	0.000	0.000	1.000	0.000
5	0.000	0.000	0.000	0.000	0.000

Table D-16 – Markov Transition Probability Matrices – Element 32 – Districts 1 and 2

D3	1	2	3	4	5
1	0.982	0.018	0.000	0.000	0.000
2	0.000	0.995	0.005	0.000	0.000
3	0.000	0.000	0.988	0.012	0.000
4	0.000	0.000	0.000	1.000	0.000
5	0.000	0.000	0.000	0.000	0.000

D5	1	2	3	4	5
1	0.989	0.011	0.000	0.000	0.000
2	0.000	0.996	0.004	0.000	0.000
3	0.000	0.000	0.975	0.025	0.000
4	0.000	0.000	0.000	1.000	0.000
5	0.000	0.000	0.000	0.000	0.000

Table D-17 – Markov Transition Probability Matrices – Element 32 – Districts 3 and 5

D7	1	2	3	4	5
1	0.982	0.018	0.000	0.000	0.000
2	0.000	0.994	0.006	0.000	0.000
3	0.000	0.000	0.973	0.027	0.000
4	0.000	0.000	0.000	1.000	0.000
5	0.000	0.000	0.000	0.000	0.000

D8	1	2	3	4	5
1	0.982	0.018	0.000	0.000	0.000
2	0.000	0.992	0.008	0.000	0.000
3	0.000	0.000	0.990	0.010	0.000
4	0.000	0.000	0.000	1.000	0.000
5	0.000	0.000	0.000	0.000	0.000

Table D-18 – Markov Transition Probability Matrices – Element 32 – Districts 7 and 8

Total	1	2	3	4	5
1	0.986	0.014	0.000	0.000	0.000
2	0.000	0.992	0.008	0.000	0.000
3	0.000	0.000	0.987	0.013	0.000
4	0.000	0.000	0.000	1.000	0.000
5	0.000	0.000	0.000	0.000	0.000

Table D-19 – Markov Transition Probability Matrix – Element 32 – Total State

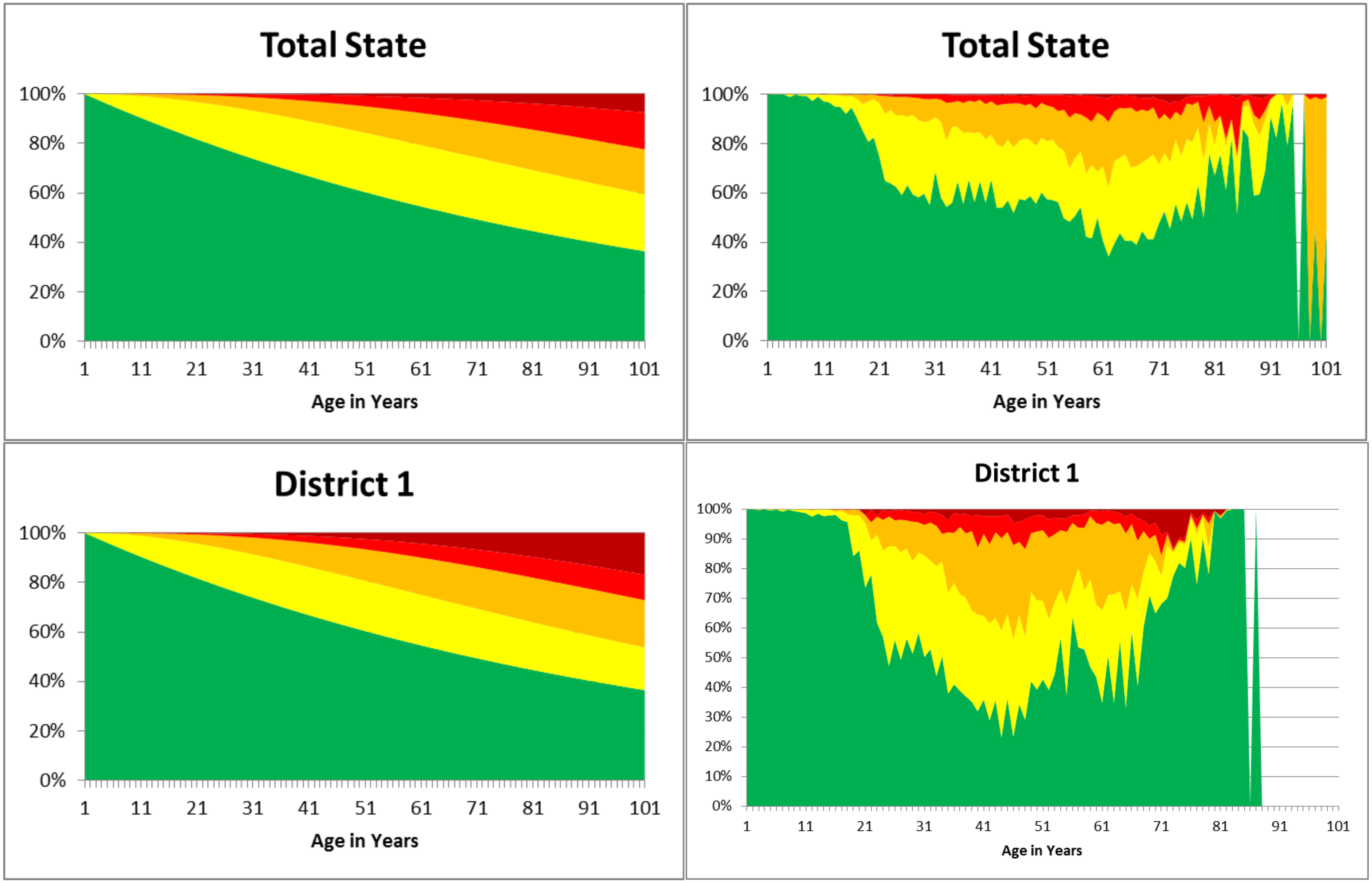

Figure D-61 – Markov Chain Prediction vs. Actual Graphs – Element 107 – Total State and District 1

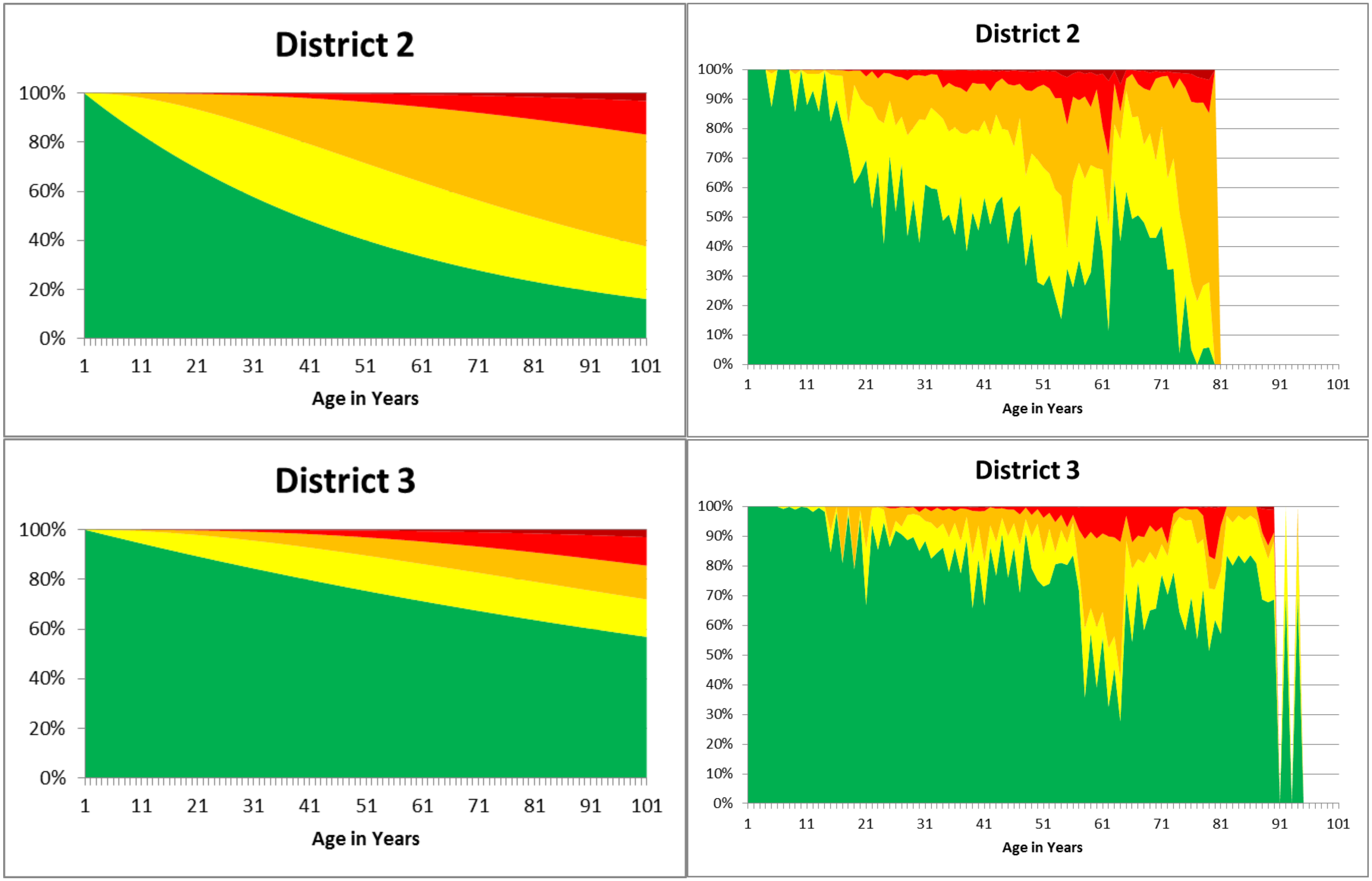

Figure D-62 – Markov Chain Prediction vs. Actual Graphs – Element 107 – Districts 2 and 3

