
FINAL REPORT

DECISION SUPPORT FOR BRIDGE PROGRAMMING AND BUDGETING

Contract No. BD 543-9

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16. Abstract This study has developed a bridge decision support tool for network-level analysis of tradeoffs between performance and funding, using a multi-objective benefit/cost analysis to predict system wide performance at any given budget or the funding requirement of any target performance level. Extensive literature review was initially done, including review of pertinent previous research done by the Florida Department of Transportation (FDOT), as well as Asset Management-related research done by the Federal Highways Administration (FHWA), National Cooperative Highway Research Program (NCHRP), and others. Performance measures were developed, compatible with the prior models inside the FDOT Pontis bridge management system, particularly the Project Level Analysis Tool (PLAT), and the use of the FDOT's Deficient Bridges List (DBL). An optimization model framework was formulated and developed using the incremental-benefit algorithm, with performance measures serving as constraints and objectives. Labeled the Network Analysis Tool (NAT), the model is developed as a Microsoft Excel spreadsheet to supplement the functionality of AASHTOWare® Pontis®. The primary purpose of the NAT is to determine the maximum level of inventory performance achievable at any given level of funding over a 10-year planning horizon. The budget constraint can be easily manipulated by the user to analyze sensitivity to funding uncertainty. Also included is the user interface mockup for the digital dashboard of the decision support tool. A use-case analysis is presented, describing how the NAT will assist in the Department's programming and budgeting decision making activities. A domain model organizes the essential concepts of the programming and budgeting problem in a manner that will serve as an outline for data requirements and software components, and provides a framework for integrating the product with FDOT's Pontis database and its existing Project Level Analysis Tool. (PLAT). During this study, a preliminary evaluation of the FHWA's NBI translator was also done, as well the formulation of a proposed new methodology for NBI translation of Pontis' element condition data to the NBI condition ratings format.					
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$$\text{ft}^2 \times 0.09290 = \text{m}^2$$

$$\text{yd}^2 \times 0.00008361 = \text{m}^2$$

$$\text{yd}^3 \times 0.7646 = \text{m}^3$$

DISCLAIMER

The opinions, findings and conclusions expressed in this publication are those of the authors and not necessarily those of the Florida Department of Transportation (FDOT) or the U.S. Department of Transportation (USDOT).

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Electronic Attachment 2: User Manual for Network Analysis Tool (NAT)
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EXECUTIVE SUMMARY

The Florida Department of Transportation (FDOT) is currently in the process of implementing the AASHTO Pontis Bridge Management System to support network-level and project-level decision making in the headquarters and district offices. Pontis is an integral part of a Department-wide effort to improve the quality of asset management information provided to decision makers. The credibility and usefulness of this information is also essential for satisfaction of the requirements of the Government Accounting Standards Board Statement 34 (GASB 34) regarding the reporting of capital assets. Previous Department research in the areas of user costs and agency costs have developed state-of-the-art models. A spreadsheet-based Project Level Analysis Tool has been developed to process and present Pontis analytical results in a form useful for bridge-level decision-making.

Strong interest has been expressed within the Department as well as in other state Departments of Transportation in having an objective network-level analysis of tradeoffs between performance and funding. GASB 34 specifically requires this capability in its modified approach, which FDOT is planning to adopt. The project level analysis tool provides all the necessary inputs for individual bridges, so what is needed now is a tool to compile and summarize all this information.

This study has developed such a tool, using benefit/cost analysis to predict system wide performance at any given budget or the funding requirement of any target performance level. This will improve programmatic decision-making by helping managers to optimize the allocation of funding among competing uses.

Extensive literature review was initially done, including review of pertinent previous research done by FDOT, as well as Asset Management-related research done by the Federal Highways Administration (FHWA), National Cooperative Highway Research Program (NCHRP), and others. State-of-the art models of bridge programming and budgeting were reviewed, identifying the methodologies employed. Pertinent information was elicited from FDOT Offices of Work Programs and Maintenance. The FDOT's overall mission, goals, and long-range objectives were studied, with emphasis on the bridge-related objectives. Some pertinent NCHRP studies (ongoing at the time of this study) were also reviewed to identify performance targets for bridge-related decision-making in other states. Based on the above-mentioned information and also ongoing efforts by FDOT to established agency-wide performance measures, the required bridge decision support performance measures were developed. These measures were compatible with the prior models inside the FDOT Pontis bridge management system, particularly the Project Level Analysis Tool (PLAT), and the use of the FDOT's Deficient Bridges List (DBL). Also studied and documented was the current bridge funding process at FDOT, including the various types of federal and state funds, and an example statistical distribution of the funds relative to type of bridge work.

A framework of optimization model was formulated and developed using the incremental-benefit algorithm, with performance measures serving as constraints and objectives. Labeled the Network Analysis Tool (NAT), the model is developed as a Microsoft Excel spreadsheet to supplement the functionality of AASHTOWare® Pontis®. The primary purpose of the NAT is to

determine the maximum level of inventory performance achievable at any given level of funding over a 10-year planning horizon. The budget constraint can be easily manipulated by the user to analyze sensitivity to funding uncertainty. When concerned with physical bridge condition, National Bridge Inventory (NBI) ratings and/or health index are most appropriate performance measures. For a broader measure of performance, it is best to use life cycle cost. A use-case analysis is presented, describing how the NAT will assist in the Department's programming and budgeting decision making activities. A domain model organizes the essential concepts of the programming and budgeting problem in a manner that will serve as an outline for data requirements and software components, and provides a framework for integrating the product with FDOT's Pontis database and its existing Project Level Analysis Tool (PLAT).

For statewide program management purposes, the primary objective to be maximized by the NAT is the percentage of structures on the State Highway System having a condition rating of either excellent or good, either for the lowest of deck, superstructure, or substructure ratings; or for the culvert rating. In order to predict this performance measure into the future as a result of programming decisions, the Federal Highway Administration's NBI Translator Program (distributed with Pontis) was used to convert predicted element conditions into predicted NBI condition ratings. In addition, several additional performance measures are computed in the PLAT and then carried over to the NAT to be used in policy analysis and the establishment of performance targets.

During this study, the FHWA's NBI translator was also evaluated for accuracy in converting Pontis' element condition data to the NBI condition ratings format. The NBI translator's shortcomings were identified. A new methodology was formulated, based on computation of condition indexes, for converting element condition data to NBI ratings. The preliminary findings of this evaluation are summarized in this report. The proposed new methodology showed a good potential for a more accurate conversion.

1. Research Background

This section presents the current status of knowledge both in terms of research activities and industry practice related to bridge programming and budgeting. Results of literature review are presented as well as the gathering of relevant data for the proposed decision support models.

1.1 Introduction and Research Objectives

The Florida Department of Transportation (FDOT) is implementing the AASHTO Pontis Bridge Management System to support network-level and project-level programming for the maintenance, repair, rehabilitation and replacement of the more than 6,200 bridges managed by the Department.

Previous research in the areas of user cost and agency costs have resulted in the development of several project planning and programming tools to assist FDOT bridge managers in the decision-making process for allocating limited funds for bridge preservation and improvement, and also for determining the optimal timings for these activities. One such tool is the Project-Level Analysis Tool (PLAT). The PLAT is a spreadsheet-based tool that serves as a digital dashboard for presenting and displaying Pontis analytical results in a manner that facilitates the bridge management process for bridge-level decision-making. The objective of the current research is to extend the capabilities of the PLAT to develop a digital dashboard for network-level bridge decision-making. This new tool will enable FDOT bridge managers to plan more optimal bridge improvement and preservation programs at the network level.

The new tool is capable of predicting network-wide performance and funding requirements, and can also perform a tradeoff analysis between performance and funding based on budgetary constraints and network performance targets. The tool compiles, summarizes, and displays network data and analysis results.

The product will be further beneficial to the Department because it will be extendable to other types of transportation assets such as pavements and rest areas, and is therefore a useful tool for the FDOT's GASB 34 implementation. The tool will also be beneficial for the FDOT Work Program Office. The Florida Statutes require the FDOT, through its central office, district offices, turnpike enterprise, metropolitan planning organizations, and local governments to develop the 5-year Work Program that lists preservation, improvement and new construction work that must be performed over the next five years in order for the Department to meet its long-term objectives. The product will therefore be of use to the FDOT Office of Financial Management, which develops the finance plan that forecasts expected revenues, expected expenditures; expected levels of federal aid, and the resulting expected cash balance in the State Transportation Trust Fund (STTF).

The three primary objectives of this research project can be summarized as follows:

1. Gather relevant data to identify performance measures related to FDOT's bridge decision making.

2. Formulate a multi-objective optimization framework for bridge decision-making at both project and network levels.
3. Develop a computer program and implement the framework of the multi-objective optimization

In this section of the report, a background is first presented on the Department's processes, as found relevant to bridge decision-making, and a review of these processes to identify pertinent performance measures. Then the literature review is discussed to show relevant works towards the formulation of proposed multi-objective optimization system.

1.2. FDOT's Asset Management Process

The Florida Department of Transportation (FDOT)'s approach to asset management strongly influences the issue of decision support programming for its bridges. Based on Vandervalk (1999) the following background information is first presented, on FDOT's asset management.

The Department is headed by a Secretary, who reports directly to the Governor of Florida. FDOT's policy oversight is established and maintained by the Florida Transportation Commission consisting of nine commissioners. The Department is operated through a decentralized organizational structure, with a central office in Tallahassee, and eight districts, including the Turnpike District, located throughout the state. Responsible for roadways, bridges, and for motor carrier compliance in the state, the agency also in its role on public transportation; provides funding and technical support to local agencies and private-sector entities (14 seaports, 22 commercial airports, 3,000 miles of main route rail, 18 local and regional transit systems, and 48 specialized systems serving the transportation disadvantaged).

With no specific office for Asset Management, the Department's Planning Office is responsible for evaluating and reporting the agency's performance relative to its goals and objectives. The agency's asset management process can be summarized as follows. First, the Florida Transportation Plan is defined for a 20-year time frame. A more detailed ten-year plan, the Program and Resource Plan, is then established, setting forth specific operating policies and performance measures that guide the development of each program. This ten-year plan indicates the program funding levels and financial and production targets expected to be balanced to the anticipated revenues. Finally, the Work Program is developed, generating a five-year listing of projects based on the Florida Transportation Plan, the Program and Resource Plan, and extensive involvement by the public and districts, before the final decision by a strong executive committee at the Department.

The Department's investment decisions are uniquely described as giving the highest priority to preservation of the system, or as indicated, "taken off the top." In other words, a form of level of service is established, and the Department ensures that level, specifically, for three categories of preservation: pavement, bridge, and routine maintenance. The bridge component is described as a bridge management system, indicating over 6,000 state-owned bridges with additional 4,000 bridges being inspected

every two years to identify which will need preventive maintenance, minor or major repair work, or replacement. The Department's desired level of service is described as:

“A bridge that meets Department standards is defined as not showing evidence of structural deterioration, not being limited by weight restrictions or not needing preventive maintenance. 90 percent of Department maintained bridges must be kept at a level that meets these standards...”

It should be noted that the maintenance rating program does not consider bridges; it rates five primary categories – roadway (potholes, etc.); roadside (shoulders), vegetation and aesthetics (mowing, litter removal), traffic services (signs, lighting), and drainage (ditches).

After the preservation and public transportation funding requirements have been satisfied, capacity funds are then programmed, with “off the top” 50% of the capacity funds going to the Florida Intrastate Highway System, ensuring the statutory-required goals of mobility and economic prosperity. For illustration purposes, during the fiscal year 2000/2001, the Department's annual budget was \$3.7 billion of which approximately \$1.2 billion was set aside for preservation needs (pavement, bridge and routine maintenance).

As mentioned in Status of the Nation's Highways, Bridges, and Transit: 2002 Conditions and Performance Report (USDOT 2002), one of the important elements needed to guide a transportation asset management program is “ the establishment of performance expectations consistent with goals, available budgets, and organizational policies.” As indicated in the 2020 Florida Transportation Plan (FDOT 1999), a long-range plan publication for FDOT, the agency's mission was clearly stated as:

“Florida will provide and manage a safe transportation system that ensures the mobility of people and goods, while enhancing economic competitiveness and the quality of our environment and communities.”

As illustrated in Figure 1, this report identifies four strategic goals and specific long-range objectives, with Goal No. 2 being the most relevant to bridge management. Based on the Florida Statute, Section 339.155(4), the FDOT also prepared an Annual Performance Report in 2000, to assess FDOT's progress on the goals and objective outlined in the 2020 transportation plan. At the time of this research, the performance report (FDOT 2000) was the most recent by FDOT. As shown in Table 1 below, there are four goals, each with its short-range objectives. The goal that is most directly related to bridge management is Goal No. 2: Preserving the system. Also pertinent to highway bridges, but not directly linked in the FDOT Plan is Goal No.1 “Traveling Safely.” Lastly, Goal No. 3 “Connecting Florida's Communities” is indirectly relevant to bridges.

In 2003, the FDOT published a “short range component” of the 2020 plan, now indicating three strategic goals: 1, Preserve and Manage a Safe, Efficient Transportation System; 2, Enhance Florida's Economic Competitiveness, Quality of Life and Transportation Safety; and 3, Organizational Excellence (FDOT 2003). This 2003 document now sets expected performance through the year 2011, and the pertinent goal to bridge management is now Goal No.1 (system preservation), but everything else remains the same, in terms of the performance measures.

Florida's Transportation Mission

Florida will provide and manage a safe transportation system that ensures the mobility of people and goods, while enhancing economic competitiveness and the quality of our environment and communities.

1***Safe transportation for residents, visitors and commerce*****2*****Preservation and management of Florida's transportation system*****Long Range Objectives**

- ◆ Adequately maintain all elements of the transportation system to protect the public's investment for the future.
- ◆ Increase the efficiency of the transportation system using appropriate technologies.
- ◆ Reduce the number of commercial vehicles that illegally exceed weight limits on Florida's public roads and bridges.
- ◆ Manage access on Florida's public roads to preserve capacity and enhance safety and mobility.
- ◆ Improve incident management to minimize the impact on traffic flow.

3***A transportation system that enhances Florida's economic competitiveness*****4*****A transportation system that enhances Florida's quality of life***

Figure 1.1. FDOT's Mission, Goals, and Long Range Objectives (Source: FDOT 1999)

Table 1.1. FDOT's Goals and Objectives in 2000 Performance Report [Source: FDOT 2000]

DEPARTMENT GOALS		SHORT RANGE OBJECTIVES
TITLE	DESCRIPTION	
1. Traveling Safely	Safe Transportation for Residents, Visitors, and Commerce.	<p>1.1. By 2006, reduce the highway fatality rate to 1.73 fatalities per million vehicle miles traveled.</p> <p>1.2. Through 2006, keep the percentage of crashes on the State Highway System where road-related conditions are a contributing factor below 1.0 percent.</p>
2. Preserving the System	Protection of the Public's Investment in Transportation	<p>2.1 Through 2006, ensure that 80% of pavement on the State Highway System meets Department standards.</p> <p>2.2 Through 2006, ensure that 90% of FDOT-maintained bridges meet Department standards while keeping all FDOT-maintained bridges open to the public safe.</p> <p>2.3 Through 2006, achieve 100% of the acceptable maintenance standard on the State Highway System.</p>
3. Connecting Florida's Communities	A Statewide Interconnected Transportation System that Enhance Florida's Economic Competitiveness	<p>3.1 Through 2006, approximately 50% of the highway capacity improvement program shall be committed for capacity improvements on the FIHS.</p> <p>3.2 Maintain mobility trends on the FIHS by keeping annual growth density at or below 4%.</p> <p>3.3 Through 2006, continue to improve intermodal connections and access by annually allotting a minimum of \$30 million in state funds for the intermodal access program</p>
4. Supporting Florida's Communities	Travel Choices to Ensure Mobility, Sustain the Quality of the Environment, Preserve Community Values and Reduce Energy Consumption.	<p>Implement the priorities of metropolitan planning organizations and local governments in annually maintaining or advancing the schedule of at least 80 % of project phases in the Department's adopted work program.</p> <p>Through 2006, increase transit ridership at twice the average rate of population growth.</p> <p>Through 2006, ensure that all air quality standards related to mobile source emissions are met.</p>

Other documents available at FDOT, indicating the overall Department's goals and bridge-related performance expectations, include the following: FDOT System Monitoring and Performance Measures, under the Florida 2003 Intelligent Transportation System Strategic Plan Update; Florida's Mobility Performance Measures Program; and AASHTO's Task Force on asset Management's presentation on FDOT's Asset Management process (Verndavalk 1999). The last report (Verndavalk 1999) indicates that FDOT's mission is

"To provide a safe interconnected transportation system that ensures the mobility of people and goods, enhances the economic prosperity and preserves the quality of our environment and communities."

1.3. Pertinent Literature Review on Performance Measures

Performance measures are indicators of work performed and the results achieved. The need for performance measures may be derived from various sources such as:

- Quality control considerations
- Evaluation of productivity of personnel or equipment
- To quantify the effectiveness of programs e.g. bridge maintenance programs
- To assess the effectiveness of proposed policies and strategies
- To evaluate the impacts of legislation and budgets
- Concern for the utilization of tax dollars by the citizenry.

Performance measures literally drive the asset management decision-making process. Performance measures assist in establishing investment levels that represent service levels and resource commitments that reflect the public's perception of the needs of transportation infrastructure assets. By studying the changes in asset performance over time and due to deterioration, maintenance planners use performance measures to establish the timing of maintenance, rehabilitation and improvement projects for infrastructure assets.

For a network of assets owned and maintained by an agency, decisions pertaining to investments are optimized according to performance goals established by elected officials and policy makers. Performance goals provide a means to convey the public's understanding of how a DOT is managing the infrastructure under its stewardship. In order to establish effective performance measures, an agency must determine the priorities of facility users with regard to standards, values, and expectations in areas such as ride quality, overall level of service, travel times, overall system mobility and accessibility. A typical performance goal may be defined in terms of the percentage of assets that meet agency performance levels or thresholds.

The process of implementing performance measures generally narrows down to deciding on the specific measure to be used in any given decision-making context. Selecting poor measures or wrong measures can defeat the entire purpose resulting in wastage of invested money, loss of technical credibility, and failure to gain the benefits that were anticipated. On the other hand it must be noted that for successful implementation,

- Measures must not be overly complex.

- Definitions, applications, and interpretations must be consistent.
- Performance measures must reflect the results as well as the data collection process.
- Measure must be in alignment with the agencies stated policies, strategies, and long-term goals.

Many transportation agencies have undertaken some initiative regarding the applicability and or implementation of performance measures in one form or the other. A brief review of some agencies experiences are presented in the following sections.

1.3.1 NCHRP Project 20-60 (2005)

This was a study by Cambridge Systematics, Inc. with PB Consult, Inc. and Texas Transportation Institute. The objectives of this project are to develop an understanding of what set of performance measures can best serve the principles of good asset management, and to recommend procedures that help an agency apply this understanding. This study will develop a practical methodology that enables a transportation agency to a) identify measures of transportation system performance that are best suited to good asset management, covering a range of investments for system preservation, operations, and capacity expansion; and b) select specific performance measures and set targets for these measures that are consistent with the needs of the agency and with good asset management practice.

The study has identified several performance measures in current use in asset management. The study categorizes performance measures by type of transportation or non-transportation application as follows: preservation, accessibility, mobility, operational efficiency, safety, environmental impacts, economic development, social impacts, and security. Within each category the performance measures are further categorized according to specific goals and objectives. For example for preservation of pavements, with a goal being asset value performance measures include book value, replacement value, network depreciation, and ratio of current value of capital assets to replacement cost. For performance measures used for structure preservation, for the goal condition, performance measures include NBI structural ratings, health index, element condition state distributions, and number of bridges with height or weight restrictions among others. This study mentioned as examples from various states, the performance measures (targets) shown in Table 1.2, for preservation of structures.

1.3.2 Task 97 of NCHRP Project 20-07

This project was undertaken by Lichtenstein Consulting Engineers, Inc. and the University of Massachusetts, Dartmouth. The authors identified the problems with using National Bridge Inventory (NBI) bridge condition ratings in bridge management systems, which require more detailed element-level data. As a result the authors proposed a number of new individual subindexes and a composite index, and compared analyses results based on these new measures with results obtained based on current NBI ratings, for example the sufficiency rating (SR).

Table 1.2. Examples of State DOT Performance Targets – Structures Preservation
(Source: NCHRP 2005)

Measure	Description	State	Target
Bridge Value Index	Ratio of current value to replacement value	Oregon	87-90%
GASB 34 Bridge Rating	0-10 scale assigned to each component-rating category	Alabama	≥ 5
Health Index	0-100 scale based on condition of several elements	Kansas	Overall ≥ 80
NBI Appraisal Ratings	0-9 scale based on deck, substructure, and superstructure condition	Ohio	$\geq 85\%$ of deck area ≥ 5
		Delaware	$75\% \geq 6$ $<10\% \leq 4$
		Washington	95% Good or fair
Number of Closed Bridges		Pennsylvania	Reduce by 50% by 2010
Number of Posted Bridges	Bridges with weight restrictions	Oregon	0
		Pennsylvania	Reduce by 30% by 2010
Structural Condition Rating	Good, fair or Poor based on 3 0-9 NBI condition codes plus 2 NBI appraisal ratings	Minnesota	Principle – 92% Fair to Good Other – 80% Fair to Good
Structurally deficient (SD)/ Functionally Obsolete (FO)	SD – FHWA-defined rating that the bridge is in structurally poor condition FO – FHWA-defined rating based on deck geometry, load carrying capacity, clearance, and approach roadway alignment	Colorado	$\leq 25\%$ SD
		Federal	$<20\%$ of NHS either SD or FO
		Georgia	$<5\%$ (based on deck area)
Structures Inventory System	1-100 scale based on condition of major elements	Utah	$50\% \geq 80; \leq 15\% \leq 49$
Sufficiency Rating	0-100 scale based on 4 factors reflecting ability to remain in service	Indiana	Interstate – 87% NHS – 85% Others-83%
		Maine	Overall- 60%
		Wyoming	NHS – 83% Others – 80%

This report proposes four individual performance subindexes and a weighted composite index as an alternative to the NBI sufficiency rating (SR). The need for this method arises from the fact that many states have begun to implement bridge management systems (BMS) that require the collection of element-level condition data that is more detailed than NBI condition ratings. Hence more specific and detailed performance information than provided by the NBI SR is needed. One goal of this study was to develop performance measures that make use of data from current element-level bridge inspection programs currently adopted by many states, without further data collection requirements.

The four subindexes are as follows:

- Condition subindex: This defines the percentage of an element that is in a condition that jeopardizes safety. The element information is summed into element categories that represent the bridges' independent failure modes. This index basically evaluates the safety of the bridge based on its element-derived condition.
- Live load subindex: This is primarily a measure of the inherent level of safety in a bridge for live loads that regularly use the bridge. This subindex is calculated from NBI inventory rating and NBI operating rating.
- Geometric subindex: This subindex evaluates the traffic safety and serviceability of a bridge based on its geometric characteristics. It calculated as a value between 0 and 1 from NBI geometric inventory data and appraisal rating data.
- Special events subindex: This subindex measures the vulnerability of a bridge to fail as a result of natural hazards or extreme events that lead to catastrophic failure. The special events subindex is a value between 0 and 1. The likelihood of a special is event is multiplied by the consequence (cost) of the event to obtain the subindex value.

Two composite performance measures were proposed as follows:

- Bridge Performance Index: This is a number between 0 and 100. The four subindexes are combined with weighting factors to that reflect each subindex's relative importance to overall bridge performance.
- Bridge Sufficiency Index (SI): This is the bridge performance index modified by an essentiality factor. The essentiality factor measures how essential the bridge is to its region of location.

The SI was used to establish eligibility criteria for federal aid programs for states. The results were consistent with current trends based on NBI SR.

1.3.3. Oregon Department of Transportation

Under the Oregon Department of Transportation (ODOT) performance management program for infrastructure, the following performance measures were used to measure trends, determine resource allocation needs, and develop process improvement measures. Some of these performance measures include:

Travel delays:

This is the hours of travel time delay per capita per year in urban areas. The goal of this performance measure is to reduce travel delays on the state network, reduce improve air quality, and to move people and goods efficiently.

Vehicle miles traveled (VMT) per capita:

This is the vehicle miles traveled per capita in Oregon metropolitan areas for non-commercial trips. The goal of this measure is to reduce VMT, and to move people and goods more efficiently.

Pavement Condition:

This is defined as percent of centerline miles rated “fair” or better out of total centerline miles on the state highway system. The goal of this measure is linked to improving road condition.

Bridge condition:

This is the percent of state highway bridges that are not deficient. The goal of this performance measure is to move people and goods efficiently.

Accidents:

Performance measures in this category include; fatalities, injuries, safe drivers, impaired drivers, use of safety belts, large trucks at-fault crashes, and rail crossing incidents among others.

1.3.4. Delaware Department of Transportation (DelDOT)

DelDOT listed the following objectives and performance measures for its 1998 annual fiscal report.

Maintain the reliability of traffic control devices as a means of getting the most out of our roadway system by:

- Responding to signal malfunctions as quickly as possible;
- Responding to sign knock-downs expeditiously;
- Replacing signals, signs, and pavement markings to keep pace with life cycle demands; and
- Maintaining pavement markings at 100% on all 1,500 ADT roads statewide.
 - Average time to restore signal outage (FY 1996 = 2 hours)
 - Average response time to restore knocked-down sign (FY 1996 = 2 hours)
 - Percentage of signs meeting FHWA reflectivity standard (Currently being developed by FHWA)
 - Percentage of 1,500 ADT pavement marked to FHWA standard (now being developed)

Maintain the State's pavement in a good state of repair as defined by existing national standards.

- Percentage of total inventory rated good or excellent using AASHTO-based rating system = 76.1% as of 9/96.

Maintain bridges to standards that will ensure that they do not require load posting due to structural deficiencies.

- Percentage of bridge inventory rated structurally deficient (FY 1996 = 9.8%)
- Delaware's deficiency rating versus other states reporting deficiency conditions (FY 1996 = 11th of 51 nationwide)

1.3.5. City of Cincinnati, Ohio

The city's Bridge Program goal is to ensure the safety and mobility of the traveling public by preserving the structural integrity of all bridges for which the city has maintenance responsibility. In this effort two performance measures have been established.

- Percent of structures inspected annually. The goal of the city is 100% inspection.
- Weighted average bridge rating. This is calculated for the network or a sub-network e.g. city bridges, or county bridges. Weighting factors are applied to each bridge rating. The weighting factor for a bridge is determined by its size in terms of deck area. The objective if the city ids to maintain a weighted average bridge rating of 6 or better.

1.3.6. City Of Quinte West, Ontario, Canada

This city used the following the performance measures to evaluate its pavement maintenance programs as part of the Municipal Performance Measurement Program (MPMP) required by the provincial government.

- Percent adequacy of pavement sections
- Operating costs. The cost required to operate the pavement sections at their required levels of service.

1.3.7. Other Studies

Capers et al. (2003) presented a set of performance-based goals, objectives, and performance measures for programming of bridges in New Jersey. The process was described for setting the goals and objectives, using a special task force consisting of state bridge engineers, capital programming office, FHWA engineers, and local agencies officials. The bridge inventory was divided into five categories: state bridges on the National Highway System (NHS); State bridges on Non-NHS; NJ transit overhead bridges; "orphan" bridge; and locally owned bridges.

The initial guidance from upper management indicated two goals: achieving a satisfactory state of repair of bridges; and ensuring maximum useful life of the bridge inventory. The bridge deck area was utilized as the measure of bridge deficiency, considering only structurally deficient bridges because the department normally considers functional improvement under a different funding program.

Assuming unconstrained availability of capital resources, a list of structurally deficient bridges were generated from the BMS, and projects were prioritized based on the following factors: current commitment to existing construction programming; structural condition (considering public safety, ability to provide intended service, and maintenance required to keep structure in service); and adjustment based on local agencies' needs. By

estimating programming needs under various scenarios, including the do-nothing situation, objectives were developed for three categories of bridges: NHS, non-NHS, and local bridges. It was decided that efforts should be expended to correct structural deficiencies on the following proportions of the different classes of bridges: 100% for NHS bridges; 50% for non-NHS bridges; and 25% for local bridges. After an evaluation of the overall needs, the department formally adopted the following goals and performance measures for the bridge program:

- Goals:
 - Eliminate the backlog of structurally deficient bridges on the NHS by 2010, and
 - Replace the two posted bridges on the state system within the next five years.
- Performance measures
 - For NHS bridges, the percentage improvement in square meters of total bridge deck area on the state highway system bridges, and
 - For Load posted bridges, the number of load-posted bridges.

For locally owned bridges, the department adopted the following goals and performance measures:

- Goals:
 - Rehabilitation and construction of structurally deficient county and local bridges must be given a high priority in New Jersey. The deck area of structurally deficient county and locally owned bridges should be reduced by 2% per year in FY98, increasing incrementally to 5% by year in FY02.
- Performance measures
 - Percentage improvements of square feet of total bridge deck area on county and locally owned bridges that are listed as structurally deficient was identified as the metric for performance.

Chase (1998) proposes developing performance measures for bridges based on performance measures that do not rely on visual inspections. As an alternative to current practices he proposes the use of non-destructive evaluation (NDE) techniques that can measure bridge properties descriptive of bridge failure modes and use these as performance measures for highway bridges. Some of these performance measures would include :

- Load capacity
- Fatigue (cracking), extent and degree
- Corrosion

1.4. FDOT's Bridge Performance Measures

Recent research and decision-making within FDOT provides a context for selecting performance measures.

1.4.1 FDOT Pontis BMS Project-Level Analysis Tool (PLAT)

Sobanjo and Thompson (2004) in developing a project-level analysis tool (PLAT) for the FDOT Pontis bridge management system (BMS) enumerated several bridge project-level attributes that can be adapted and used as performance measures for network analysis.

These include:

Benefits: Benefit is expressed as an economic quantity, a savings in life-cycle costs of doing something as compared to doing nothing.

Benefit-cost ratio: This is the ratio of the benefit of a maintenance action or strategy, to the cost of performing the action or strategy.

Needs (\$):

Needs are actions that would be most cost effective to perform on a bridge right away if there were no funding/ budgetary constraints. Needs has been used as an economic condition measure.

Urgency:

Urgency is a benefit/cost ratio of doing work in the first year rather than the second year, assuming that the candidate with the lowest life-cycle cost is chosen in each year.

Urgency is an economic criterion to prioritize bridges for immediate attention.

Failure cost, Failure risk:

Failure cost is the sum of user and agency cost associated with impact of failure of a bridge or bridge element to satisfy its functional requirements, including the costs of emergency repairs and replacement.

Bridge Health Index:

This is the weighted average condition measure of a bridge or a subset of an inventory. It includes all element condition states, weighting each element by its failure cost or another suitable measure of economic importance. As a result the emphasis is on the elements with the biggest economic impact on the bridge.

Attributes currently recorded in the Pontis databases that are relevant as performance measures are described below.

Element condition Index:

This is a health index for a subset of elements on a structure for a given element type.

HBRR Eligibility Ranking:

This is the number of structures and deck area of structures eligible for federal funding for rehabilitation and replacement.

Work:

This is the dollar amount of work done or to be done on a bridge or an element or group of elements over a given time horizon.

Other attributes described in the literature relevant to Pontis implementation are as follows:

Average NBI condition ratings:

This is the average of the NBI ratings deck condition, superstructure condition, substructure condition, channel rating, and culvert rating.

Sufficiency Rating (NBI):

The NBI sufficiency rating is a numeric value calculated to evaluate a highway bridge and is indicative of bridge sufficiency to remain in service. A value of 100% represents an entirely sufficient bridge whereas a value of zero represents an entirely insufficient or deficient bridge.

User costs:

Bridges have functional deficiencies that affect the level of service provided to road users. The economic impacts of such deficiencies are termed user costs. Functional improvements may be undertaken to eliminate user costs. Examples of functional deficiencies include deficient roadway width, vertical under clearance restriction; load capacity deficiency, and delays caused by moveable bridge openings.

1.4.2. FDOT Bridge Task Team Performance Measures

The FDOT Bridge Performance Measure Task Team (BPMTT) reviewed a number of currently used bridge performance measures as candidates for implementation to enhance the FDOT BMS. The review was based on the Florida Transportation Commission (FTC) guidelines for performance measures, which require, among other factors, that performance measures be:

- Simple and clear to laypersons.
- Relevant to areas of most concern to the public.
- Quantitative.
- Such that they can be derived from existing data.

Performance measures that were identified and reviewed include:

- Pontis health index
- Overall bridge condition index
- Remaining life / average age
- Number of functionally obsolete bridges
- Number of structurally deficient bridges
- Number bridges planned for repair lettings versus actual lettings
- Number of bridges planned for replacement lettings versus actual lettings
- Percentage of bridges meeting FDOT standards.

The BPMTT recommended that the overall bridge condition index be used as the primary performance measure since it met the FTC criteria. The overall bridge condition rating is derived as follows:

“Bridges consist of deck, superstructure, and substructure. Bridge inspectors assign a numerical condition rating to each of the components. The national rating scale is: 9 = excellent, 8 = very good, 7 = good, 6 = satisfactory, 5 = fair, 4 = poor, 3 = serious, 2 = critical, 1 = failing, 0 = failed. A “good” bridge has all three components rated as good, or better. A “poor” bridge is one defined as having at least one of the components rated as poor. All the remaining combinations of ratings are considered to be fair. “

It was also recommended that the department set thresholds for the percentages of network bridges in each rating as a measure of system performance. The Task team also recommended the following as secondary or alternative performance measures subject to modifications:

- Number bridges planned for repair lettings versus actual lettings.

- Number of bridges planned for replacement lettings versus actual lettings, and
- Percentage of bridges meeting FDOT standards.

For future development the task team recommended a new primary measure for functionally obsolete bridges that have significant safety issues, and also the use of the Pontis bridge health index. The Pontis bridge health index was rejected for implementation because it was not considered simple and clear to laypersons.

It must be noted however that the recommendations of this study were tailored to the needs of the FTC, and therefore might give less weight to sound theoretical backing, in favor of simplicity and political considerations. A review of the 2004 Florida Statutes provides a perspective for the relationship between the FTC and the FDOT.

The FTC evaluates the FDOT tentative work program before it is submitted to the Executive office of the Governor and the legislative appropriations committees. The FTC conducts statewide public hearings to solicit comments, suggestions, and checks for compliance with applicable laws, financial soundness, and consistency with local government comprehensive plans. The statutes also define the legal framework for the disbursement of funds to finance the adopted work plan. It is therefore imperative that performance measures are consistent with these tasks from an engineering and non-engineering perspective.

1.4.3. FDOT Deficient Bridge List – 2004 Repairs and Replacements

The deficient bridges list (DBL) is prepared by the FDOT State Maintenance Office. The DBL reflects current system capabilities for recording bridge information using the Pontis BMS attributes. The unique identifier for this database is the combination of both the bridge number and the project financial management (FM) number. The bridge-project unique identifier provides a means for tracking all repair and replacement work by the BMS. The attributes recorded can be categorized as follows:

Bridge Data:

These consist of attributes predominantly derived from the National Bridge Inventory (NBI) attributes. Examples include Bridge number, financial management number, maintenance responsibility, structure type, route, and feature intersected.

Condition Data:

These are numerical condition ratings (NCR) used to describe the existing physical conditions as compared to the as-built condition, from periodic inspections. The ratings are on a scale of 0-9, with 0 being failed condition (bridge is out of service and beyond corrective action, and 9 being excellent condition (like new). Examples of these attributes include deck NCR, superstructure NCR, substructure NCR, channel/ waterway NCR and culvert NCR.

Proposed Improvement Data:

These attributes code the proposed improvement and preservation actions on a bridge in the preceding year and the current year. They include: action category, action type, deficiency discovery date, action status, deficiency rating, and sufficiency rating.

The DBL is the basis for selecting bridges for the state Bridge Replacement Program (BRP). The BRP addresses bridges on the state highways, local roads, federal-aid highways, and off-federal aid highways, and its objectives are consistent with the Florida Statutes. These objectives place primary emphasis on structurally deficient or weight-restricted bridges on the state highway system. The following bridge replacement stipulations can be used as constraints in the optimization and trade off analyses involving bridges in the inventory:

- Deficient bridges needing replacement must be identified as either a) strength replacement, or b) economy replacement.
- The action category (from the proposed improvement Data attribute(s)) for these action types is designated RP - replacement.
- All deficient bridges with action type attribute being strength replacement must be programmed for replacement within 6 years of deficiency identification.
- All deficient bridges with action type attribute being economy replacement must be programmed for replacement within 9 years of deficiency identification.
- Structurally sound bridges that require functional improvement are to be programmed using other district allocated funds.
- Funds should be programmed for construction, by specific bridge site, within the first two years of the Work Program.

The State Maintenance Office is however proposing the following changes to future policy:

- All structurally deficient bridges that are scheduled to receive repairs to correct the deficiency shall be programmed for work within 6 years of the deficiency identification.
- All other bridges needing repairs shall be programmed for work within available funding.
- The maintenance office shall annually monitor the number of bridges identified as needing repair to determine adequacy of funding.

These proposed changes could also be programmed into optimization and trade off analyses for resource allocation.

1.5. The FDOT's Bridge Funding Process

The funding for bridgework in the state of Florida can be described under the following categories: bridge replacement, bridge rehabilitation and repair, and emergency repairs. Bridge (and transportation) funding includes federal sources, state sources, and local sources. A description of the work types and the relevant funding sources are illustrated in Figures 1.2 and 1.3 but also described in the following sections.

1.5.1. Bridge Replacement

Bridge replacement involves the construction of new bridges to replace an existing deficient structure. Bridge replacement is administered through the State Bridge

Replacement Program (BRP). The BRP addresses bridges on the state highway, local road, federal aid highway, and off-federal highway systems. However, the primary emphasis of this program is to fund structurally deficient bridges on the state highway system. Bridges eligible for this program must be listed on the state Deficient Bridge List (DBL) developed annually by the State Maintenance Office. The Department's policy imposes limits on the duration, which a bridge may stay on the DBL without being replaced or attended to.

Bridges on the State Highway System are funded using state and/ or federal funds, described as follows:

Federal Funding: The federal aid bridge program fund (BRAC) is allocated statewide and managed by the Statewide Bridge Program Manager. Any state bridge that has been inventoried and inspected in accordance with the National Bridge Inspection System (NBIS), and meets minimum FHWA criteria is qualified for replacement funding through BRAC. Bridges that do not qualify for BRAC must be funded by other federal, state, or local sources. The **BZAC** funds provide funding for off federal aid highways. The requirement however is that the BZAC will be limited to fifteen percent of available federal-aid bridge replacement and rehabilitation funds.

Matching: For federal funding the Department is required to provide its share of funds that will be matched by federal funds in its financial plans and legislative budgetary requests.

Supplementary Federal Funds: Supplementary federal funds are also available through the Minimum Guarantee (MGBP) fund and the National Highway Funds (NHBR). The MGBP fund may be used for projects that do not meet federal condition/ inventory criteria to be eligible for BRAC funds. NHBR funds may be used for programming after BRAC funds have been exhausted.

State Funding: The state Bridge Replacement Program addresses state bridges not eligible for replacement under the federal aid programs, through the **BNBR** fund. Another state program the state funded bridge construction programs is the **DIH**. Statewide priorities are based on the annual bridge replacement candidate list developed by each district.