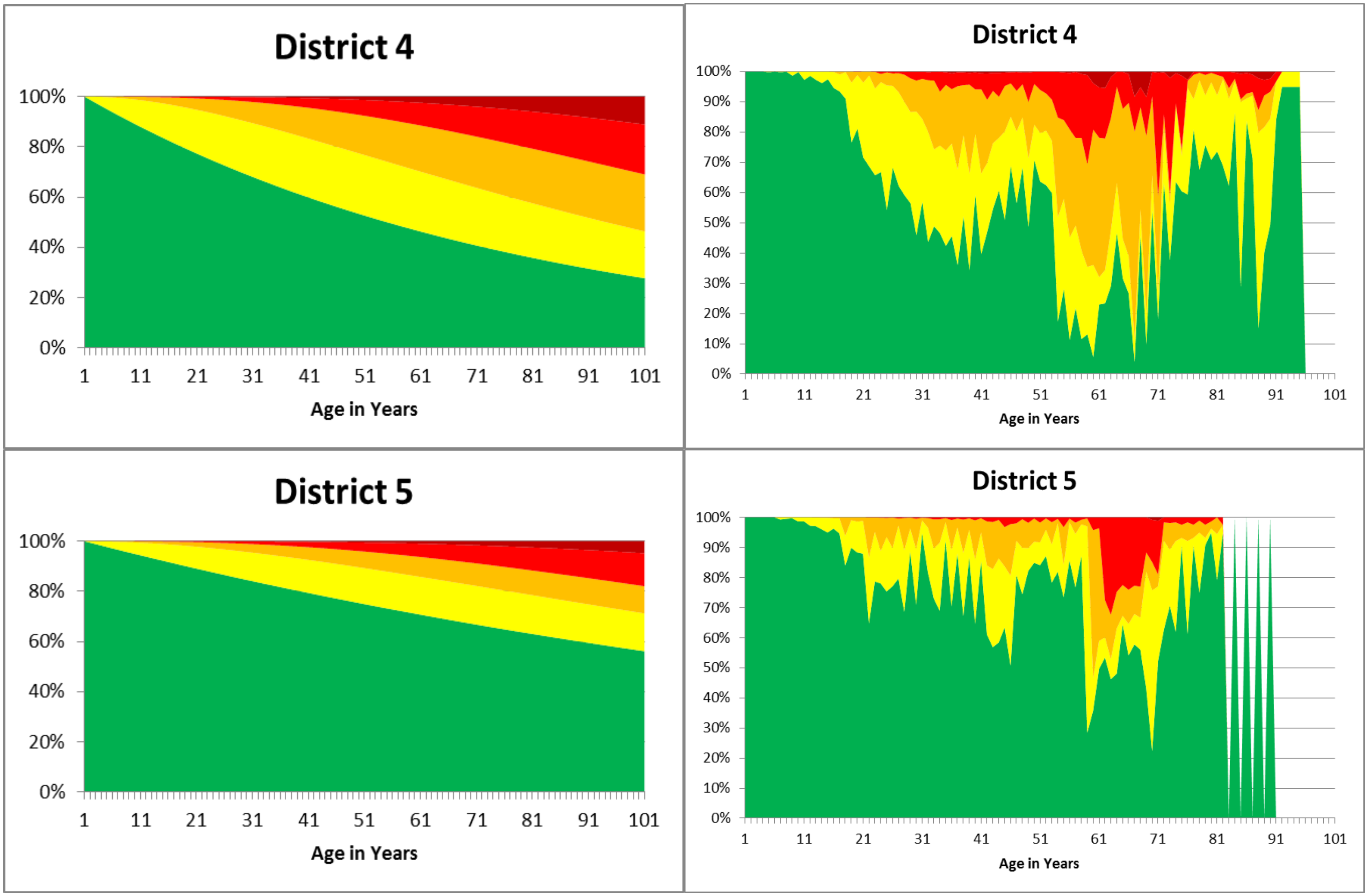

Figure D-63 – Markov Chain Prediction vs. Actual Graphs – Element 107 – Districts 4 and 5

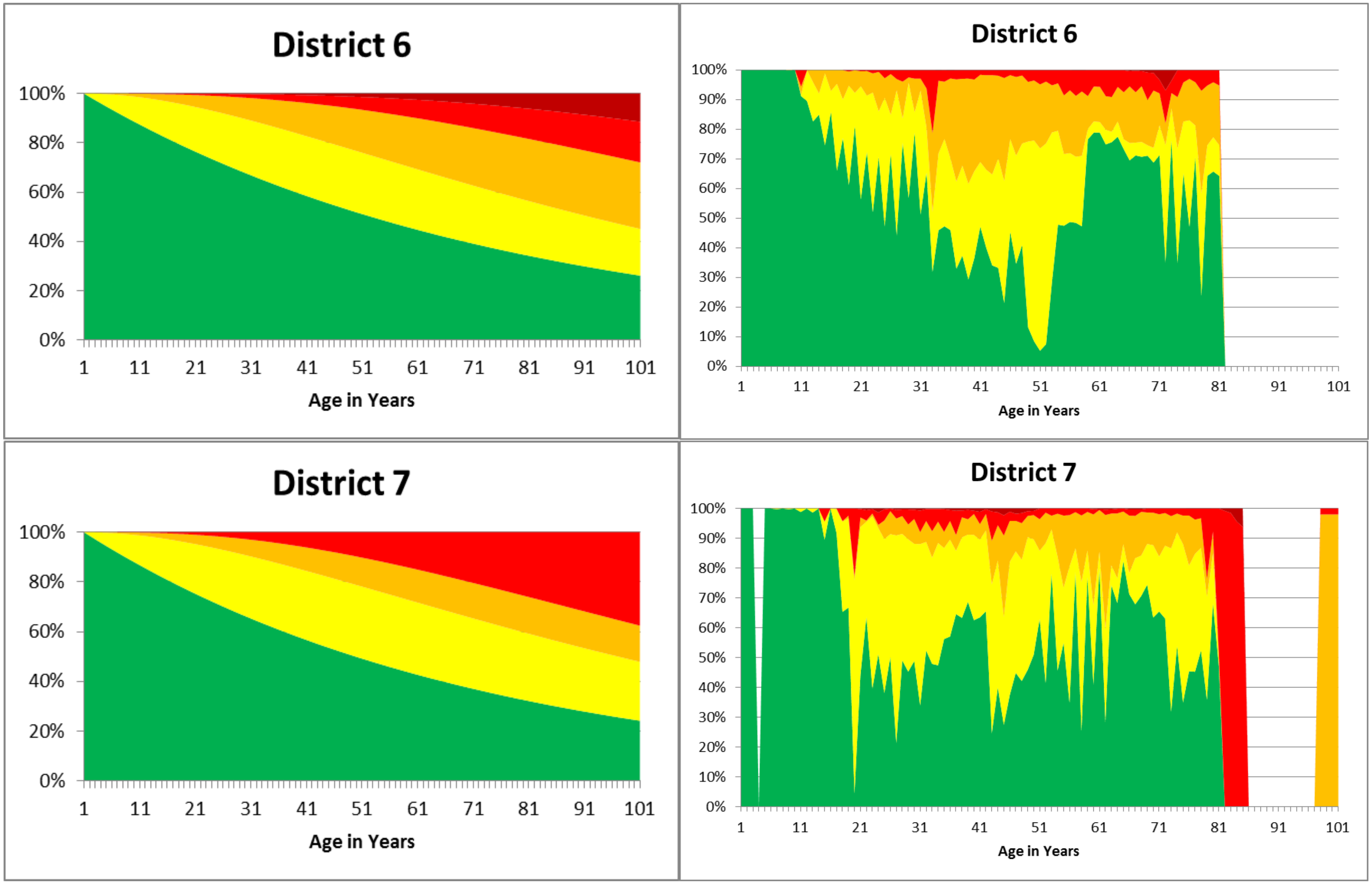

Figure D-64 – Markov Chain Prediction vs. Actual Graphs – Element 107 – Districts 6 and 7