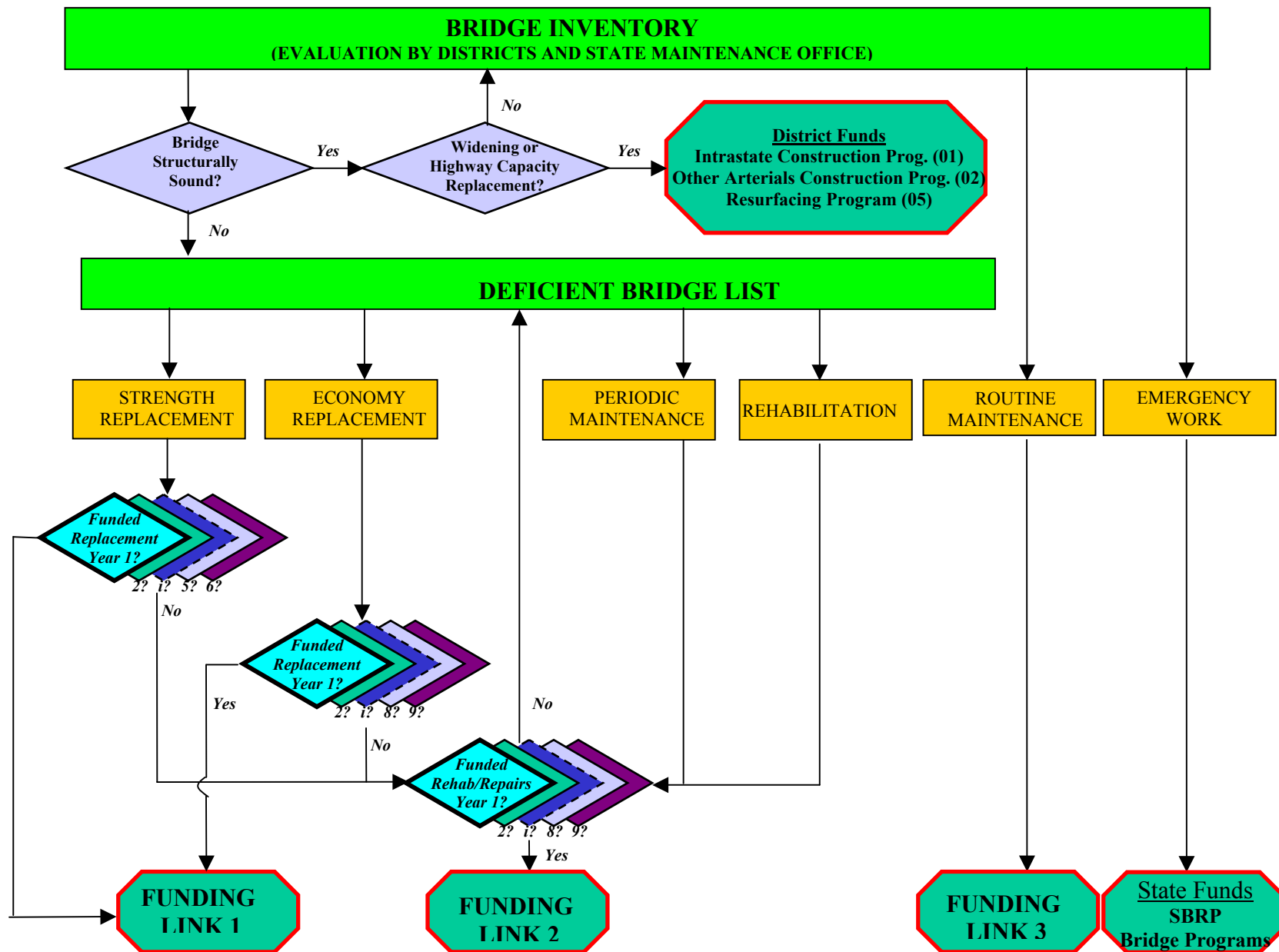


Figure 1.2. Funding Flow Chart for FDOT Bridges (Part 1)

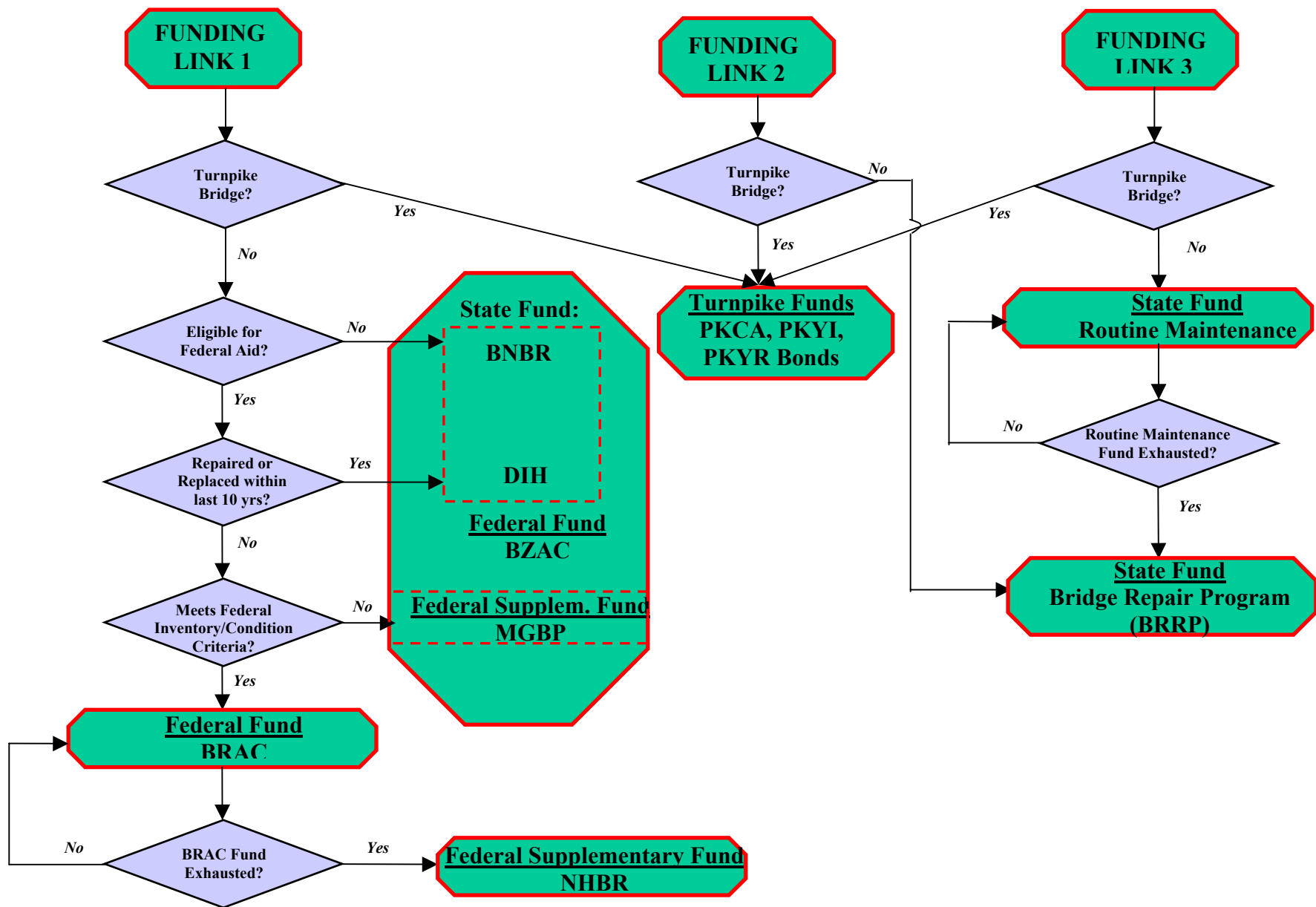


Figure 1.3. Funding Flow Chart for FDOT Bridges (Part 2)

1.5.2. Bridge Rehabilitation

Bridge rehabilitation work involves activities such as widening, railing replacement, and bridge raising. These are items for improvements that are not related to structural deterioration. The State Bridge Repair Program addresses routine maintenance, periodic maintenance, and specified rehabilitation work activities on bridge structures for which the DOT has maintenance responsibilities. The Bridge Rehabilitation and Repair Program (BRRP) funds are allocated by the state to each district based on several factors such as their portion of the total state inventory, tonnage of structural steel, and total quantity of deck area among others. BRRP funds may not be used for bridge replacement or routine maintenance. However with the prior approval of the Engineer of Structure Maintenance, BRRP funds may be used for minor widening that is incidental to a structural repair project.

1.5.3. Turnpike Bridges

The Turnpike Enterprise Bridge Program includes the replacement of bridges on the Turnpike System or bridge projects funded by turnpike funds. The ***PKYI***, ***PKYR***, and PKCA Bond funds are used to provide funding for replacement and rehabilitation and repair projects on the turnpike system.

1.5.4. Emergency Repairs

The statewide Reimbursable Bridge Repair Program (RBRP) is used for emergency structural repairs on bridges and overhead sign facilities damaged by marine or vehicular traffic. These funds are approved by the State Maintenance Office and disbursed to the District upon request. The funds disbursed are then accounted for by amending the district's work program, and subsequently the state work program.

1.5.5. Federal-Aid Discretionary Programs

The Federal Highway Administration (FHWA) administers several discretionary programs through its various offices. These discretionary programs represent special funding categories where FHWA solicits for candidates and selects projects for funding based on applications received. Each program has its own eligibility and selection criteria that are established by law, by regulation, or administratively. These programs are truly discretionary by FHWA with final decision being made by FHWA. These programs include: Bridge, Innovative Bridge Research and Construction, Intelligent Transportation System Integration Program, Interstate Maintenance, and Public Lands Highways among others.

1.6. The 2004 Florida Statutes and Bridge Funding

The Florida Statutes provide the legal framework for the allocation of public funds to the FDOT, and also the allocation of funds within the FDOT among its administrative districts for capital investment projects such as building new roads and bridges, and maintenance and rehabilitation of existing facilities. The highlights of the 2004 Florida Statutes regarding performance measures are summarized as follows:

- The department is required to submit a “tentative work program” to the legislature listing all transportation projects planned for each fiscal year. This program is to be developed by the central office based on the “district work programs”. If passed, the tentative works program becomes the “adopted works program”
- Nature and Scope of the Tentative and Adopted Works Program:
 - The tentative and adopted work programs must be based on a complete balanced financial plan for all funds managed by the department.
 - The work programs must be so planned as to deplete the estimated resources of each fund for the fiscal year.
 - For anticipated federally funded projects, state funds must be set aside for matching purposes.
 - The department is not required to match federal-aid funds that are allocated for use on projects that are not on the State Highway System. In such cases the metropolitan planning organization involved will be responsible for providing the matching funds.
 - To foster local efforts to improve the State Highway System by a district or a county, the department shall allocate funds for new construction to these districts based on population and tax revenues collected. Funds will also be allocated for resurfacing, bridge repair and rehabilitation, bridge fender system construction or repair, based on the results of quantitative needs assessments.
 - The department shall allocate at least 50% of any new “discretionary highway capacity funds” to the Florida Strategic Intermodal System. Any remaining discretionary highway capacity funds shall be allocated to the districts for new construction.

1.7. Gathering Relevant Data

In order to estimate typical annual budgets of the bridge program, and the associated funding sources under the FDOT work programs, two files were obtained: The State Transportation Improvement Program (STIP) Report, and the FDOT work program report (File TWP03).

1.7.1 State Transportation Improvement Program (STIP) Report

The State Transportation Improvement Program (Excel file) for 2004-2005 fiscal year was downloaded from the Florida Department of Transportation (FDOT) website from the Office of the Work Program under the Federal Aid Management heading.

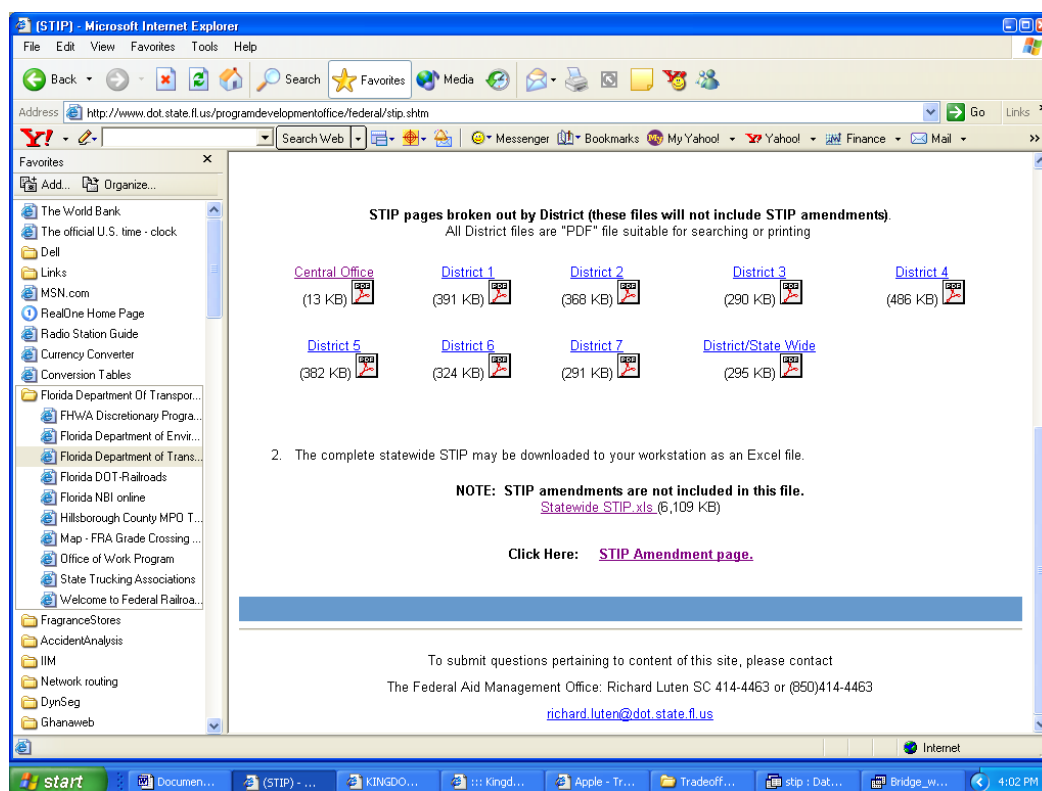


Figure 1.4. STIP Reports' Location on FDOT Website

The Excel file was imported into an Access file and queried to sort out the projects related to bridges. The results of the query were exported back to an Excel file for further manipulation. A Pivot table was used to display the Work_Mix entries by the amount of money spent in each case and the source of funding. The Pivot table has the versatility to show the results on a county-by-county basis and also to display the entire results statewide. A similar analysis was done for federal funds disbursed to MPO for the 2004-2005 fiscal year. The original data were downloaded from the Office of the Work Program web page on the FDOT web site under the heading Federal Obligations to MPOs.

The files downloaded from FDOT included one showing Federal aid to Metropolitan areas, and another file showing the FDOT's State Transportation Improvement Plan (STIP). The STIP file has been analyzed here to show the various proportions and amount budgeted by FDOT for the various work types (replacement, repair, etc.), and also the funding sources. The work types (work mix is the term used for the work program) were filtered (see the STIP worksheet) to leave only bridge-related projects. It was assumed that the work category of interchanges is not bridge-related work. It is expected that this cost information would help provide sample budget data for the optimization model for FDOT. As shown in the following graphs and tables, the results could be summarized statewide or by county location or specific work mix, and also by type of funding.

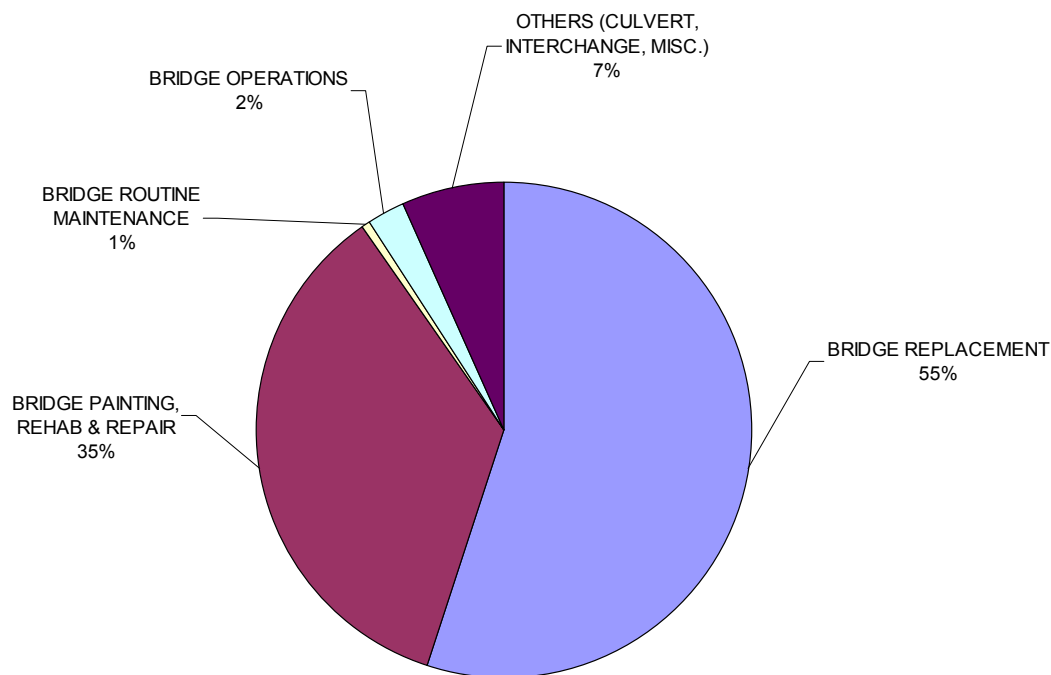


Figure 1.5 Overall View of STIP's Bridge-Related Fund Allocation for FY 2004/05

Table 1.3 STIP Funding Allocations for Replacement-Type Work (Source: FDOT STIP Report 2004/05)

FUND	REPLACEMENT TYPE WORK FUNDS	TOTAL ALL TYPE WORK	PERCENT PER FUND SPENT ON REPL	PERCENT FUND SOURCE DISTRIBUTION OF REPLACEMENT WORK
BNBR	\$53,104,267	\$63,197,764	84.0	14.1
BRAC	\$266,081,410	\$287,257,243	92.6	70.8
BRP	\$13,994,429	\$31,209,772	44.8	3.7
BRRP	\$0	\$169,040,228	0.0	0.0
BZAC	\$31,074,658	\$40,463,815	76.8	8.3
DIH	\$3,113,984	\$22,358,676	13.9	0.8
MGBP	\$3,895,007	\$7,344,558	53.0	1.0
PKYI	\$4,527,196	\$45,149,916	10.0	1.2
PKYR	\$36,261	\$16,616,872	0.2	0.0
Grand Total	\$375,827,212	\$682,638,844	55.1	100

Table 1.4 STIP Funding Allocations for Painting, Repair and Rehabilitation Type Work
(Source: FDOT STIP Report 2004/05)

FUND	PAINTING, REPAIR AND REHAB TYPE WORK FUNDS	TOTAL ALL TYPE WORK	PERCENT PER FUND SPENT ON PAINT/REHAB/REPAIR	PERCENT FUND SOURCE DISTRIBUTION OF PAINTING/REHAB/REPAIR WORK
BNBR	\$10,093,497	\$63,197,764	16.0	4.2
BRAC	\$14,075,380	\$287,257,243	4.9	5.9
BRP	\$17,215,342	\$31,209,772	55.2	7.2
BRRP	\$160,940,228	\$169,040,228	95.2	67.1
BZAC	\$4,470,114	\$40,463,815	11.0	1.9
DIH	\$13,208,752	\$22,358,676	59.1	5.5
MGBP	\$3,449,551	\$7,344,558	47.0	1.4
PKYI	\$41,602	\$45,149,916	0.1	0.0
PKYR	\$16,463,591	\$16,616,872	99.1	6.9
Grand Total	\$239,958,057	\$682,638,844	35.2	100

Table 1.5 STIP Funding Allocations for Routine Maintenance Type Work (Source:
FDOT STIP Report 2004/05)

FUND	BRIDGE-ROUTINE MAINTENANCE TYPE WORK FUNDS	TOTAL ALL TYPE WORK	PERCENT PER FUND SPENT ON ROUTINE MAINTENANCE	PERCENT FUND SOURCE DISTRIBUTION OF ROUTINE MAINTENANCE WORK
BNBR		\$63,197,764	0.0	0.0
BRAC	\$1,937,000	\$287,257,243	0.7	46.1
BRP		\$31,209,772	0.0	0.0
BRRP		\$169,040,228	0.0	0.0
BZAC	\$2,241,010	\$40,463,815	5.5	53.4
DIH	\$22,000	\$22,358,676	0.1	0.5
MGBP		\$7,344,558	0.0	0.0
PKYI		\$45,149,916	0.0	0.0
PKYR		\$16,616,872	0.0	0.0
Grand Total	\$4,200,010	\$682,638,844	0.6	100.0

Table 1.6 Suggested Budget Limits for Bridge Program Work Types

TYPE OF WORK	SUGGESTED BUDGET LIMITS	REMARKS	PERCENT DISTRIBUTION OF WORK TYPES
FED-AID ETC. REPLACEMENT	\$266,081,410	BRAC+NHBR	40.3
REPLACEMENT NON FED AID	\$105,182,345	BNBR+DIH+BZAC+MGDP+BRP(?)	15.9
PAINTING, REHAB AND REPAIR	\$223,452,864	ALL EXCEPT PKYI AND PKYR	33.8
ROUTINE MAINTENANCE	\$4,200,010	BRAC+BZAC+DIH	0.6
TURNPIKE BRIDGES	\$61,766,788	PKYI+PKYR	9.3
TOTAL	\$660,683,417		100.0
MISC REMAINING	\$21,955,427		

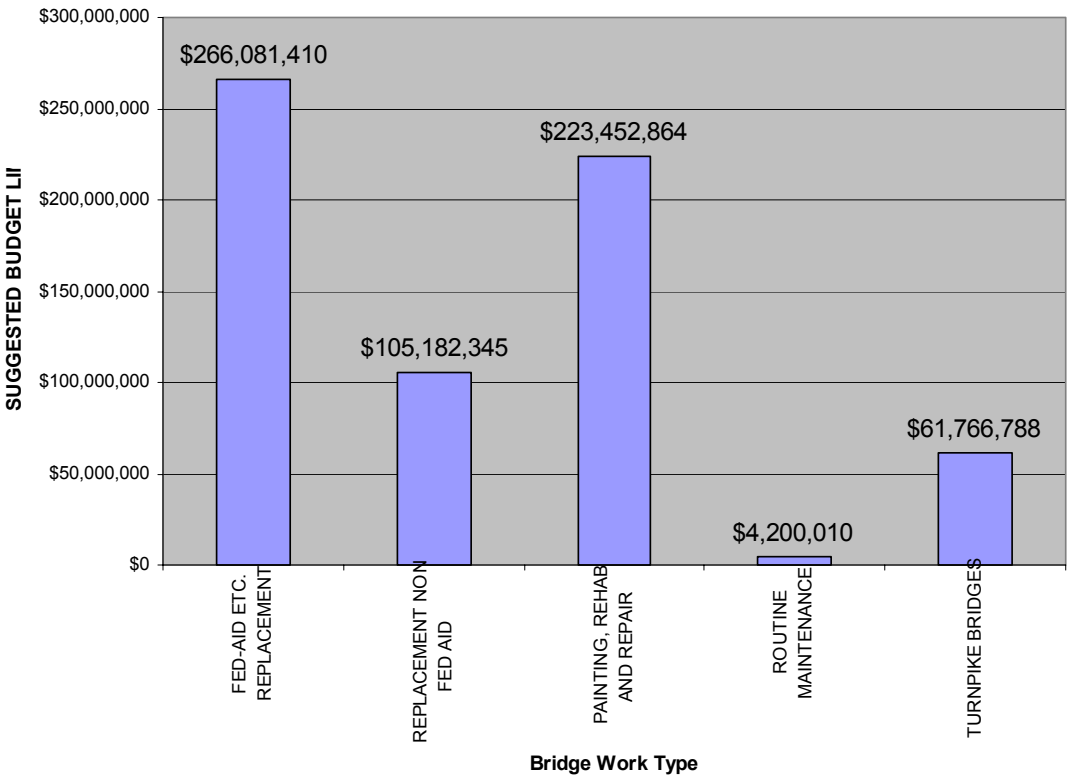


Figure 1.6. Fund Source Distribution Of Work Types Based On STIP 2004/05

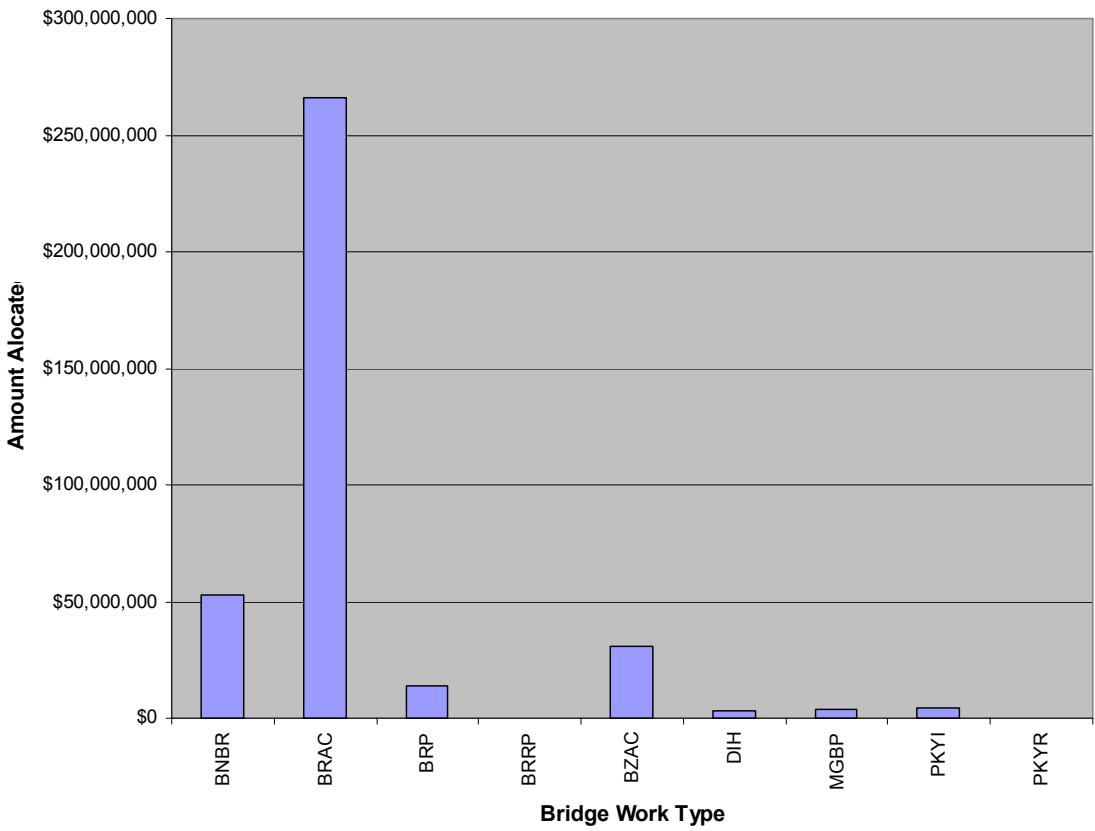


Figure 1.7. STIP Fund Source Distribution Of Replacement Type Work For FY 2004/05

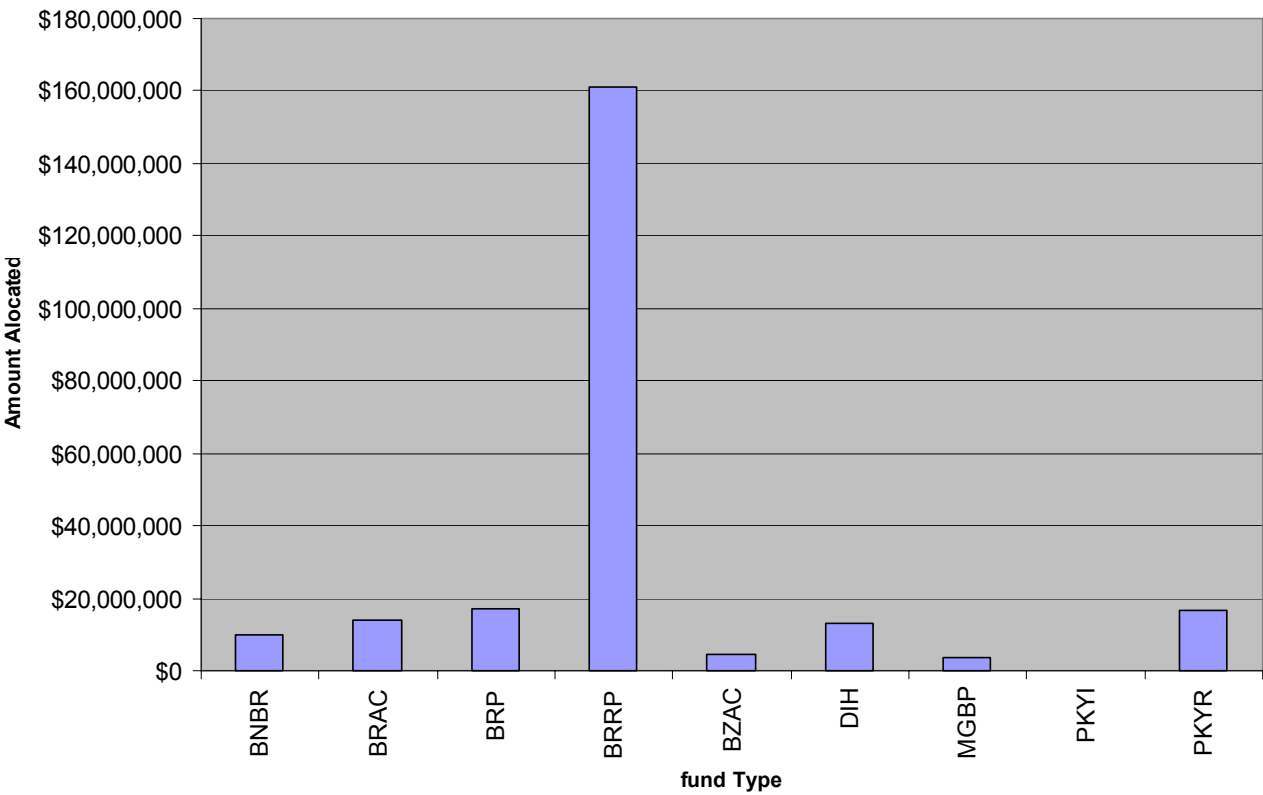


Figure 1.8. STIP Fund Source Distribution Of Painting, Rehab And Repair Type Work For FY 2004/05

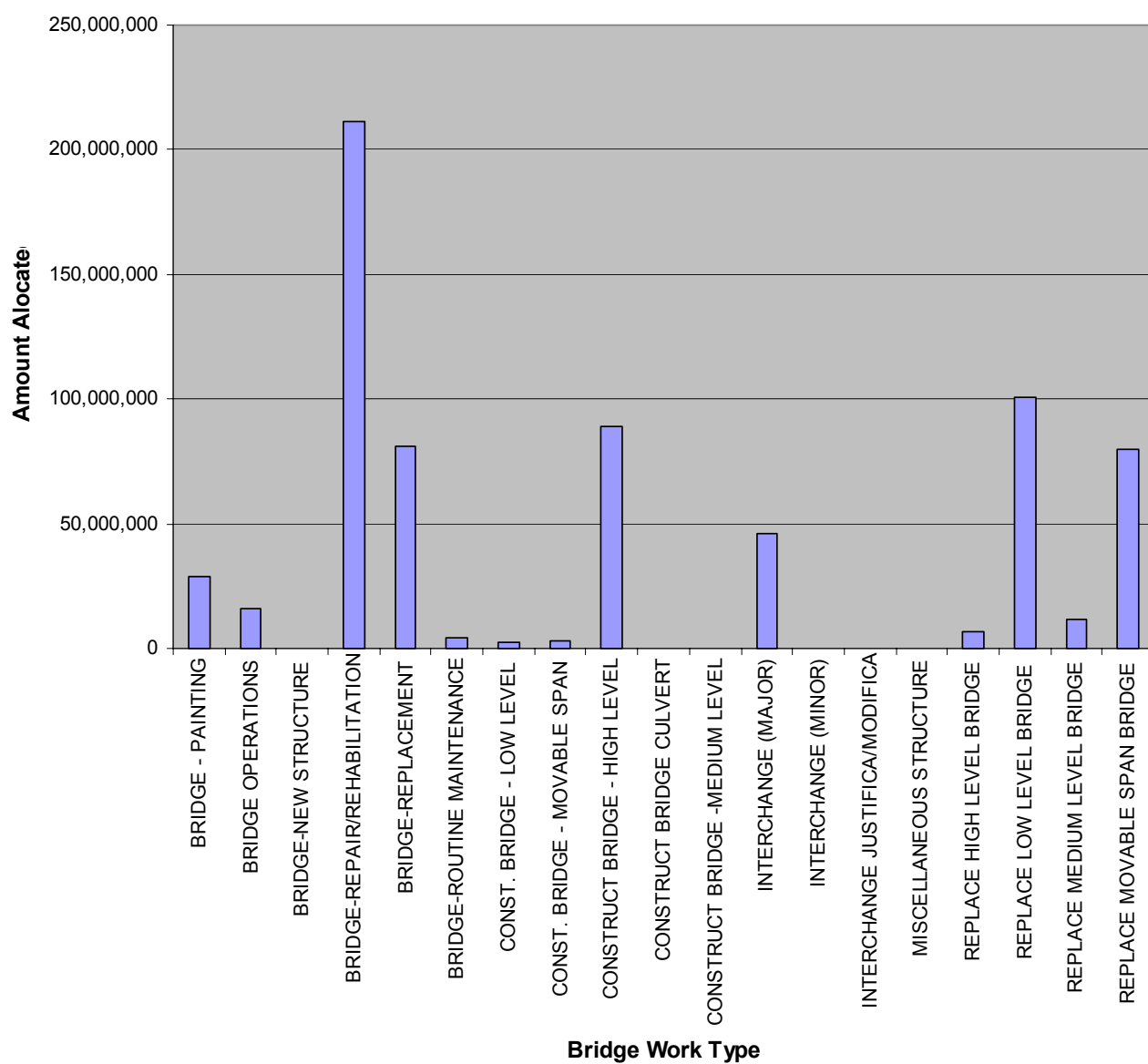


Figure 1.9. STIP Total Fund Allocation By Specific Bridge Work Mix for FY 2004/05

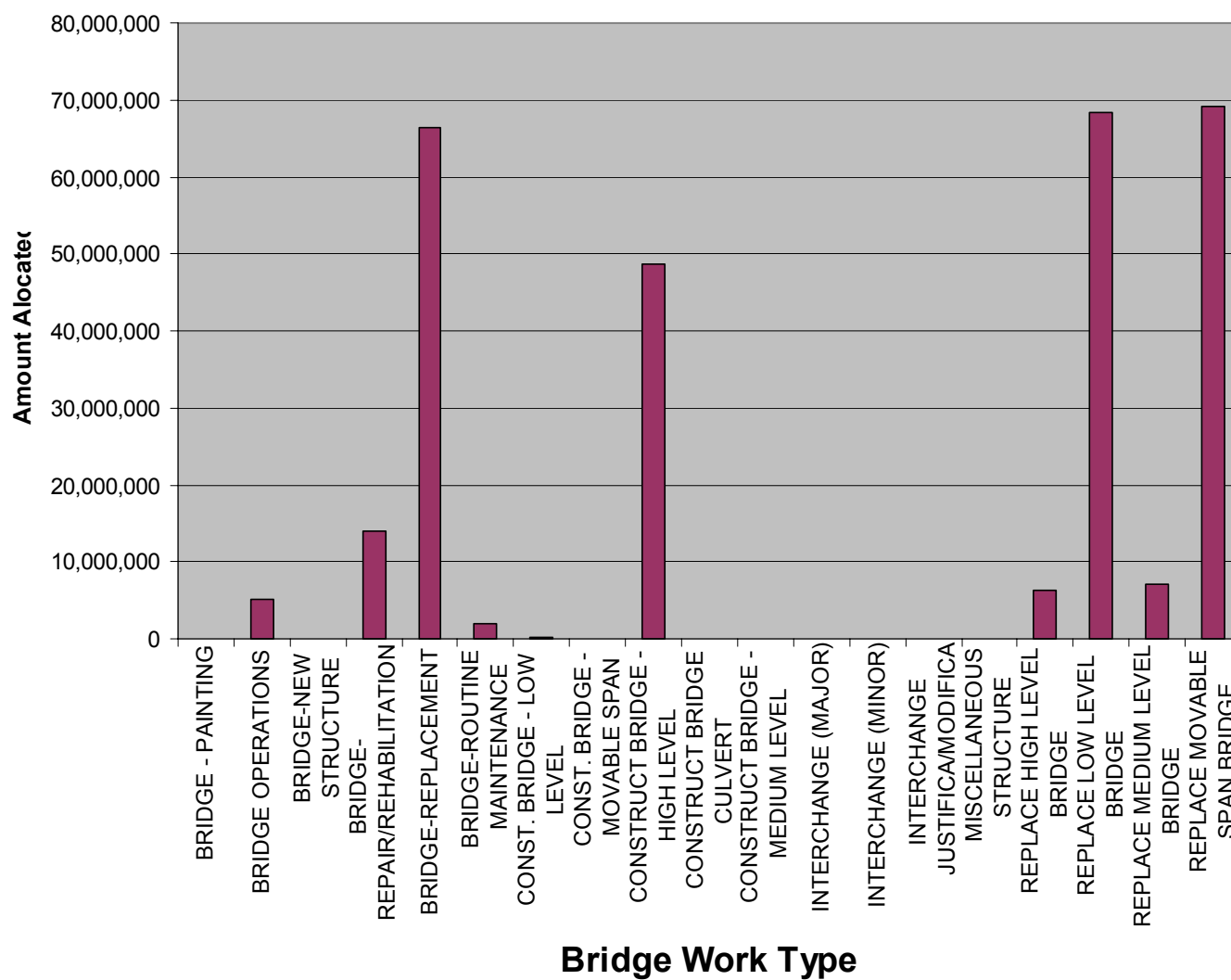


Figure 1.10. STIP Bridge-Related BRAC Fund Allocation for FY 2004/05

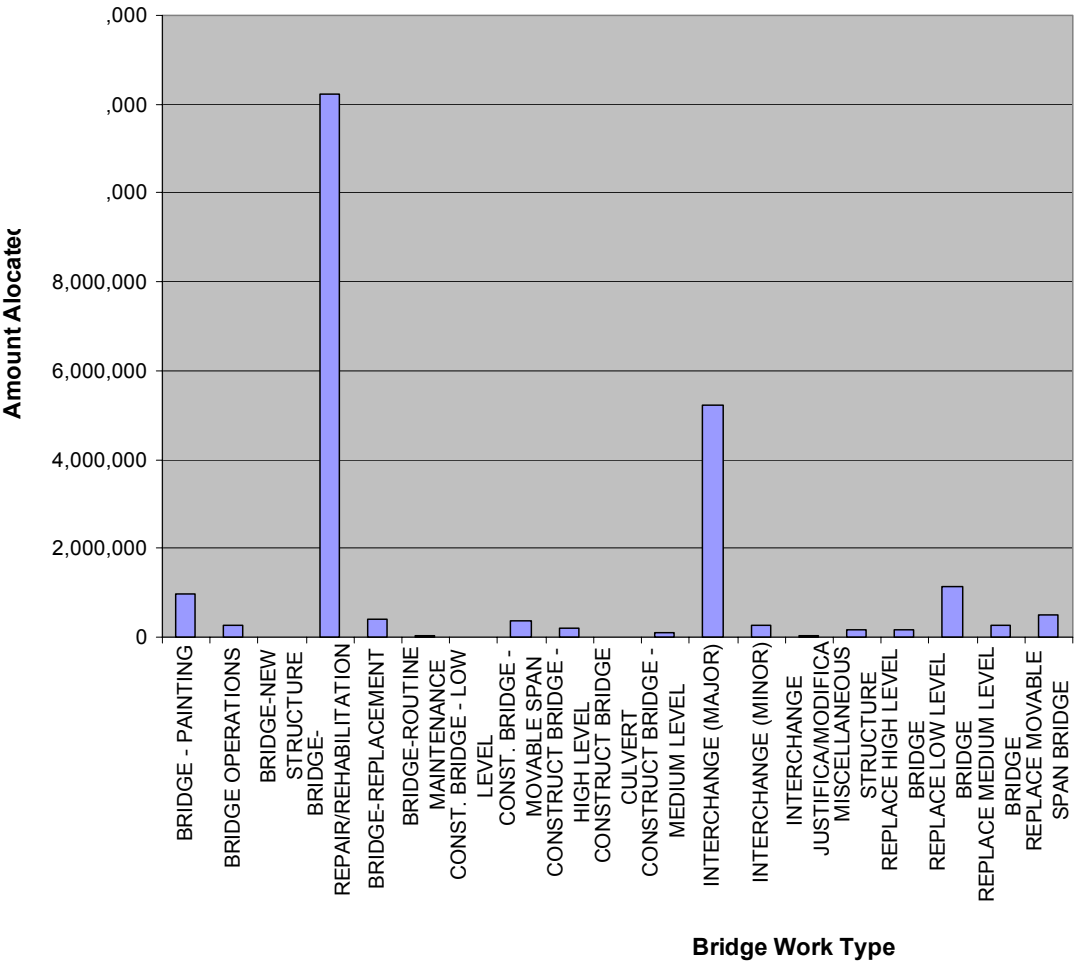


Figure 1.11. STIP Bridge-Related DIH Fund Allocation for FY 2004/05

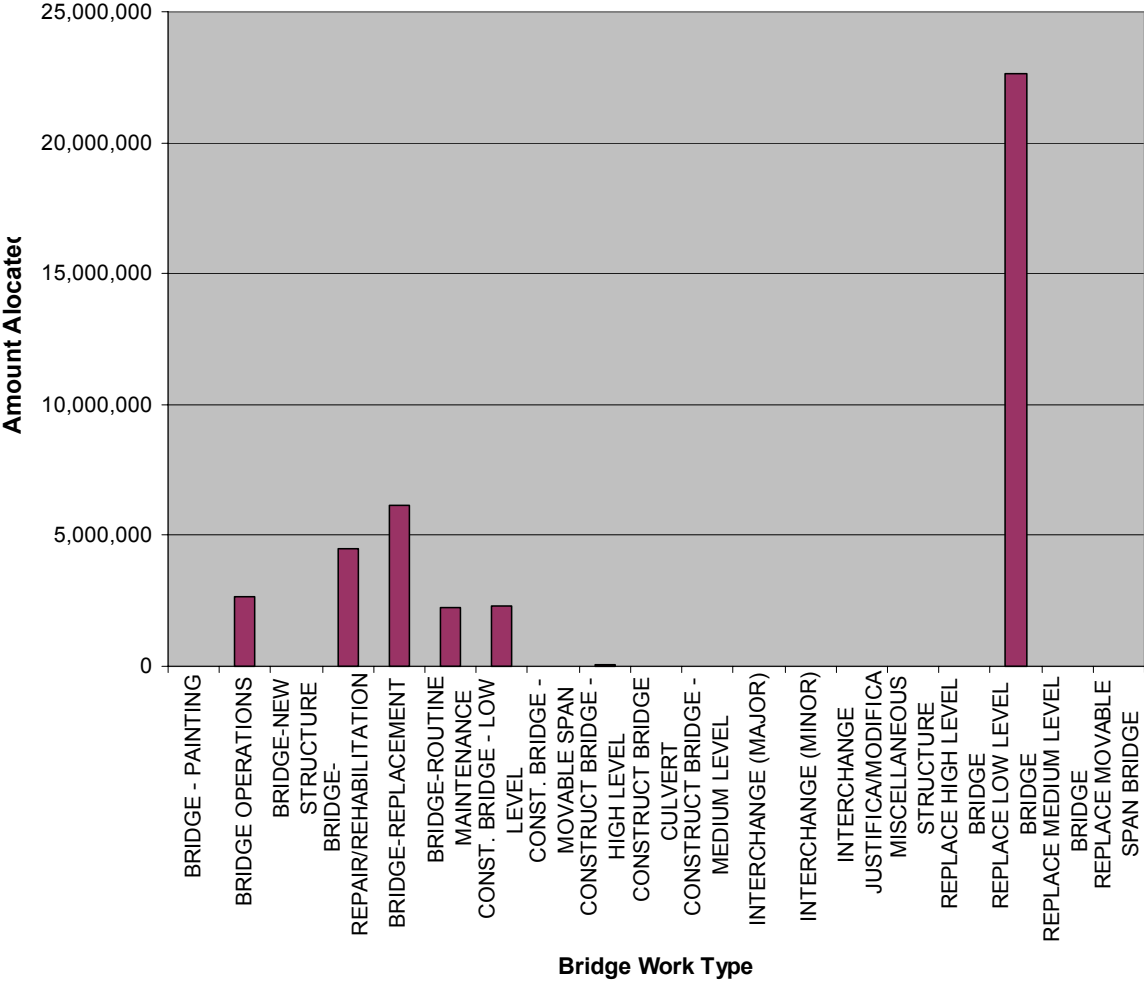


Figure 1.12. STIP Bridge-Related BZAC Fund Allocation for FY 2004/05

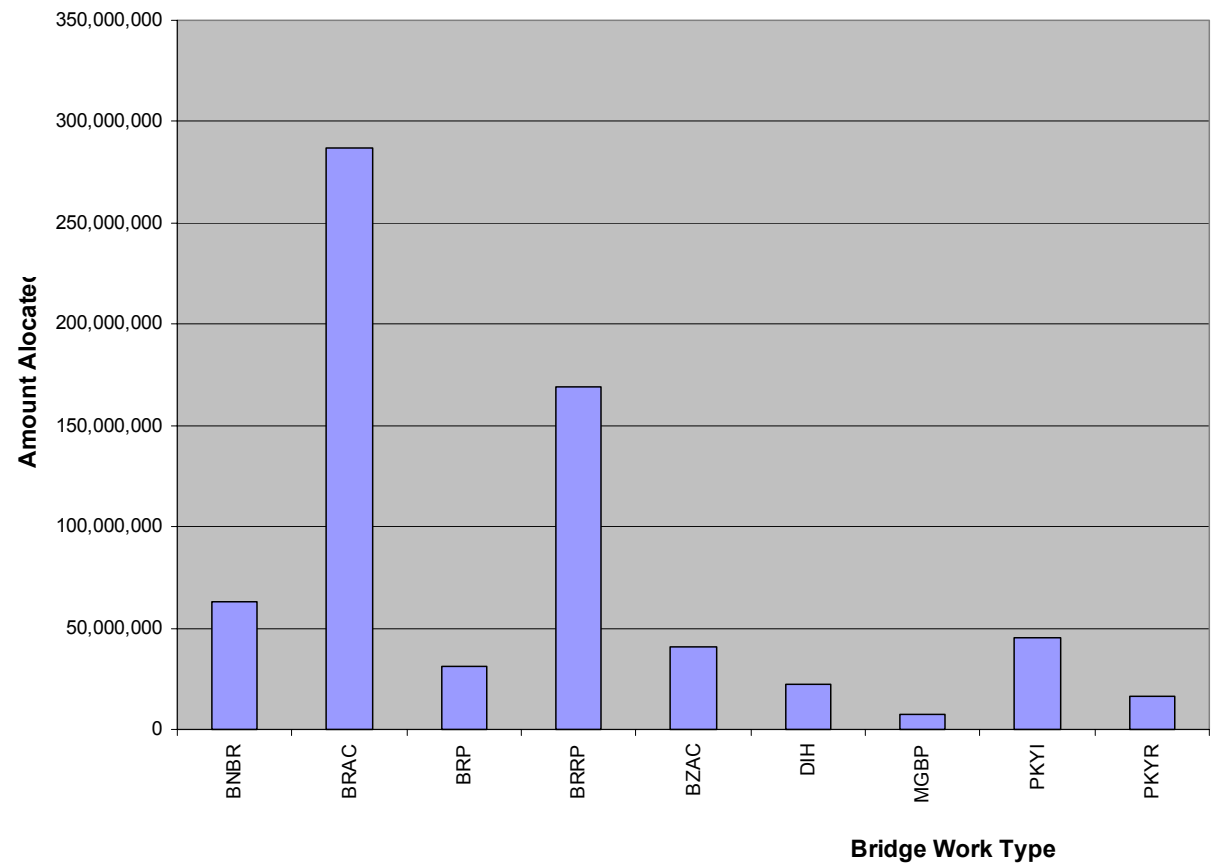


Figure 1.13. STIP's Bridge-Related Total Fund Allocation (All Work Types) for FY 2004/05