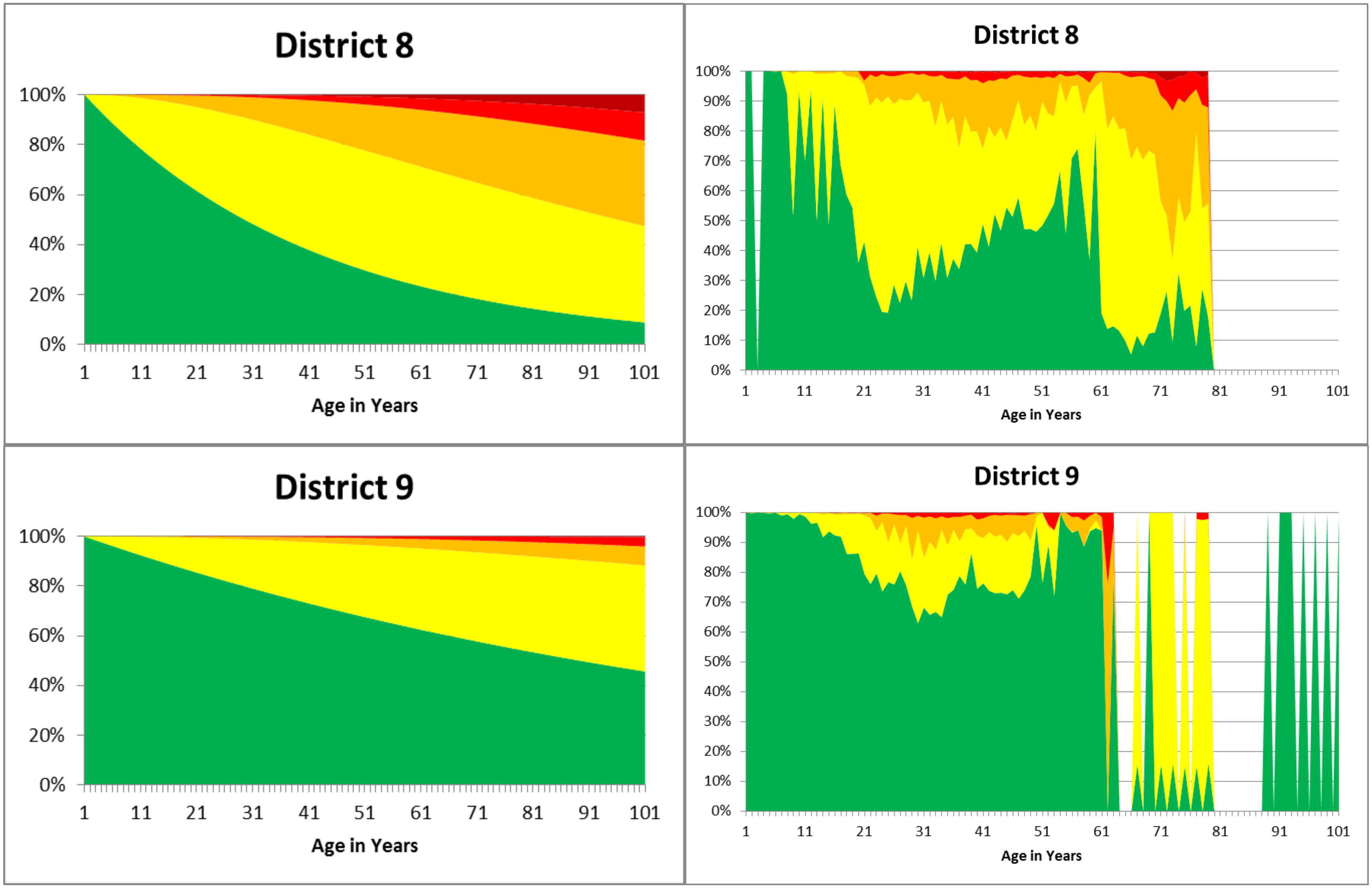

Figure D-65 – Markov Chain Prediction vs. Actual Graphs – Element 107 – Districts 8 and 9

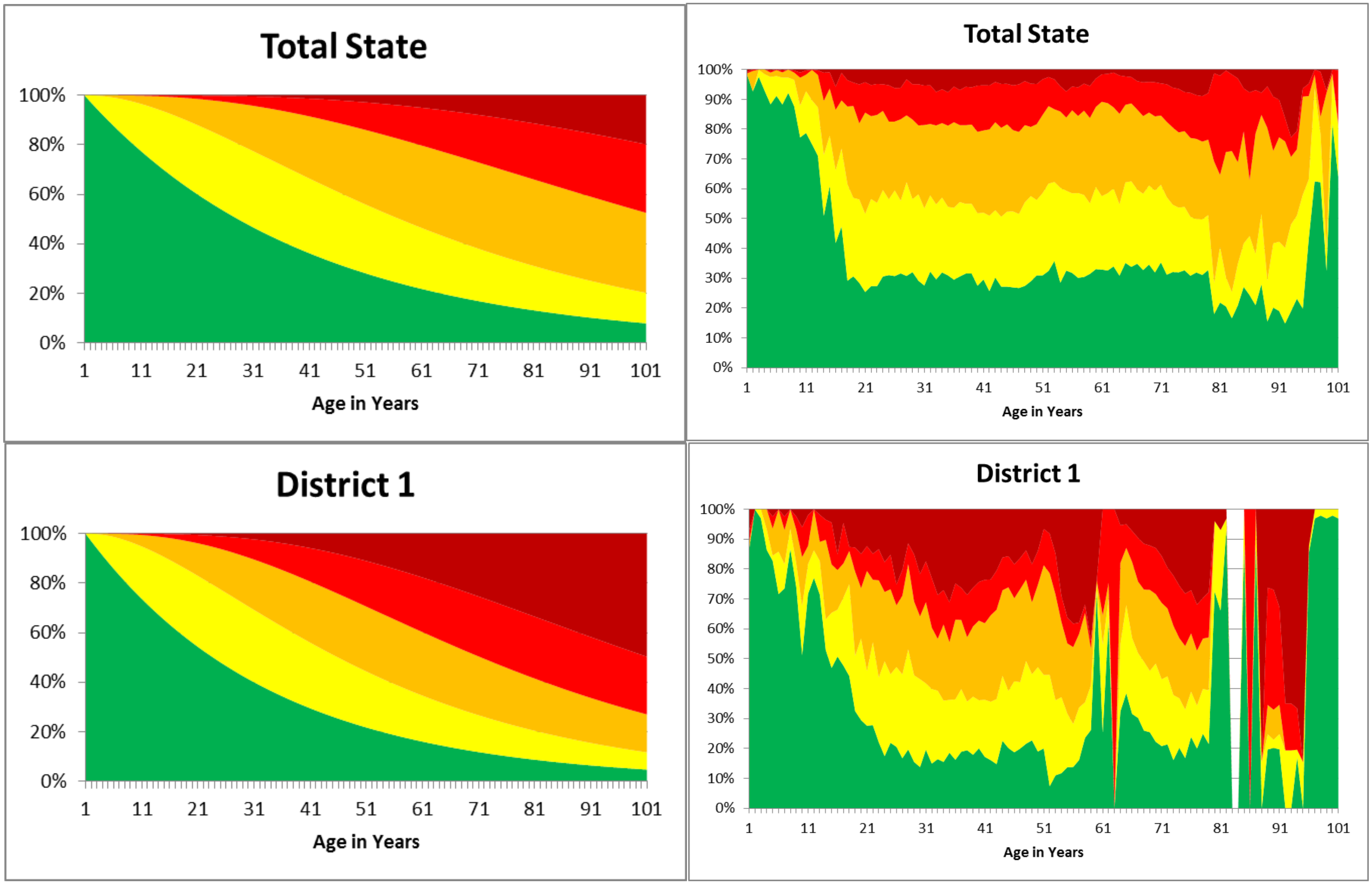

Figure D-66 – Markov Chain Prediction vs. Actual Graphs – Element 108 – Total State and District 1

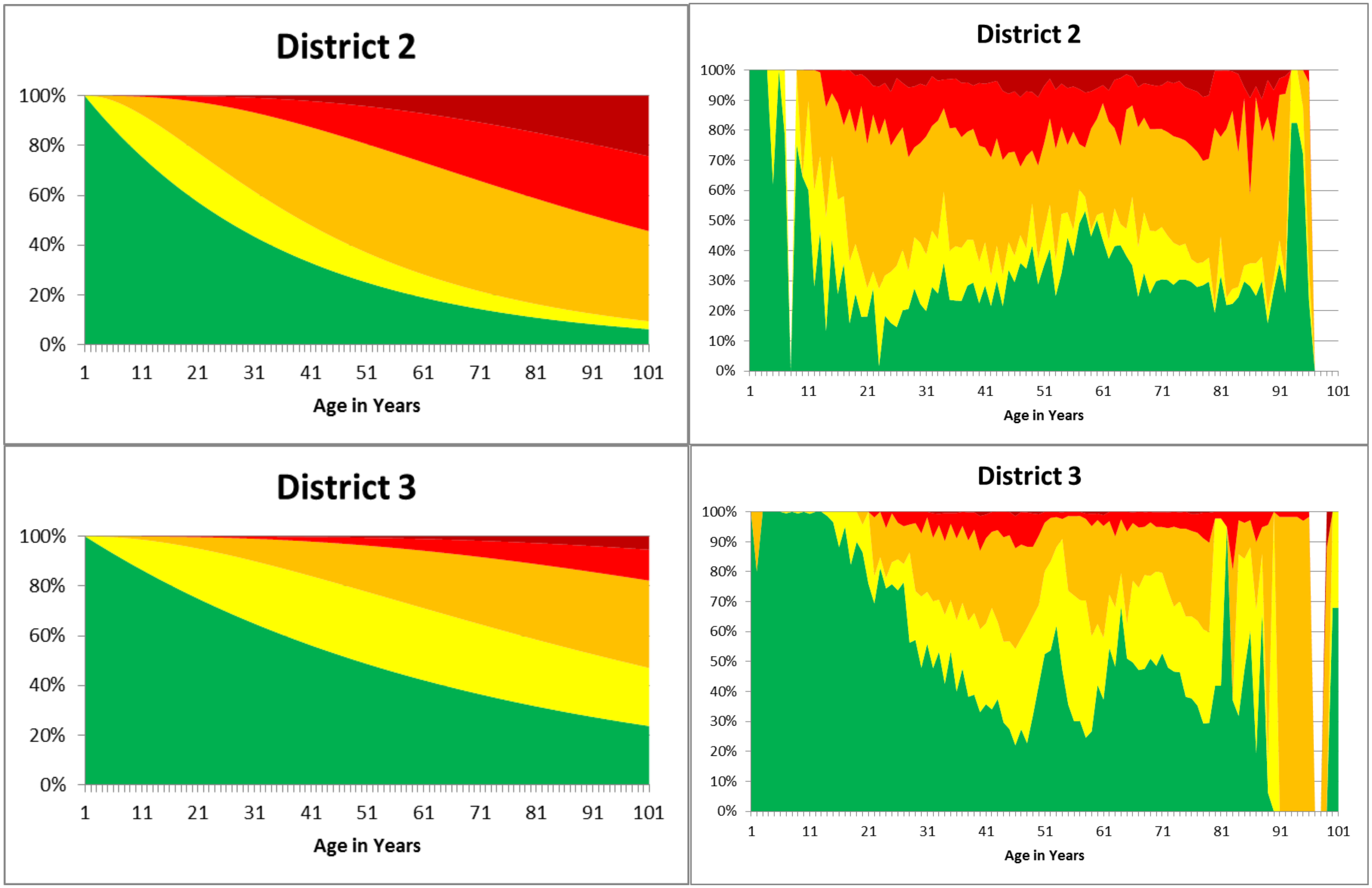

Figure D-67 – Markov Chain Prediction vs. Actual Graphs – Element 108 – Districts 2 and 3