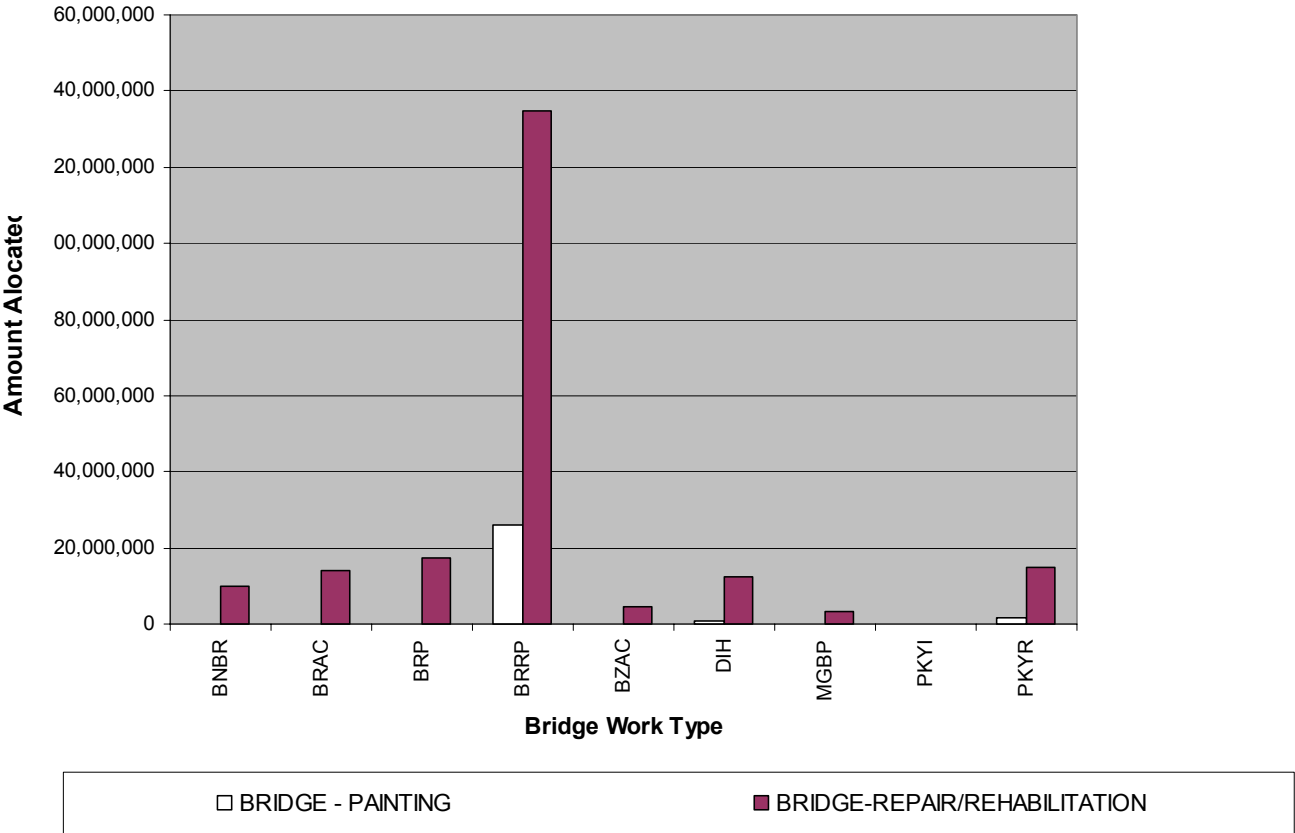


Figure 1.14. STIP's Bridge-Painting and Rehab/Repair (Types) Work Fund Allocation for FY 2004/05

1.7.2 FDOT Work Program Report (File TWP03)

This report file TWP03 (FDOT Work Program) downloaded from the FDOT website, shows the current work program for various work types for the fiscal years 2005 to 2010. The work types were filtered to leave only projects with bridge descriptions (the best available criterion). Yearly costs were summarized, in terms of % and actual amount for the period 2005 to 2010. From the previous analysis on the STIP report for fiscal year 2004, the proportions allocated to different work types (replacement, repair, etc.) are incorporated to view expected yearly budgets by work type. It is expected that this would help provide sample budget data for a multi-period optimization model for FDOT. The following tables and graphs summarize the findings of this analysis of the Work Program Report.

Table 1.7. Multi-Period Estimates of FDOT's Annual Budget Based on Current Bridge Work Program for FY 2005 – 2010

YEAR	BUDGET	ESTIMATED	ROUNDED
2005	\$834,163,663.00	45.1%	45
2006	\$180,210,448.00	9.7%	10
2007	\$231,593,880.00	12.5%	12
2008	\$178,961,169.00	9.7%	10
2009	\$215,689,186.00	11.7%	12
2010	\$209,592,547.00	11.3%	11
TOTALS	\$1,850,210,893.00	100.0%	100

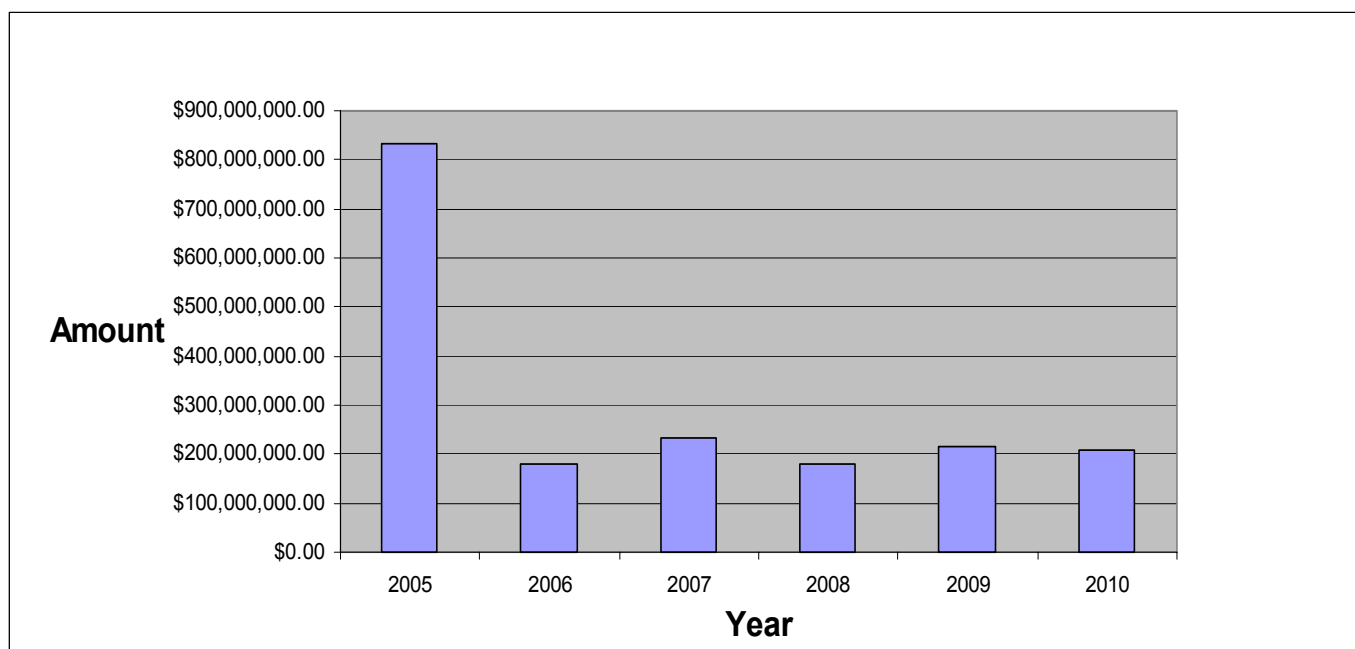


Figure 1.15. Multi-Period Estimates of FDOT's Annual Budget Based on Current Bridge Work Program for FY 2005 – 2010

FUND SOURCES	% DISTRIB.	2005	2006	2007	2008	2009	2010
FED-AID ETC. REPLACEMENT	40%	\$266,307,000.41	\$57,532,239.75	\$73,936,415.88	\$57,133,407.05	\$68,858,837.53	\$66,912,483.70
REPLACEMENT NON FED AID	16%	\$105,271,521.20	\$22,742,573.00	\$29,227,166.24	\$22,584,913.89	\$27,219,992.58	\$26,450,596.25
PAINTING, REHAB AND REPAIR	34%	\$223,642,312.88	\$48,315,076.74	\$62,091,161.80	\$47,980,140.50	\$57,827,055.48	\$56,192,524.38
ROUTINE MAINTENANCE	1%	\$4,203,570.87	\$908,128.01	\$1,167,062.69	\$901,832.57	\$1,086,914.74	\$1,056,192.17
TURNPIKE BRIDGES	9%	\$61,819,155.41	\$13,355,242.13	\$17,163,224.31	\$13,262,659.13	\$15,984,541.05	\$15,532,724.35
TOTALS	100%	\$661,243,560.77	\$142,853,259.63	\$183,585,030.92	\$141,862,953.13	\$170,977,341.37	\$166,144,520.84

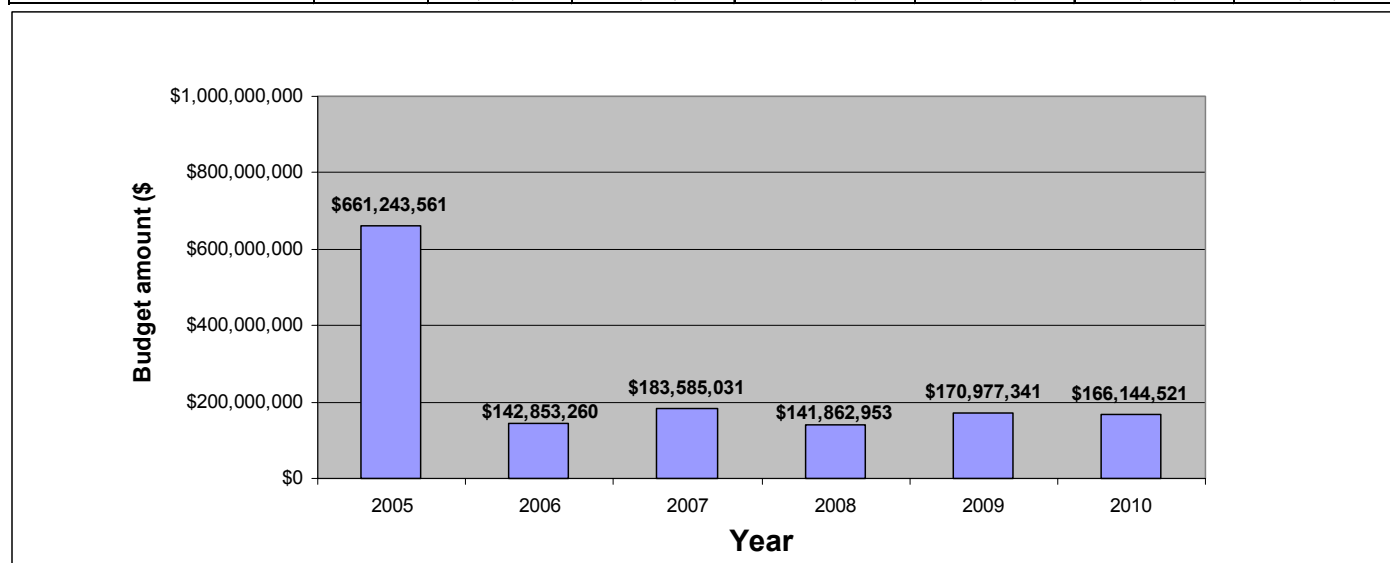


Figure 1.16. Projected Yearly Budgets for 2005 -- 2010 (Total \$1,467 million) Based on 2004 STIP Funding and Current Bridge Work Program for FY 2005 – 2010

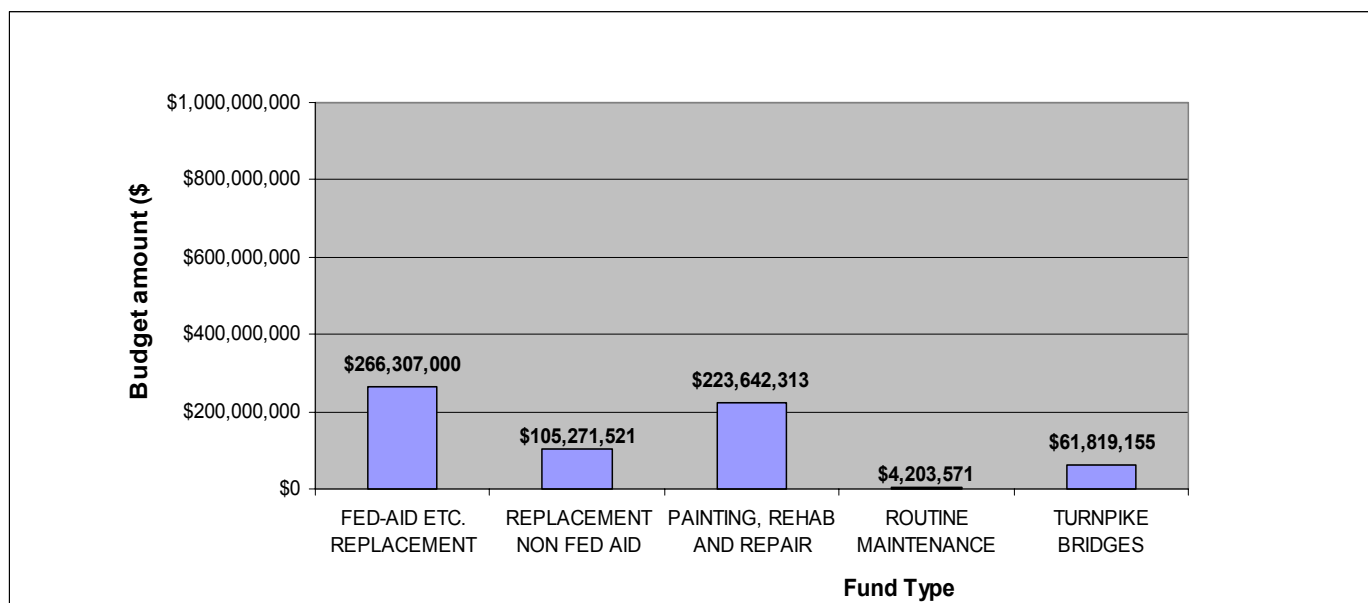


Figure 1.17. Projected Budget Breakdown By Fund Type for 2005 (Total \$661 million)
Based on 2004 STIP Funding and Current Bridge Work Program for FY 2005 – 2010

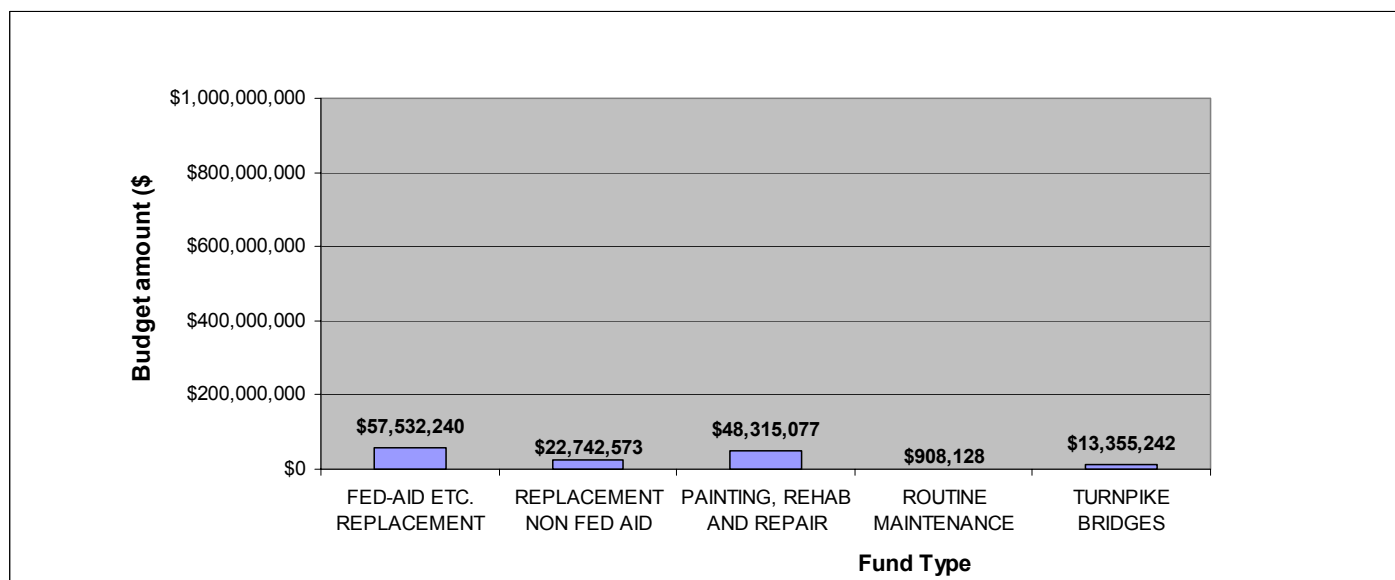


Figure 1.18. Projected Budget Breakdown By Fund Type for 2006 (Total \$143 million)
Based on 2004 STIP Funding and Current Bridge Work Program for FY 2005 – 2010

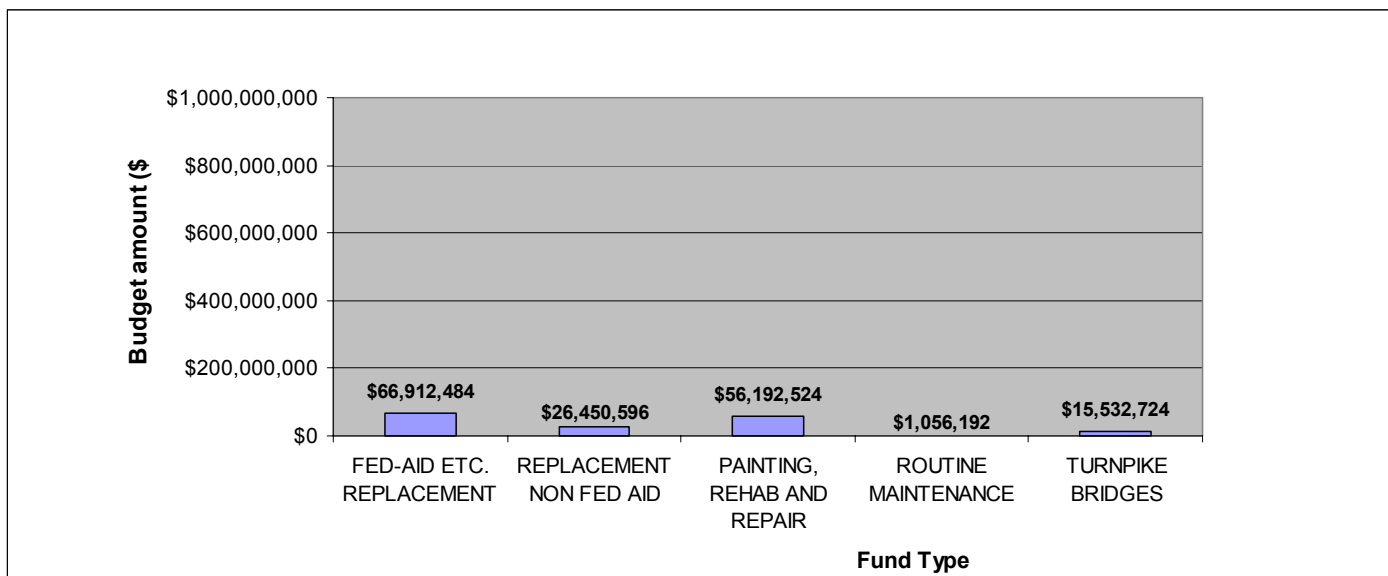


Figure 1.19. Projected Budget Breakdown By Fund Type for 2010 (Total \$166 million)
Based on 2004 STIP Funding and Current Bridge Work Program for FY 2005 – 2010

2. Methodology and Model Development

This section describes the framework design for a new Network Analysis Tool (NAT), an Excel spreadsheet model to supplement the functionality of AASHTOWare® Pontis®. Also included is the user interface mockup which was used for planning for the development of the digital dashboard of the decision support tool. A use-case analysis is presented, describing how the NAT will assist in the Department's programming and budgeting decision making activities. A domain model organizes the essential concepts of the programming and budgeting problem in a manner that will serve as an outline for data requirements and software components, and provides a framework for integrating the product with FDOT's Pontis database and its existing Project Level Analysis Tool. Performance measures serving as constraints and objectives are described, and the network optimization methodology is presented.

2.1 Use Case Analysis

The software module resulting from the present research is intended to be used by various Department management personnel to support asset management decisions involving prioritizing, scheduling, and budgeting of bridge work. Activities making up the decision making process are described in the form of a use-case model. A use-case is a specific class of activity, performed by a human decision-maker with assistance from the intended software module. One benefit of a use-case analysis is that essential assumptions about procedures, terminology, and preferences are made explicit so they can be reviewed and refined. This promotes clear understanding and well-designed functionality that fits the needs of intended users.

Another benefit is the ability of use-cases to anchor much of the analytical and software design and development. In this memorandum, major requirements (including inputs and outputs) of the analytical models and software are justified against the background of the identified use cases. Use-cases generate information that helps set priorities for project and product resources such as user interface, algorithm execution time, and software development time. Ultimately, use-case analysis helps provide the outline and structure for the user interface, reports, documentation, and test plan for the decision support software module.

Use-case analysis as a design methodology is described in numerous standard texts, including [Jacobson 1995] and [Schneider 1998]. The information in this report utilizes the graphical conventions of the Unified Modeling Language [Booch 1999; Fowler 2000] that have been tailored as needed to clearly communicate the most important decisions associated with network level bridge management. In the context of decision-making, two perspectives are elaborated: characterization of users; and characterization of decision-making activities to be addressed by the research product. Later in this memorandum, the results of the use-case analysis are further developed into a set of functional requirements for the tradeoff analysis and decision support tool. So the problem-oriented perspective in this chapter leads to the solution-oriented perspective in later chapters.

2.1.1 Characterization of users

The software module is intended to serve a planning process for programming and budgeting of maintenance and improvement of existing bridges. This is an important statement for defining the

population of intended users. Specific Department staff involved in the process, who are prospective users of the research product, are:

District Structures and Facilities Engineer (DSFE). Each of the Department's eight districts has an engineer responsible for project selection and priority setting among identified bridge needs. This person uses a variety of performance measures and shifts easily between a network level view and a bridge level view. The DSFE communicates the district's needs and priorities to the statewide level through an annual series of negotiation meetings known as the "gaming" process, and the Deficient Bridge List (DBL) process.

Statewide Bridge Maintenance Planner. One or more staff in the State Maintenance Office have the responsibility of establishing statewide policies and performance objectives for the bridge inventory, and participate in statewide priority-setting discussions. These personnel are generally trained as civil engineers and have the need and expertise to work with bridges at both the network level and bridge level with engineering-based performance measures.

Statewide Program Manager. One or more staff in the Work Programs Office have responsibility for supporting the Department's capital and maintenance budgeting process regarding bridges, and identify specific projects to be included in the annual update of the State Transportation Improvement Program (STIP). These staff generally are not engineers. They are concerned mainly with the Department's official performance measures and use them for budget negotiations and public reporting, rather than for any diagnostic or engineering purpose. When any of these three users engage in network level use-cases, they are referred to in this memorandum as Program Managers. These jobs are typically inter-disciplinary in nature, requiring an understanding of economics, planning, computing, basic systems analysis, and more than a passing familiarity with engineering and policy analysis. Often, these people serve as an interface between the political world and the engineering world, the center of an agency-wide asset management process.

It is assumed that all the users are computer-literate and be able to use standard office software tools such as word processors and spreadsheets, as well as more specialized software already developed for their job functions such as accounting systems and the Pontis bridge management system. They are assumed to have at their desks a computer capable of running these types of software effectively, and have in-house Information Technology support to help them solve common computer problems and gain access to necessary enterprise databases.

2.1.2 Use cases

Compared to the Project Level Analysis Tool (PLAT) [Thompson and Sobanjo 2004], the product of the current research will take a network level perspective appropriate for programming and budgeting. District Structures and Facilities Engineers and Statewide Bridge Maintenance Planners use the PLAT to examine each bridge and decide what candidates to advance into the programming process. A candidate may represent do-nothing, rehabilitation, replacement, or a custom set of actions. At the network level, DSFEs, Statewide Maintenance Planners, and Statewide Program Managers set priorities among bridges and decide which bridges to fund each year to satisfy budget constraints and try to meet performance targets.

Use cases for the PLAT were already defined in Thompson [2001]. The current research adds one use-case to the PLAT and then defines the network level use cases associated with programming

and budgeting. Figure 1 shows the additional use cases, employing the same graphical conventions as the original design for the PLAT.

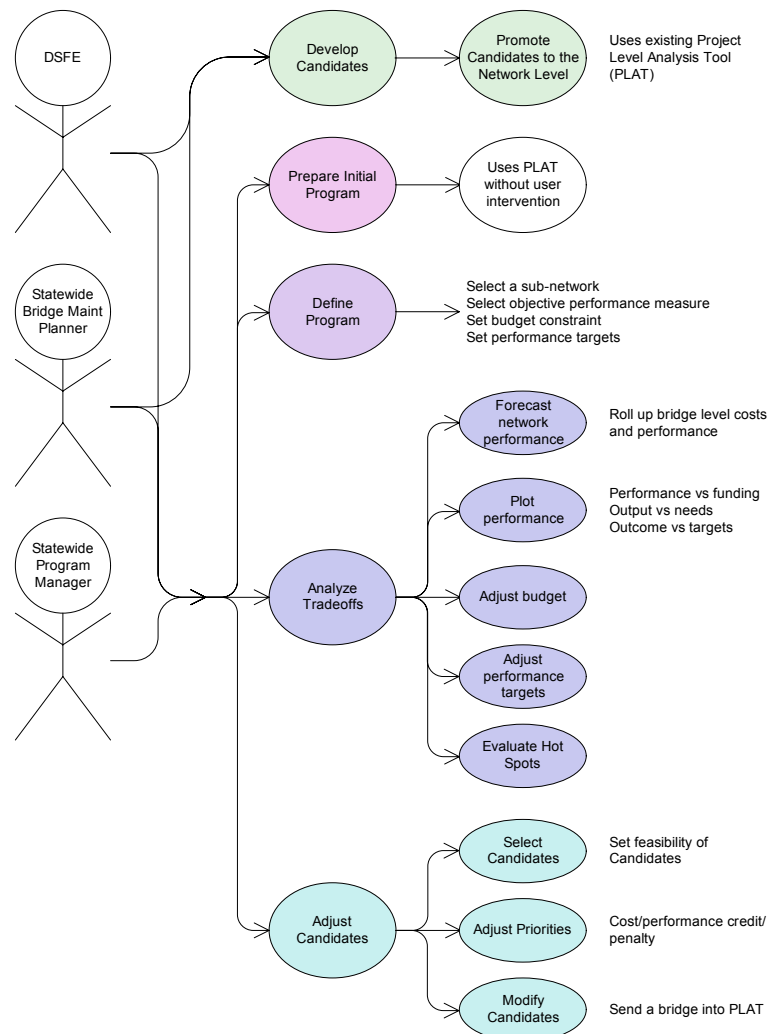


Figure 2.1. Use Case Model

Develop candidates. The existing PLAT has extensive functionality for developing candidates, but provides all of its own display and reporting functionality and does not send results to any other system. In order to add a programming and budgeting module, it is necessary to communicate the essential results of the PLAT, for each bridge, to the network level.

This means creating a storage place for project level results and adding a feature to the PLAT to decide which candidates, if any, should be sent there. The storage place will be referred to as the Analytical Database. Its technical characteristics will be defined later in the project, but for now it is merely a holding place to gather project-level decisions made at various times throughout the year so they can be put to use at the network level.

The essential information needing to be communicated between project level and network level is, for each bridge and each possible implementation year, a list of alternative interventions. Each

intervention must be characterized by its initial cost and a set of performance measures such as predicted condition and life cycle cost. At the network level, it is not necessary to know anything about the elements on each bridge, or to do any type of predictive modeling, since this will already have been done in the PLAT. The PLAT user may elect to send any or all of the candidates to the network level, and will need a user interface to accomplish this.

Prepare initial program. In any given year, most bridges in the inventory need little or no attention from engineers and planners, because they are in very good condition. It is desirable, therefore, that there be a way to create a reasonable set of candidates for these bridges automatically. Fortunately, the PLAT already has models to generate and evaluate default candidates. All that is necessary is a function to run the PLAT on every bridge and save these results in the Analytical Database.

This initialization function can be run on a specific date each year to begin the programming and budgeting process. After this initialization, work performed on a particular bridge in the PLAT and saved to the Analytical Database will over-ride the default candidates for that bridge. Bridges that were not visited in the PLAT will still have valid information in them that can be used by the NAT.

Define program. Program management is a process of reconciling competing objectives of resource utilization and performance, by means of selection and scheduling of actions. For most purposes, it is understood as a process of making choices of project scope and timing across an entire asset inventory or subset. However, for more senior managers and most elected officials, it is more often understood as a sort of economic supply curve -- a representation of how much performance can be purchased at various levels of investment. Program managers typically lack adequate time resources or expertise to evaluate engineering tradeoffs, but this does not mean such tradeoffs are unimportant. It merely means that the tradeoffs should already have been considered by engineers, and the results should be communicated to program managers in an efficient and consistent manner.

Program managers typically are responsible for their decisions and choose what criteria they will consider. These are more often governed by economic than engineering considerations. A Program Manager builds one or more programs, each of which has a set of objectives and constraints. Programs may represent different subsets of the inventory, may focus on different goals, or may merely be experimental alternatives to each other. A program may be built over several days, or over the course of an entire year, so it is necessary to keep track of the status of its development by saving and retrieving any partially- or fully-developed programs for subsequent review and possible modification.

Development of a program begins with the selection of a sub-network and identification of the performance measure of interest. The list of available candidates from the PLAT is evaluated and structured according to the performance tradeoff. An automated process can arrange the candidates in priority order according to each separate performance criterion, and can build an analytical data structure that describes how the selection of candidates jointly affects all the performance measures of interest. The inputs needed for this process are the costs and performance measures already calculated at the bridge level.

Analyze Tradeoffs. After the initial preparation, the Program Manager takes control and manipulates the budget constraint and performance targets. The Program Manager views a number

of graphical presentations of tradeoffs and sensitivity analysis to acquire an understanding of what goals are achievable with available inputs.

Adjustments to the inputs yield immediate feedback on forecast outputs and outcomes. This makes it easy to adjust budgets and performance targets and see the results in real-time.

Adjust Candidates. In addition to adjusting and viewing network level performance measures, the Program Manager typically seeks to view and adjust individual candidates. The non-engineer can still perform useful work at this level if the Maintenance Planner has provided a good set of alternatives. All such adjustments involve selecting or deselecting candidates, or making economic adjustments to reflect non-economic factors. For example, the manager might apply a penalty to a candidate that involves significant traffic disruption. A DSFE or Statewide Bridge Maintenance Planner may start the analysis from the network level – investigating the options for the bridge from network-level optimization standpoint — and then proceed down to the bridge-level to determine the appropriate courses of action. In this way it is possible to switch back and forth between bridge- and network-levels to fine-tune a program.

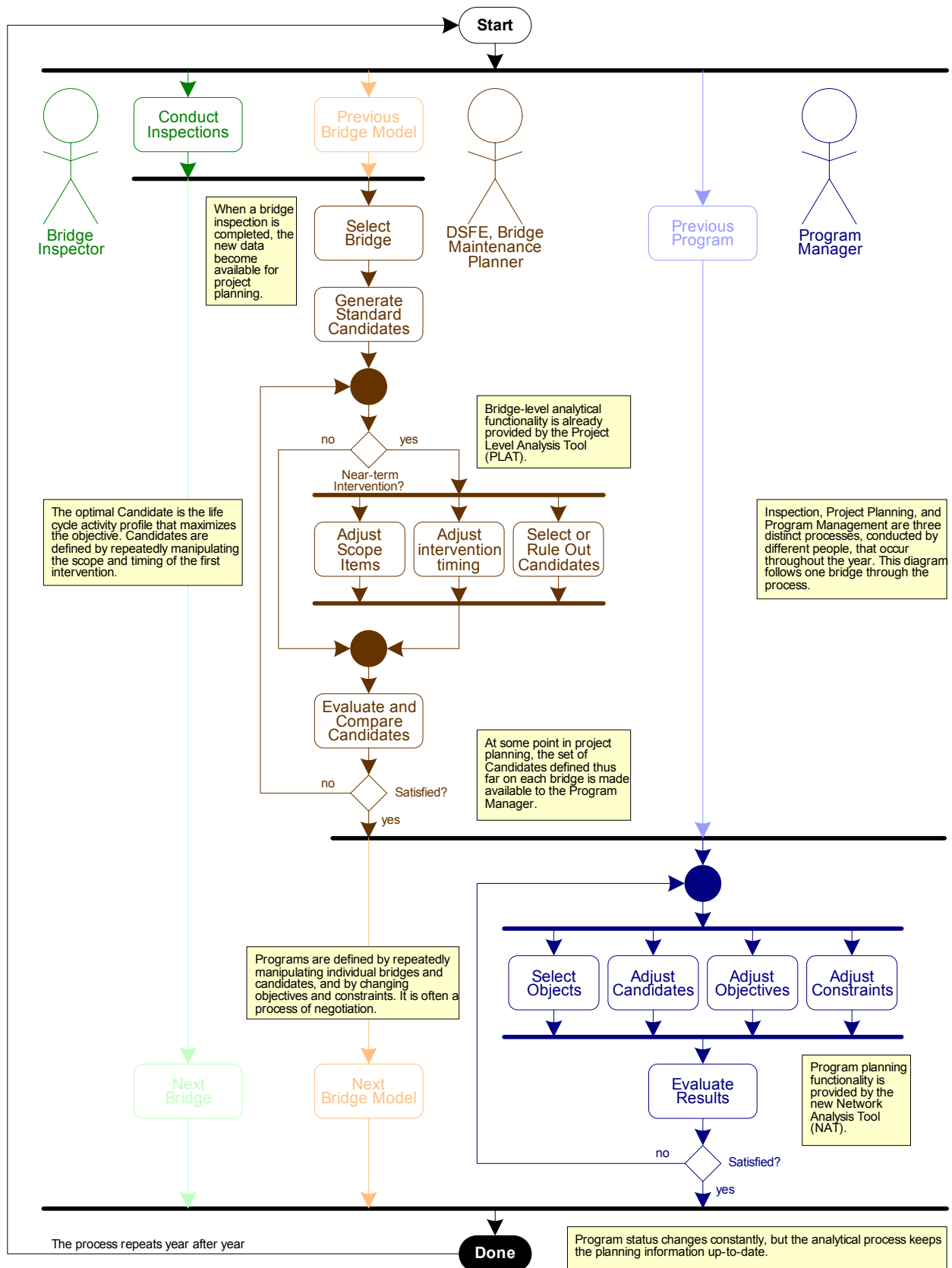


Figure 2.2. Activity Diagram

2.2 Domain model

Against the background of use-cases, it is possible to establish an outline for the required capabilities of the software module. The main issues are still problem-oriented because they describe the aspects of the decision-support problem that the software is intended to model. Most important is a thorough understanding of how the objects manipulated by the software relate to the real-world problems of bridge management.

Documentation and analysis of the problem domain takes the form of a Domain Model, a diagram and narrative that gives a comprehensive view of the problem structure. The model has both dynamic and static components: the dynamic components describe the work flow of the real-world activities modeled by the software; while the static components show how concepts are permanently related to each other.

Effective use of any tool for bridge management involves provision of step-by-step instructions on how to use the tool, including data preparation and interpretation of results and outputs. The dynamic view of the domain model, shown in the form of an Activity Diagram (Figure 2, above), identifies the step-by-step workflows for the relevant bridge management business processes, including both existing and new activities. In order to provide support for the indicated workflows, the research product will be developed to utilize computer data structures and algorithms that are consistent with such workflows.

The static view of the problem domain, in the form of a Class Diagram (Figure 3), is a map of the real-world objects and concepts for which computational effort will be expended and data will be manipulated. The Class Diagram divides the problem into small modules, each having its own data store and analytical functionality. Later in this study, the features of the class diagram will translate into a structure of database tables, worksheets, and executable code modules.

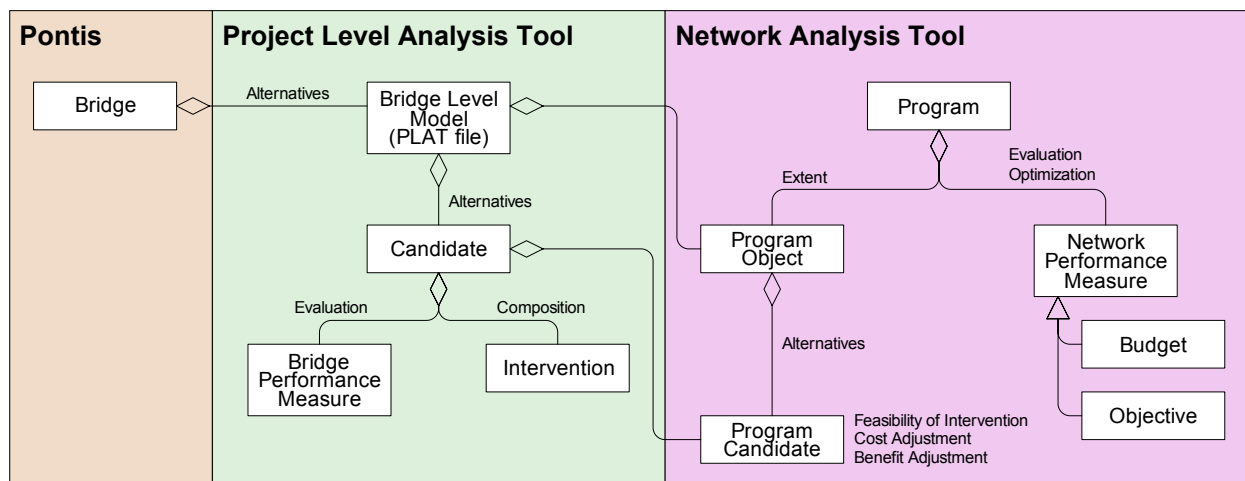


Figure 2.3. Class Diagram

2.2.1 Dynamic view

Figure 2.3 (above) presents an overview of the dynamic aspects of the decision-support problem, focusing on two primary business processes: bridge-level planning (brown) and program planning (blue). Activities associated with both models occur all year round, but the diagram also shows the

traced path of project development decision-support for one bridge.