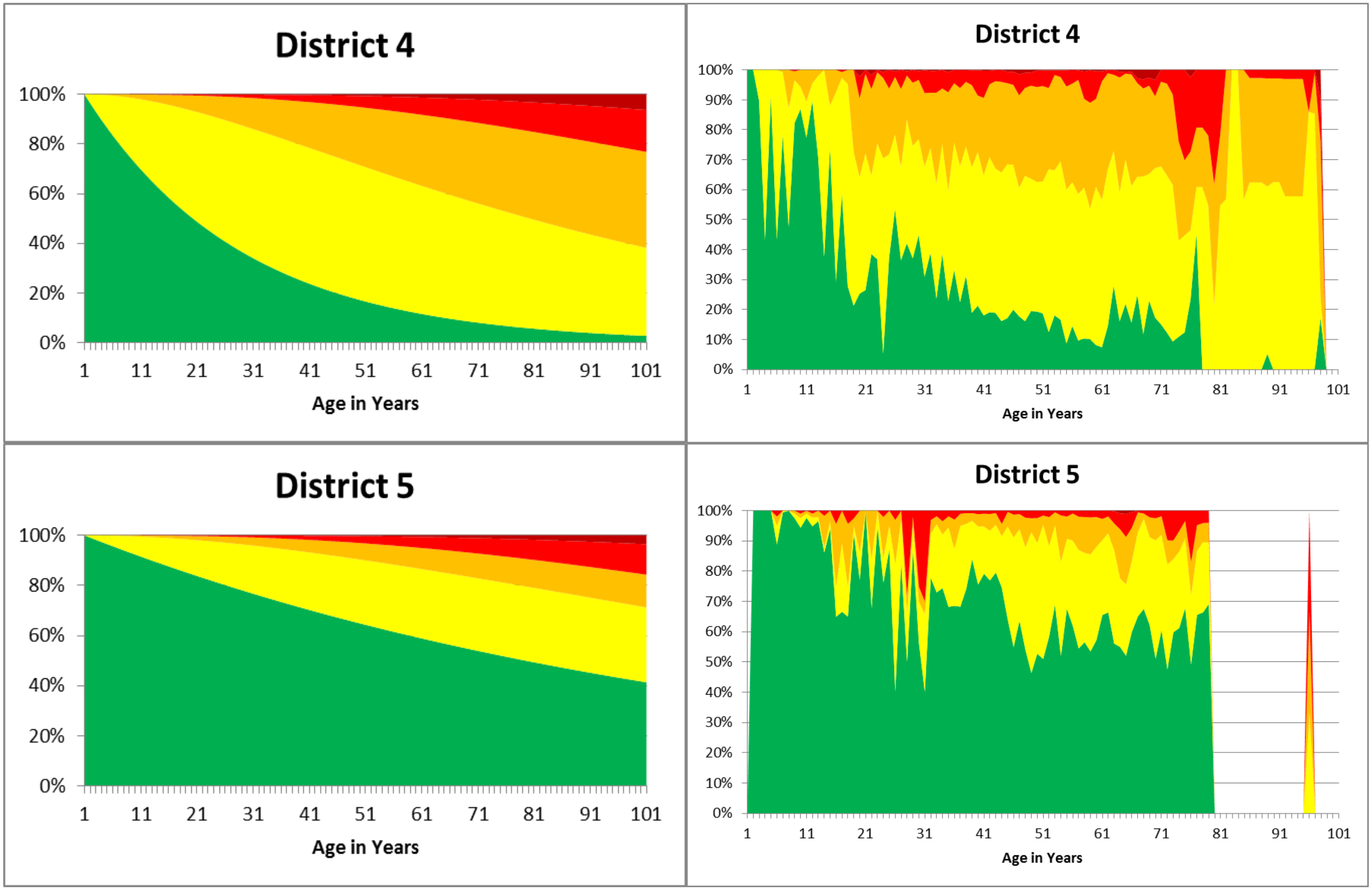

Figure D-68 – Markov Chain Prediction vs. Actual Graphs – Element 108 – Districts 4 and 5

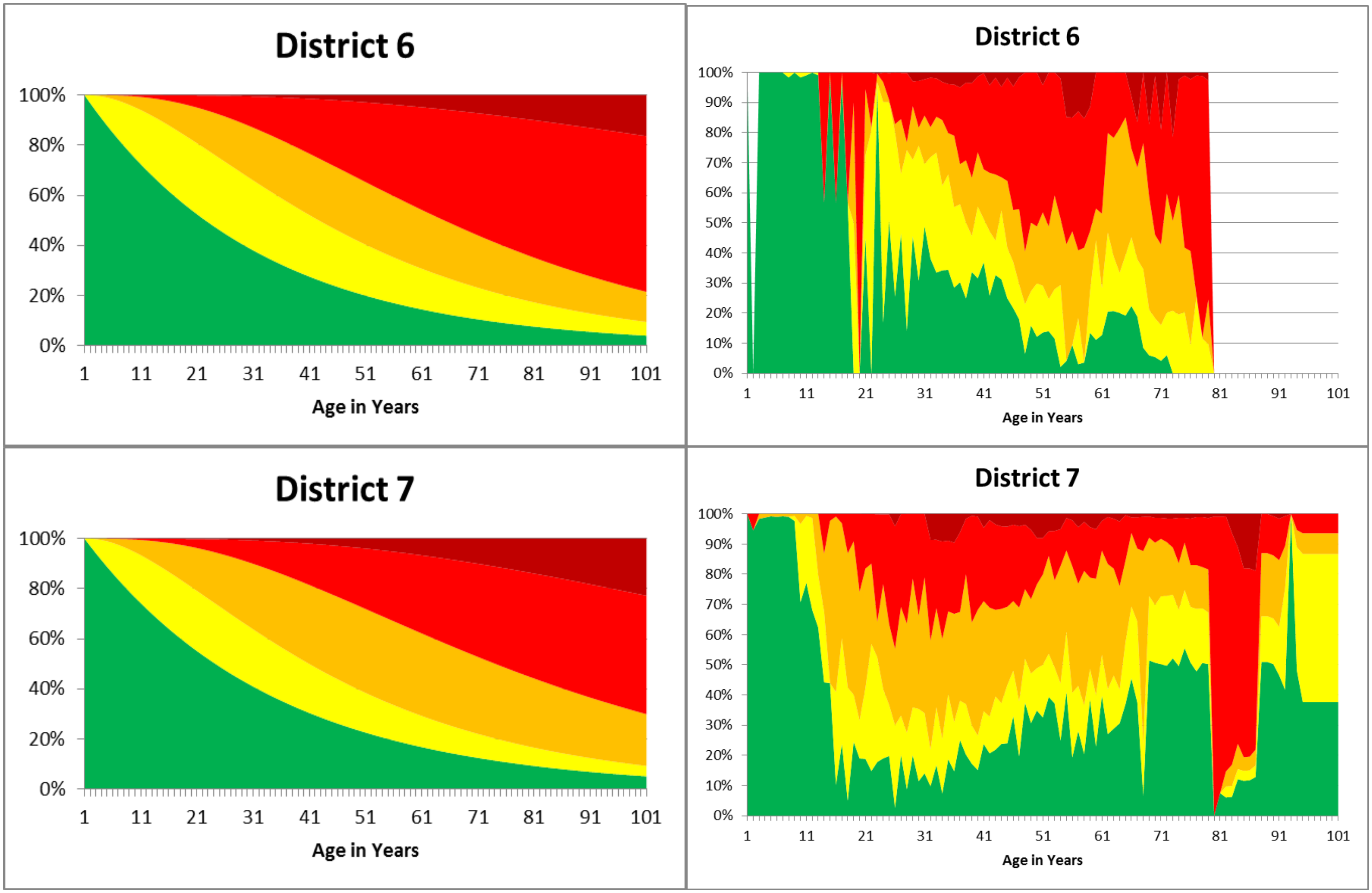

Figure D-69 – Markov Chain Prediction vs. Actual Graphs – Element 108 – Districts 6 and 7