Over the course of a cycle of two-year length (typically), bridge inspections are completed. After completion of each bridge inspection, data are stored in the Pontis database and subsequently used for many purposes including project planning.

At any given point in time, the project planner is able to view the entire bridge inventory, some with recent inspections and some with inspections up to two years old. The engineer typically seeks to focus on one bridge at a time and may consequently select for analysis either a recently-inspected bridge, or a bridge that has an urgent or high-priority need.

FDOT's existing Project Level Analysis Tool (PLAT) already provides the functionality needed for project planning. It generates a set of standard candidates, and then allows the creation of custom candidates, if desired. The engineer can evaluate the expected performance of the standard and custom candidates at any time, and make adjustments. When satisfied with the candidates, the engineer makes them available for program management.

Program management typically starts with a list of bridges and their candidates provided by the bridge-level planning process. Program planning activities are a part of budgeting, programming, and policy-making activities that happen all year round, so the process is asynchronous with bridge-level planning. Each time a program is analyzed, it makes use of whatever candidates are made available to it at the point in time when they are needed.

A program could have various meanings depending on the perspectives and needs of the end user: it could be a simple list of bridges with general plans to do some work; a specific list of projects needing to proceed into the project development pipeline; a set of performance goals and objectives; or a funding request, authorization, or appropriation. In fact, a program is a means of reconciling the needs of a variety of stakeholders by manipulating a schedule of bridge work. It is the product of a negotiation. Therefore a decision-support system for program planning should be considered a tool to support negotiation.

To design this decision support framework, we regard every aspect of the negotiation to be open to consideration: the selection of bridges, the scope and timing of work, the objectives to be achieved, and the requisite level of funding. Some of the tradeoffs are very clear: more funding yields better performance. Performance objectives are then set based on both public expectations and funding availability. These are uncertain variables. In particular, expectations about funding availability change constantly with ongoing discussions about Federal and State authorizations and appropriations.

Therefore, the decision-making process is again modeled as a loop of continuous refinement and evaluation. In each pass through the loop, changes may be made to the selection of bridges to be considered, the specific timing and scope of work on each bridge, the objectives to be achieved, and commitments to specific levels of performance and spending.

2.2.2 Static view

If the dynamic view brings out the “verbs” of the decision-support problem, then there is another perspective that brings out the “nouns.” This is the static view. It is useful to think of the static view as an outline of the data we will need about all the things and concepts that the model will

manipulate. However, the static view is a broader (but less detailed) concept than a database design, because it also includes data that are not stored permanently, that may be generated “on-the-fly” or viewed only in reports. The static view focuses on the relationships among objects, the division of responsibility among different parts of the system, and the level of detail of key topics of analysis, as described in the class diagram (Figure 3, above). This class diagram formed the outline of the database design in a later stage of the study.

It is assumed that the decision support software will be separate from, but linked to, Pontis and the PLAT. Therefore, the domain model abstracts the objects that it needs from these systems, which then act as an outline for the system interfaces. These interfaces will be a combination of software and data storage that act as an adapter between Pontis, the PLAT, and the NAT.

The Project Level Analysis Tool describes alternative futures for a bridge, including a selection of feasible candidates, with their scope and timing of work, and a forecast of resulting performance and condition of the bridge and its elements. Candidates are the organizing concept for the bridge-level model. Each candidate is a life cycle activity profile, a time series of program periods when an intervention may take place on one bridge. Each intervention is the collection of work to be undertaken in one year. For the network model it is not necessary to know about the individual scope items making up an intervention; it is only necessary to know the cost and performance to expect from each candidate as a function of its year of intervention.

In the Network Analysis Tool, the organizing concept is a program, which is a collection of selected candidates and the network performance that would be forecast if the selections are implemented. More specifically, a program is the selection of candidates that would result on a subset of the bridge inventory if a defined set of objectives and constraints are applied.

It is important to note that a program, as defined in the present study, does not actually contain candidates, but merely refers to them. So a candidate may be used by multiple Programs and does not have to be defined at the same time that the program is defined. This will be very important for data management efficiency and for efficient distribution of the computational workload.

2.3 Performance measures

The primary purpose of the Network Analysis Tool is to determine the maximum level of inventory performance achievable at any given level of funding. The budget constraint is intended to be easily manipulated by the user to analyze sensitivity to funding uncertainty. Performance may be measured in several ways, depending on the purpose of the analysis. If physical condition is the only concern, then NBI ratings and/or health index are most appropriate. For a broader measure of performance that includes the direct effect of bridges on road users and the value of preventive maintenance opportunities, it is best to use life cycle cost.

PLAT currently analyzes a nine-year program horizon in its calculation of performance measures. It will need to be extended to 10 years to support a 10-year horizon in the NAT.

2.3.1 NBI condition ratings

For statewide program management purposes, the primary objective to be maximized by the NAT is the percentage of structures on the State Highway System having a condition rating of either excellent or good, either for the lowest of deck, superstructure, or substructure ratings; or for the culvert rating. This is interpreted as the percent whose lowest NBI condition rating is at least 6 (FDOT 2005).

In order to predict this performance measure into the future as a result of programming decisions, the Federal Highway Administration's NBI Translator Program (distributed with Pontis) will be used to convert predicted element conditions into predicted NBI condition ratings. This functionality will be added to the PLAT. Deck, superstructure, substructure, and culvert condition ratings will be computed separately and made available to the PLAT user on its dashboard graphs. They will also be passed as performance measures to the NAT.

In addition, several additional performance measures will be computed in the PLAT and then carried over to the NAT to be used in policy analysis and the establishment of performance targets.

2.3.2 Initial cost and needs

Initial cost will be used as the basis of the budget constraint in the NAT. When plotting bridge needs vs funding, bridge needs are defined as the candidates giving the lowest life cycle cost (including both agency and user costs) in each year. If funding is not adequate to meet all needs, it means that future costs are forecast to be higher than they would be if all needs were met.

2.3.3 Health index

The Health Index was first proposed by the California Department of Transportation as a type of weighted average condition measure for a bridge or any subset of an inventory. It includes all condition states, weighting each element by its failure cost or by some other appropriate weight. This gives emphasis to elements that have the biggest economic impact on bridge functionality. Prioritization by health index gives the same results as "worst-first" prioritization, which understates the importance of preventive maintenance on the better condition states. As a measure of current inventory condition, however, the Health Index is a consistent way to reduce the voluminous data in an element inspection into a simpler quantity that can be compared across bridges and over time. The Health Index is computed as follows:

Health Index

$$HI = \frac{CEV}{TEV} \times 100$$

Current Element Value

$$CEV = \sum_e C_{ef} \sum_i^{N_e} Q_{ei} \left(1 - \frac{i-1}{N_e-1}\right)$$

Total Element Value

$$TEV = \sum_e C_{ef} \sum_i^{N_e} Q_{ei}$$

where C_{ef} is the failure cost for element e

Q_{ei} is the quantity of element e in condition state i

N_e is the number of condition states in element e

At the network level, health index will be computed by separately accumulating CEV and TEV over the entire inventory, then performing the HI computation only for the inventory as a whole. This gives greater emphasis to bridges with higher replacement costs.

A separate health index will be computed in the PLAT and NAT for painted steel elements. This will make it possible to use the NAT to develop a program focused solely on painting.

2.3.4 Life cycle cost

The existing life cycle cost analysis in the PLAT will be used at the network level to develop programs that minimize life cycle cost, defined as the present value in perpetuity of all forecast agency and user costs. A benefit measure will be derived from life cycle cost by subtracting the life

cycle cost of a candidate from the life cycle cost of the do-nothing candidate. This will also enable a benefit/cost ratio to be used at the network level.

2.4 Network optimization

The problem of maximizing one objective subject to one constraint is known as the multiple-choice knapsack problem. The application described here is more particularly known as the capital budgeting problem. This is a famous problem in the operations research literature [Lorie and Savage 1955, Freville 2004] and has many possible solution methods. Exact solutions to the capital budgeting problem are surprisingly difficult to find, especially for a full-size state bridge inventory. But there is an approximate solution method that reliably produces solutions very close to the true optimum much more quickly than any exact method. This is called the incremental benefit/cost (IBC) method [McFarland et al, 1983, Farid et al. 1988]. The speed of this method, and particularly a software architecture that is able to vary the constraint without re-solving the entire problem, will be very important in accomplishing the goal of a very user-friendly and responsive decision support tool.

An important aspect of the IBC method is that it produces near-optimal (and not guaranteed-optimal) solutions. It is possible in principle to take an IBC solution, investigate variations on it, and possibly come up with a somewhat better solution. However, the IBC method does offer a softer guarantee, that if the solution is not optimal, the maximum amount of sub-optimality (the additional total benefit that is possible but was not found) is limited to the benefit of the largest candidate selected. For a real-size problem, this is within the margin of uncertainty in the budget constraints and other inputs, so the small sub-optimality is considered acceptable as a practical matter.

2.4.1 Diminishing Marginal Returns

The IBC method relies on an economic concept called the Law of Diminishing Marginal Returns. This is a concept describing the economic relationships among alternative uses of the same investment capital. Each bridge has several alternative candidates with varying levels of investment and performance benefit. If funding is constrained, it is desirable to find the highest-benefit use for the money. If more funding becomes available, then additional investment can be made in the same bridges to increase the benefit. If the benefits of the various alternative candidates on a bridge are plotted against costs, the curve in Figure 4 is a typical result.

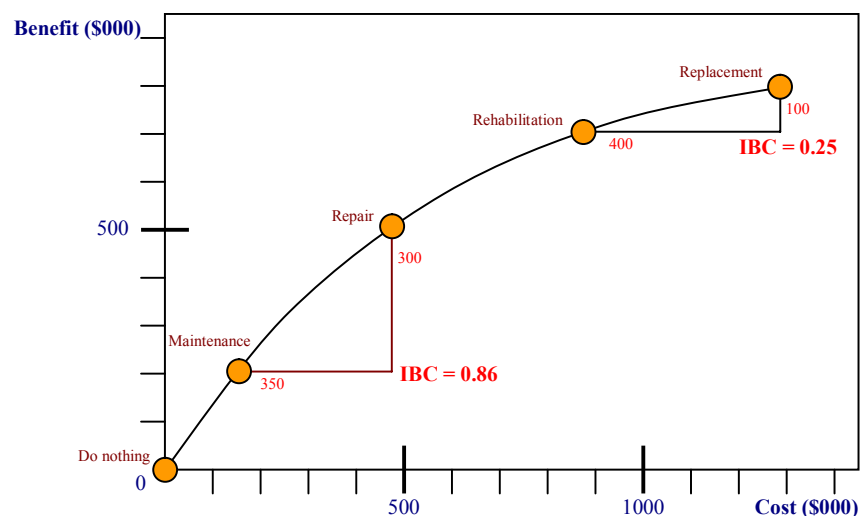


Figure 2.4. Diminishing Marginal Returns

When interpreting this example, “benefit” is defined as the savings in life cycle cost of doing something, rather than doing nothing, or the improvement in condition from doing something rather than doing nothing. If benefit is positive, this means that the discounted future cost savings exceeds the initial cost. So any positive benefit is good.

If the scope of work on the bridge is upgraded from Maintenance to Repair, the additional cost is \$350,000 and the additional benefit is \$300,000, for a marginal return, or incremental benefit/cost ratio (IBC) of 0.86. Similarly, if the scope of work is upgraded from Rehabilitation to Replacement, the cost increases by \$400,000 while the benefit increases by only \$100,000, for an IBC of 0.25. This typical pattern, where each incremental investment produces a less-than-proportionate increase in benefits, is called the Law of Diminishing Marginal Returns. Under this rule, more expensive alternatives have progressively smaller IBC ratios. In other words, the first dollar gives the greatest benefit and the last dollar gives the smallest benefit. So in a program with a very high or unconstrained budget, the last alternative considered will be the one with a high additional cost but a small additional benefit. However, this will generally be the alternative with the smallest IBC ratio.

To understand why this curve must always be concave downward, imagine a situation where Repair costs are more than Rehabilitation. If this were true, then Rehabilitation would have higher benefits at lower cost, so it would always be a more economical choice. Because of the competition in any real bridge inventory among a large number of investments, any Candidate that has benefits too low, or costs too high, to fit the diminishing marginal returns curve, will be less attractive than other investments on the same bridge or other bridges. This is equivalent to saying that bridge maintenance projects behave like normal economic goods (rather than Giffen(?) goods). Bridge maintenance models as they have been developed in practice, with discounting, will practically always behave mathematically like a normal good.

2.4.2 Incremental benefit/cost algorithm

The IBC heuristic maintains a list of investment candidates sorted by the ratio of change in benefit, divided by change in cost. Benefit can be any measure that is additive over the entire bridge inventory, so an increase in benefit on one bridge also increases benefit by the same amount for the inventory as a whole. On each bridge, a set of alternative candidates is defined, starting with do-nothing at zero cost and zero benefit, and ending with total replacement at maximum cost and benefit. The rule of diminishing marginal returns is essential to the heuristic, so candidates failing to satisfy this rule are eliminated from consideration. The general steps of the heuristic are as follows:

1. Screen the candidates for diminishing marginal returns on each bridge.
2. Candidates of all bridges are combined and the joined list is sorted by decreasing IBC.
3. Select do-nothing for each bridge.
4. Process the candidate list in IBC-sorted order. At each stage the budget constraint is checked.
5. Each candidate replaces the previously-selected candidate on the same bridge, and then the total cost and performance are updated.
6. The heuristic stops after scanning through the complete list or earlier if the performance constraint is satisfied or the budget constraint becomes too tight to allow the next candidate to be added.

Figure 5 shows a flowchart of this algorithm. Depending on the choice of convention, the stopping criterion may allow the final candidate to exceed the budget, or may require that the candidate fit within the remaining budget. In the linear approximation of the knapsack problem, the final candidate is trimmed so it fits the remaining budget exactly. The remaining budget if not used will lead to loss of some benefit in the objective function. This is referred to as the integrality gap in the Knapsack problem. An alternative way to reduce the integrality gap is to continue scanning down the list and try to fit smaller candidate projects.

The computationally-intensive part of the IBC heuristic is a sorting algorithm selected for computational efficiency based on the means of updating the candidate list. Often it is convenient to maintain a data structure, such as a binary tree, that allows individual bridges to be modified without resorting the whole list. Many common operations, such as changing an individual candidate or moving the budget constraint, can be performed without re-sorting the list, giving instantaneous performance even for very large problems.

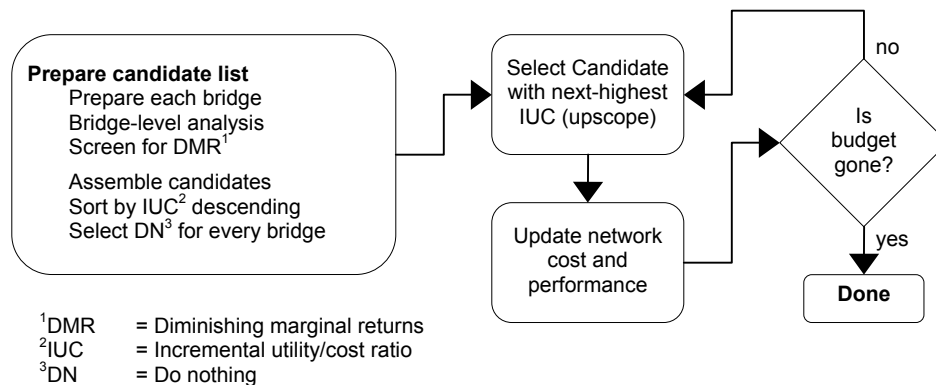


Figure 2.5. Flow Chart of The Incremental Benefit/Cost Algorithm

2.4.3 Example of the IBC algorithm

The left side of Table 1 lists four bridges with a total of 10 alternative candidates (Alt). Each bridge has a do-nothing alternative labeled “0”, which has zero cost and benefit by definition. Life cycle cost (LCC) is calculated by the PLAT for each alternative. Benefit is the LCC of do-nothing minus the LCC of the alternative being considered. Incremental benefit/cost ratio (IBC) is the ratio of change in benefit divided by change in cost, relative to the next-less expensive alternative on the same bridge. By definition the do-nothing alternatives do not have an IBC because there is no less expensive alternative.

These candidates can be placed in priority order by sorting by IBC. The right side of Table 1 shows the result. The right-most column of this table is the cumulative cost of the four-bridge program as each increment of funding is added, if investments are selected in order of IBC. Please note that cumulative values are not just the cumulative sum of the cost column. This is because when we determine the cumulative amount of money for the bridge network and select any candidate for a bridge on the list we also need to de-select the previously selected candidate for that bridge. For example, if Alt #2 of Bridge #1 is added to the program (seventh row of the table), then the \$700,000 cost of Alt #2 is added, but this replaces Alt #1, whose \$200,000 cost is subtracted. This is a net increase in cost of \$500,000, which increases the cumulative value from \$600,000 to

\$1,100,000.

If no funding is available, do-nothing must be selected for all four bridges, so the total program cost is zero. If \$1.7 million is available, there is enough money to perform Alt #1 on Bridges #2-3, and there is also enough to up-scope Bridge #1 to Alt #2. If \$2.6 million is available, then there is enough money to upscope Bridge #3 and to perform the work on Bridge #4.

Table 2.1. Example of the IBC Algorithm

Candidates grouped by bridge						Sorted by IBC				
Bridge	Alt	Cost	LCC	Benefit	IBC	Bridge	Alt	Cost	Cum	
1	0	0	2400	0	--	1	0	--	0	0
1	1	200	2000	400	2.00	2	0	--	0	0
1	2	700	1400	1000	1.20	3	0	--	0	0
2	0	0	3000	0	--	4	0	--	0	0
2	1	500	2550	450	0.90	1	1	2.00	200	200
3	0	0	2600	0	--	3	1	1.50	400	600
3	1	400	2000	600	1.50	1	2	1.20	700	1100
3	2	600	1850	750	0.75	2	1	0.90	500	1600
4	0	0	1900	0	--	3	2	0.75	600	1800
4	1	800	1340	560	0.70	4	1	0.70	800	2600

All economic quantities in \$000s

Most agencies have uncertainty in both funding and project readiness, so it is common to over-program by using a budget level larger than the amount actually anticipated. So when there is a residual, as in the case of a \$1.7 million budget where \$100,000 is left over, the extra amount is typically ignored. At any given budget level, total benefits are maximized by following this priority list, within a reasonable level of uncertainty.

A useful property of this heuristic is that it is not necessary to re-sort or make any other changes in the IBC-sorted candidate list in response to changes in the budget constraint. This makes it very easy to graph performance vs. funding.

2.5 User Interface

The decision support tool to be delivered in this study is envisioned to have four worksheets:

Dashboard, where most of the work is done. This provides tools and data displays to set the network subset, budget, and performance target. It shows relevant information about current conditions and future tradeoffs.

Candidates, where the user may decide, for each bridge, which candidates are to be considered. The program manager will sometimes want to fine-tune a program by eliminating certain candidates from consideration, or by limiting the range of intervention years for which a candidate is to be considered. This worksheet has one row per bridge, and shows the current performance levels for each bridge. Its functionality is essentially similar to the Screening worksheet in the PLAT, including the ability to sort and customize the list, and the ability to launch a bridge in the PLAT.

Selections, which shows the list of candidates that would be selected for the specified inventory

subset, performance measure, and budget constraint. This worksheet can be sorted and customized, and can launch a selected bridge in the PLAT.

Configuration, where the user can set various options that govern the behavior of the software.

2.5.1 Dashboard

Figure 6 is a mockup of the dashboard screen for the proposed decision support tool. On one screen, it presents all the controls and outputs that the program manager will normally need, to explore the tradeoff between performance and funding for the entire bridge inventory or any subset of it. The sections of the dashboard are as follows.

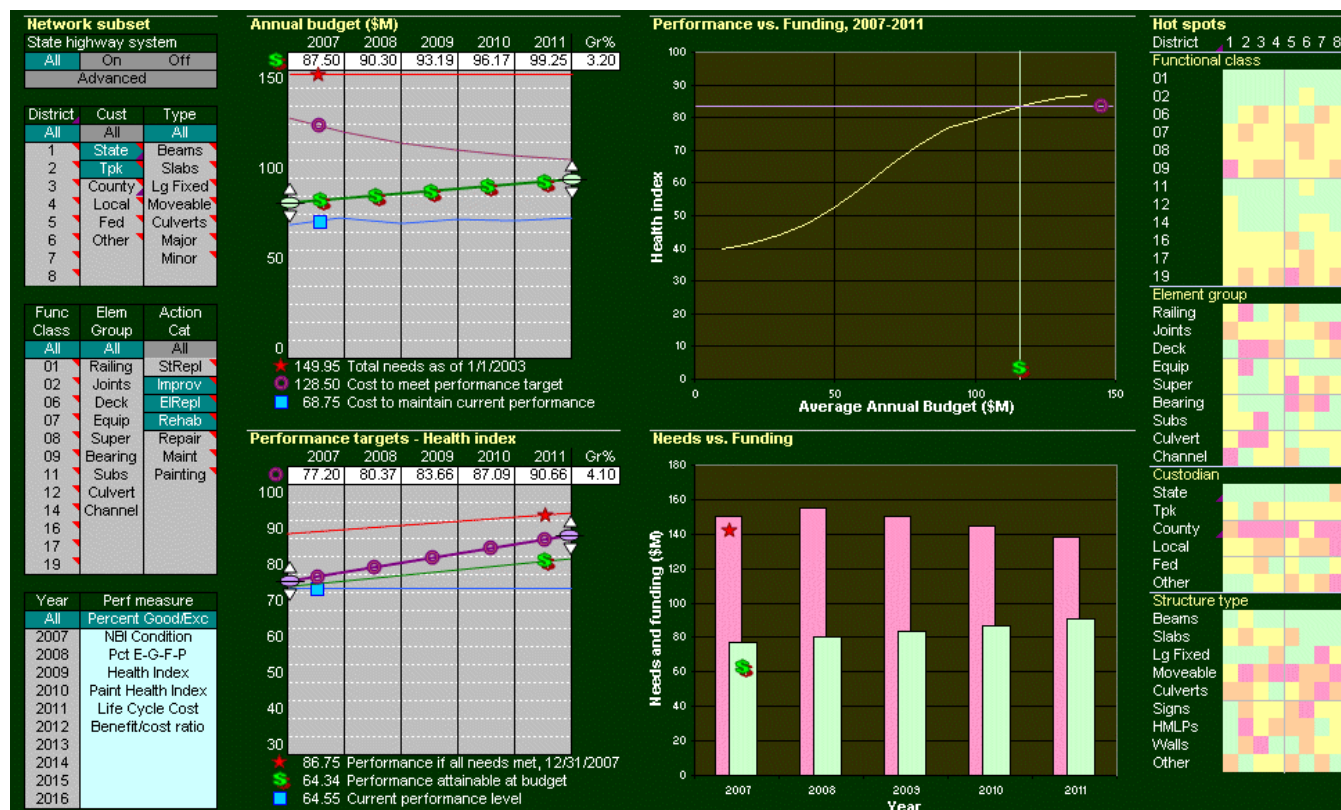


Figure 2.6. Dashboard Mockup

Network subset. Users can click cells in this area of the worksheet to include portions of the bridge inventory selected according to district, custodian, structure type, functional class, element group, and action category. Each of these columns has a cell labeled “All” at the top, which clears the selections below it.

In the “Type” column, “Major” bridges are those with a deck area corresponding to a replacement cost of at least \$10 million. The unit replacement cost to use for this computation is specified as a configuration option.

In the section labeled “State highway system,” the user may choose to analyze only the bridges on the state highway system, or all bridges off the system, or both. For this purpose, the state highway system includes all bridges with NBI owner (item 22) codes of 01, 31, or 33, with the exception of district 6 bridges having owner code 31 (metro Dade toll authority bridges).

The analysis normally excludes sign structures, light poles, mast arms, and walls. This exclusion can be changed using a configuration option.

Near the top of the Network subset area of the screen is a button labeled “Advanced.” This brings up a dialog box where more customized selections can be made, over-riding the selections on the main screen. Users can select individual design and material types (NBI items 43 a and b), for example to single out segmental bridges, or provide an SQL WHERE clause that operates on any data in the bridge table of Pontis.

Performance measures. Performance measures can be forecast for any individual year in the next 10, or as an average over all 10 years. The incremental benefit/cost algorithm will optimize this measure for any given funding level. If the “NBI Condition” performance measure is selected, the performance vs. funding graph will show the four NBI condition ratings (deck, superstructure, substructure, and culvert) separately as network averages. If the “Pct E-G-F-P” performance measure is selected, the graph will show the minimum NBI condition rating as a percent of the inventory at or above each of three condition ranges: Excellent (minimum NBI rating of at least 8), Good (at least 6), or Fair (at least 5, the rest are Poor).

Annual budget. This section of the worksheet is where the user sets the budget constraint. The annual budgets may be entered individually at the top, or the first year budget and growth rate may be entered, causing the others to be calculated. The graph labeled by dollar signs shows the amounts entered. On the same scale, the graph also shows total needs, the cost to meet the performance target (see below), and the cost to maintain current performance. All of these apply to the subset of bridges specified on the screen.

Both the Annual budget and Performance targets sections may be expanded to a greater number of years, as a configuration option. The initial setting is five years. The first year is also a configuration option.

Performance targets. In this section the user sets targets for the selected performance measure. These may be entered individually, or the first year’s target and growth rate may be entered, causing the others to be calculated. The graph labeled by donuts shows the amounts entered. On the same scale, the graph also shows the forecast performance if all needs are met, the performance level attainable with the funding level entered in the Annual budget section, and the current performance level in the inventory.

Performance vs. Funding. This section shows the performance level attainable at any given budget level. It therefore shows the sensitivity of performance to funding.

Needs vs. Funding. This graph shows the needs forecast for each year, when the budget is constrained as specified. This is compared to the actual budget constraint. If needs are shown to grow on this graph, then the budget is not enough to support a sustainable bridge program.

Hot spots. This section is a cross-tabulation of performance for various subdivisions of the bridge inventory. The colors indicate quartiles of performance among all the cells, so the reddest ones are the portions of the inventory where performance is worst. This presentation helps the decision maker to identify parts of the inventory that may need extra funding or attention.

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Appendix B: Evaluation of FHWA's NBI Translator

This section describes the results of an analysis of the FHWA's National Bridge Inventory (NBI) translator program, using Florida bridge inventory data. The NAT program utilizes a measure derived from NBI condition ratings as its primary performance measure, but Florida conducts its bridge inspection based on the AASHTO CoRe Elements, for the Pontis BMS software. In order to utilize the NBI ratings, a translation is therefore required. Also available is the bridge inspection data where the NBI inspections were carried out simultaneously with the bridge element-based inspections. The purpose of this exercise was to establish the relationship between the actual NBI inspection data and the NBI translated data from Pontis inspections. Also presented is a simplified methodology for NBI translation based on Pontis element condition indexes.

B1.0 Methodology of the NBI Translator Program (BMSNBI)

The University of Colorado Boulder and Colorado Department of Transportation conducted a study, with the objective of the developing methods for generating National Bridge Inventory (NBI) condition ratings for deck, superstructure, substructure and culvert from element-level condition data in a bridge management system database. The study report discusses the process for generating of NBI condition ratings, as well as the application of the developed BMSNBI software tool. The commonly recognized (CoRe) elements were defined to include all components, which affect NBI rating fields together. This includes smart flags, which describe special types of distress for which deterioration models are not available.

The generation of the NBI condition ratings is described as a four-step process: (1) elements are grouped into NBI fields (deck, superstructure, substructure, or culvert); (2) each element's condition state observations are converted separately to NBI condition ratings; (3) these ratings are now aggregated for each NBI field; and finally, (4) the NBI ratings are modified by condition reports for smart flags. The translation of condition ratings is done in a table-driven procedure that assigns an NBI condition rating based on the percentage of an element observed to be at or above each condition state. Weights are assigned to the elements in cases where more than one element contributes to a single NBI field. These weights are calculated on the basis of dimensions and quantities of elements.

According to the study report, BMSNBI has two basic operations. The first operation is to generate NBI condition ratings and report errors in the input data. Second, BMSNBI allows the user to review errors, and to provide special instructions for NBI generation for individual structures. These errors occur due to the following reasons: missing expected elements for an NBI field; elements that are not recognized by the program; or inconsistent data in the bridge model. The errors in BMSNBI are of four levels: Fatal, Warning, Notice, and OK. These error levels indicate how severely the NBI ratings are affected. A Fatal error indicates that at least one NBI rating was not generated. A Warning indicates that an NBI rating is probably wrong. A Notice indicates that an NBI rating may be wrong. OK indicates that all NBI ratings are probably correct.

Table B1. Table for NBI Generation (Hearn et al. 1997)

Requirements on Element Quantities			NBI Rating
P_1	\geq	$M_{1,9}$	9
$P_1 + P_2$	\geq	$M_{2,9}$	
$P_1 + P_2 + P_3$	\geq	$M_{3,9}$	
$P_1 + P_2 + P_3 + P_4$	\geq	$M_{4,9}$	
P_1	\geq	$M_{1,8}$	8
$P_1 + P_2$	\geq	$M_{2,8}$	
$P_1 + P_2 + P_3$	\geq	$M_{3,8}$	
$P_1 + P_2 + P_3 + P_4$	\geq	$M_{4,8}$	

P_i denotes the percentages of element quantities in the respective condition state as indicated in the BMS condition report. Checking the sum of percentages against a minimum required value enforces the four simultaneous requirements for each NBI rating value. The required sums, called mapping constants, are shown as the $M_{i,j}$ in Table B1. The percentages in the condition states report must satisfy all four requirements to qualify for the corresponding NBI rating. Also, the Constants $M_{i,j}$ for table-driven NBI generation are constrained as

$$M_{i,j} \leq M_{i+1,j}$$

The constraints are designed to require a higher threshold for higher NBI ratings. Based on data from bridge inspections in which both BMS element condition reports and NBI condition ratings were recorded, the mapping constants $M_{i,j}$ constitute an optimal set, having been calibrated to yield minimum error in NBI generation. Examples of the tables used for NBI generation are shown in Tables B2 to B5 for deck, superstructures, and substructure.

The BMSNBI software typically runs as a standalone program on desktop computers, but also comes integrated with the Pontis 4.x software. On inquiry with the FHWA regarding the latest version of the standalone software, the research team was advised to use the version with the Pontis, as it is the latest version. The first step in running BMSNBI involves data preparation for the input file, the elements.prn file. The field definitions of the required data are shown in Table B6. It was necessary to modify the elements.prn file because of the specific non-CoRe elements used in the Florida inventory. With the new elements.prn file, the NBI translator was run using the Florida bridge inventory.

After integrating the Pontis version of the NBI translator into the Project Level Analysis Tool, the performance of the combination was evaluated over a large number of bridges. Several problems were noted:

- The translator generates a maximum NBI condition rating of 7, which occurs only when all contributing elements are entirely in condition state 1 (perfectly new condition). It was observed that even the most insignificant deterioration would reduce the NBI condition to 6. Using typical Florida deterioration models, bridges stayed in NBI rating level 6 for only a short

time before proceeding to level 5. This behavior is unacceptably far removed from actual deterioration experience as observed by FDOT inspectors.

- When PLAT results were analyzed further in the NAT, it was found that simulated network conditions were unrealistically poor, relative to actual levels routinely maintained by current FDOT maintenance and funding policies. This was due to unrealistically low NBI condition levels produced by the translator program.
- Because of the software architecture of the NBI translator program, its use made a PLAT analysis take more than twice as long (in terms of software execution time) as when the translator was not used.

It should be emphasized that these problems don't stem from any error or malfunction in the NBI translator. Rather, the problems occur because the translator program was not intended or tested to be used in a simulation-type program such as Pontis or PLAT.

Our testing does not cast any doubt on the translator's original requirement to generate Federal funding eligibility information in a manner consistent with visual inspections under the National Bridge Inspection Standards. The problem is most acute for bridges in relatively good condition, which normally would not be eligible for Federal funding, but are of great concern for the planning of preventive maintenance and repairs.

Our conclusion from this analysis is that the NBI translator program is not suitable for use in maintenance planning tools such as PLAT and NAT. If NAT is to produce performance measures based on NBI condition ratings but appropriate for maintenance planning, it is necessary to produce a new type of translator that gives more accurate results for bridges in NBI condition levels of 6 and above.

Table B2. BMSNBI Mapping Scheme for Reinforced Concrete Deck and Slab (Hearn et al. 1997)

	M_{i,j}	NBI
$P_1 \geq$	0	9
$P_1 + P_2 \geq$	0	
$P_1 + P_2 + P_3 \geq$	0	
$P_1 + P_2 + P_3 + P_4 \geq$	101	
$P_1 \geq$	0	8
$P_1 + P_2 \geq$	0	
$P_1 + P_2 + P_3 \geq$	0	
$P_1 + P_2 + P_3 + P_4 \geq$	101	
$P_1 \geq$	100	7
$P_1 + P_2 \geq$	100	
$P_1 + P_2 + P_3 \geq$	100	
$P_1 + P_2 + P_3 + P_4 \geq$	100	
$P_1 \geq$	0	6
$P_1 + P_2 \geq$	100	
$P_1 + P_2 + P_3 \geq$	100	
$P_1 + P_2 + P_3 + P_4 \geq$	100	
$P_1 \geq$	0	5
$P_1 + P_2 \geq$	0	
$P_1 + P_2 + P_3 \geq$	100	
$P_1 + P_2 + P_3 + P_4 \geq$	100	
$P_1 \geq$	0	4
$P_1 + P_2 \geq$	0	
$P_1 + P_2 + P_3 \geq$	0	
$P_1 + P_2 + P_3 + P_4 \geq$	100	
$P_1 \geq$	0	3
$P_1 + P_2 \geq$	0	
$P_1 + P_2 + P_3 \geq$	0	
$P_1 + P_2 + P_3 + P_4 \geq$	0	
$P_1 \geq$	0	2
$P_1 + P_2 \geq$	0	
$P_1 + P_2 + P_3 \geq$	0	
$P_1 + P_2 + P_3 + P_4 \geq$	0	
$P_1 \geq$	0	1
$P_1 + P_2 \geq$	0	
$P_1 + P_2 + P_3 \geq$	0	
$P_1 + P_2 + P_3 + P_4 \geq$	0	

Table B3. BMSNBI Mapping Scheme for Painted Steel Superstructure (Hearn et al. 1997)

	M_{i,j}	NBI
$P_1 \geq$	0	9
$P_1 + P_2 \geq$	0	
$P_1 + P_2 + P_3 \geq$	0	
$P_1 + P_2 + P_3 + P_4 \geq$	101	
$P_1 \geq$	0	8
$P_1 + P_2 \geq$	0	
$P_1 + P_2 + P_3 \geq$	0	
$P_1 + P_2 + P_3 + P_4 \geq$	101	
$P_1 \geq$	100	7
$P_1 + P_2 \geq$	100	
$P_1 + P_2 + P_3 \geq$	100	
$P_1 + P_2 + P_3 + P_4 \geq$	100	
$P_1 \geq$	0	6
$P_1 + P_2 \geq$	50	
$P_1 + P_2 + P_3 \geq$	50	
$P_1 + P_2 + P_3 + P_4 \geq$	100	
$P_1 \geq$	0	5
$P_1 + P_2 \geq$	0	
$P_1 + P_2 + P_3 \geq$	30	
$P_1 + P_2 + P_3 + P_4 \geq$	75	
$P_1 \geq$	0	4
$P_1 + P_2 \geq$	40	
$P_1 + P_2 + P_3 \geq$	40	
$P_1 + P_2 + P_3 + P_4 \geq$	55	
$P_1 \geq$	0	3
$P_1 + P_2 \geq$	0	
$P_1 + P_2 + P_3 \geq$	0	
$P_1 + P_2 + P_3 + P_4 \geq$	0	
$P_1 \geq$	0	2
$P_1 + P_2 \geq$	0	
$P_1 + P_2 + P_3 \geq$	0	
$P_1 + P_2 + P_3 + P_4 \geq$	0	
$P_1 \geq$	0	1
$P_1 + P_2 \geq$	0	
$P_1 + P_2 + P_3 \geq$	0	
$P_1 + P_2 + P_3 + P_4 \geq$	0	

Table B4. BMSNBI Mapping Scheme for Prestressed Concrete Superstructure (Hearn et al. 1997)

	M_{i,j}	NBI
$P_1 \geq$	0	9
$P_1 + P_2 \geq$	0	
$P_1 + P_2 + P_3 \geq$	101	
$P_1 \geq$	100	8
$P_1 + P_2 \geq$	100	
$P_1 + P_2 + P_3 \geq$	100	
$P_1 \geq$	65	7
$P_1 + P_2 \geq$	100	
$P_1 + P_2 + P_3 \geq$	100	
$P_1 \geq$	0	6
$P_1 + P_2 \geq$	100	
$P_1 + P_2 + P_3 \geq$	100	
$P_1 \geq$	0	5
$P_1 + P_2 \geq$	20	
$P_1 + P_2 + P_3 \geq$	85	
$P_1 \geq$	0	4
$P_1 + P_2 \geq$	0	
$P_1 + P_2 + P_3 \geq$	35	
$P_1 \geq$	0	3
$P_1 + P_2 \geq$	0	
$P_1 + P_2 + P_3 \geq$	35	
$P_1 \geq$	0	2
$P_1 + P_2 \geq$	0	
$P_1 + P_2 + P_3 \geq$	0	
$P_1 \geq$	0	1
$P_1 + P_2 \geq$	0	
$P_1 + P_2 + P_3 \geq$	0	

Table B5. BMSNBI Mapping Scheme for Reinforced Concrete Substructure (Hearn et al. 1997)

	M_{i,j}	NBI
$P_1 \geq$	0	9
$P_1 + P_2 \geq$	0	
$P_1 + P_2 + P_3 \geq$	101	
$P_1 \geq$	0	8
$P_1 + P_2 \geq$	0	
$P_1 + P_2 + P_3 \geq$	101	
$P_1 \geq$	95	7
$P_1 + P_2 \geq$	100	
$P_1 + P_2 + P_3 \geq$	100	
$P_1 \geq$	0	6
$P_1 + P_2 \geq$	100	
$P_1 + P_2 + P_3 \geq$	100	
$P_1 \geq$	0	5
$P_1 + P_2 \geq$	85	
$P_1 + P_2 + P_3 \geq$	100	
$P_1 \geq$	0	4
$P_1 + P_2 \geq$	40	
$P_1 + P_2 + P_3 \geq$	60	
$P_1 \geq$	0	3
$P_1 + P_2 \geq$	0	
$P_1 + P_2 + P_3 \geq$	20	
$P_1 \geq$	0	2
$P_1 + P_2 \geq$	0	
$P_1 + P_2 + P_3 \geq$	0	
$P_1 \geq$	0	1
$P_1 + P_2 \geq$	0	
$P_1 + P_2 + P_3 \geq$	0	

Table B6. The Field Definitions for the ELEMENTS,PRN file

Field	Format	Codes										
Element ID	The element numbers used by BMS. Element IDs are in the range 0-999. Integer, I3	0 – 999										
Element NBI Field	A single digit identifying an element's NBI assignment. Codes are Integer, I3	1 Deck 2 Superstructure 3 Substructure 4 Culvert 5 No NBI assignment										
Element Material	A single digit identifying an element's material. Codes are: Integer, I3	1 Unpainted Steel 2 Painted Steel 3 Prestressed Concrete 4 Reinforced Concrete 5 Timber 6 Smart Flag 7 Masonry 0 Unknown Material										
Element Type	Codes to identify elements with special attributes. Codes distinguish between decks and slabs, between the two types of truss elements, between truss elements and other superstructure elements, and between abutments and piers. Element type is important in error checking, in allowing slab elements to contribute to NBI ratings for superstructure, and in separating abutments and piers for NBI substructure ratings. Codes are: Integer, I3	<table><tr><td>Deck</td><td>1 Deck 2 Slab</td></tr><tr><td>Superstructure</td><td>1 Superstructure 2 Truss Bottom Chord 3 Truss Top</td></tr><tr><td>Substructure</td><td>1 Substructure 2 Abutments</td></tr><tr><td>Culvert</td><td>1 Culvert Elements</td></tr><tr><td>Smart Flags</td><td>1 Smart Flags</td></tr></table>	Deck	1 Deck 2 Slab	Superstructure	1 Superstructure 2 Truss Bottom Chord 3 Truss Top	Substructure	1 Substructure 2 Abutments	Culvert	1 Culvert Elements	Smart Flags	1 Smart Flags
Deck	1 Deck 2 Slab											
Superstructure	1 Superstructure 2 Truss Bottom Chord 3 Truss Top											
Substructure	1 Substructure 2 Abutments											
Culvert	1 Culvert Elements											
Smart Flags	1 Smart Flags											
Element Dimension	A single digit identifying the dimension for element quantity. Codes are: Integer, I3	0 Smart Flags 1 Each 2 Linear measure ¹ 3 Square measure ¹										
Element Name	Text, 1x, A45	Alphanumeric										
Element short name	Text, A9	Alphanumeric										

¹ BMSNBI works with any consistent set of units. The same NBI ratings will be generated for element condition reports in US customary units or in metric units, provided that all elements are measured with a single system of units.

B2.0 Proposed New Methodology for NBI Translation

Following the initial evaluation of the FHWA's BMSNBI translation program, an effort was made in developing an alternative model for translating BMS element condition data to NBI condition ratings. The proposed methodology is not complicated. First the list of bridge elements is identified as well as the pertinent Pontis tables. Using the element's number of defined condition states, along with the percentage distribution of element fractions in each state, a condition index is computed, ranging from zero to one or 0% to 100%. A simple mapping is then constructed between the estimated condition index and a linear scale of NBI ratings between the failed NBI condition level (typically 3) and the excellent level (typically 9).

A pontis table identifying element categories (elcatdfs) was slightly modified to assign bridge components (deck, superstructure, and substructure) to each element; it was noted that culverts were classified in the original table as substructures but this will be corrected. For each bridge, the elements comprising a bridge component are assigned weighting factors, to reflect the importance of each element to the component. These weight factors for a particular component do not have to add to one or 100%, and they are shown in an input table for each core element. In the proposed model, the weighting factors are normalized for each component, and used to compute a weighted average of the translated NBI ratings.

The model was implemented using Microsoft Access 2000 tables and a Visual Basic computer program. For the first trial of the model, the translation process is done for each bridge component separately and results then combined. The bridge inventory input tables are therefore by bridge component type. For now, the input tables were developed in Microsoft Excel, employing various lookup functions and then converted to Access tables. The computer program first estimates at each bridge site, the number of elements per each bridge component, and also normalizes the element weight factors for the component. Then the factors are used to compute the translated NBI ratings from an aggregate of the individual element's translated ratings, i.e. the sum of the expected NBI ratings for each element. The results are displayed on the screen and also stored as Access tables.

The following tables and figures illustrate the various steps and results from the process. A comparison was made between the proposed (new) model and the BMSNBI (old) program, using the results of translated ratings from the same Florida bridge inventory. The error in terms of an absolute difference (+ or – ignored) was computed, between the translated ratings and the actual ratings recorded by the bridge inspectors. Based on the computed error values, it was observed that the proposed model was on the overall, more accurate for bridge decks and superstructures but a little bit less accurate than the BMSNBI for the substructures and culverts. The proposed model was particularly relatively more accurate for the ratings “6” or higher among the bridge decks and superstructures. It is believed that the results from the proposed model can be improved by refinement in terms of the following: bridge component definition and assignment to elements; the weight factors; and the NBI rating scale.

Table B7. Microsoft Excel spreadsheet showing the element condition index computations.

elemkey	quantity	pctstate1	qtystate1	pctstate2	qtystate2	pctstate3	qtystate3	pctstate4	qtystate4	pctstate5	qtystate5	statecnt	expected state	% cond.
12	1391.69	0.00	0.00	100.00	1391.69	0.00	0.00	0.00	0.00	0.00	0.00	5.00	3.00	0.60
301	27.00	0.00	0.00	100.00	27.00	0.00	0.00	0.00	0.00	0.00	0.00	3.00	1.00	0.33
331	213.19	99.43	211.98	0.57	1.22	0.00	0.00	0.00	0.00	0.00	0.00	4.00	3.99	1.00
321	2.00	100.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.00	4.00	1.00
475	26.21	100.00	26.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.00	4.00	1.00
205	4.00	100.00	4.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.00	4.00	1.00
215	27.00	100.00	27.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.00	4.00	1.00
234	27.00	100.00	27.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.00	4.00	1.00
290	1.00	100.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.00	4.00	1.00
396	1142.00	100.00	1142.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.00	4.00	1.00
107	533.09	0.00	0.00	100.00	533.09	0.00	0.00	0.00	0.00	0.00	0.00	5.00	3.00	0.60
311	10.00	100.00	10.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.00	3.00	1.00
313	10.00	80.00	8.00	20.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00	3.00	2.60	0.87
12	1462.11	100.00	1462.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.00	5.00	1.00
301	37.19	97.54	36.27	2.46	0.91	0.00	0.00	0.00	0.00	0.00	0.00	3.00	2.95	0.98
302	42.00	0.00	0.00	100.00	42.00	0.00	0.00	0.00	0.00	0.00	0.00	3.00	1.00	0.33
331	161.00	100.00	161.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.00	4.00	1.00
321	2.00	100.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.00	4.00	1.00
475	41.76	100.00	41.76	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.00	4.00	1.00
205	9.00	100.00	9.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.00	4.00	1.00
215	40.23	100.00	40.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.00	4.00	1.00
234	58.52	100.00	58.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.00	4.00	1.00
394	864.93	99.94	864.37	0.06	0.56	0.00	0.00	0.00	0.00	0.00	0.00	4.00	4.00	1.00
109	562.05	99.78	560.83	0.22	1.22	0.00	0.00	0.00	0.00	0.00	0.00	4.00	4.00	1.00
310	56.00	100.00	56.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.00	3.00	1.00

Table B8. Microsoft Excel spreadsheet demonstrations of the translation computations.

brkey	elemkey	ecatkey	ecatname	Suggested Bridge Component	Element Weighting Factor for Bridge	Condition Index	NBI Rating	Rounded NBI Rating	Normalized Weight Factors	Bridge Component Rating	Rounded NBI Component Rating	elemshort
010070	12	6	Decks/Slabs	Deck	100	60.0%	6.6	7	0.714	6.71	7	Bare Concrete Deck
010070	301	3	Joints	Deck	20	33.3%	5.0	5	0.143			Pourable Joint Seal
010070	331	9	Railing	Deck	20	99.7%	9.0	9	0.143			Conc Bridge Railing
010070	321	5	Other Elements	Others	100	100.0%	9.0	9				R/Conc Approach Slab
010070	475	5	Other Elements	Others	100	100.0%	9.0	9				R/Conc Walls
010070	205	2	Substructure	Substructure	100	100.0%	9.0	9	0.270	9.00	9	R/Conc Column
010070	215	2	Substructure	Substructure	100	100.0%	9.0	9	0.270			R/Conc Abutment
010070	234	2	Substructure	Substructure	100	100.0%	9.0	9	0.270			R/Conc Cap
010070	290	C	Channel	Substructure	20	100.0%	9.0	9	0.054			Channel
010070	396	2	Substructure	Substructure	50	100.0%	9.0	9	0.135			Other Abut Slope Pro
010070	107	1	Superstructure	Superstructure	100	60.0%	6.6	7	0.500	7.60	8	Paint Stl Opn Girder
010070	311	4	Bearings	Superstructure	50	100.0%	9.0	9	0.250			Moveable Bearing
010070	313	4	Bearings	Superstructure	50	86.7%	8.2	8	0.250			Fixed Bearing
010071	12	6	Decks/Slabs	Deck	100	100.0%	9.0	9	0.625	8.49	8	Bare Concrete Deck
010071	301	3	Joints	Deck	20	98.4%	8.9	9	0.125			Pourable Joint Seal
010071	302	3	Joints	Deck	20	33.3%	5.0	5	0.125			Compressn Joint Seal
010071	331	9	Railing	Deck	20	100.0%	9.0	9	0.125			Conc Bridge Railing
010071	321	5	Other Elements	Others	100	100.0%	9.0	9				R/Conc Approach Slab
010071	475	5	Other Elements	Others	100	100.0%	9.0	9				R/Conc Walls
010071	205	2	Substructure	Substructure	100	100.0%	9.0	9	0.286	9.00	9	R/Conc Column
010071	215	2	Substructure	Substructure	100	100.0%	9.0	9	0.286			R/Conc Abutment
010071	234	2	Substructure	Substructure	100	100.0%	9.0	9	0.286			R/Conc Cap
010071	394	2	Substructure	Substructure	50	100.0%	9.0	9	0.143			R/Conc Abut Slope Pr
010071	109	1	Superstructure	Superstructure	100	99.9%	9.0	9	0.667	9.00	9	P/S Conc Open Girder
010071	310	4	Bearings	Superstructure	50	100.0%	9.0	9	0.333			Elastomeric Bearing

Table B9. The modified pontis (elcatdfs) table.

ecatkey	ecatname	ecatcode	ecatpos	ecatcolor	Bridge Component
	Missing	-1	12	-1	
0	Unspecified	0	11	-1	
1	Superstructure	1	4	-1	Superstructure
2	Substructure	2	7	-1	Substructure
3	Joints	3	2	-1	Deck
4	Bearings	4	5	-1	Superstructure
5	Other Elements	5	10	-1	Others
6	Decks/Slabs	6	1	-1	Deck
7	Smart Flags	7	9	-1	
8	Movable	8	6	-1	
9	Railing	9	3	-1	Deck
C	Channel	10	8	-1	Substructure

Table B10. The Element Weighting Factor Table For Florida Bridge Elements (Part 1)

Element ID	ecatkey	ecatname	Suggested Bridge Component	Element Weighting Factor	Element Name
12	6	Decks/Slabs	Deck	100	Bare Concrete Deck
13	6	Decks/Slabs	Deck	100	Unp Conc Deck/AC Ovl
28	6	Decks/Slabs	Deck	100	Steel Deck/Open Grid
29	6	Decks/Slabs	Deck	100	Steel Deck/Conc Grid
30	6	Decks/Slabs	Deck	100	Corrug/Orthotpc Deck
31	6	Decks/Slabs	Deck	100	Timber Deck
32	6	Decks/Slabs	Deck	100	Timber Deck/AC Ovly
38	6	Decks/Slabs	Deck	100	Bare Concrete Slab
39	6	Decks/Slabs	Deck	100	Unp Conc Slab/AC Ovl
54	6	Decks/Slabs	Deck	100	Timber Slab
55	6	Decks/Slabs	Deck	100	Timber Slab/AC Ovly
98	6	Decks/Slabs	Deck	100	Conc Deck on PC Pane
99	6	Decks/Slabs	Deck	100	PS Conc Slab
101	1	Superstructure	Superstructure	100	Unpnt Stl Box Girder
102	1	Superstructure	Superstructure	100	Paint Stl Box Girder
104	1	Superstructure	Superstructure	100	P/S Conc Box Girder
105	1	Superstructure	Superstructure	100	R/Conc Box Girder
106	1	Superstructure	Superstructure	100	Unpnt Stl Opn Girder
107	1	Superstructure	Superstructure	100	Paint Stl Opn Girder
109	1	Superstructure	Superstructure	100	P/S Conc Open Girder
110	1	Superstructure	Superstructure	100	R/Conc Open Girder
111	1	Superstructure	Superstructure	100	Timber Open Girder
112	1	Superstructure	Superstructure	50	Unpnt Stl Stringer
113	1	Superstructure	Superstructure	50	Paint Stl Stringer
115	1	Superstructure	Superstructure	50	P/S Conc Stringer
116	1	Superstructure	Superstructure	50	R/Conc Stringer
117	1	Superstructure	Superstructure	50	Timber Stringer
120	1	Superstructure	Superstructure	50	U/Stl Thru Truss/Bot
121	1	Superstructure	Superstructure	50	P/Stl Thru Truss/Bot
125	1	Superstructure	Superstructure	50	U/Stl Thru Truss/Top
126	1	Superstructure	Superstructure	50	P/Stl Thru Truss/Top
130	1	Superstructure	Superstructure	100	Unpnt Stl Deck Truss
131	1	Superstructure	Superstructure	100	Paint Stl Deck Truss
135	1	Superstructure	Superstructure	100	Timber Truss/Arch
140	1	Superstructure	Superstructure	100	Unpnt Stl Arch
141	1	Superstructure	Superstructure	100	Paint Stl Arch
143	1	Superstructure	Superstructure	100	P/S Conc Arch
144	1	Superstructure	Superstructure	100	R/Conc Arch
145	1	Superstructure	Superstructure	100	Other Arch
146	1	Superstructure	Superstructure	50	Misc Cable Uncoated
147	1	Superstructure	Superstructure	50	Misc Cable Coated
151	1	Superstructure	Superstructure	50	Unpnt Stl Floor Beam
152	1	Superstructure	Superstructure	50	Paint Stl Floor Beam
154	1	Superstructure	Superstructure	50	P/S Conc Floor Beam
155	1	Superstructure	Superstructure	50	R/Conc Floor Beam
156	1	Superstructure	Superstructure	50	Timber Floor Beam
160	1	Superstructure	Superstructure	50	Unpnt Stl Pin/Hanger
161	1	Superstructure	Superstructure	50	Paint Stl Pin/Hanger
201	2	Substructure	Substructure	100	Unpnt Stl Column
202	2	Substructure	Substructure	100	Paint Stl Column
204	2	Substructure	Substructure	100	P/S Conc Column
205	2	Substructure	Substructure	100	R/Conc Column
206	2	Substructure	Substructure	100	Timber Column
207	2	Substructure	Substructure	100	P/S Conc Holl Pile
210	2	Substructure	Substructure	100	R/Conc Pier Wall
211	2	Substructure	Substructure	100	Other Mtl Pier Wall
215	2	Substructure	Substructure	100	R/Conc Abutment
216	2	Substructure	Substructure	100	Timber Abutment
217	2	Substructure	Substructure	100	Other Mtl Abutment
220	2	Substructure	Substructure	100	R/C Sub Pile Cap/Ftg
230	2	Substructure	Substructure	100	Unpnt Stl Cap
231	2	Substructure	Substructure	100	Paint Stl Cap
233	2	Substructure	Substructure	100	P/S Conc Cap
234	2	Substructure	Substructure	100	R/Conc Cap
235	2	Substructure	Substructure	100	Timber Cap
240	2	Substructure	Substructure	100	Metal Culvert
241	2	Substructure	Substructure	100	Concrete Culvert
242	2	Substructure	Substructure	100	Timber Culvert
243	2	Substructure	Substructure	100	Misc Culvert
290	C	Channel	Substructure	20	Channel
298	2	Substructure	Substructure	100	Pile Jacket Bare

Table B11. The Element Weighting Factor Table For Florida Bridge Elements (Part 2)

Element ID	ecatkey	ecatname	Suggested Bridge Component	Element Weighting Factor	Element Name
299	2	Substructure	Substructure	100	Pile Jacket/Cath Pro
300	3	Joints	Deck	20	Strip Seal Exp Joint
301	3	Joints	Deck	20	Pourable Joint Seal
302	3	Joints	Deck	20	Compressn Joint Seal
303	3	Joints	Deck	20	Assembly Joint/Seal
304	3	Joints	Deck	20	Open Expansion Joint
310	4	Bearings	Superstructure	50	Elastomeric Bearing
311	4	Bearings	Superstructure	50	Moveable Bearing
312	4	Bearings	Superstructure	50	Enclosed Bearing
313	4	Bearings	Superstructure	50	Fixed Bearing
314	4	Bearings	Superstructure	50	Pot Bearing
315	4	Bearings	Superstructure	50	Disk Bearing
320	5	Other Elements	Others	100	P/S Conc Appr Slab
321	5	Other Elements	Others	100	R/Conc Approach Slab
330	9	Railing	Deck	20	Metal Rail Uncoated
331	9	Railing	Deck	20	Conc Bridge Railing
332	9	Railing	Deck	20	Timb Bridge Railing
333	9	Railing	Deck	20	Other Bridge Railing
334	9	Railing	Deck	20	Metal Rail Coated
356	7	Smart Flags	0	100	Steel Fatigue SmFlag
357	7	Smart Flags	0	100	Pack Rust Smart Flag
358	7	Smart Flags	0	100	Deck Cracking SmFlag
359	7	Smart Flags	0	100	Soffit Smart Flag
360	7	Smart Flags	0	100	Settlement SmFlag
361	7	Smart Flags	0	100	Scour Smart Flag
362	7	Smart Flags	0	100	Traf Impact SmFlag
363	7	Smart Flags	0	100	Section Loss SmFlag
369	7	Smart Flags	0	100	Sub.Sect Loss SmFlag
370	7	Smart Flags	0	100	Alert Smart Flag
386	2	Substructure	Substructure	100	Fender/Dolphin Uncoa
387	2	Substructure	Substructure	100	P/S Fender/Dolphin
388	2	Substructure	Substructure	100	R/Conc Fender/Dolphi
389	2	Substructure	Substructure	100	Timber Fender/Dolphi
390	2	Substructure	Substructure	100	Other Fender/Dolphin
393	2	Substructure	Substructure	100	Blkhd Sewl Metal Unc
394	2	Substructure	Substructure	50	R/Conc Abut Slope Pr
395	2	Substructure	Substructure	50	Timber Abut Slope Pr
396	2	Substructure	Substructure	50	Other Abut Slope Pro
397	1	Superstructure	Superstructure	50	Drain. Syst Metal
398	1	Superstructure	Superstructure	50	Drain. Syst Other
399	3	Joints	Deck	20	Other Xpansion Joint
474	5	Other Elements	Others	100	Walls Uncoated
475	5	Other Elements	Others	100	R/Conc Walls
476	5	Other Elements	Others	100	Timber Walls
477	5	Other Elements	Others	100	Other Walls
478	5	Other Elements	Others	100	MSE Walls
487	5	Other Elements	Others	100	Sign Member Horiz
488	5	Other Elements	Others	100	Sign Member Vertical
489	5	Other Elements	Others	100	Sign Foundation
495	5	Other Elements	Others	100	Uncoat High Mast L.
496	5	Other Elements	Others	100	Painted High Mast L.
497	5	Other Elements	Others	100	Galvan. High Mast L.
498	5	Other Elements	Others	100	Other High Mast L.P.
499	5	Other Elements	Others	100	H. M. L. P. Found.
540	8	Movable	0	100	Open Gearing
541	8	Movable	0	100	Speed Reducers
542	8	Movable	0	100	Shafts
543	8	Movable	0	100	Shaft Brgs and Coupl
544	8	Movable	0	100	Brakes
545	8	Movable	0	100	Emergency Drive
546	8	Movable	0	100	Span Drive Motors
547	8	Movable	0	100	Hydraulic Power Unit
548	8	Movable	0	100	Hydraulic Piping Sys
549	8	Movable	0	100	Hydraulic Cylinders
550	8	Movable	0	100	Hopkins Frame
560	8	Movable	0	100	Locks
561	8	Movable	0	100	Live Load Shoes
562	8	Movable	0	100	Counterweight Suppor
563	8	Movable	0	100	Acc Ladd & Plat
564	8	Movable	0	100	Counterweight
565	8	Movable	0	100	Trun/Str and Cur Trk

Table B12. The Element Weighting Factor Table For Florida Bridge Elements (Part 3)

Element ID	ecatkey	ecatname	Suggested Bridge Component	Element Weighting Factor	Element Name
570	8	Movable	0	100	Transformers
571	8	Movable	0	100	Submarine Cable
572	8	Movable	0	100	Conduit & Junc. Box
573	8	Movable	0	100	PLCs
574	8	Movable	0	100	Control Console
580	8	Movable	0	100	Navigational Lights
581	8	Movable	0	100	Operator Facilities
582	8	Movable	0	100	Lift Bridge Spec. Eq
583	8	Movable	0	100	Swing Bridge Spec. E
590	8	Movable	0	100	Resistance Barriers
591	8	Movable	0	100	Warning Gates
592	8	Movable	0	100	Traffic Signals

Table B13. Sample Data From The Input Table For Substructures

brkey	elemkey	ecatkey	ecatname	BridgeComponent	ElementWeightFactor	ConditionIndex	NBIRating	RoundedNBIRating
860001	204	2	Substructure	Substructure	100	0.92	8.500	8
860001	205	2	Substructure	Substructure	100	1.00	9.000	9
860001	215	2	Substructure	Substructure	100	1.00	9.000	9
860001	220	2	Substructure	Substructure	100	0.50	6.000	6
860001	290	C	Channel	Substructure	20	1.00	9.000	9
860001	298	2	Substructure	Substructure	100	1.00	9.000	9
860001	389	2	Substructure	Substructure	100	0.67	7.011	7
860001	396	2	Substructure	Substructure	50	1.00	9.000	9
860002	215	2	Substructure	Substructure	100	0.50	6.000	6
860002	290	C	Channel	Substructure	20	1.00	9.000	9
860003	210	2	Substructure	Substructure	100	1.00	9.000	9
860003	215	2	Substructure	Substructure	100	1.00	9.000	9
860003	290	C	Channel	Substructure	20	1.00	9.000	9
860008	205	2	Substructure	Substructure	100	1.00	9.000	9
860008	210	2	Substructure	Substructure	100	0.99	8.942	9
860008	215	2	Substructure	Substructure	100	1.00	9.000	9
860008	220	2	Substructure	Substructure	100	1.00	9.000	9
860008	234	2	Substructure	Substructure	100	1.00	9.000	9
860008	290	C	Channel	Substructure	20	1.00	9.000	9
860008	298	2	Substructure	Substructure	100	1.00	9.000	9
860008	387	2	Substructure	Substructure	100	0.99	8.966	9
860008	396	2	Substructure	Substructure	50	1.00	9.000	9

BRIDGE ELEMENTS - NBI TRANSLATOR PROGRAM (DRAFT VERSION)

Substr

BridgeID	No. of Elements	SumWtFactors
010001	2.00	120.00
010003	2.00	120.00
010004	5.00	370.00
010005	5.00	370.00
010006	2.00	120.00
010007	5.00	370.00
010008	5.00	370.00
010009	5.00	370.00
010010	2.00	120.00
010011	3.00	220.00
010012	2.00	120.00
010013	2.00	120.00
010014	2.00	120.00
010015	2.00	120.00
010016	2.00	120.00
010017	2.00	120.00
010018	2.00	120.00
010019	6.00	470.00
010020	2.00	120.00
010021	5.00	370.00
010024	2.00	120.00
010026	2.00	120.00

Substr

Figure B1. First Step Of The Proposed Translator Program

BRIDGE ELEMENTS - NBI TRANSLATOR PROGRAM (DRAFT VERSION)

Substr

BridgeID	Translated Rating
010003	9
010004	6
010005	9
010006	8
010007	6
010008	8
010009	8
010010	8
010011	5
010012	5
010013	6
010014	6
010015	6
010016	6
010017	6
010018	6
010019	4
010020	7
010021	6
010024	8
010026	7
010028	9

Substr

PROCESSED ALL RECORDS!

Figure B2. Second step of the proposed Translator program

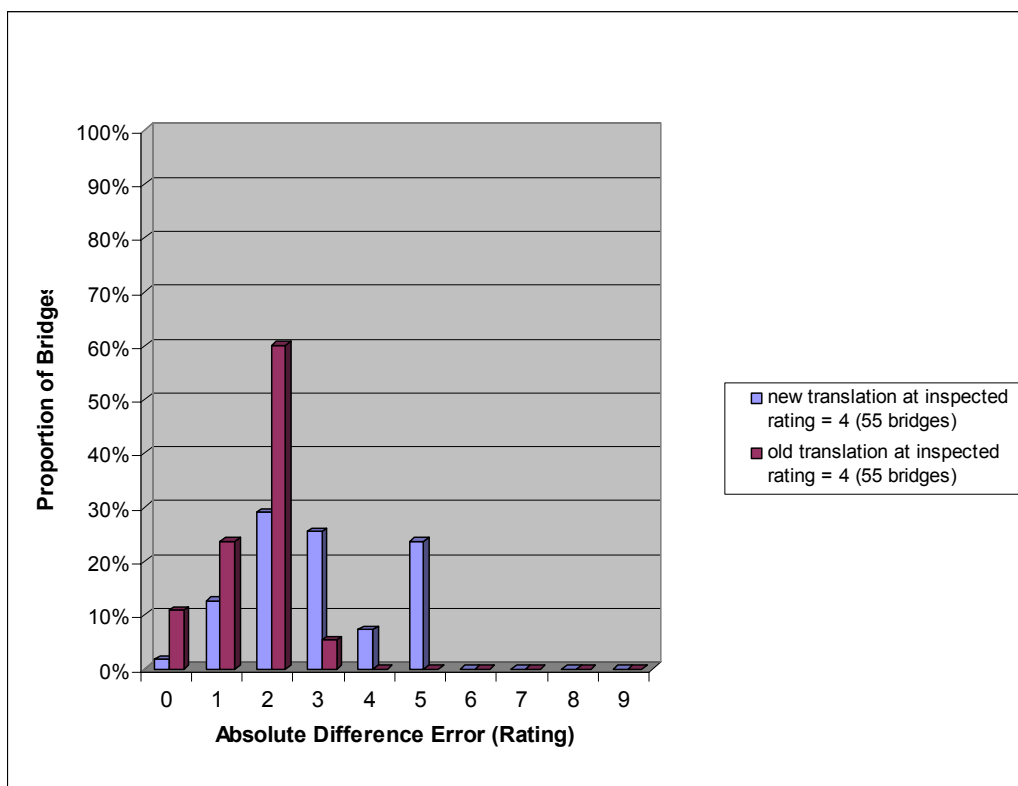


Figure B3. Comparison of Translated Deck Ratings at Recorded Inspected Rating “4”

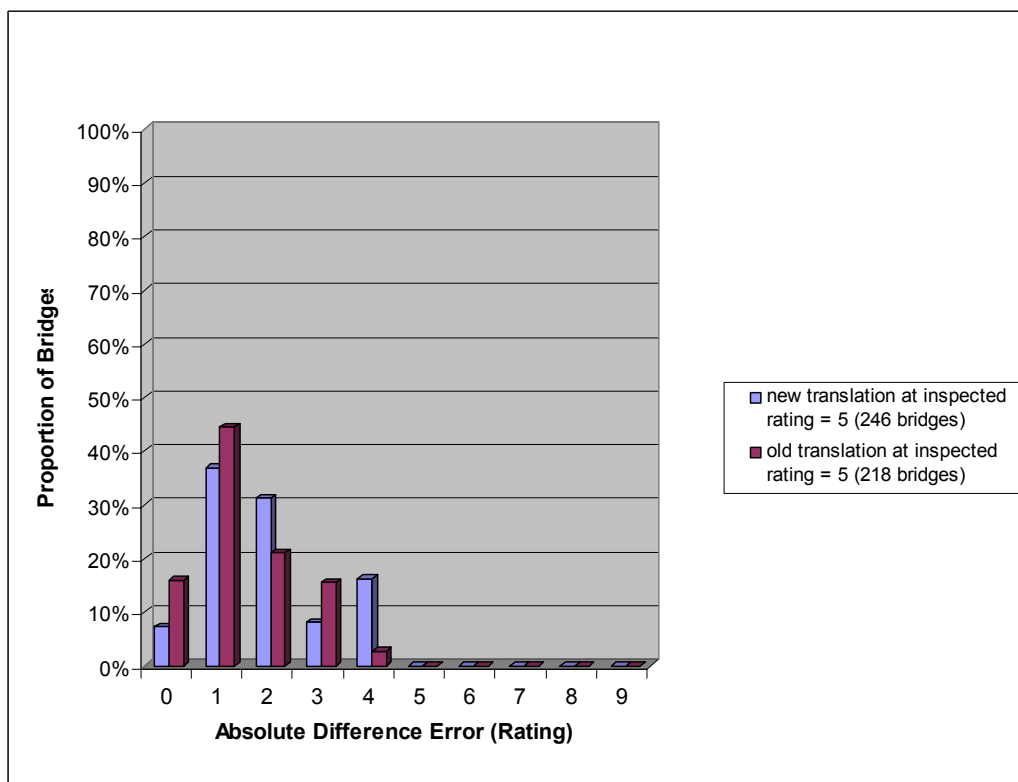


Figure B4. Comparison of Translated Deck Ratings at Recorded Inspected Rating “5”

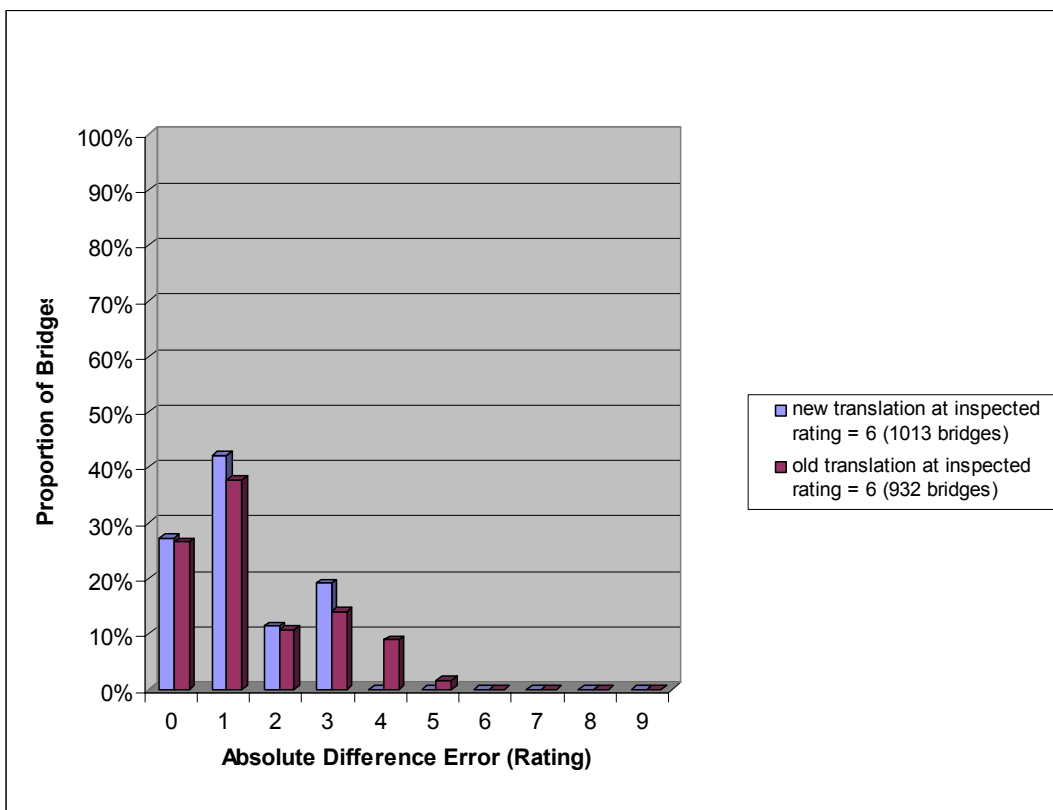


Figure B5. Comparison of Translated Deck Ratings at Recorded Inspected Rating “6”

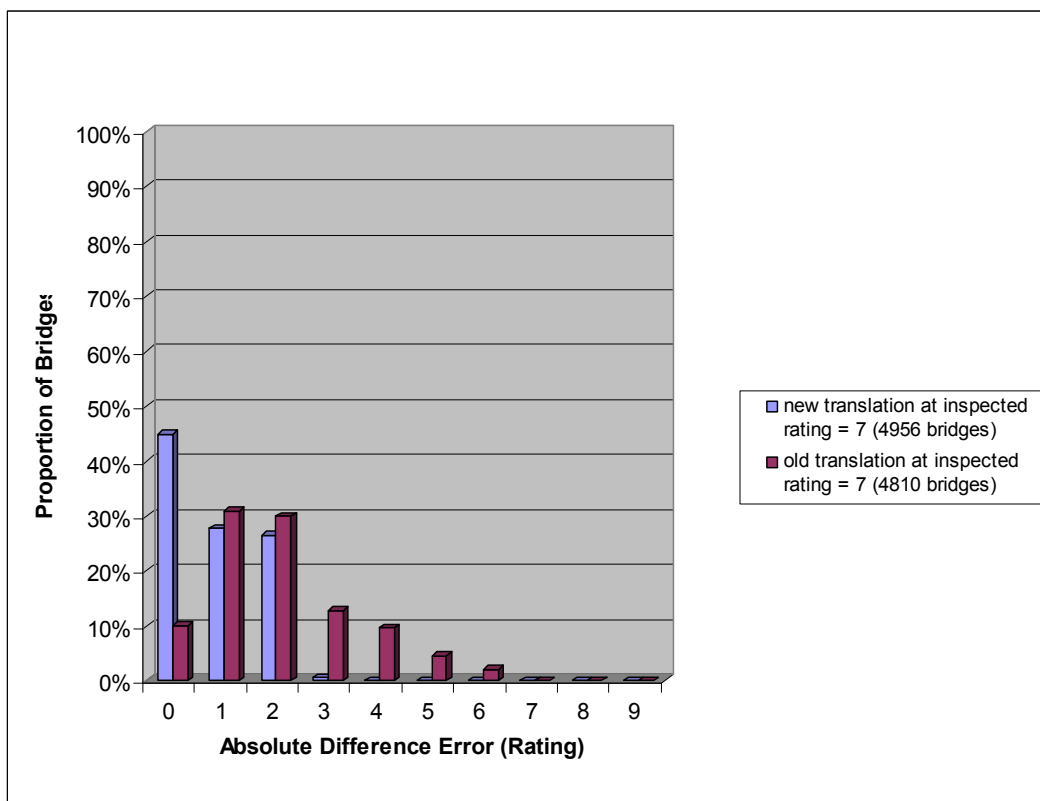


Figure B6. Comparison of Translated Deck Ratings at Recorded Inspected Rating “7”

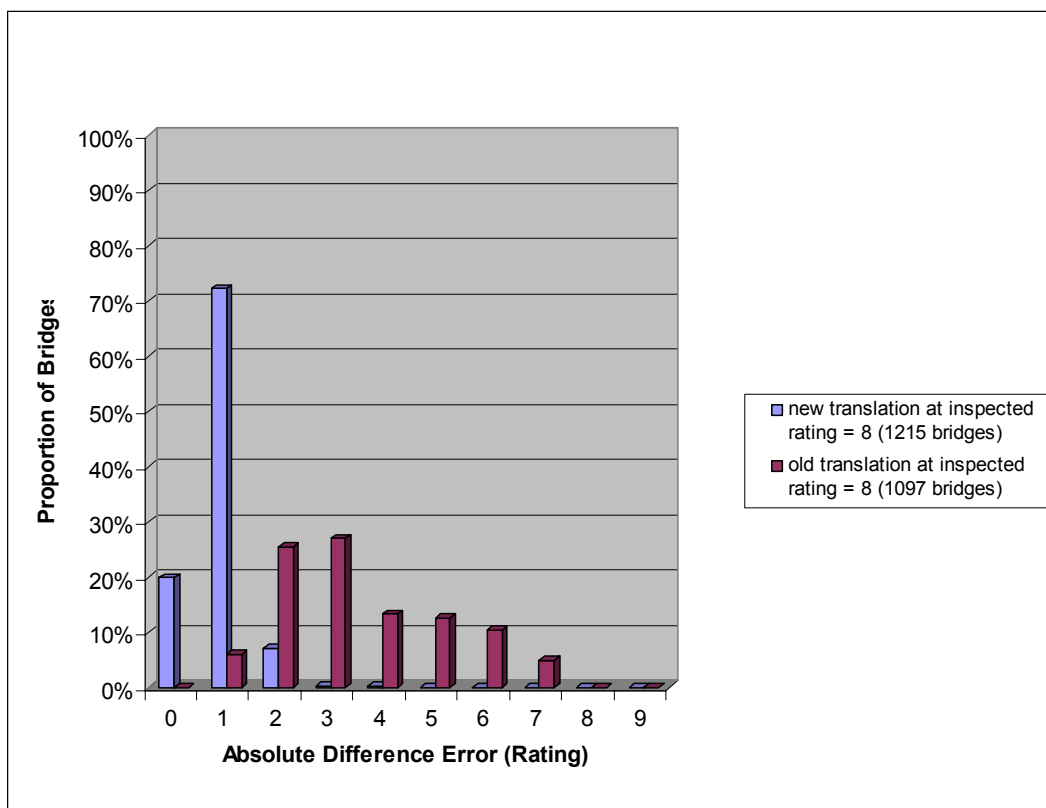


Figure B7. Comparison of Translated Deck Ratings at Recorded Inspected Rating “8”

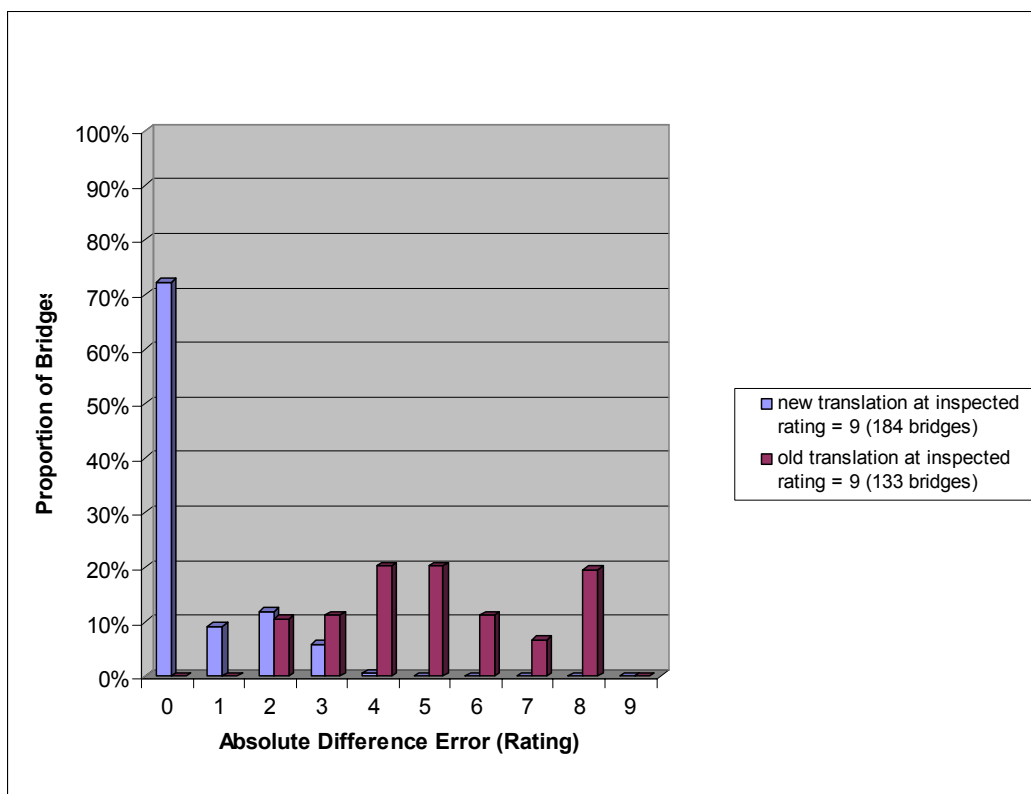


Figure B8. Comparison of Translated Deck Ratings at Recorded Inspected Rating “9”

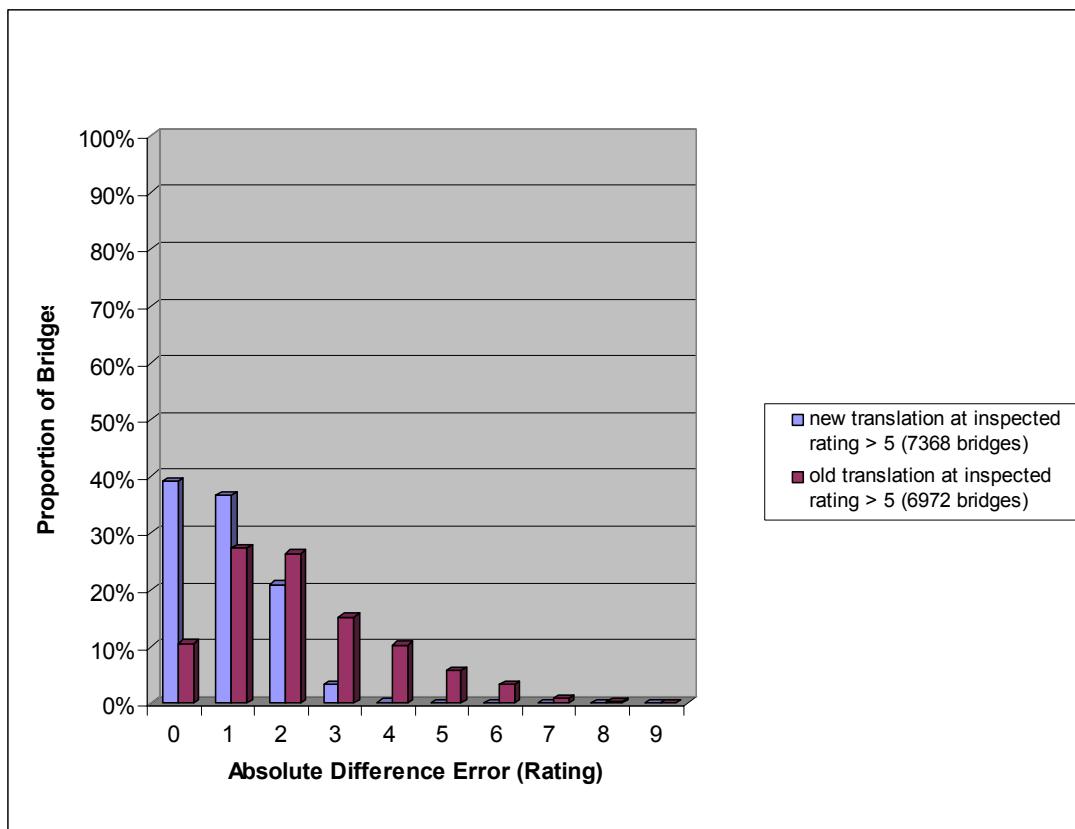


Figure B9. Comparison of Translated Deck Ratings at Recorded Inspected Ratings “6” and Higher