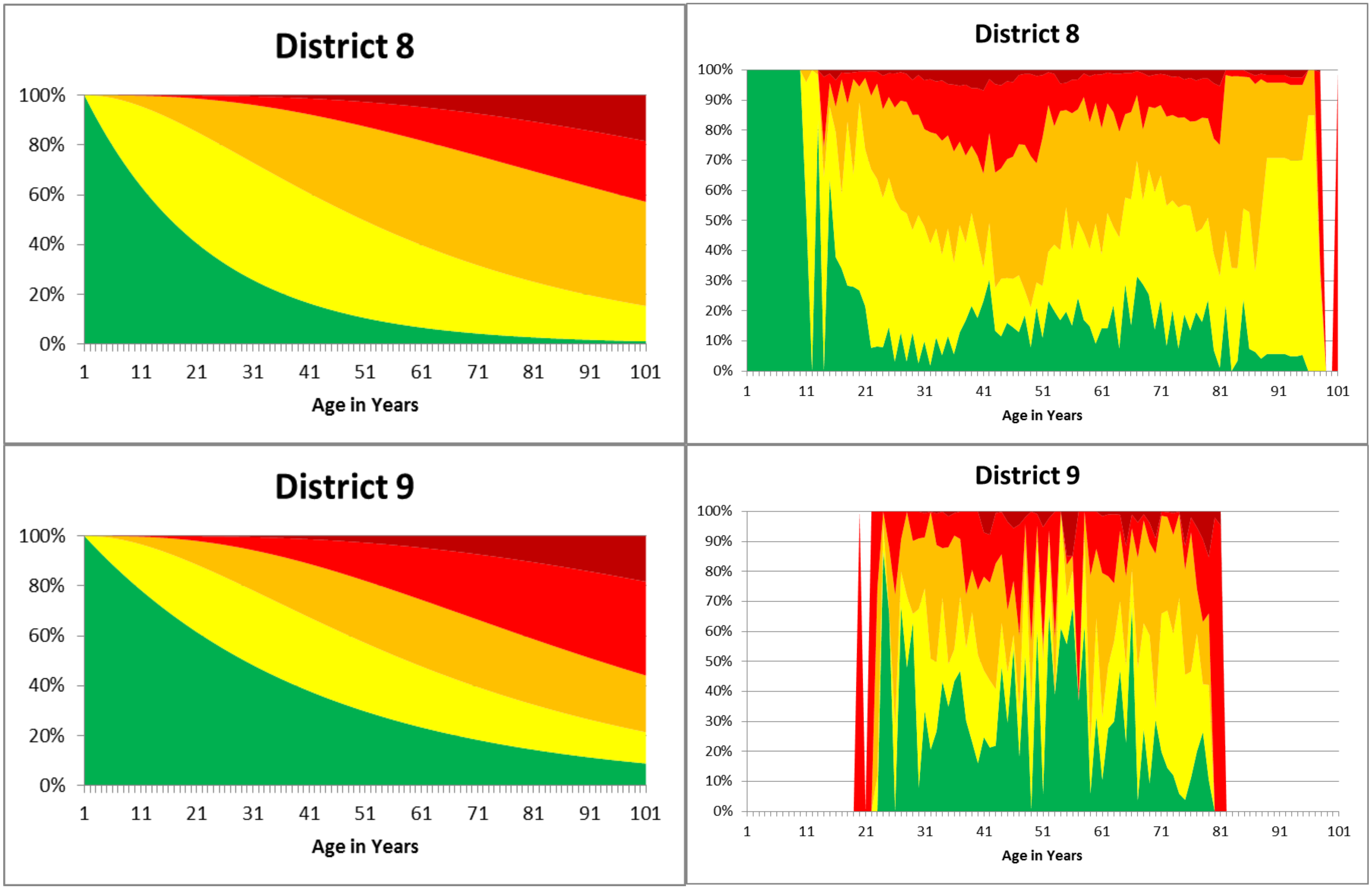

Figure D-70 – Markov Chain Prediction vs. Actual Graphs – Element 108 – Districts 8 and 9

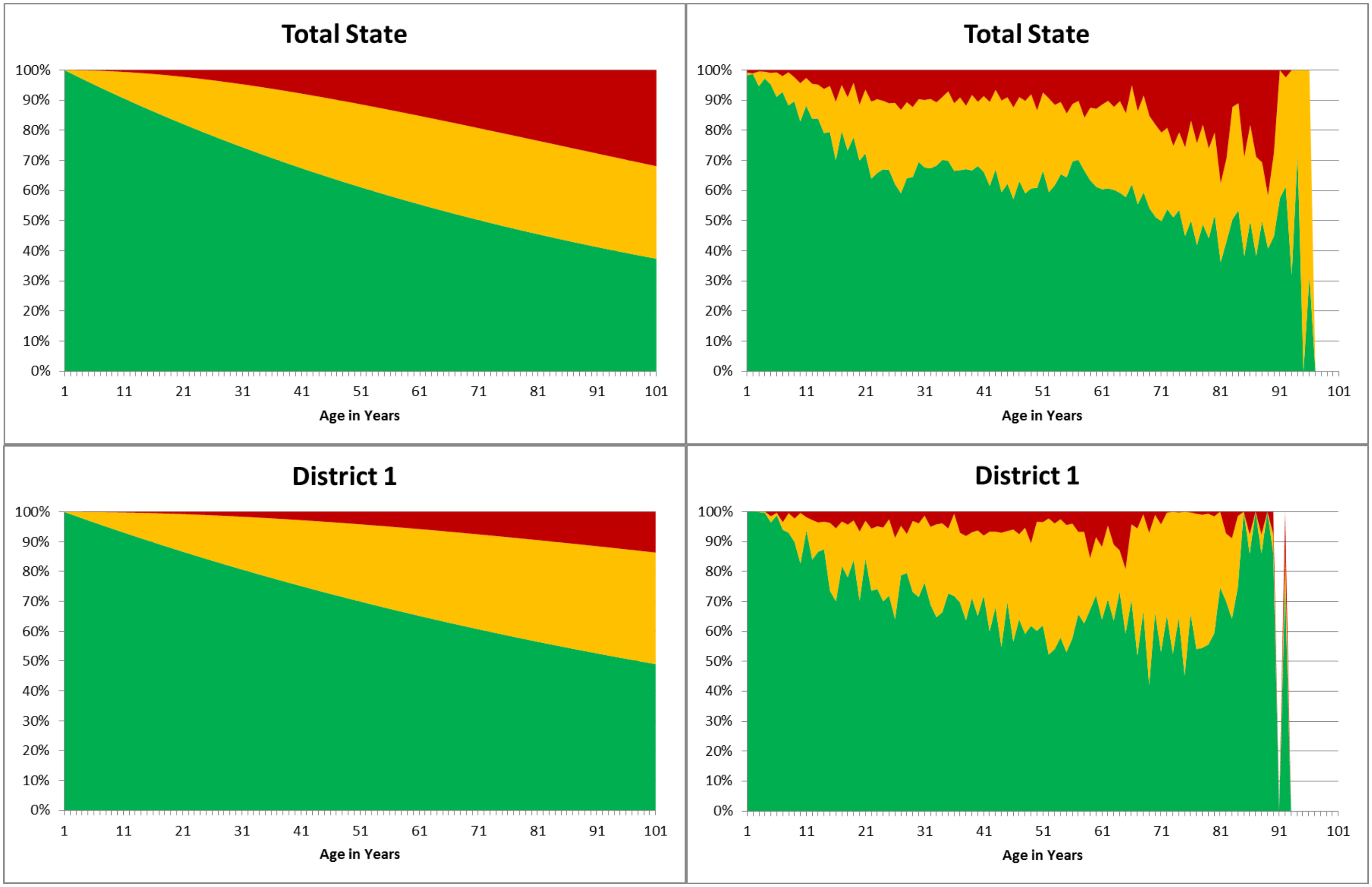

Figure D-71 – Markov Chain Prediction vs. Actual Graphs – Element 302 – Total State and District 1