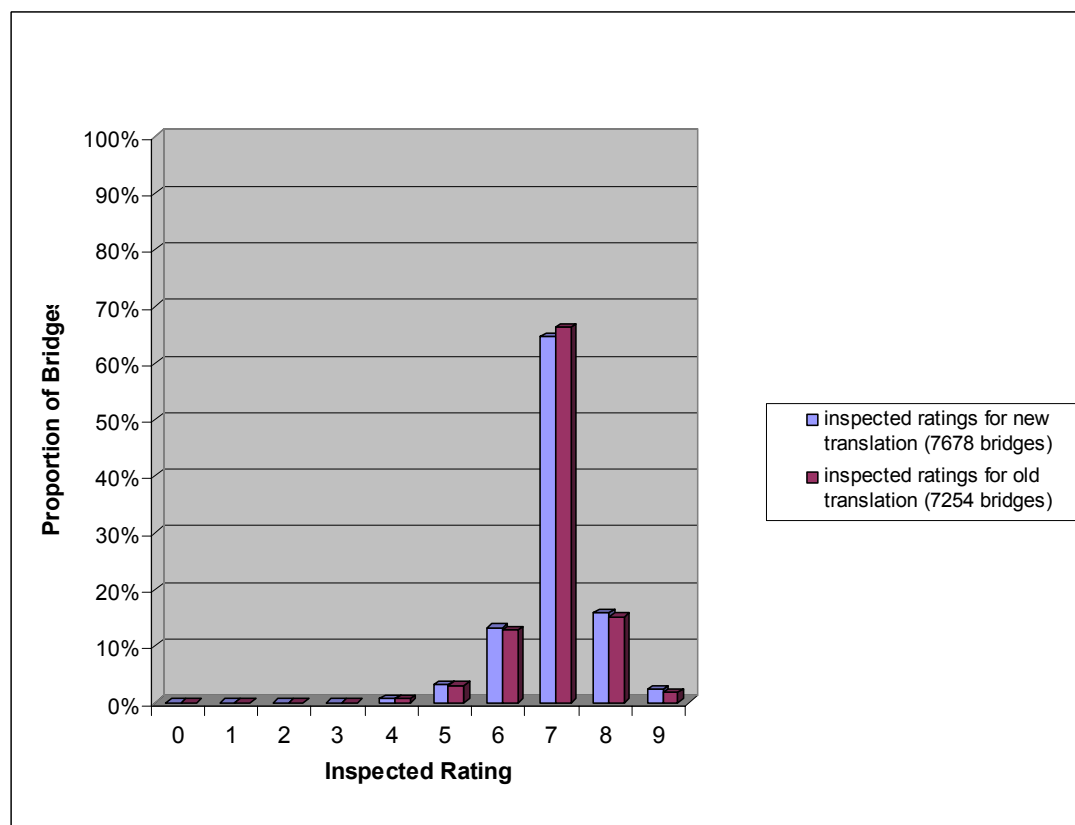


Figure B10. Comparison of Inventory Data on Inspected Deck Ratings

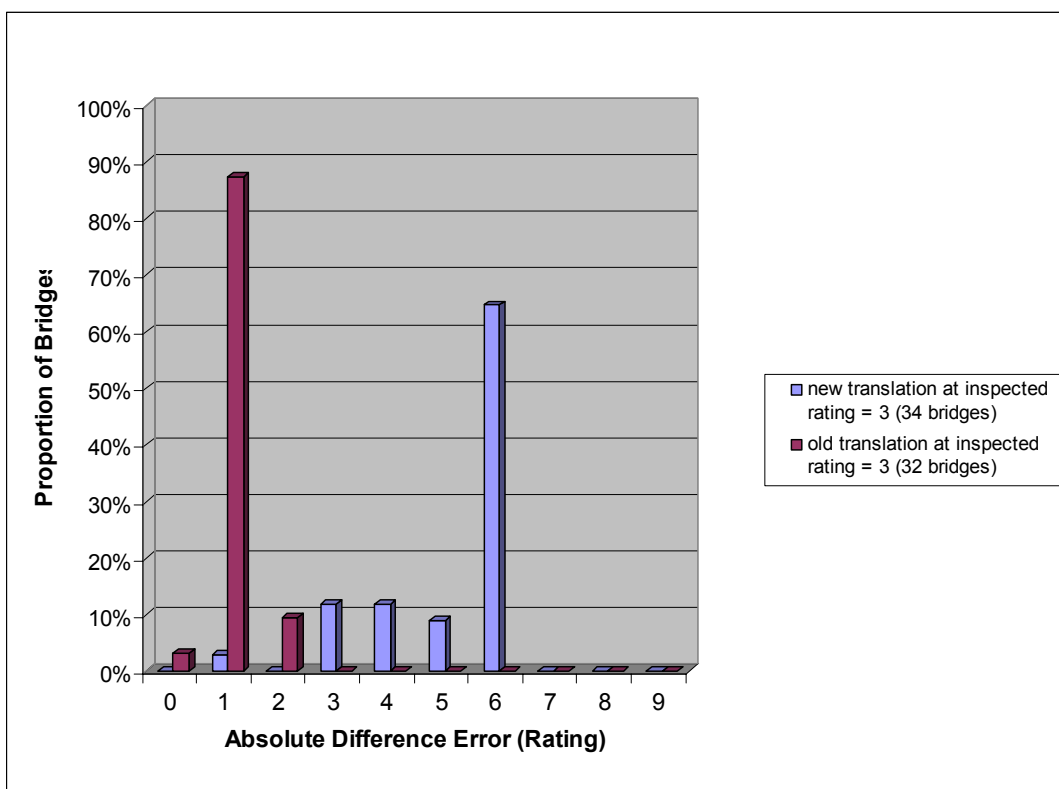


Figure B11. Comparison of Translated Superstructure Ratings at Recorded Inspected Rating “3”

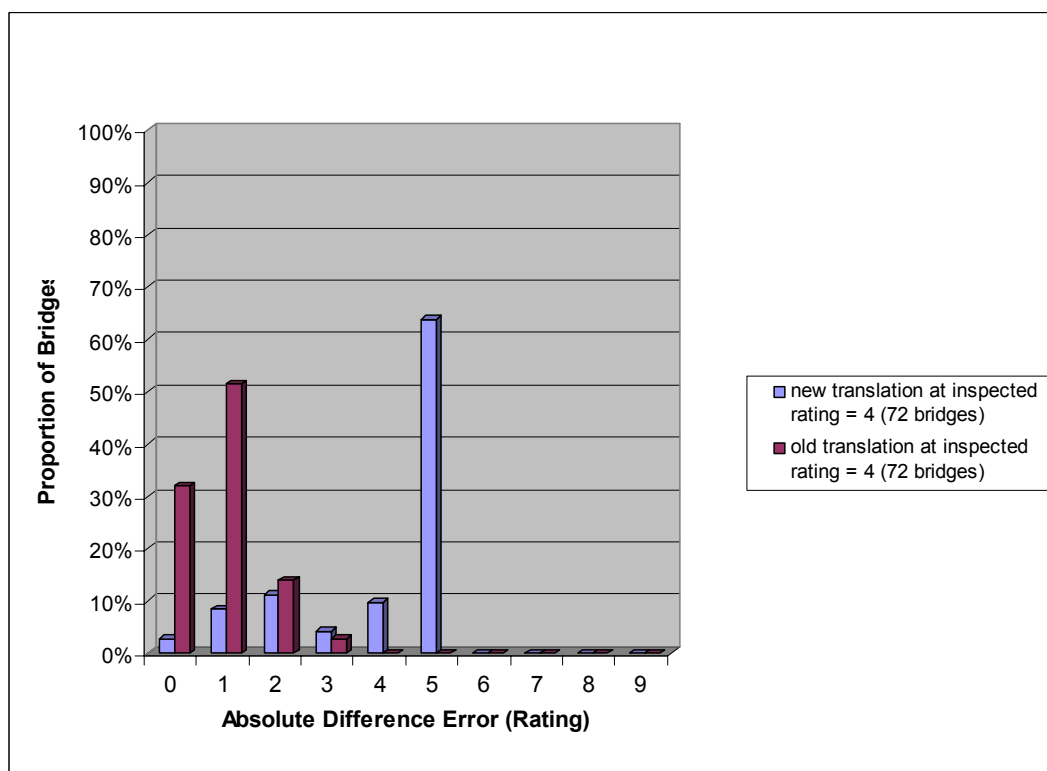


Figure B12. Comparison of Translated Superstructure Ratings at Recorded Inspected Rating “4”

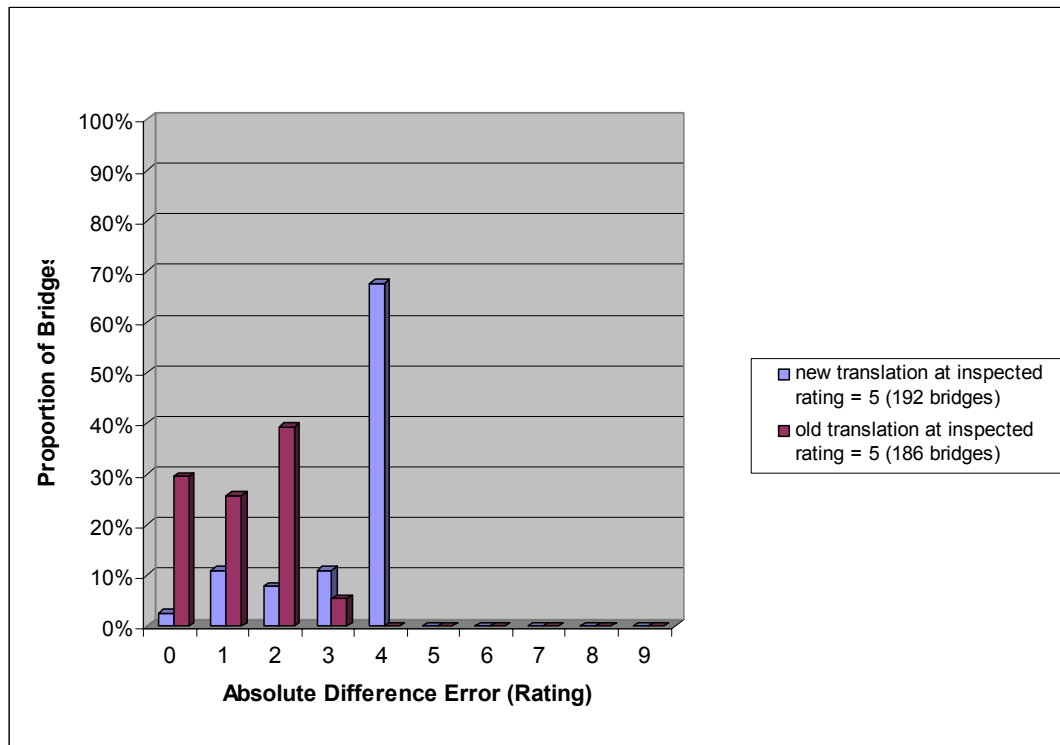


Figure B13. Comparison of Translated Superstructure Ratings at Recorded Inspected Rating “5”

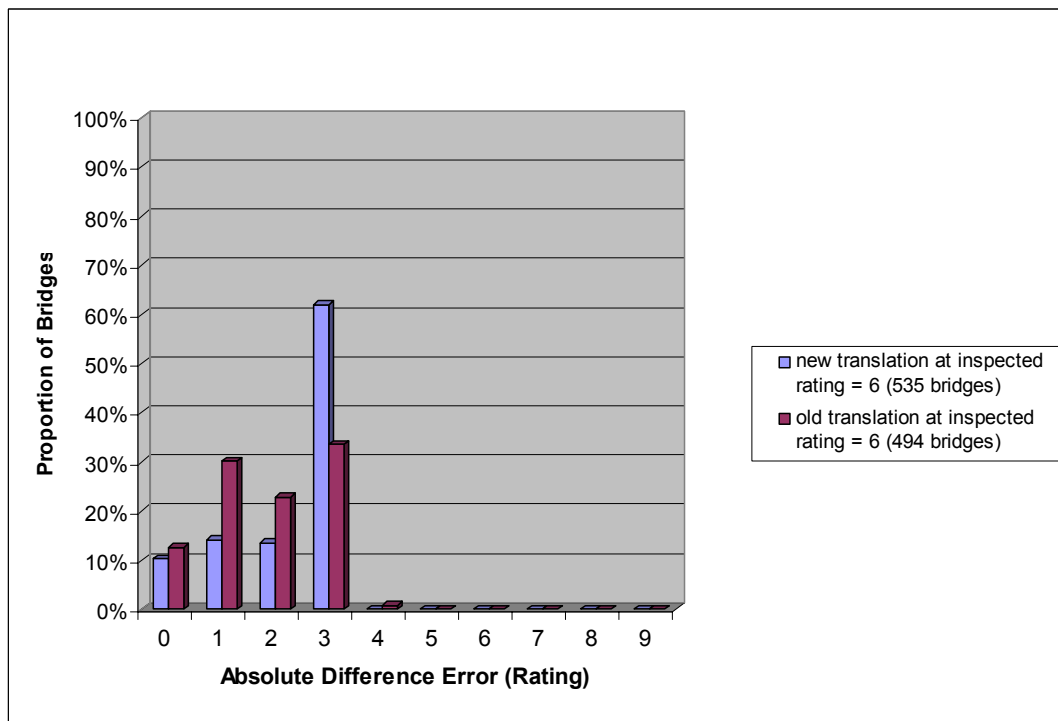


Figure B14. Comparison of Translated Superstructure Ratings at Recorded Inspected Rating “6”

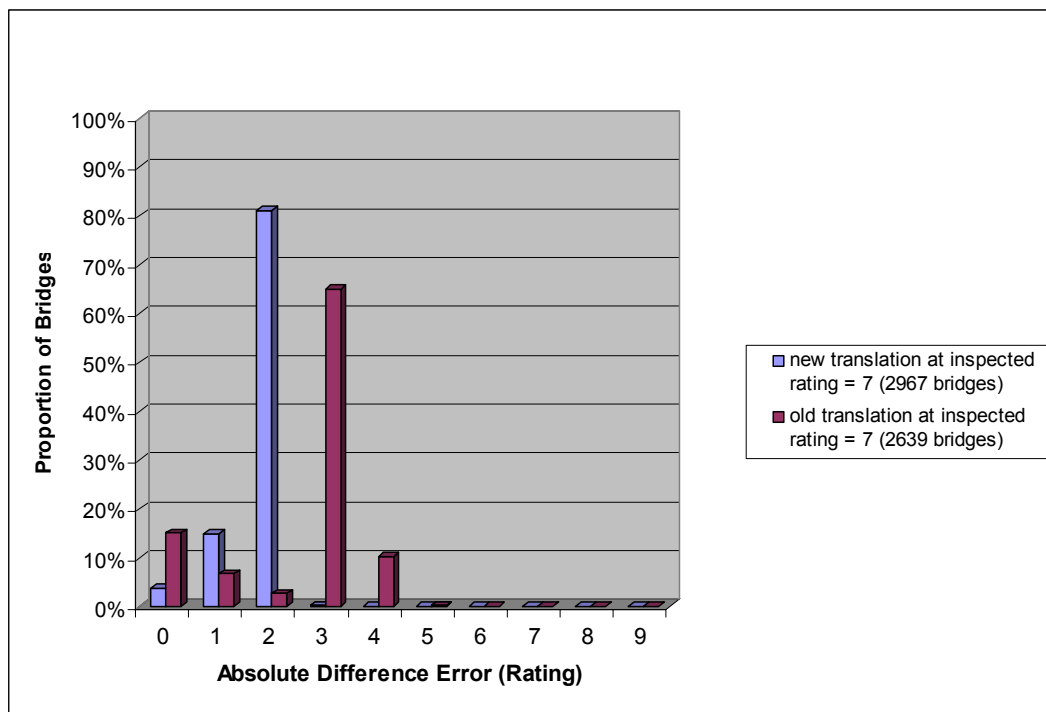


Figure B15. Comparison of Translated Superstructure Ratings at Recorded Inspected Rating “7”

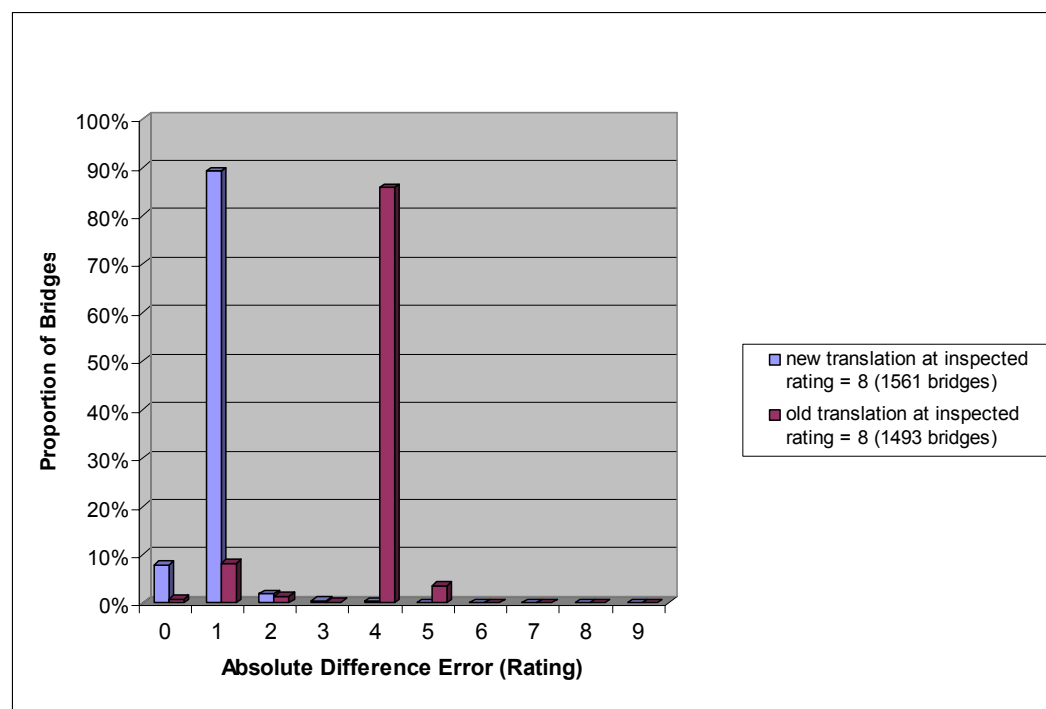


Figure B16. Comparison of Translated Superstructure Ratings at Recorded Inspected Rating “8”

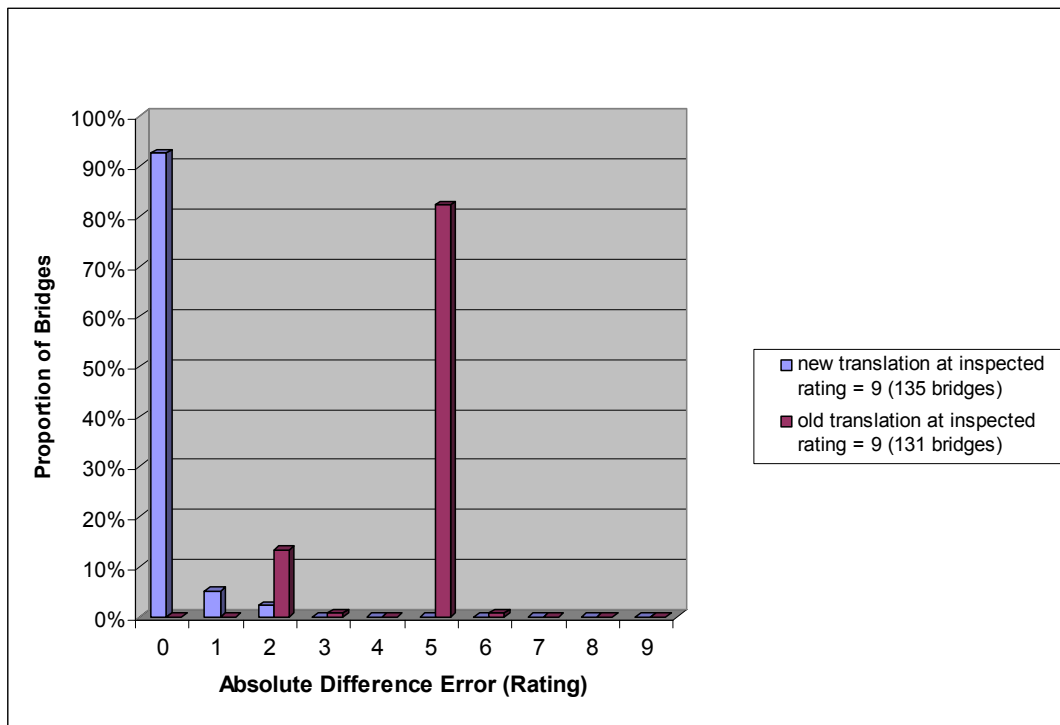


Figure B17. Comparison of Translated Superstructure Ratings at Recorded Inspected Rating “9”

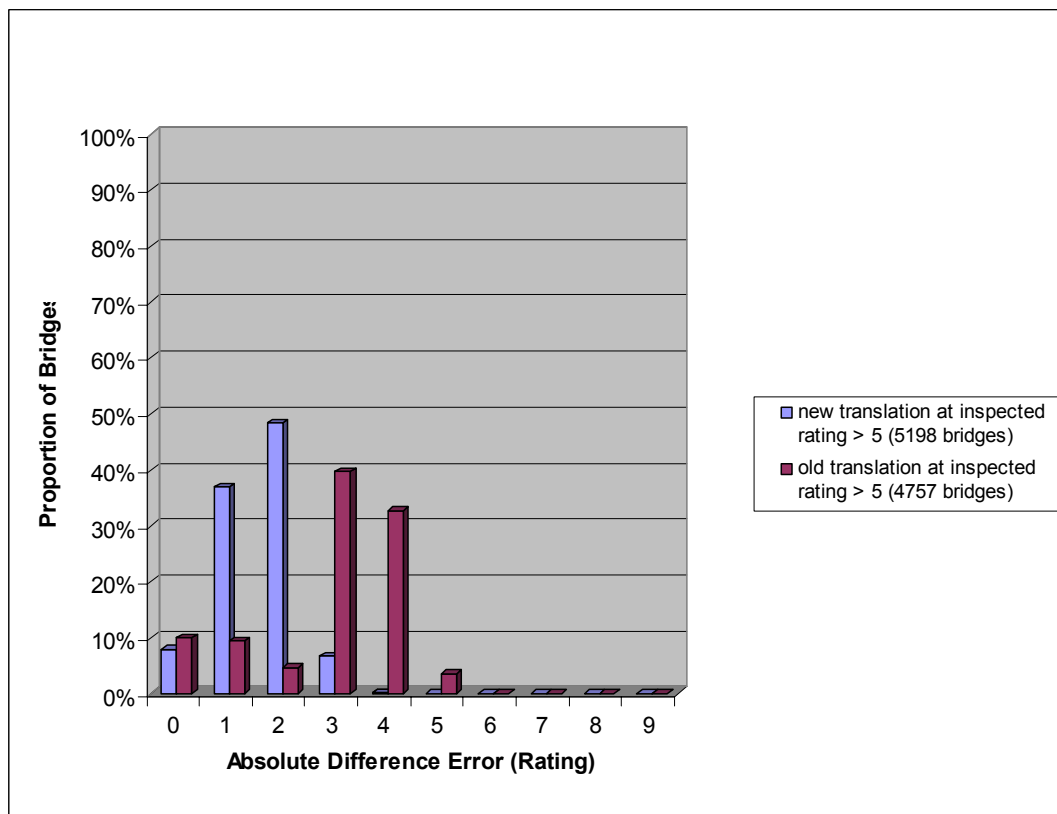


Figure B18. Comparison of Translated Superstructure Ratings at Inspected Ratings “6” and Higher

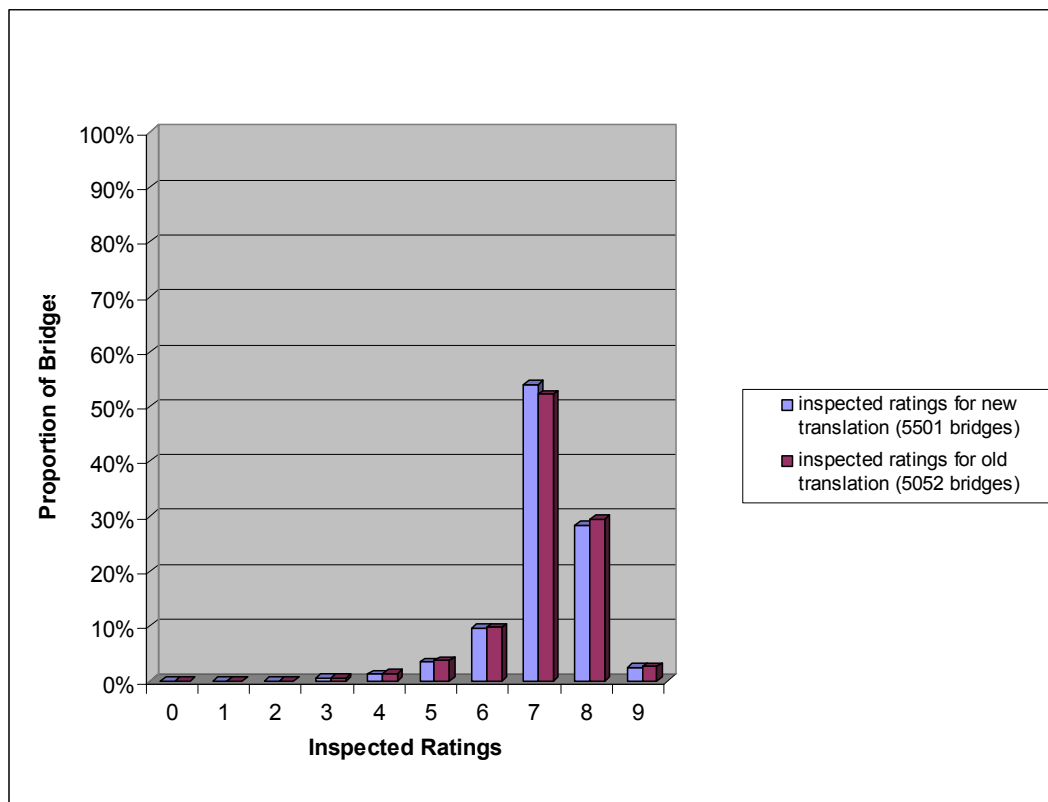


Figure B19. Comparison of Inventory Data on Inspected Superstructure Ratings

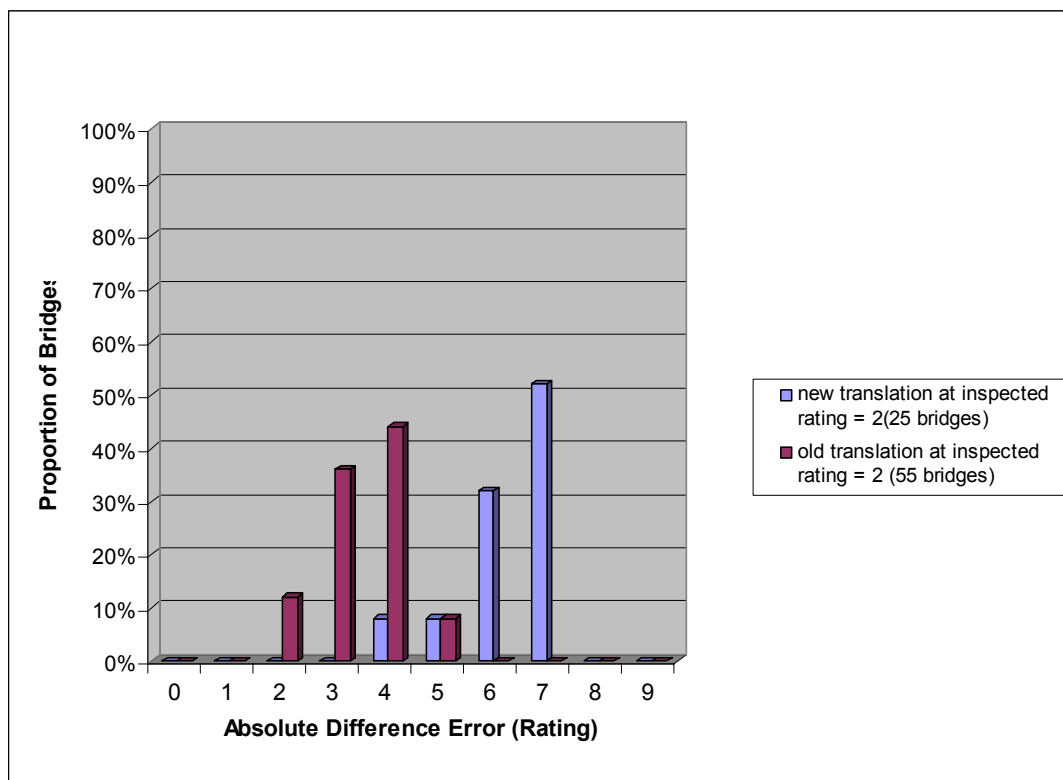


Figure B20. Comparison of Translated Substructure Ratings at Recorded Inspected Rating “2”

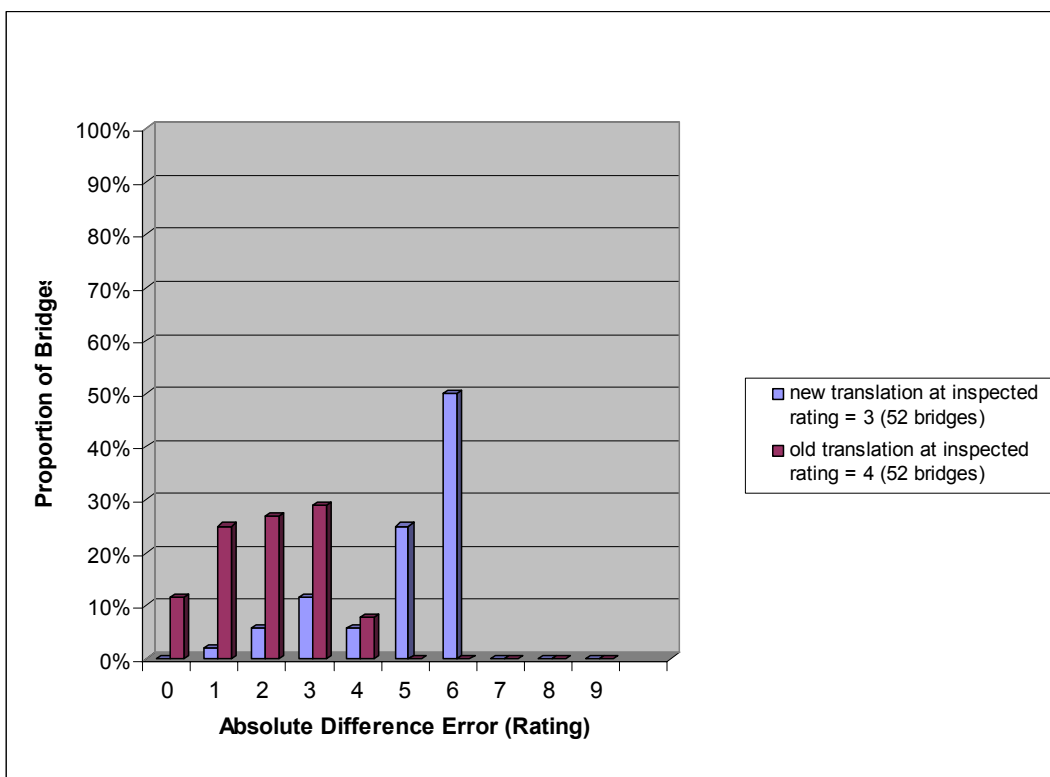


Figure B21. Comparison of Translated Substructure Ratings at Recorded Inspected Rating “3”

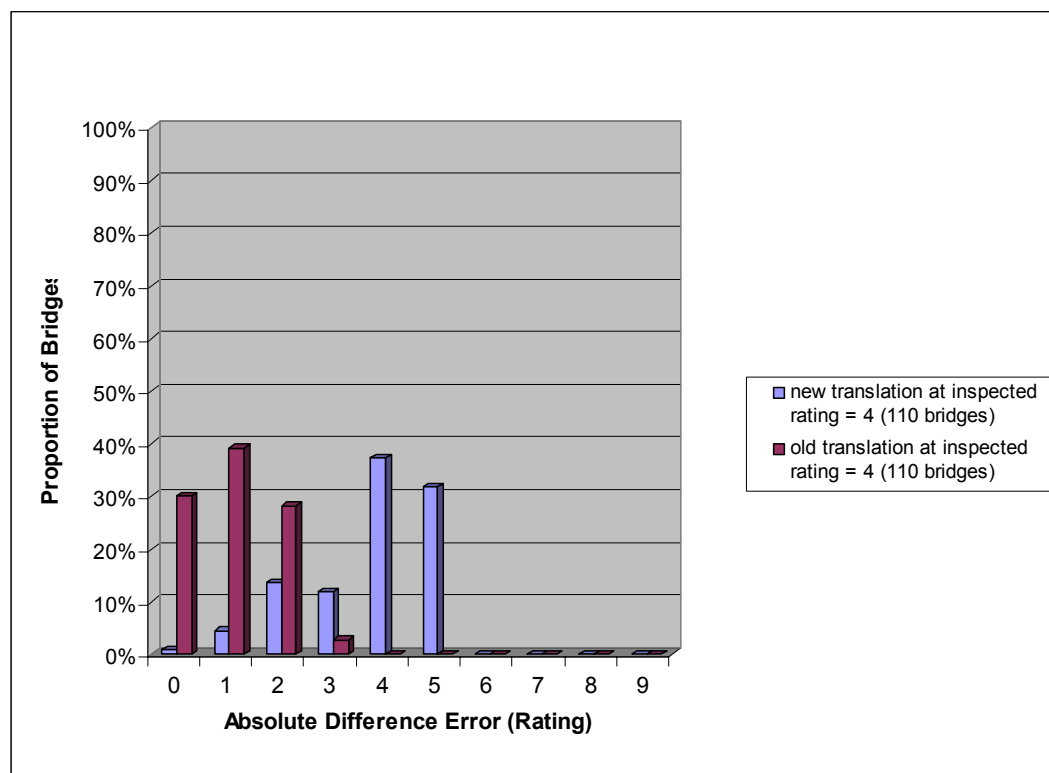


Figure B22. Comparison of Translated Substructure Ratings at Recorded Inspected Rating “4”

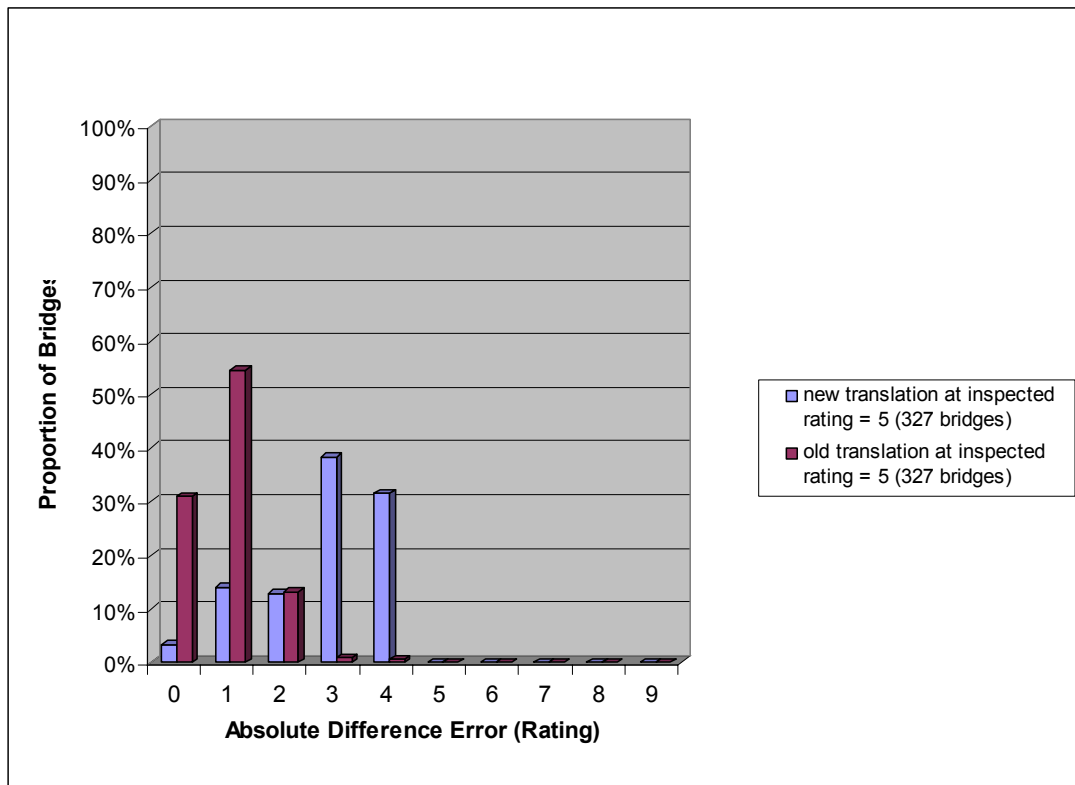


Figure B23. Comparison of Translated Substructure Ratings at Recorded Inspected Rating “5”

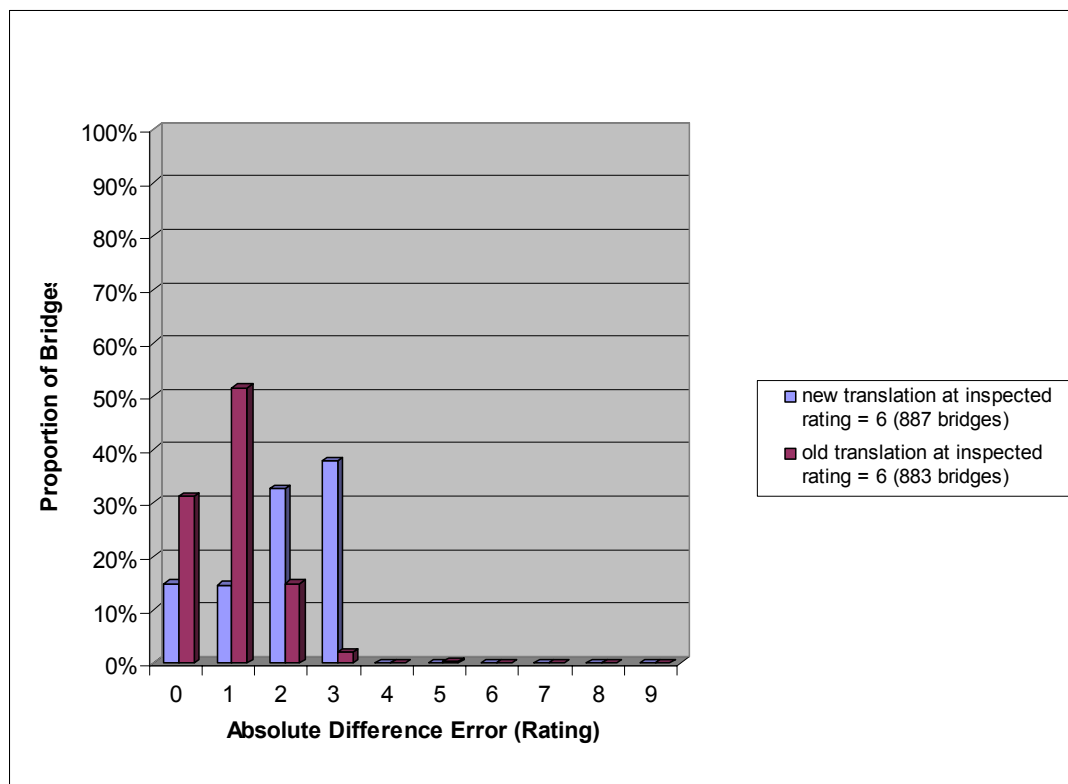


Figure B24. Comparison of Translated Substructure Ratings at Recorded Inspected Rating “6”

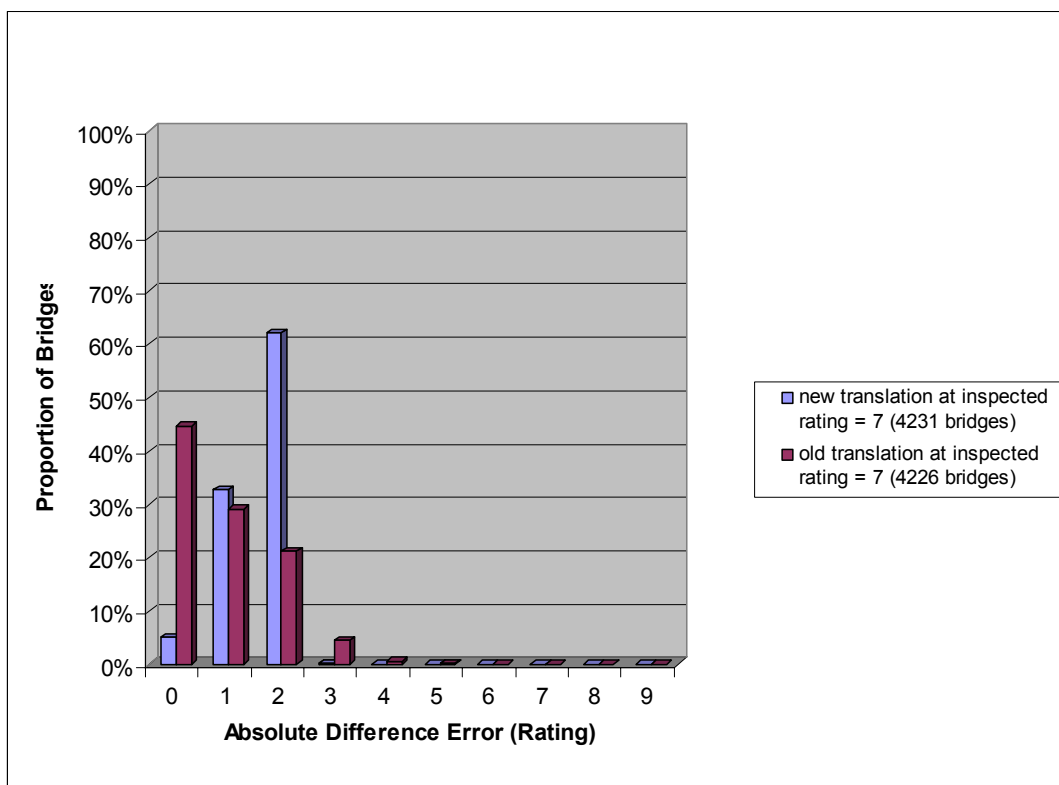


Figure B25. Comparison of Translated Substructure Ratings at Recorded Inspected Rating “7”

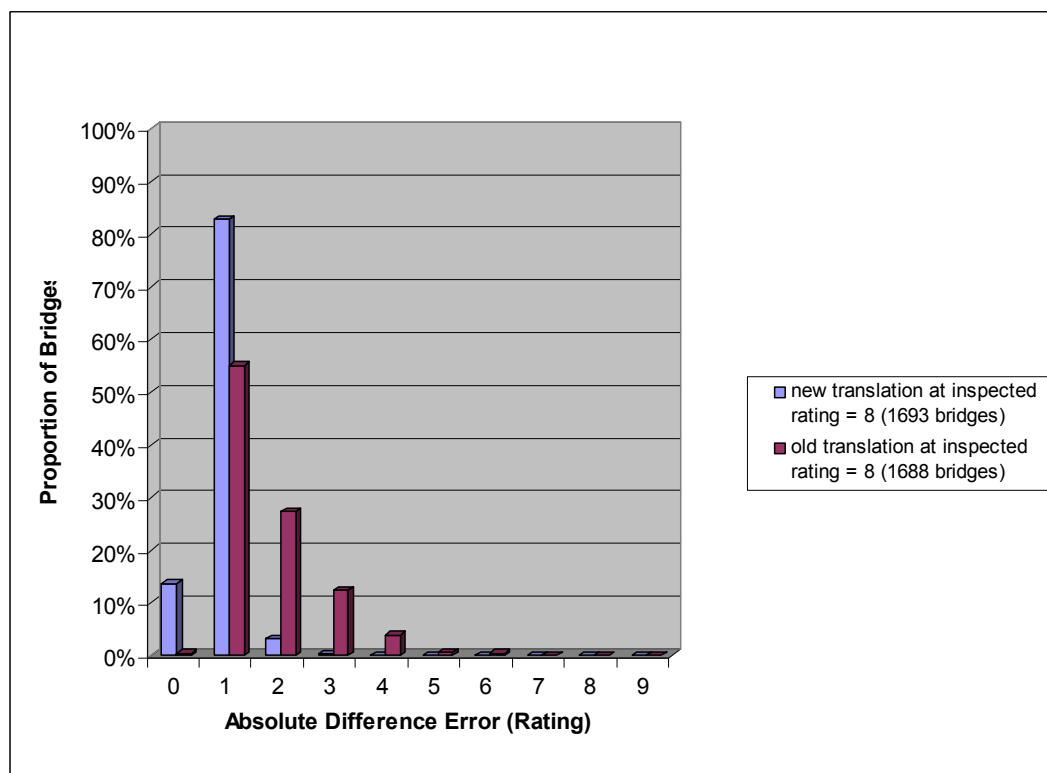


Figure B26. Comparison of Translated Substructure Ratings at Recorded Inspected Rating “8”