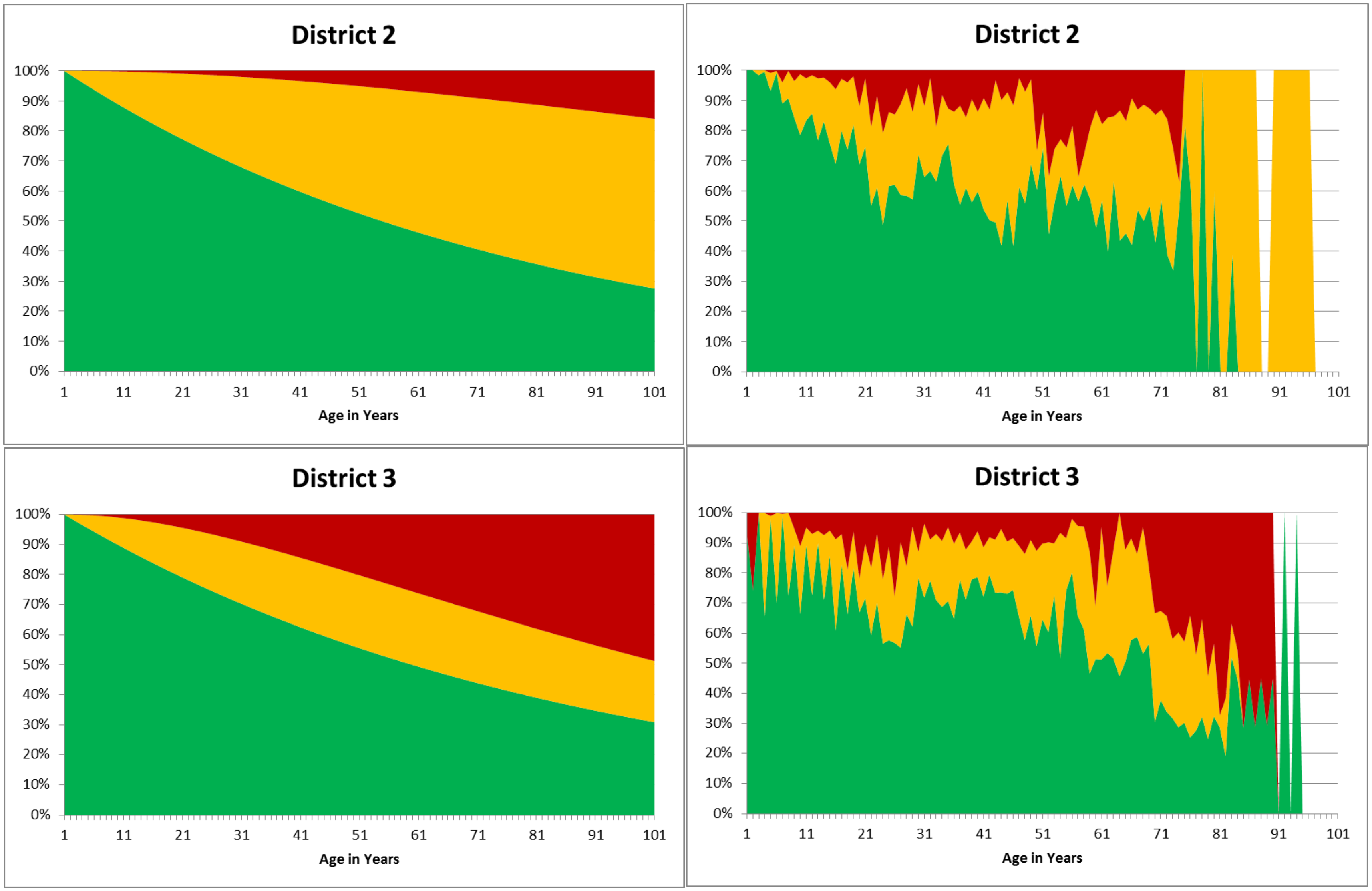

Figure D-72 – Markov Chain Prediction vs. Actual Graphs – Element 302 – Districts 2 and 3

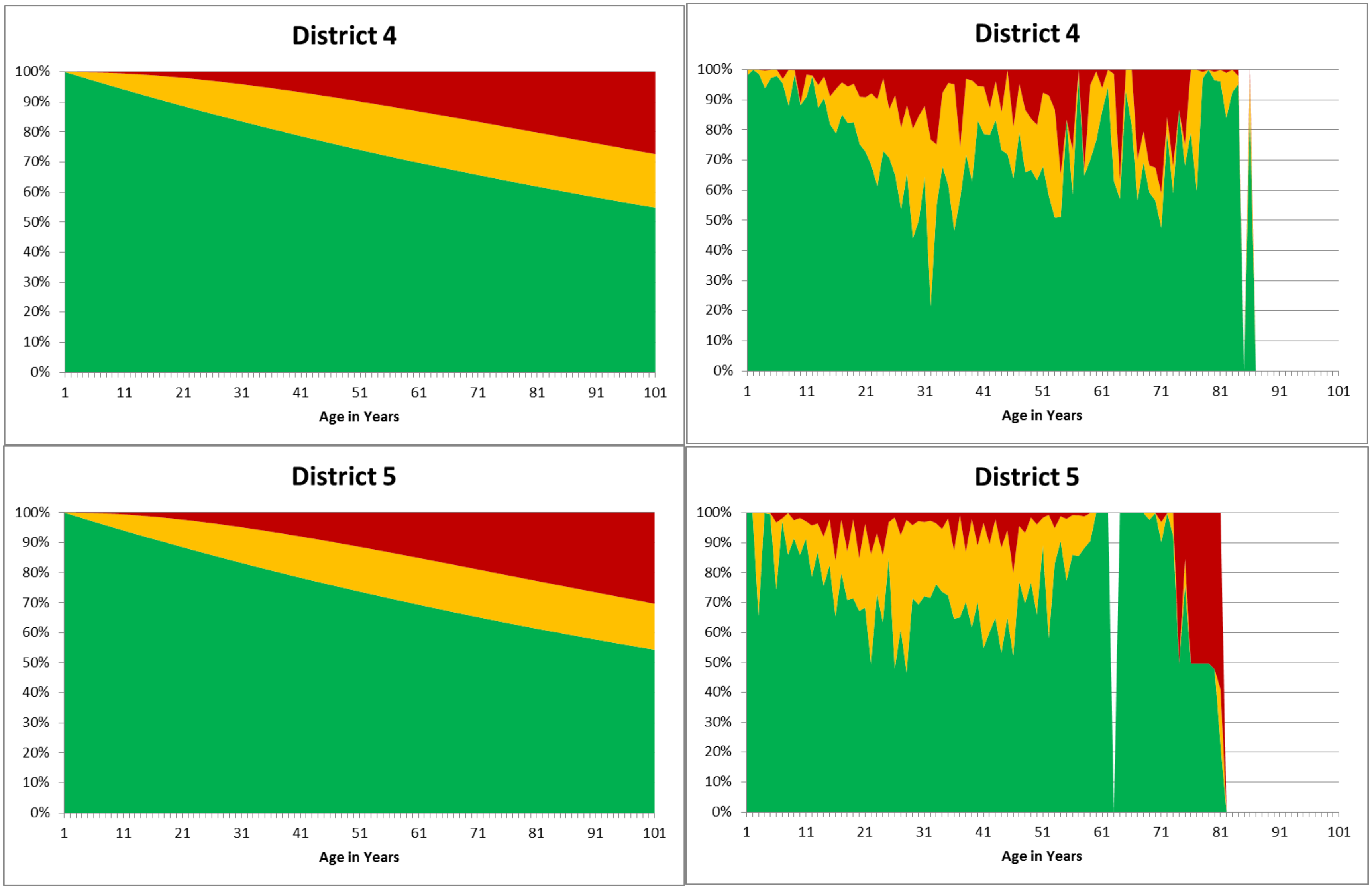

Figure D-73 – Markov Chain Prediction vs. Actual Graphs – Element 302 – Districts 4 and 5

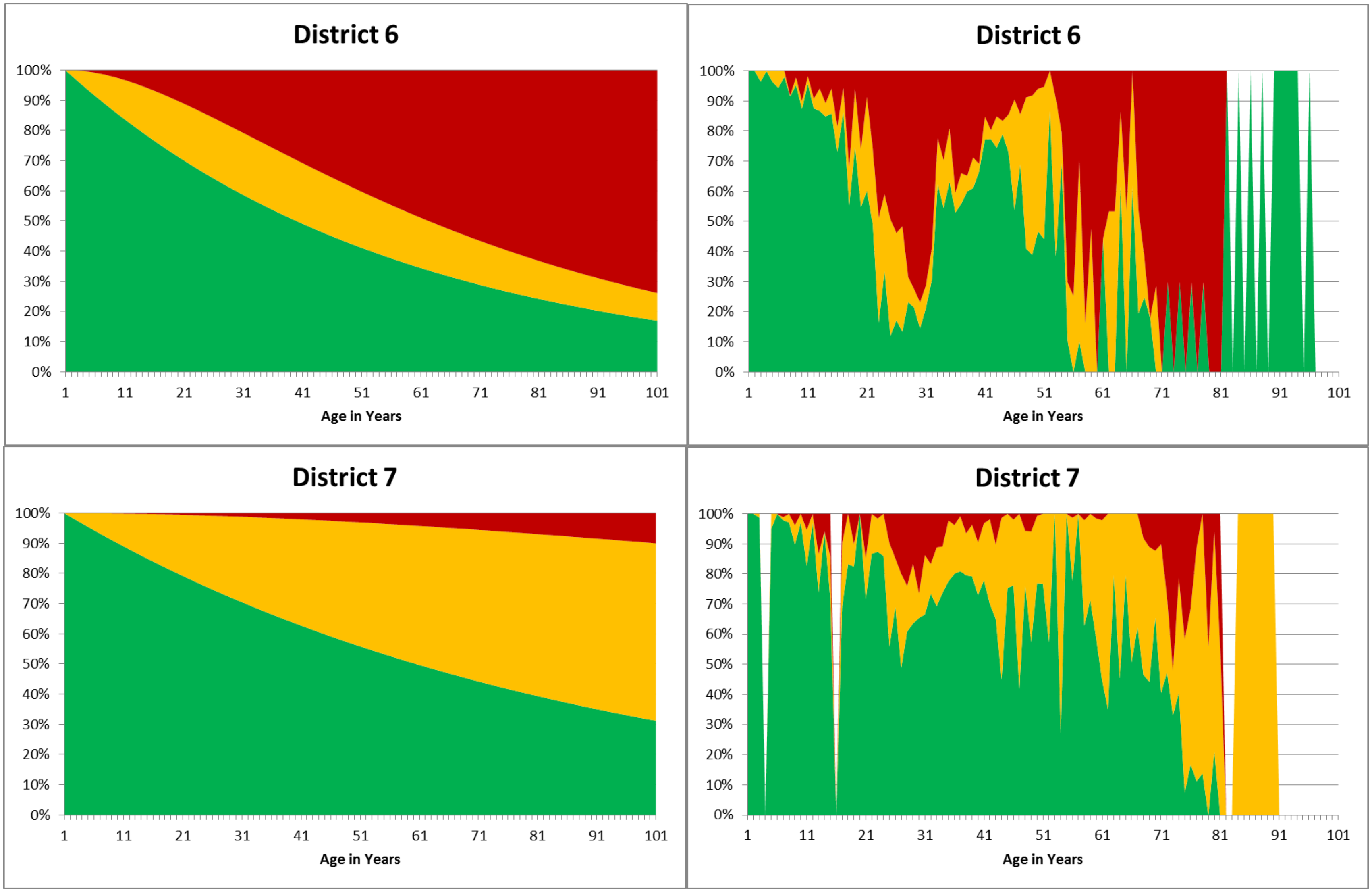

Figure D-74 – Markov Chain Prediction vs. Actual Graphs – Element 302 – Districts 6 and 7

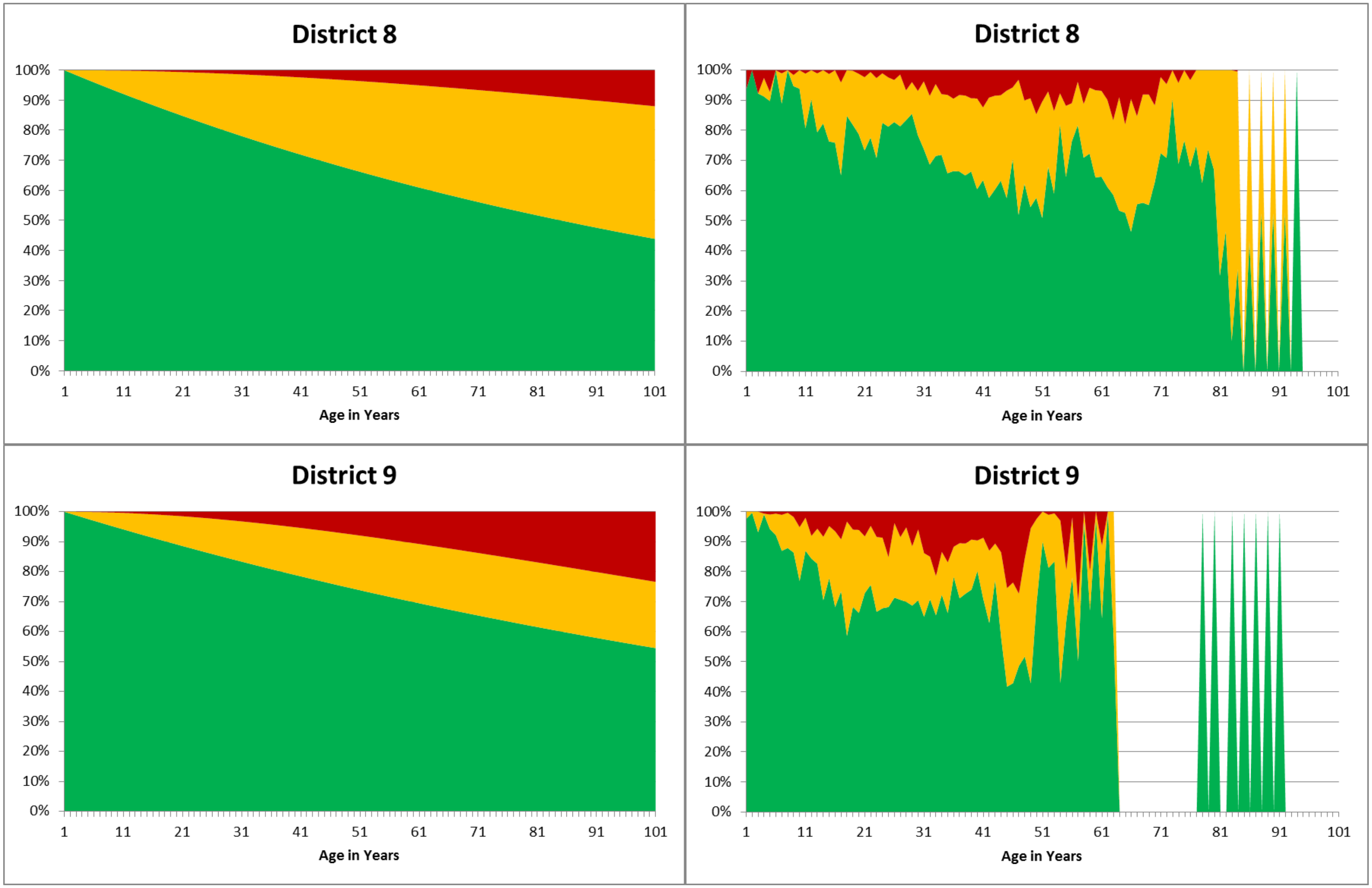

Figure D-75 – Markov Chain Prediction vs. Actual Graphs – Element 302 – Districts 8 and 9

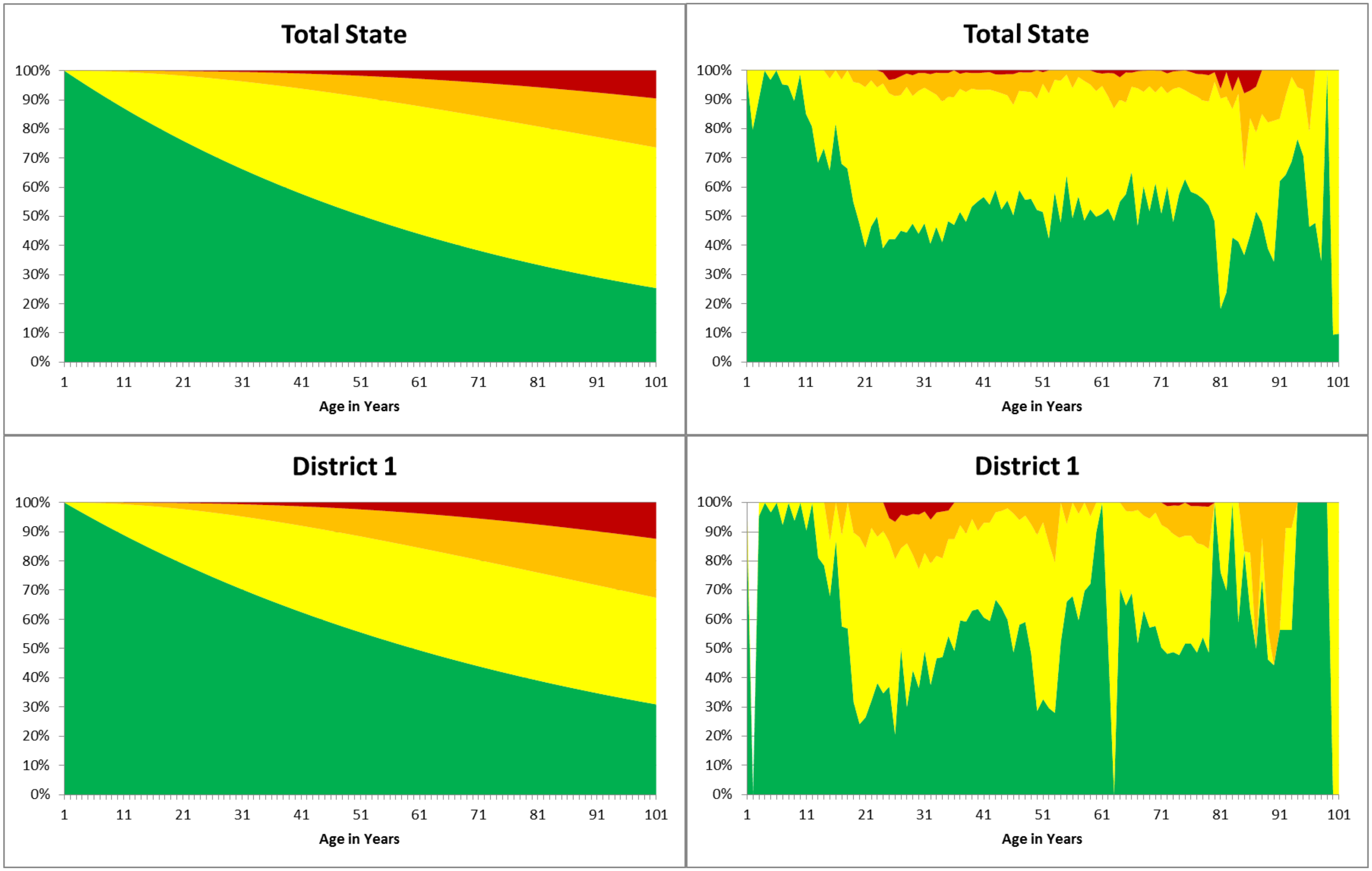

Figure D-76 – Markov Chain Prediction vs. Actual Graphs – Element 32 – Total State and District 1