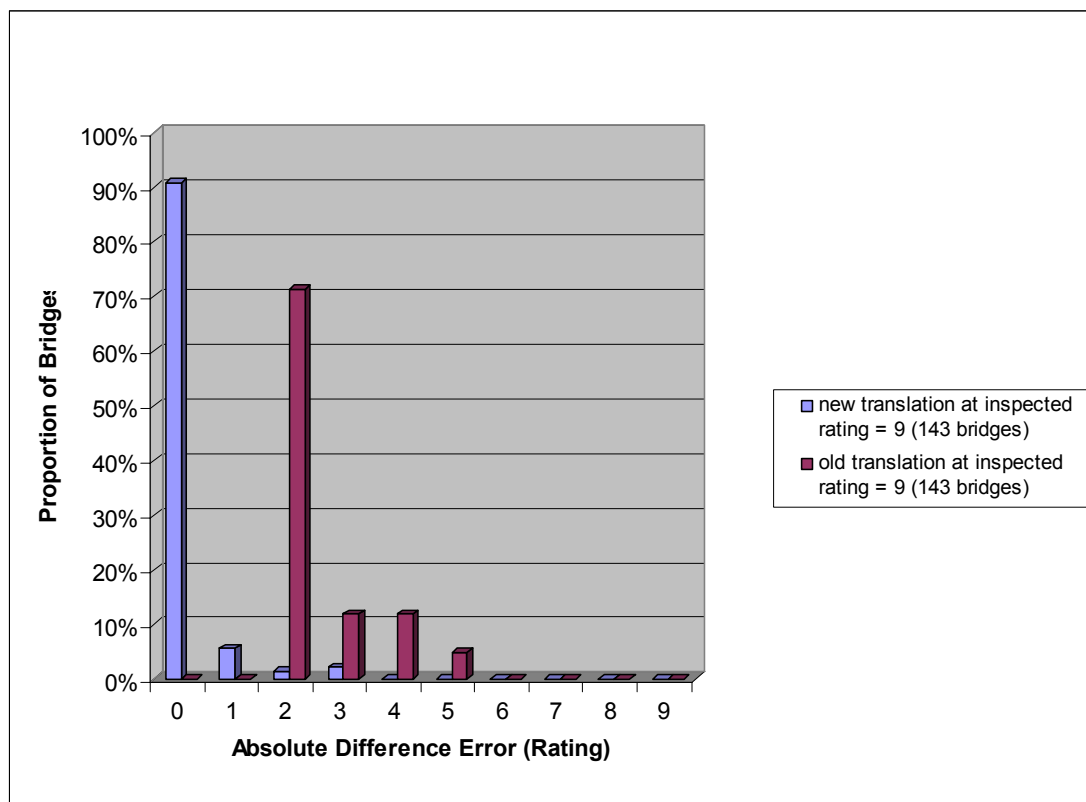


Figure B27. Comparison of Translated Substructure Ratings at Recorded Inspected Rating “9”

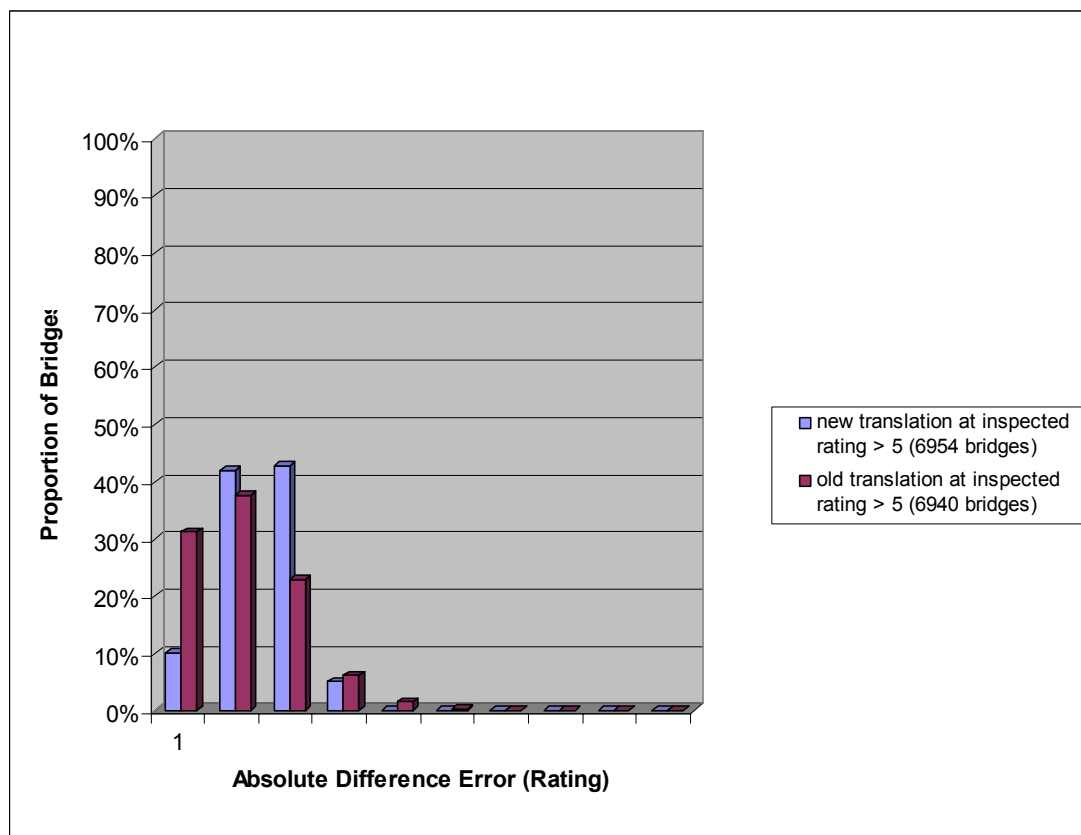


Figure B28. Comparison of Translated Substructure Ratings at Inspected Ratings “6” and Higher

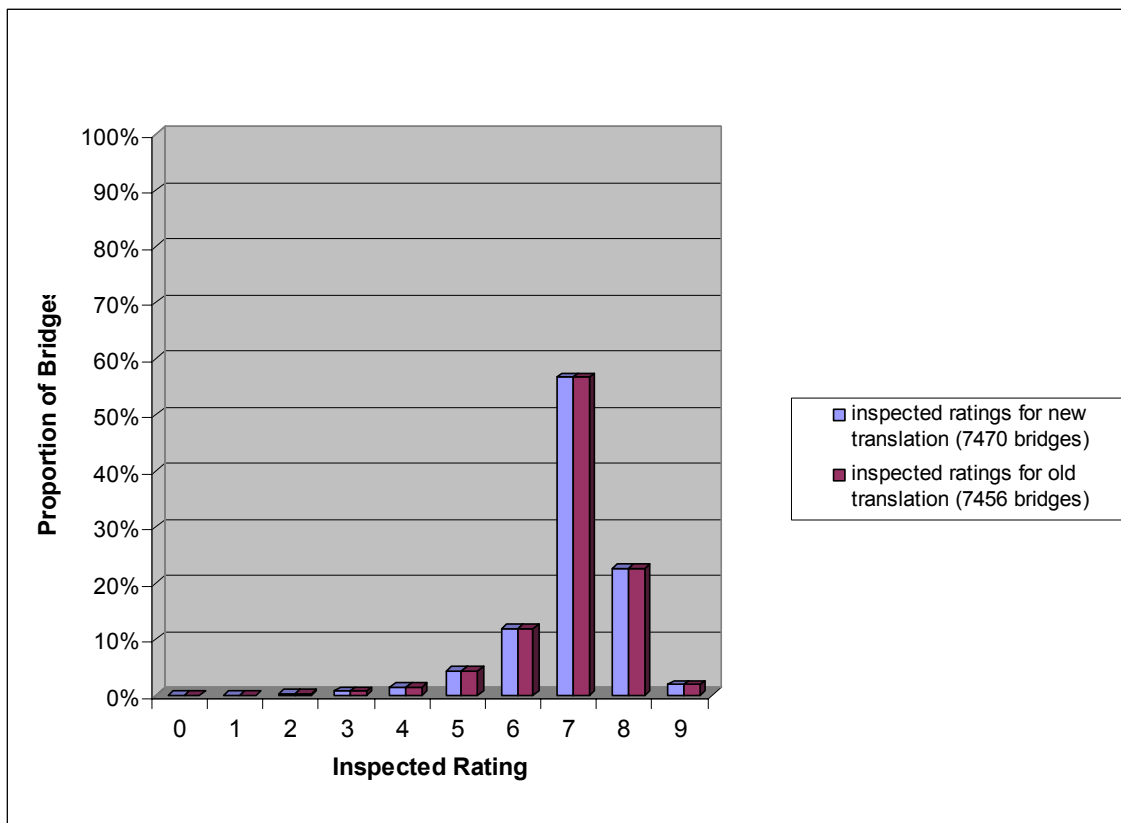


Figure B29. Comparison of Inventory Data on Inspected Substructure Ratings

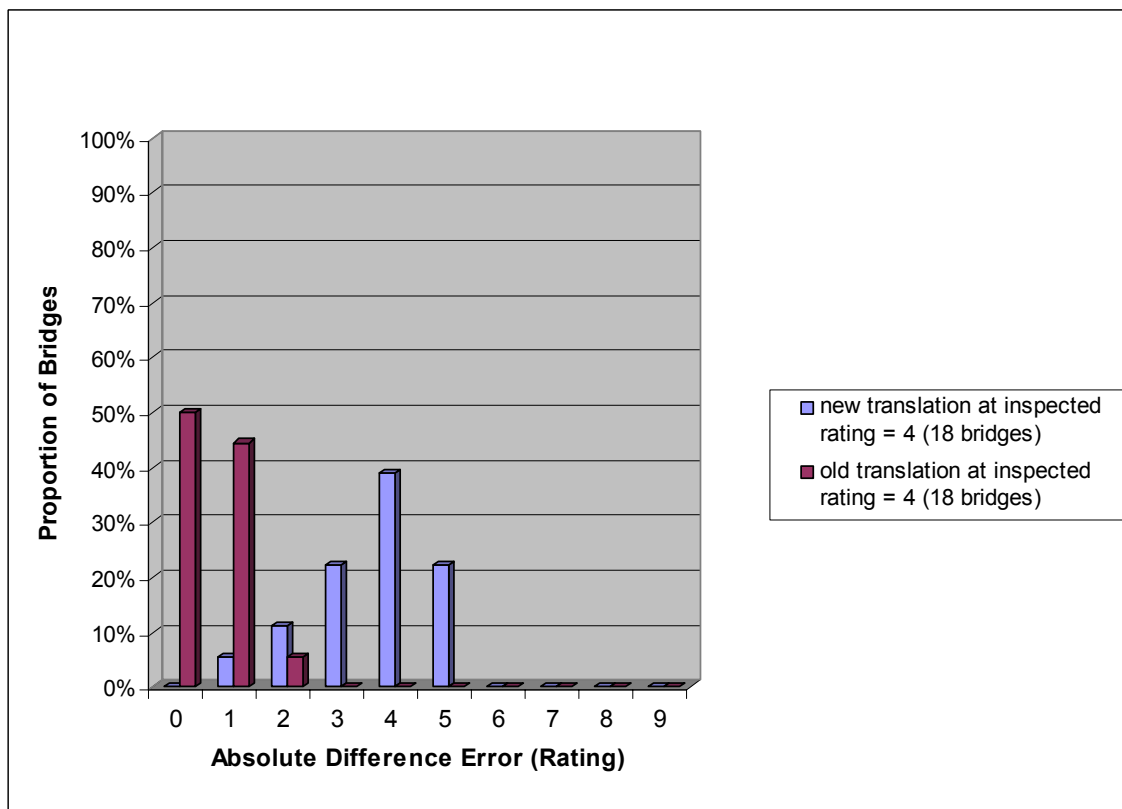


Figure B30. Comparison of Translated Culvert Ratings at Recorded Inspected Rating “4”

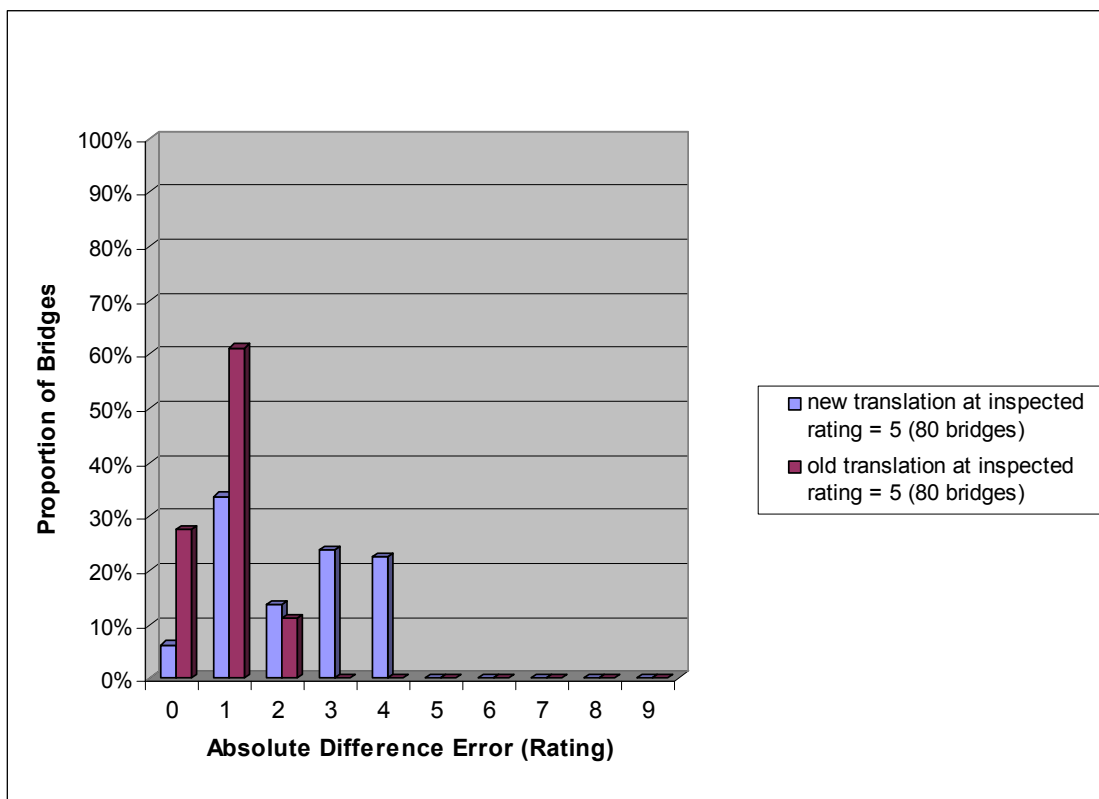


Figure B31. Comparison of Translated Culvert Ratings at Recorded Inspected Rating “5”

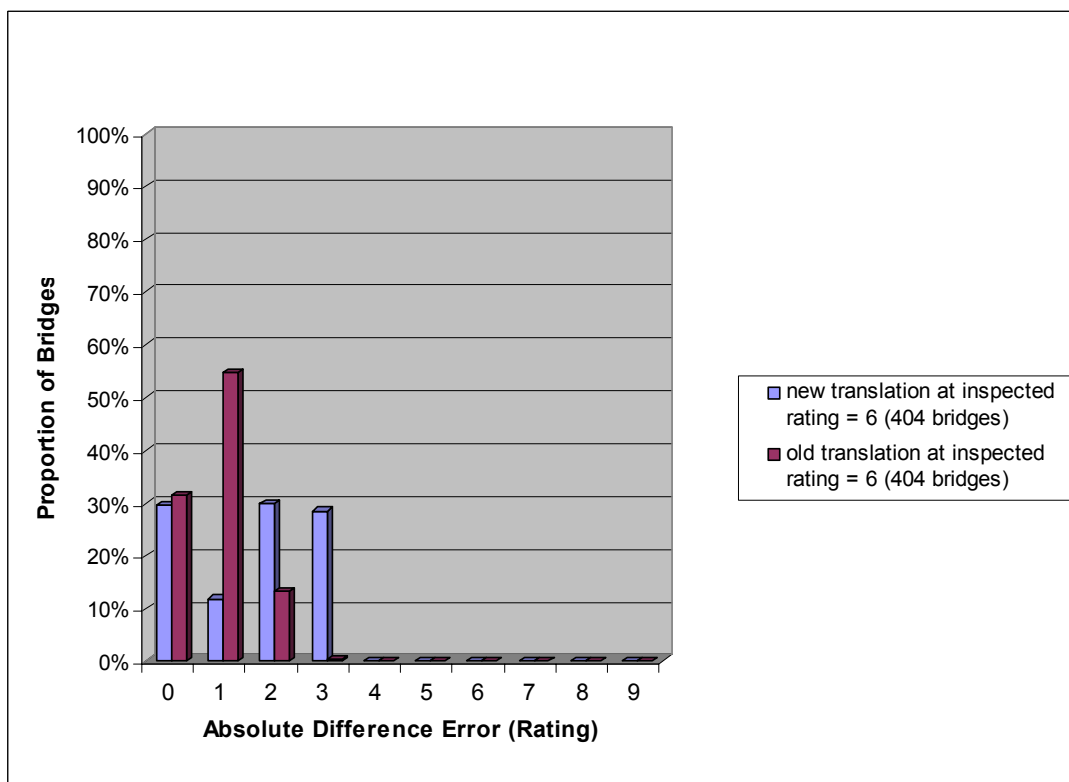


Figure B32. Comparison of Translated Culvert Ratings at Recorded Inspected Rating “6”

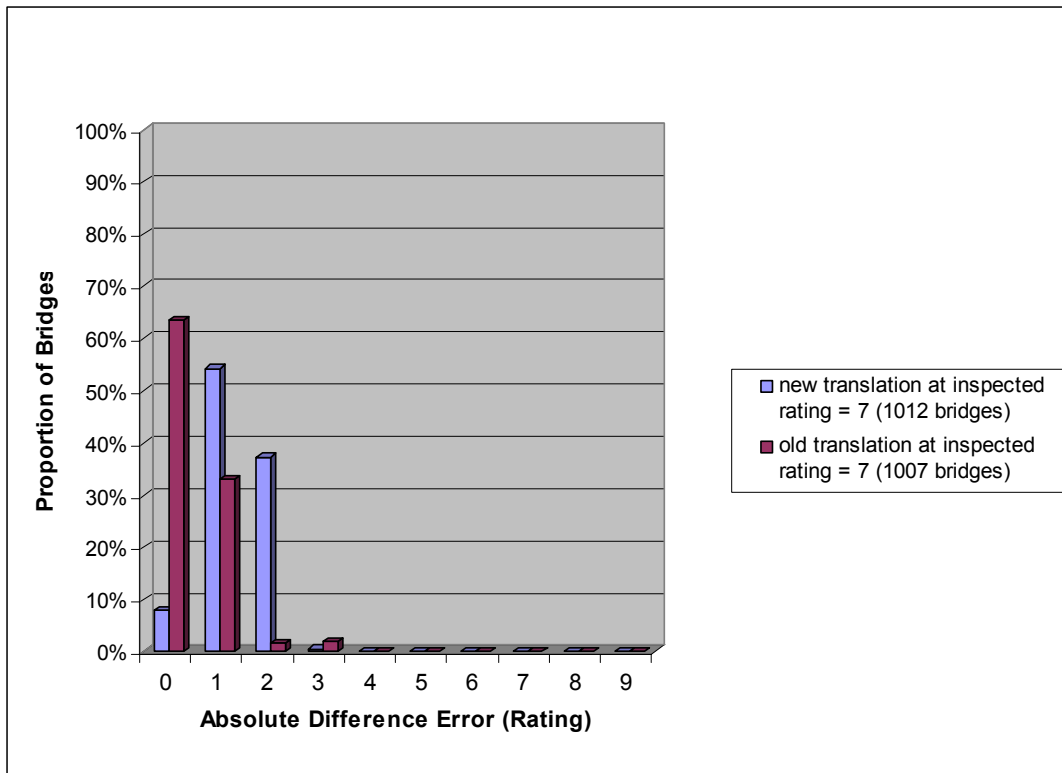


Figure B33. Comparison of Translated Culvert Ratings at Recorded Inspected Rating “7”

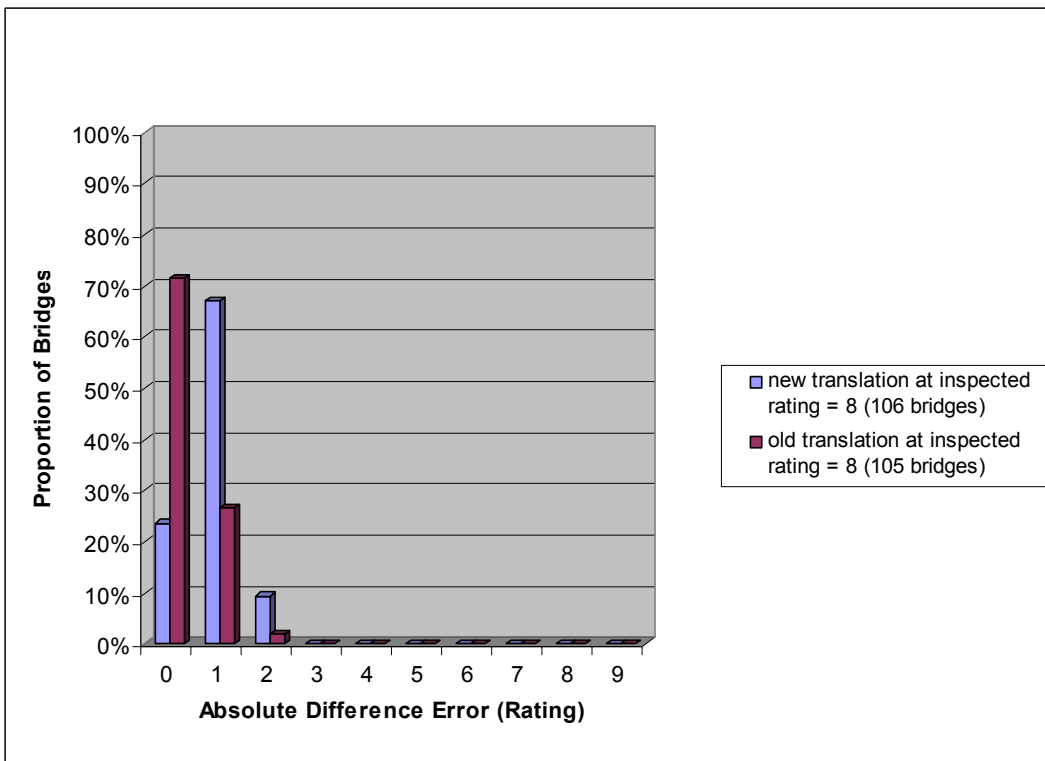


Figure B34. Comparison of Translated Culvert Ratings at Recorded Inspected Rating “8”

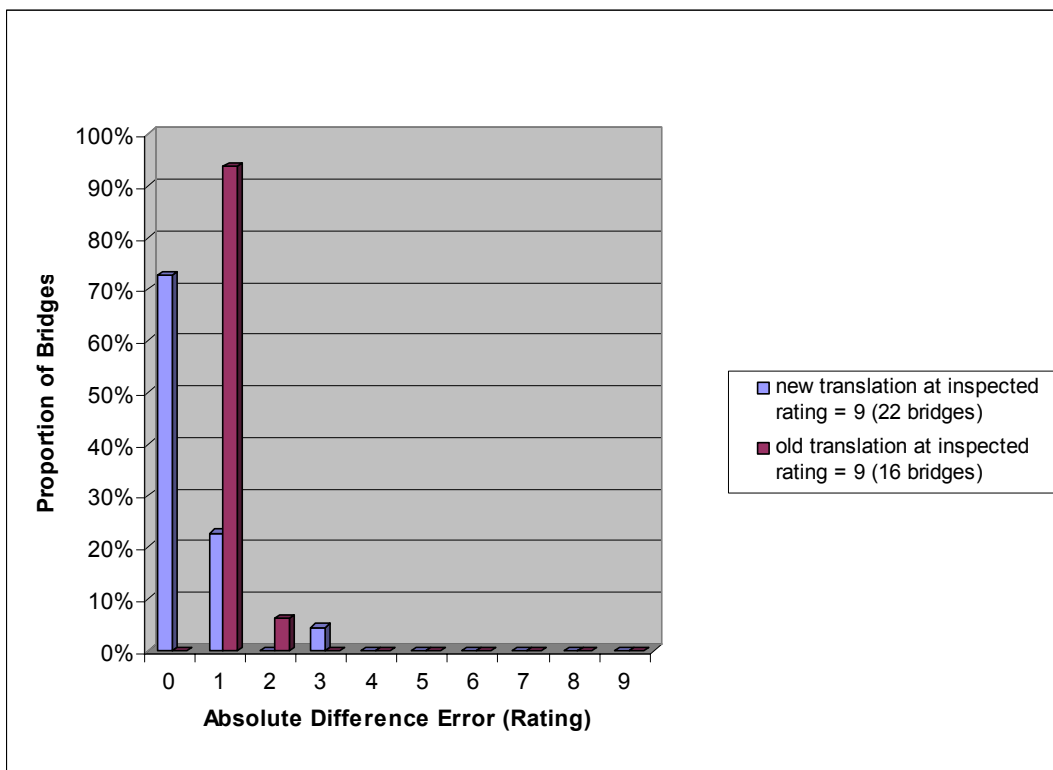


Figure B35. Comparison of Translated Culvert Ratings at Recorded Inspected Rating “9”

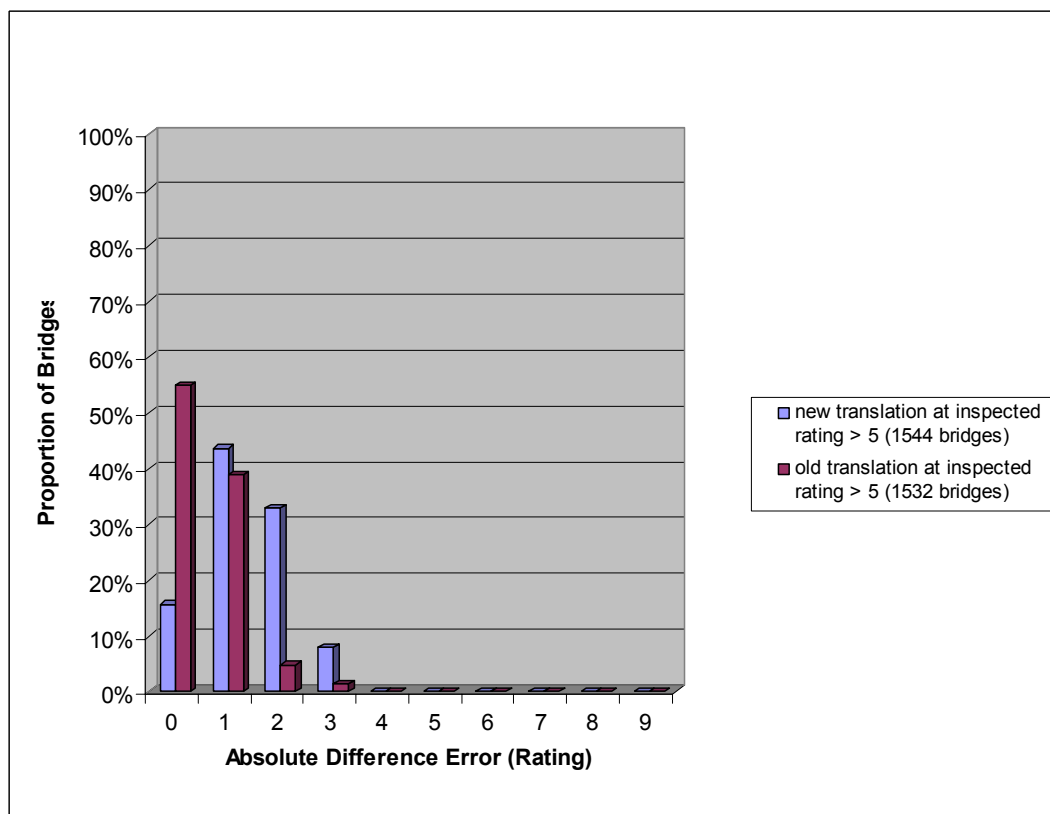


Figure B36. Comparison of Translated Culvert Ratings at Inspected Ratings “6” and Higher

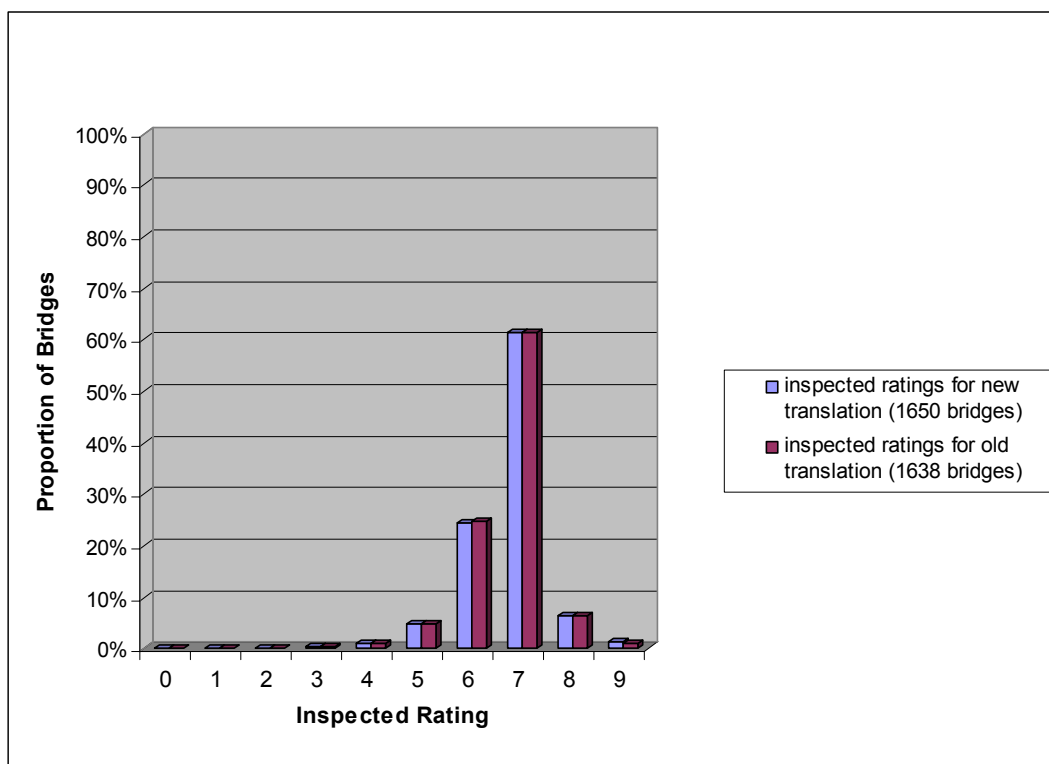


Figure B37. Comparison of Inventory Data on Inspected Culvert Ratings

Table B14. Summary of Average Errors in Translated Ratings

Inspected Rating	Deck		Superstructure		Substructure		Culvert	
	New Model	Old Model	New Model	Old Model	New Model	Old Model	New Model	Old Model
2	6.00	4.00	6.80	2.00	6.28	3.35	5.00	2.50
3	4.00	1.57	5.18	1.06	4.96	1.96	4.17	2.00
4	2.95	1.60	4.01	0.88	3.75	1.04	3.61	0.56
5	1.89	1.44	3.30	1.20	2.80	0.86	2.23	0.84
6	1.23	1.46	2.27	1.80	1.94	0.89	1.57	0.83
7	0.83	2.03	1.78	2.50	1.57	0.88	1.31	0.42
8	0.89	3.53	0.96	3.72	0.90	1.67	0.86	0.30
9	0.53	5.09	0.10	4.58	0.15	2.50	0.36	1.06
5 and less	2.15	1.50	3.74	1.12	3.41	1.14	2.62	0.89
6 and more	0.89	2.25	1.54	2.87	1.43	1.11	1.33	0.53

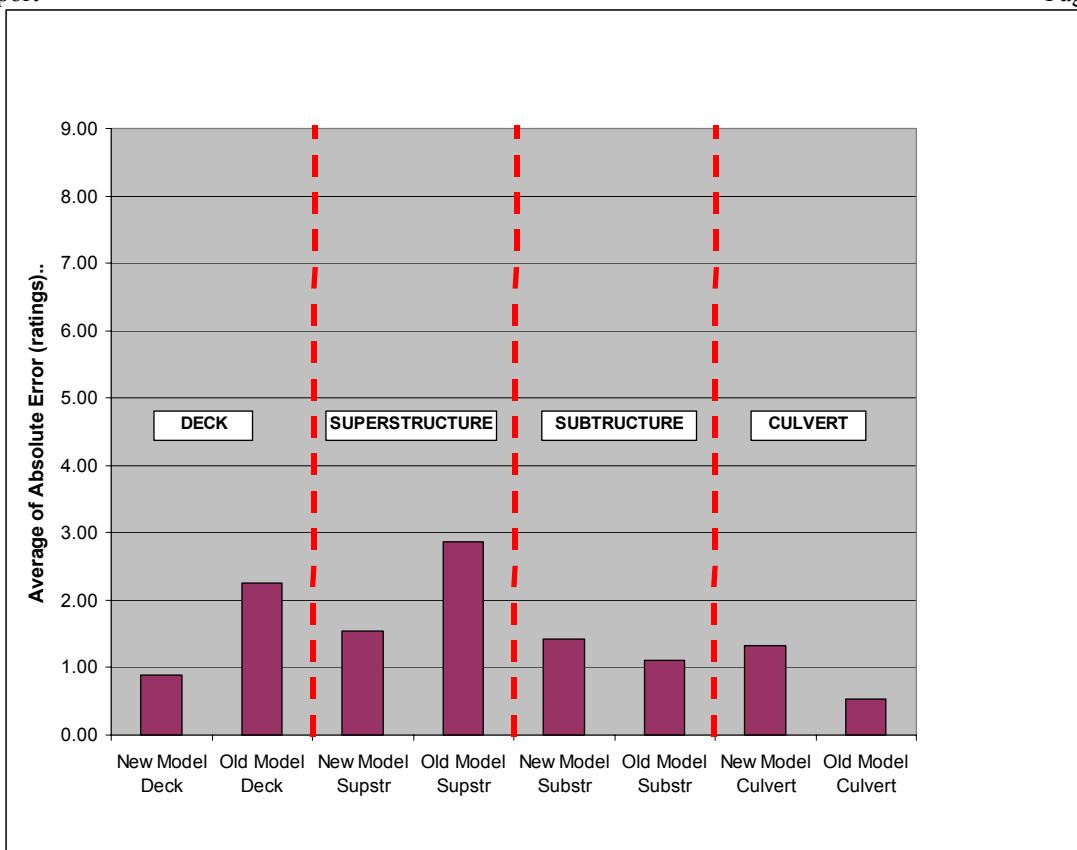


Figure B38. Variation in Accuracy of New and Old Models for Translating Ratings "6" and Higher

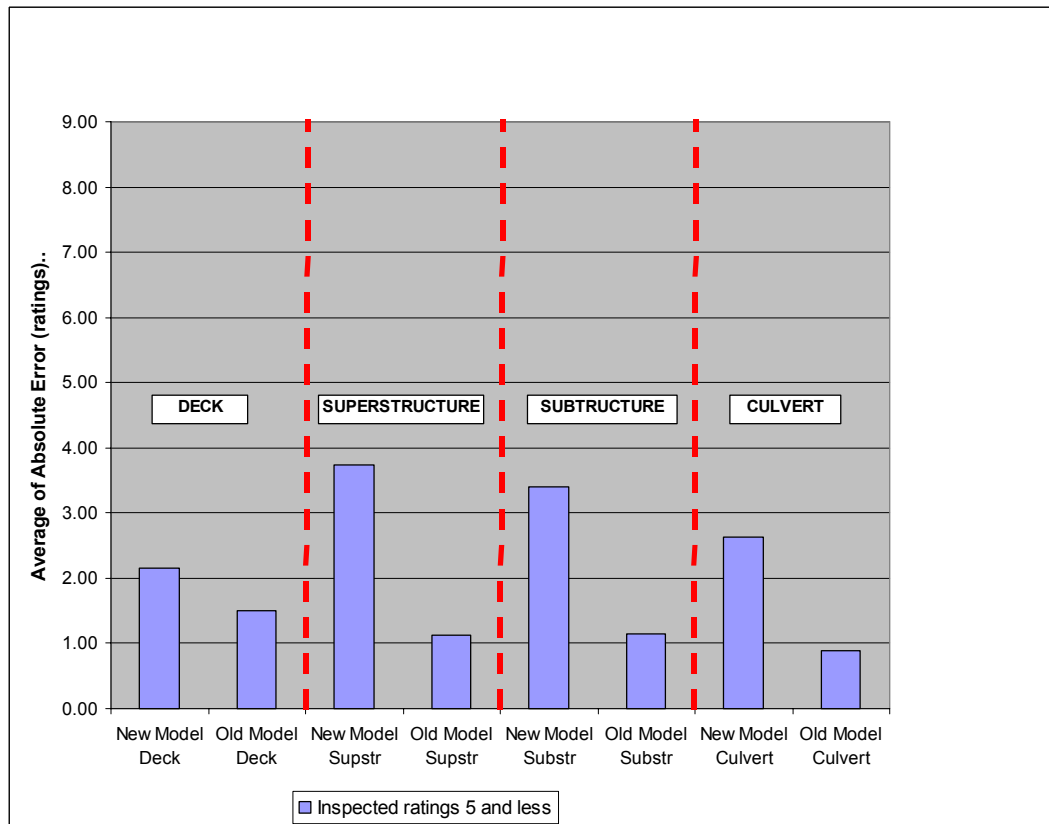


Figure B39. Variation in Accuracy of New and Old Models for Translating Ratings "5" and Less

NETWORK ANALYSIS TOOL

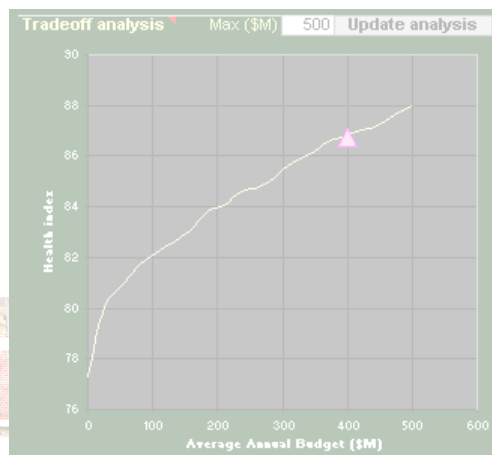
Release 2.0

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Overview

Since 1997 the Florida Department of Transportation has undertaken a number of necessary research and implementation activities to support the Pontis Bridge Management System. These activities include an upgrade of the biennial bridge inspection process to include element-level data; deployment of the Pontis software and database to district and central offices; customization of the administrative features of Pontis to support the FDOT work order process; development of new Pontis-compatible models for user costs, agency costs, deterioration probabilities, truck height and weight, and moveable bridge openings; and development of a Project Level Analysis Tool (PLAT) to apply these state-of-the-art tools to individual bridges. Pontis was designed as an open system to address the most generic bridge management functionality while leaving many opportunities for each bridge owner to customize it to satisfy unique agency requirements.

This Users Manual presents the Network Analysis Tool (NAT), a companion tool to PLAT intended to aggregate PLAT results into a network-wide analysis of costs and performance. NAT is intended to help District Structures and Facilities Engineers, Maintenance Planners, and Program Management staff with information for bridge programming and budgeting. It summarizes bridge needs on any subset of the bridge inventory, and shows how performance measures vary according to funding levels and allocation.

The activity diagram at the end of this section shows how NAT fits into an annual process which includes Pontis and PLAT. The combination of PLAT and NAT serves a number of business processes as described in the following paragraphs.

Develop candidates. PLAT analyzes possible life cycle futures for a bridge, in terms of the scope and timing of candidate projects, and calculates costs and performance measures for these candidates. It allows the maintenance planner or engineer to define new candidates and analyze those as well. Toolbar buttons in PLAT can save the resulting candidates to a PLAT Results Database, where they become available for use in the NAT. Over the course of a year, engineers will review new inspection results from Pontis, decide on candidates, and save these to the PLAT Results Database as needed.

Prepare initial program. In any given year, most bridges in the inventory need little or no attention from engineers and planners, because they are in very good condition. PLAT has a feature to automatically analyze all the bridges in any subset of the inventory to create an initial program plan. After this initialization, work performed on a particular bridge in the PLAT and saved to the Analytical Database will over-ride the default candidates for that bridge. Bridges that were not visited in the PLAT will still have valid information in them that can be used by the NAT.