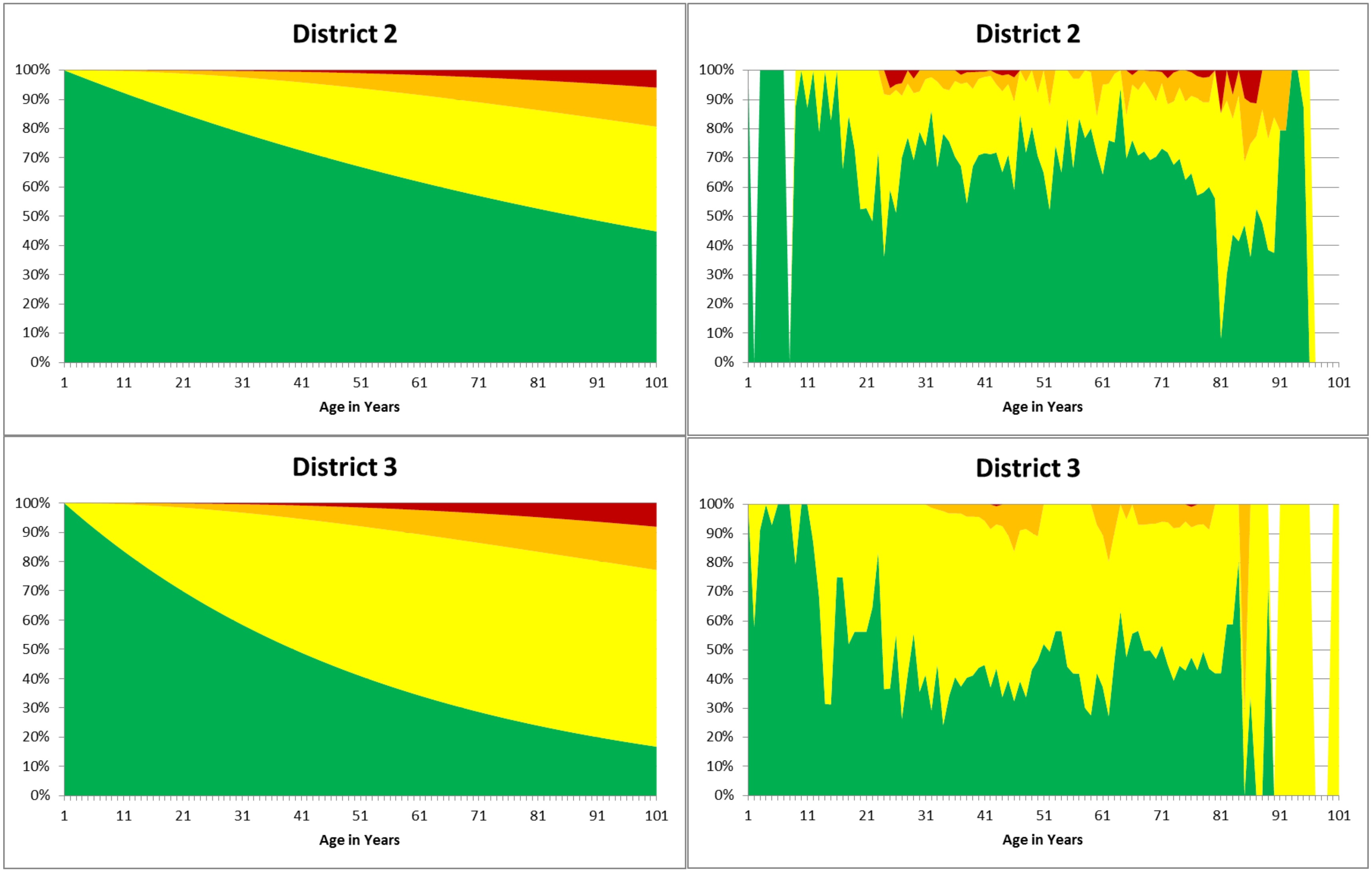

Figure D-77 – Markov Chain Prediction vs. Actual Graphs – Element 32 – Districts 2 and 3

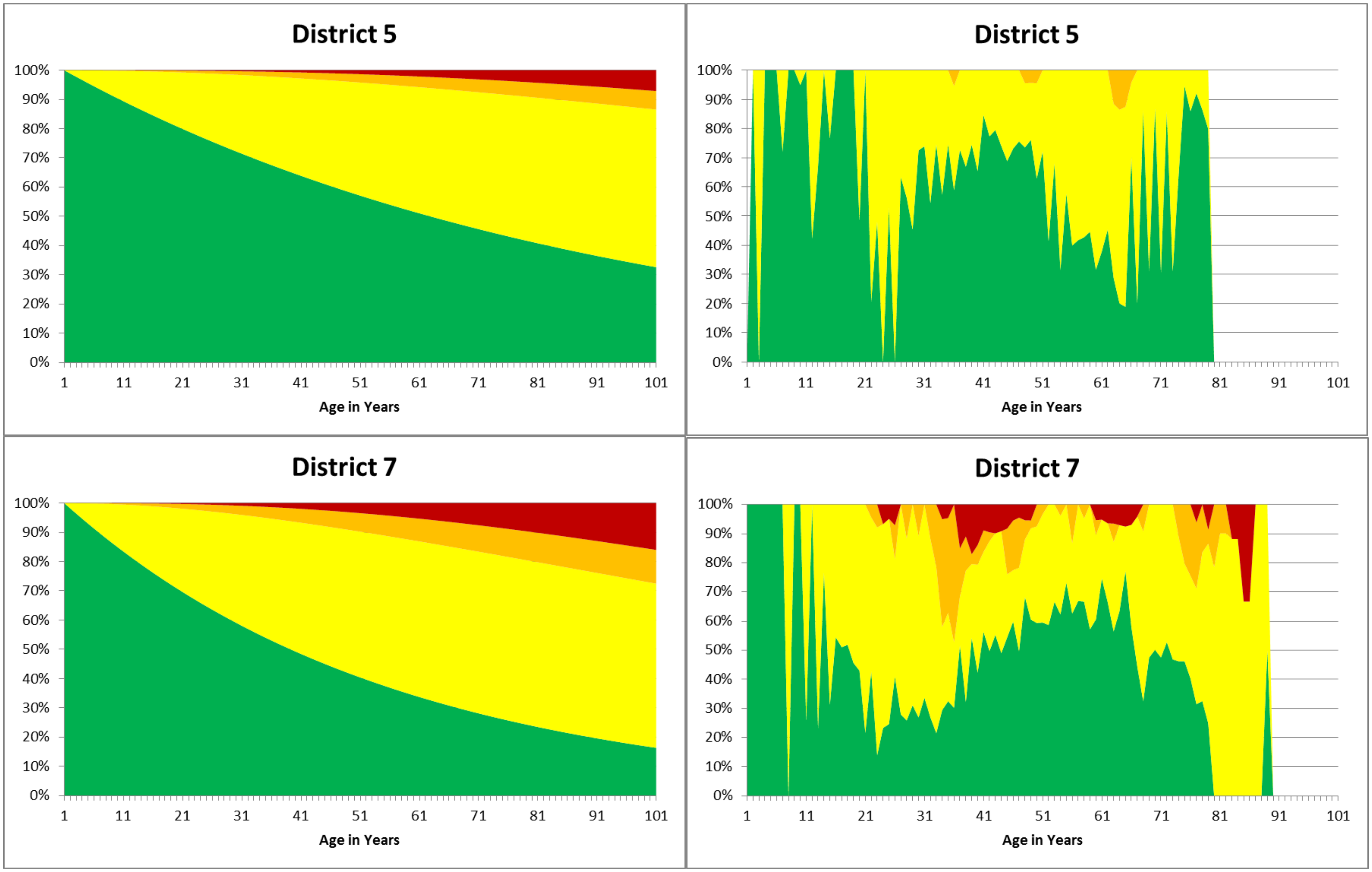

Figure D-78 – Markov Chain Prediction vs. Actual Graphs – Element 32 – Districts 5 and 7

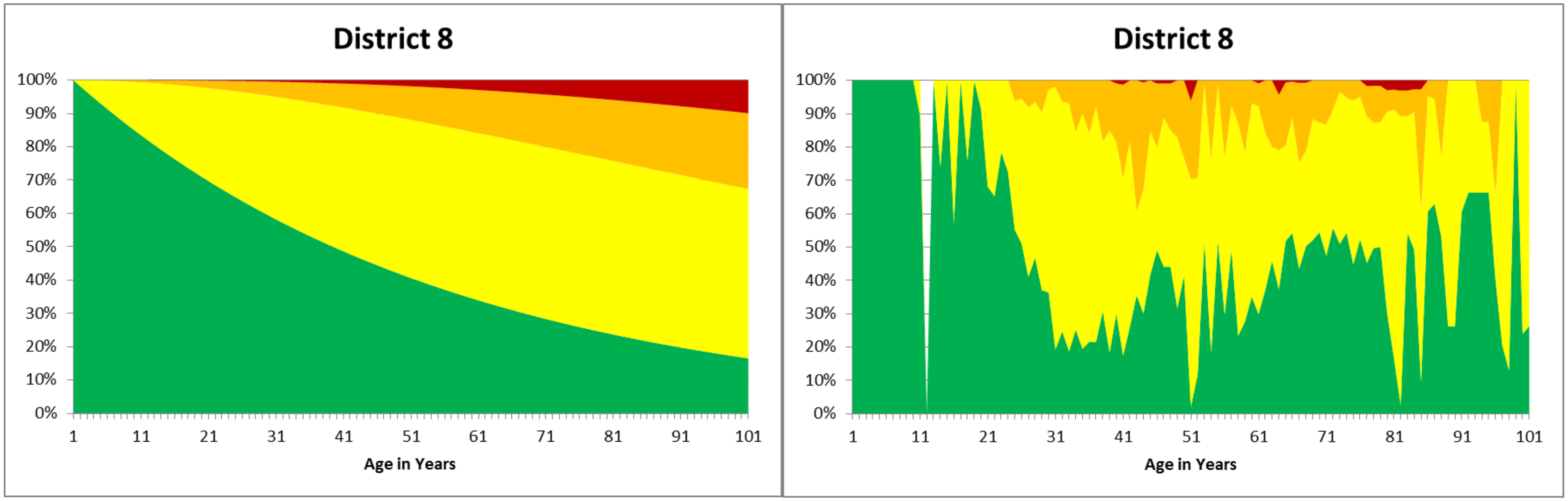

Figure D-79 – Markov Chain Prediction vs. Actual Graphs – Element 32 – District 8