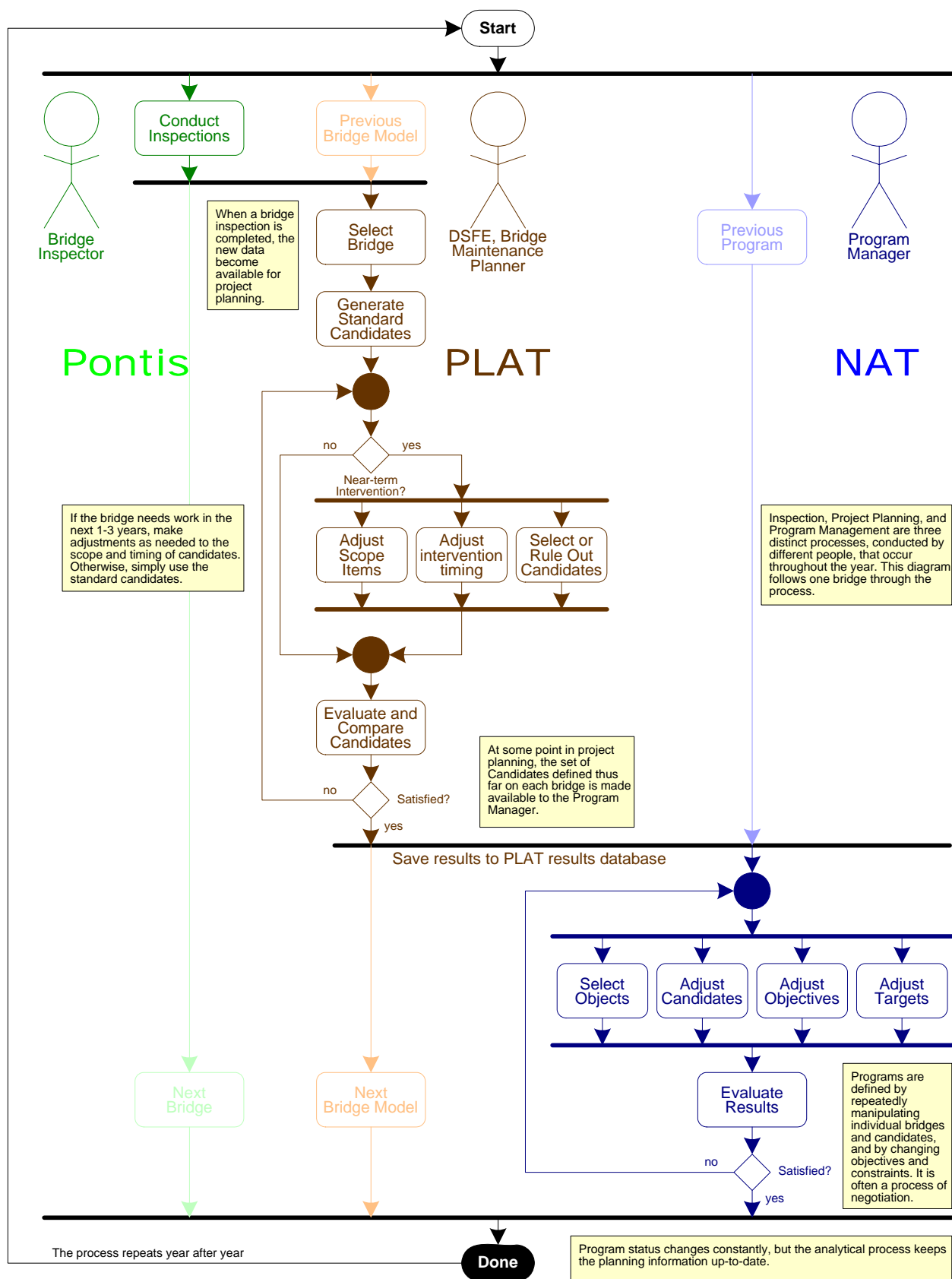
Define program. Program management is a process of reconciling competing objectives of resource utilization and performance, by means of selection and scheduling of actions. For most purposes, it is understood as a process of making choices of project scope and timing across an entire asset inventory or subset. However, for more senior managers and most elected officials, it is more often understood as a sort of economic supply curve -- a representation of how much performance can be purchased at various levels of investment. Program managers typically lack adequate time resources or expertise to evaluate engineering tradeoffs, but this does not mean such tradeoffs are unimportant. It merely means that the tradeoffs should already have been considered by engineers, and the results should be communicated to program managers in an efficient and consistent manner.

Development of a program begins with the selection of a sub-network and identification of the performance measure of interest. An automated process arranges the available candidates from PLAT in priority order according to each separate performance criterion and develops an economic structure of the performance/cost tradeoff. The inputs needed for this process are the costs and performance measures already calculated at the bridge level.

Analyze Tradeoffs. After the initial preparation, the Program Manager takes control and manipulates the budget constraint and performance targets. The Program Manager views a number of graphical presentations

of tradeoffs and sensitivity analysis to acquire an understanding of what goals are achievable with available inputs. Adjustments to the inputs yield immediate feedback on forecast outputs and outcomes. This makes it easy to adjust budgets and performance targets and see the results in real-time.

Adjust Candidates. In addition to adjusting and viewing network level performance measures, the Program Manager typically seeks to view and adjust individual candidates. The non-engineer can still perform useful work at this level if the Maintenance Planner has provided a good set of alternatives. All such adjustments involve selecting or deselecting candidates, or making economic adjustments to reflect non-economic factors. For example, the manager might apply a penalty to a candidate that involves significant traffic disruption. A DSFE or Statewide Bridge Maintenance Planner may start the analysis from the network level – investigating the options for the bridge from network-level optimization standpoint — and then proceed down to the bridge-level to determine the appropriate courses of action. In this way it is possible to switch back and forth between bridge- and network-levels to fine-tune a program.

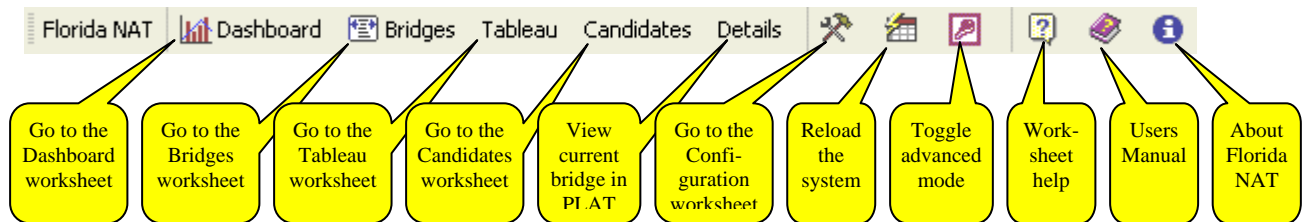


Getting Started

Welcome to the Florida network analysis tool! This is an Excel model designed to work with Pontis and the Project Level Analysis Tool (PLAT), using life cycle cost analysis to gain an understanding of the relationship between performance and funding for an inventory of bridges.

To use the system, you need Microsoft Excel 2002 (XP) or higher, and Adobe Acrobat Reader 4 or higher (just for the Users Manual). Your Pontis administrator should have posted an Excel template file and a Users Manual in the directory where your Microsoft Office templates normally are found, and should have sent you a Windows shortcut file for launching the system. If this is not the case, you can prepare the system for normal use by consulting the chapter on [Administration](#).

For most purposes you'll work on the [Dashboard](#) worksheet, occasionally consulting the [Bridges](#), [Tableau](#), and [Candidates](#) worksheets when you need more detail. You'll navigate the system using the toolbar, which looks like this:



To learn how the network optimization works, see the chapter, [Optimization Model](#). A set of quick lessons is provided first, to get you started in understanding and using the tool effectively:

[Setting up the analysis](#)
[Specifying a budget](#)
[Setting performance targets](#)
[Drilling down](#)

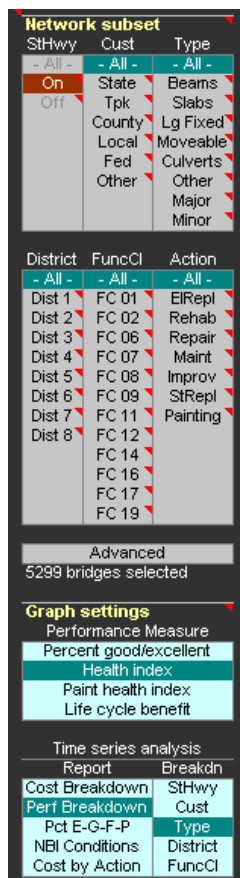
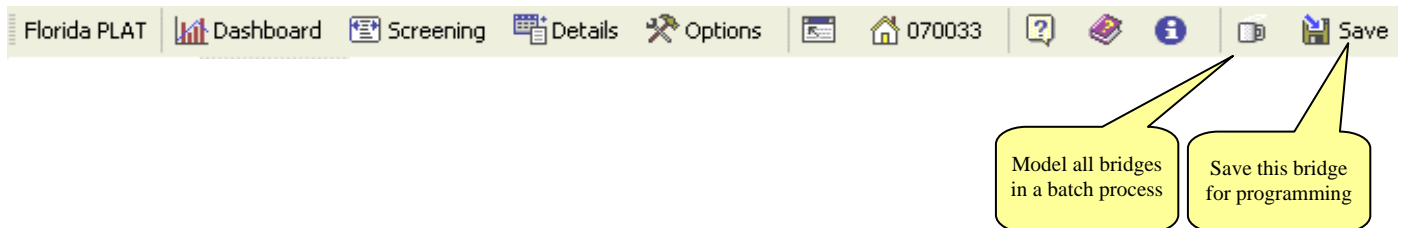
For most technical support matters, the first person to call is your Pontis system administrator. If you have questions or need help with the optimization analysis, or if you spot a bug, contact Paul Thompson at 303-681-2425 or pdth@pdth.com.

We hope you'll find the tool indispensable as you plan your program and budget. Please let us know if you have any feedback. Thank you very much for your help and support!

Setting Up the Analysis

The NAT depends for its inputs on a separate system, the Florida Project Level Analysis Tool (PLAT). PLAT conducts a life cycle cost analysis of each bridge, predicting [performance measures](#) that illustrate the tradeoff between scoping and timing of work. At the network level, reducing the budget causes work on some of the bridges to be postponed. Those bridges still need work and will incur expenditures eventually, but their scope may change because of further deterioration. NAT uses this information to predict what will happen at the network level as funding is regulated.

Before running NAT, you'll need to make sure you have used PLAT to update the project-level analysis results, which are stored in a [PLAT Results Database](#). This should be checked at least once a year. The right-most toolbar buttons on the PLAT toolbar are used for this purpose, as indicated below. See the later chapter, [Administration](#), and the separate PLAT Users Manual for more information.

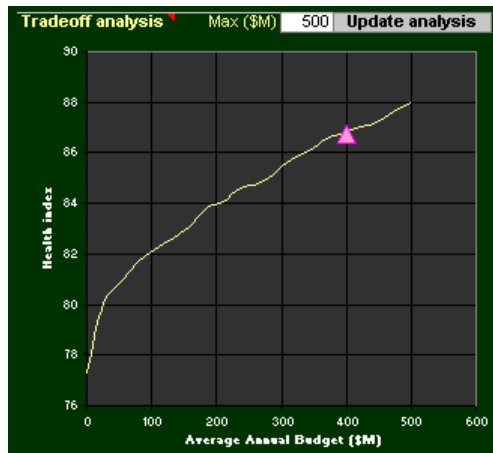


Once the PLAT Results are ready, you'll need to decide what parts of the inventory to analyze. This is done in the [Dashboard Control Panel](#), shown at left and described below.

You'll also need to select a [performance measure](#), which determines how candidate investments are prioritized. Naturally, whichever measure of performance you use for priority-setting, is the one that will be improved the most in the [optimization](#). The best way to understand the differences that your choice of performance measure will make, is to try out all the possibilities to see what interventions are selected.

Once you have made these choices, you are ready to work with [budgets](#).

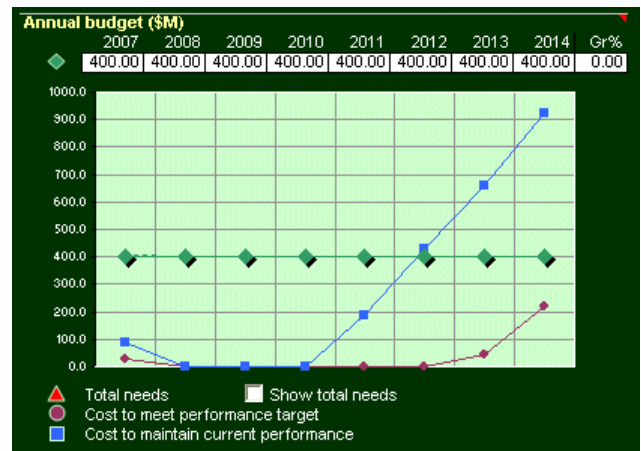
Specifying a Budget



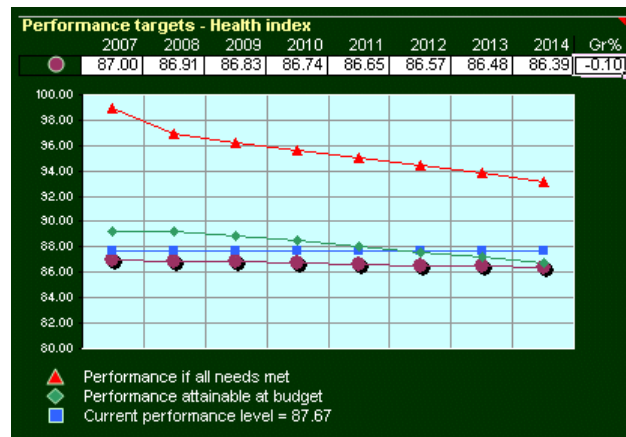
From the perspective of an economic model, any budget level is conceivable, even zero. But the more money you put into a program, the better will be the [performance](#) you get out. Allowing an inventory to deteriorate will gradually increase the overall needs, raising the future cost of keeping the transportation network in service. The budget analysis helps you attach hard numbers to this tradeoff and thought process.

One way to get a quick idea of how funding affects performance, is to use the [Dashboard](#)'s [Tradeoff Analysis](#) graph, shown at left. Set a maximum budget level, higher than you think would ever happen, and if necessary, click the "Update analysis" button to cause the program to calculate and plot a series of 20 different annual budget levels. You can pick a point on this graph as a starting place for your own budget analysis.

The [Budget Pane](#) (right) on the Dashboard gives you several tools for entering and evaluating annual funding levels. Each time you make a change in the budget, the Dashboard updates itself automatically. The first year budget and the growth rate work together to set all the annual budgets all at once. You can see on the graph the cost of maintaining current performance and the cost of satisfying a performance target.



Setting Performance Targets

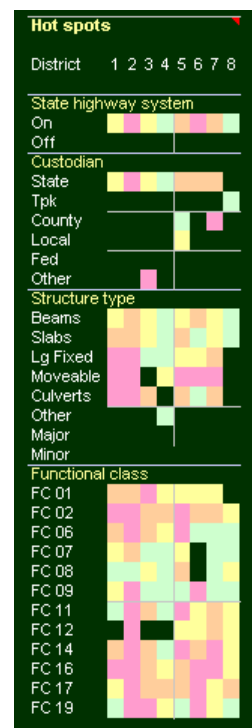
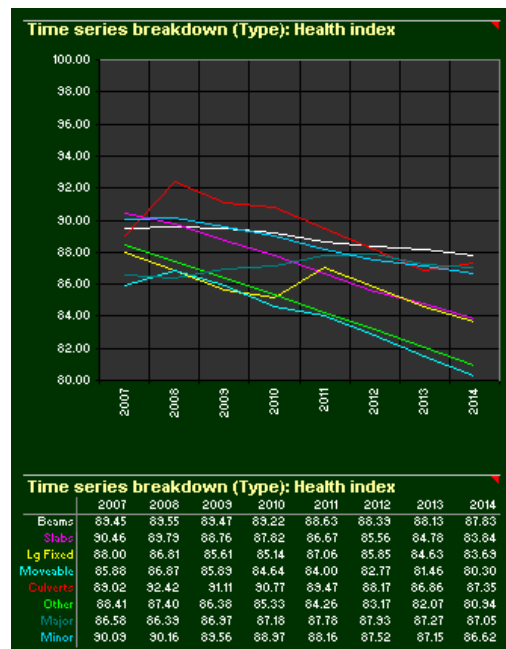


You can evaluate the performance of your program and set targets using the [Performance Target Pane](#) on the [Dashboard](#) (left). Targets don't change what the optimization model decides to program, but they do give you useful feedback on the [Budget Pane](#), in terms of the cost to achieve the given target.

You can compare related performance measures and see how they vary in different parts of the network, using the [Time Series Analysis](#) (below). The bottom part of the [Control Panel](#) has buttons you can click to control the choice of data displayed in this graph and table.

The Dashboard also has a [Hot Spot](#) chart (right), which gives you a multi-dimensional view of current condition of your bridge inventory.

Based on the Time Series Analysis and Hot Spot chart, you may decide to focus on a portion of your inventory to work on just the performance there. You can do this by making selections from the [Control Panel](#) to specify which bridges you want to analyze. Then you can set budgets and performance targets for just that more restricted group of bridges.



Drilling Down

Network-Level Analysis				<div><input checked="" type="checkbox"/> Show excluded bridges</div> <div><input type="checkbox"/> Show do-nothing bridges</div>														
Bridges																		
Please click the buttons at left to operate on each bridge																		
On/Off	Cond. Year	Bridge ID	Structure Name	State Hwy	Dist	Cost	Struc Type	Func Class	Major	Replace Cost (\$1000)	TEV (\$1000)	Point TEV (\$1000)	CFV (\$1000)	Point CFV (\$1000)	Health Index	Point Health Index	Utility	Incr. Utility Cost
On	2008	010032	US 41 NB OVER ALLIGATOR C	1	1	1	2	3	2	469	4347	0	4484	0	30.6	0.0	100.0	308.5
On	2007	010033	US 41 NB OVER OYSTER CK.	1	1	1	2	3	2	182	3236	0	3168	0	36.1	0.0	100.0	18083.7
On	2012	010035	EL JOBEAN BRIDGE EB	1	1	1	1	3	2	3124	24643	6	16801	6	68.2	100.0	100.0	46.3
On	2008	010042	US-41 OVER SUNSET CANAL	1	1	1	2	3	2	623	8076	0	6302	0	85.5	0.0	100.0	232.3
On	2009	010045	US 41 OVER MORNING STAR CANAL	1	1	1	2	3	2	866	9777	0	8428	0	86.2	0.0	100.0	167.1
On	2007	010053	US 41 SB OVER ALLIGATOR C	1	1	1	2	3	2	524	5510	0	5124	0	33.0	0.0	100.0	18553.6
On	2007	010056	US 41 SB OVER OYSTER CK	1	1	1	2	3	2	316	4093	0	3377	0	37.2	0.0	100.0	11395.1
On	2007	010065	AIRPORT ROAD OVER I-75	1	1	1	1	4	2	830	8653	5611	7947	5273	31.8	34.0	100.0	5224.5
On	2010	010066	S JONES LOOP RD/ I-75	1	1	1	1	6	2	1121	11800	7312	10782	6432	31.4	88.8	100.0	129.1
On	2011	010063	I-75 SB/ALLIGATOR CREEK	1	1	1	1	1	2	1336	16448	8970	12584	6252	76.5	63.7	100.0	108.3
On	2010	010070	I-75 NB /ALLIGATOR CREEK	1	1	1	1	1	2	1127	13718	7478	10603	5212	77.3	63.7	100.0	128.4
On	2011	010071	I-75 SB OVER KINGS HIGHWAY	1	1	1	1	7	2	1183	8640	0	8414	0	37.4	0.0	100.0	122.4
On	2010	010072	I-75 NB OVER KINGS HIGHWAY	1	1	1	1	7	2	1183	8643	0	8410	0	37.3	0.0	100.0	122.4
On	2009	010073	I-75 SB / JONES LOOP RD	1	1	1	1	1	2	782	10424	5100	8392	4315	86.3	84.6	100.0	185.0
On	2009	010074	I-75 NB / JONES LOOP RD	1	1	1	1	1	2	782	10431	5100	8435	4314	30.5	84.6	100.0	185.0
On	2008	010078	I-75 SB/SANDY HARTMANS C	1	1	1	2	1	2	338	4388	0	4331	0	86.8	0.0	100.0	363.5
On	2010	010080	I-75 SB/RIVERSIDE DR & RR	1	1	1	1	1	2	1011	7288	0	7039	0	36.6	0.0	100.0	143.2
On	2010	010081	I-75 NB/RIVERSIDE DR & RR	1	1	1	1	1	2	1011	8134	0	7894	0	37.0	0.0	100.0	143.2
On	2009	010082	I-75 SB / TUCKERS GRADE	1	1	1	1	1	2	788	10074	5273	8351	4757	88.3	30.2	100.0	183.6
On	2009	010083	I-75 NB / TUCKERS GRADE	1	1	1	1	1	2	732	10083	5273	9022	4836	83.5	31.7	100.0	182.7
On	2011	010093	US 17 OVER SHELL CREEK	1	1	1	2	2	2	1347	8897	0	7032	0	73.7	0.0	100.0	107.4
On	2007	010095	US 17 SHELL CK N SLOUGH	1	1	1	2	2	2	465	4508	0	3841	0	85.2	0.0	100.0	6794.3
On	2010	010098	SR 776 GOTTFRIED CREEK	1	1	1	1	10	2	1021	8580	0	7728	0	30.1	0.0	100.0	141.7
On	2008	010100	SR 776 OVER JAMES CREEK	1	1	1	1	10	2	1756	45044	0	44313	0	88.8	0.0	100.0	81.0

Network-Level Analysis														
Optimization Tableau														
This worksheet is not intended to be edited and should not be referenced by formulas. Click any b														
2007 bridges	Action	Cost	CumCost	IUC	2008 bridges	Action	Cost	CumCost	IUC	2009 bridges	Action	Cost	CumCost	IUC
870651	200	100	100	334.00	162024	100	263			170010	100	263		
870263	200	400	500	83.50	870401	100	521			170010	100	263		
870010	100	1300	1800	58.62	770072	100	263			170010	100	263		
170060	300	1000		52.10	720552	200	280			170010	100	263		
873003	600	2600	4400	48.35	750604	300	1426			170010	100	263		
083001	100	13600		47.38	100582	100	247			170010	100	263		
100028	100	419400	423800	47.27	330488	300	630			170010	100	263		
150046	600	543200	367000	40.48	330483	300	630			170010	100	263		
340048	100	10100	37700	37.33	870732	300	418			170010	100	263		
100337	300	3300	380400	37.27	160250	100	504			170010	100	263		
780017	100	15800	336200	36.05	330487	300	412			170010	100	263		
030085	100	33300		35.65	164506	300	1230			170010	100	263		
720138	100	18300	1014500	34.63	330486	300	413			170010	100	263		
873004	300	2700	1017200	34.13	160268	100	264			170010	100	263		
730004	600	193400	1216600	31.92	870583	300	330			170010	100	263		
050031	100	900		31.22	330525	300	734			170010	100	263		
720321	100	21200	1237800	31.03	720575	200	242			170010	100	263		
870785	100	2300	1240100	30.83	860625	200	446			170010	100	263		
870154	100	2300	1243000	30.41	870530	300	330			170010	100	263		
870002	100	1100	1244100	30.36	750485	200	307			170010	100	263		
030035	100	2300		30.22	100519	300	225			170010	100	263		
700160	100	3100	1247200	30.13	770085	100	173			170010	100	263		
720338	100	36600	1283800	29.33	750548	300	213			170010	100	263		
720230	100	37000	1320800	29.74	750547	300	208			170010	100	263		

NAT has features to let you look down into the [optimization](#) to see how it selects and prioritizes bridges, and what it does to each individual bridge. You can see the list of included bridges on the [Bridges](#) worksheet (above), which reflects the choices you made on the [Control Panel](#) and also lets you exclude individual bridges. You can sort the bridges any way you like to understand what is included in the list.

To see the priority ordering of bridges in the optimization, use the [Tableau](#) worksheet (left). This shows, for each year of the program, how each bridge stacks up against all the other bridges. From the Bridges or Tableau worksheets, you can navigate to the [Candidates](#) worksheet for more detail about the results for each bridge. You can also use the Details button on the toolbar to bring up the bridge in the PLAT to understand how it was analyzed and see the scope vs. timing tradeoff.

Worksheet Reference

The network analysis tool is an Excel workbook file containing 5 worksheets with user information. All of them are available by clicking in the toolbar. (The Diagnostics and Scratch worksheets are for internal use by the software.) The worksheets are:

[Dashboard](#)

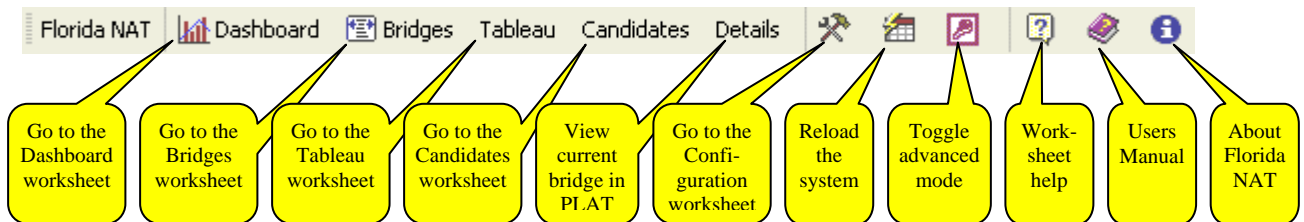
[Bridges](#)

[Tableau](#)

[Candidates](#)

[Configuration](#)

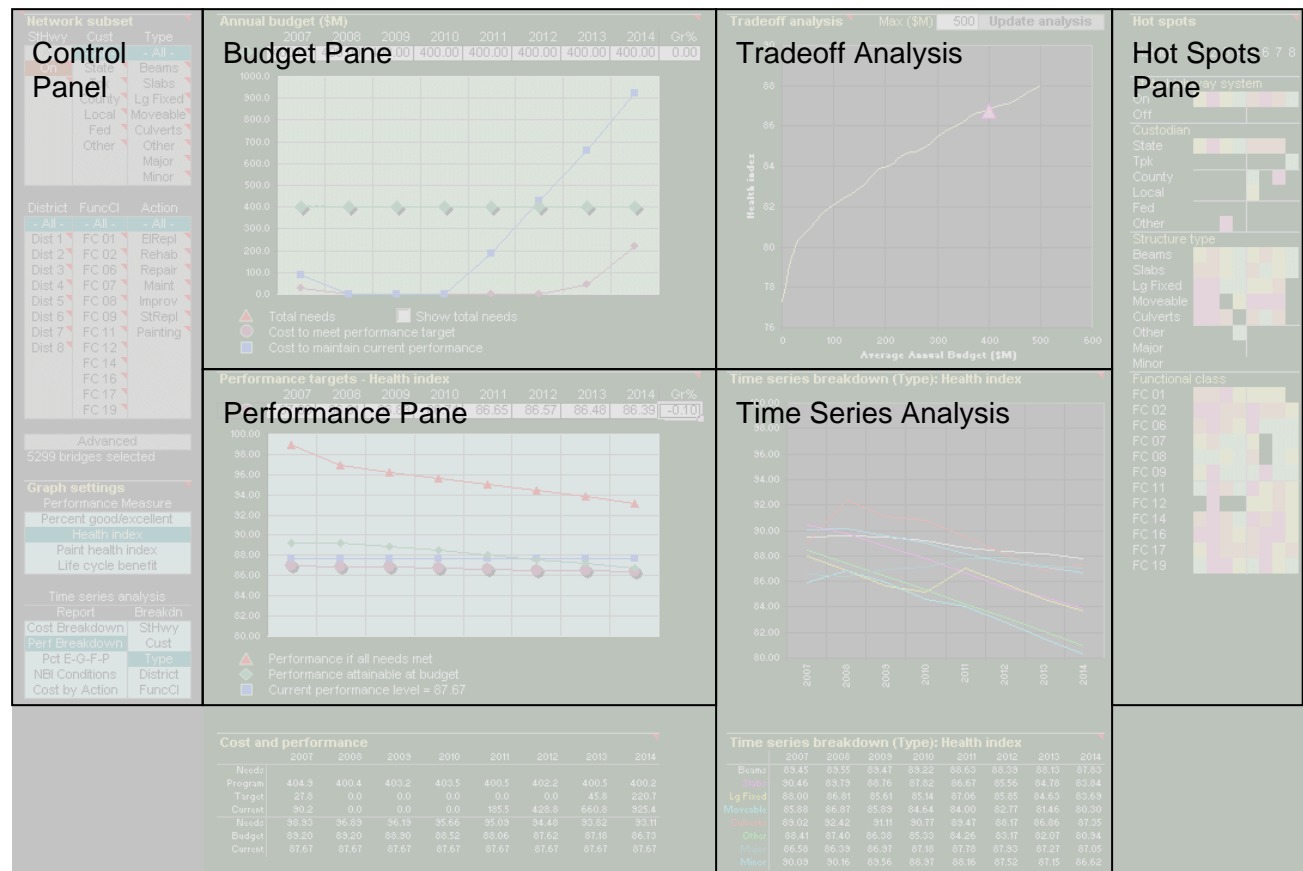
Most of the time you will navigate through the system using the toolbar, which looks like this:



Advanced mode is generally used only if you want to [customize](#) the workbook or if you need access to Excel toolbars. Most of the time you'll want Normal mode instead.

NAT keeps track of one bridge as the “current bridge”. Initially this is the first bridge listed on the Bridges worksheet. If you click a bridge in the Bridges worksheet or the Tableau worksheet, then that becomes the current bridge. Subsequently, clicking the Candidates button will show the candidates on that bridge, and clicking the Details button will show that bridge in the PLAT.

Dashboard



The Dashboard provides most of the controls and outputs of the system in one convenient layout. This makes it quick and easy to work with any subset of the inventory, any [performance measure](#), funding constraints, and performance targets. The diagram above shows the sections of the Dashboard worksheet, which are:

- [Control Panel](#) – By clicking buttons in this section you can choose a subset of the inventory, select a performance measure, and control what is plotted in the time series pane.
- [Budget Pane](#) – This is where you set budget constraints and see the funding requirements for various performance targets.
- [Tradeoff Analysis](#) – A convenient way to see how changes in budget affect the performance level at the end of the program horizon, to help in setting the budget constraints.
- [Performance Target Pane](#) – This is where you set performance targets and see what performance is attainable each year.
- [Time Series Analysis](#) – Here you can see the changes in cost and performance each year, and make comparisons between different performance measures or different subsets of the inventory.
- [Hot Spots Pane](#) – Using color codes, this section shows the parts of the inventory having the best and worst performance.

In addition, just below the Performance Pane is a table of the costs and performance data plotted in the Budget and Performance Panes. Just to the right of the Hot Spots graph (not shown in the diagram above) you can find the numbers that are plotted in the Tradeoff Analysis.

Control Panel

The screenshot shows the Control Panel interface with the following sections:

- Network subset:** A table with columns StHwy, Cust, and Type. The StHwy column has a dropdown menu with 'On' selected. The Cust column has a dropdown menu with 'State' selected. The Type column has a dropdown menu with 'Beams' selected.
- District:** A list of districts from Dist 1 to Dist 8, each with a dropdown menu set to 'All'.
- FuncCl:** A list of functional classes from FC 01 to FC 19, each with a dropdown menu set to 'All'.
- Action:** A list of actions from ElRepl to Painting, each with a dropdown menu set to 'All'.
- Advanced:** A button labeled 'Advanced' with the text '5299 bridges selected' below it.
- Graph settings:** A list of graph settings including Performance Measure, Percent good/excellent, Health index, Paint health index, and Life cycle benefit.
- Time series analysis:** A list of time series analysis reports including Cost Breakdown, Pert Breakdown, Pct E-G-F-P, NBI Conditions, Cost by Action, StHwy, Cust, Type, District, and FuncCl.

The Control Panel governs what is displayed on the rest of the [Dashboard](#). By clicking on the buttons in this area, you set the subset of the inventory to be analyzed, the performance measure used for optimization, and the display of the time series analysis.

NETWORK SUBSET

The upper half of the Control Panel is devoted to choosing a subset of the inventory. There are six dimensions from which to make selections:

State Highway System – indicates ownership. A bridge is on the state highway system if its NBI owner code (NBI 21) is 1 (state highway agency), 31 (state toll authority), or 33 (turnpike); with the exception of District 6 bridges having owner code 31.

Custodian – an indication of maintenance responsibility. A bridge is in “State” custody if its NBI item 21 code is 1, 11, 21, or 31. It is “Local” if NBI 21 is 3, 4, 12, 25, or 32.

Structure Type – The choices here depend on NBI item 43b: Beams (2,3,4,5,6,7,22), Slabs (1), Large fixed bridges (9,10,11,12,13,14,21), Moveable (15,16,17), and Culverts (19). A bridge is considered “Major” if its deck area is at least the deck area threshold given on the Configuration worksheet; otherwise it is considered “Minor”.

District – The FDOT district number.

Functional Class – Functional classes as indicated.

Action Category – Classification of action categories as defined in the PLAT: Element Replacement, Rehabilitation, Repair, Maintenance, Functional Improvements, Structure Replacement, and Painting.

In each case you can choose “All” to refrain from subsetting the inventory on that dimension. You can make multiple selections from a list in order to include more than one category. If you make selections from more than one list, only bridges that qualify on every list will be included.

NAT has a feature to limit its analysis to the State Highway System and/or just one district. This is specified on the [Configuration](#) worksheet. This feature makes the system load faster. If either of these is specified, the Control Panel indicates this by showing the corresponding list in gray with a red highlighted selection.

If the six lists don’t give you the subset you want, NAT has the ability to accept any SQL query based on any columns in the Pontis bridge, userbrdg, roadway, or inspevnt tables. Simply click the Advanced button to enter your query. Here’s an example query: “bridge.county='015' and roadway.adtttotal>1000 and inspevnt.dkrating<'6'”.

Whenever you change your subset settings, the Dashboard shows just under the Advanced button how many bridges you have selected. You can see the selected list on the [Bridges](#) worksheet.

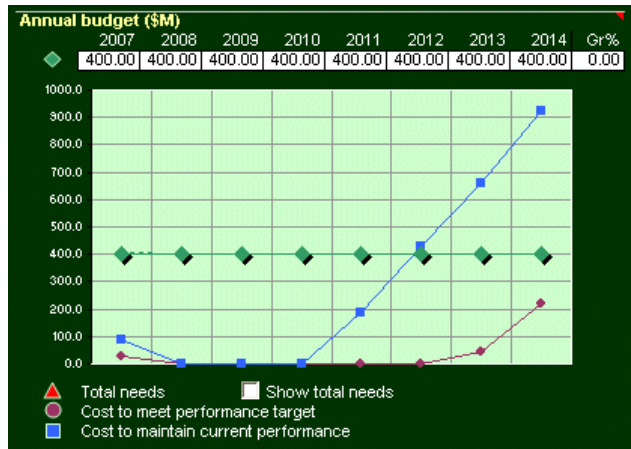
GRAPH SETTINGS

In the [Performance Measure](#) list, you must select one measure to be used in the [network optimization model](#) and in the tables and graphs on the [Dashboard](#).

TIME SERIES ANALYSIS

From the Report list, select one of the standard time series report layouts. For the two Breakdown reports, you can also choose how you want the subset of bridges broken out in the [time series analysis](#).

Budget Pane



Use this section of the [Dashboard](#) to set the budget constraints for your analysis. The graph shows the following information:

Green: The budget constraints you entered are shown with a solid green line. The amount programmed by the [model](#) is shown with a dashed line. Usually these lines are very close together so only the budget is visible. However it is possible for the amount programmed to be either above or below the budget. It can be above the budget because the optimization model programs interventions to use all the available money, and the last intervention might go a bit over the budget. It can be below the budget if there weren't enough needs to use up all the available funds.

Red: Total needs, meaning all the work that can possibly be programmed on all the bridges. This is usually a very large number that makes the rest of the graph hard to see, so a check box is provided to turn this line on or off.

Purple: Cost to meet the performance target, which is set in the [Performance Target Pane](#).

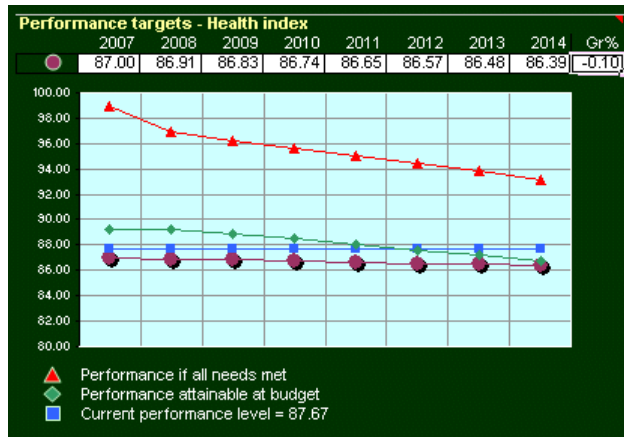
Blue: Cost to maintain the current performance of the network, which is shown in the [Performance Target Pane](#).

The optimization model works best if you omit inflation in the budget constraints. This decision is made in the PLAT by specifying a real discount rate that also excludes inflation. However, you may still want to model a uniformly increasing or decreasing level of real funding. This can be done by specifying a growth rate in the upper right corner of the Budget Pane. When you enter this growth rate (expressed in positive or negative percent), the budgets for each year are recomputed automatically based on the first-year budget. Similarly, if a growth rate is specified, entering a budget in the first year will cause all the other years' budgets to be computed automatically.

You can leave any or all years' budget constraints blank to model an unlimited budget.

If you change the inventory subset in the [Control Panel](#), you will also probably need to change the budget constraints.

Performance Target Pane



The Performance Target Pane allows you to set annual goals for [performance](#) of the subset of bridges you selected. These targets don't affect what work is programmed by the [model](#). The ability to reach a performance target in a given year depends on what was programmed by the model in earlier years of the analysis. The graph shows the following data:

Purple: The performance target you specified.

Red: Performance that would be achieved if all needs are met in a given year (i.e. no funding constraint), depending on what was programmed in earlier years of the analysis. This is the maximum possible level of the performance target.

Green: The performance achievable at the funding level set in the [Budget Pane](#). This is the performance resulting from the work programmed by the model.

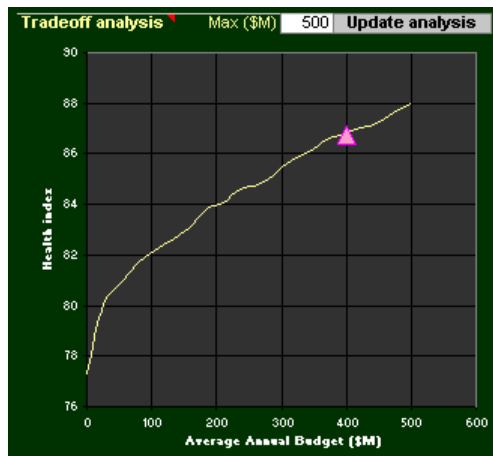
Blue: Current performance of the subset of bridges. The graph legend shows the numerical value. This performance number is computed as the forecast performance at the beginning of the program horizon.

You can model a uniformly increasing or decreasing performance target. This can be done by specifying a growth rate in the upper right corner of the Performance Target Pane. When you enter this growth rate (expressed in positive or negative percent), the targets for each year are recomputed automatically based on the first-year target. Similarly, if a growth rate is specified, entering a target in the first year will cause all the other years' targets to be computed automatically.

You can leave any or all years' targets blank to turn off the target analysis.

If you change the inventory subset or the choice of performance measure in the [Control Panel](#), you will probably need to change the performance targets as well.

Tradeoff Analysis



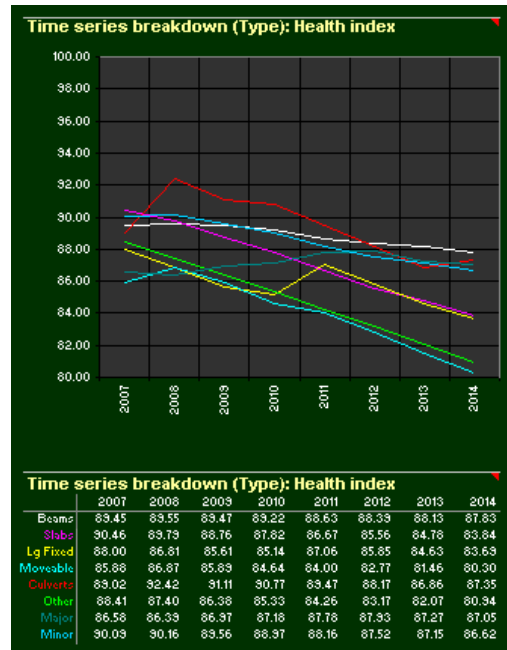
This graph helps you set your [budget constraints](#) by showing you what maximum [performance](#) is achievable at the end of the program horizon at any uniform annual budget level. It is a sort of supply curve for performance of the inventory subset you are analyzing.

To produce this graph, the [model](#) repeats itself 20 times for uniform increments of funding from zero to the maximum that you enter in the top center of the pane. Since the computations are time-consuming, they don't update automatically. If a change in [Control Panel](#) settings invalidates the graph, it is merely erased. To recompute it, simply click the "Update analysis" button or change the maximum budget level.

Based on the settings in the [Budget Pane](#), the red triangle shows the forecast performance of the program with the funding levels given.

If you would like to see the numbers that are plotted in this graph, simply scroll the [Dashboard](#) to the right, past the [Hot Spots Pane](#).

Time Series Analysis

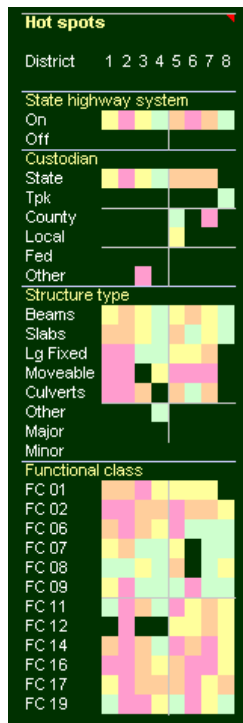


This graph gives you several options to see how costs and performance change over time. You can compare related sets of [performance measures](#), or compare different portions of the [inventory subset](#) you selected.

Lines in this graph are color-coded to the rows of the table just below it. The table also shows the numbers plotted in the graph.

The bottom portion of the [Control Panel](#) determines what information is displayed in this pane.

Hot Spots



This graphic display breaks up the inventory subset you specified in the [Control Panel](#), comparing performance according to the selected [performance measure](#). Each area of the pane is a 2-dimensional breakdown by district and one other classification of bridges.

Within each area, the cells are sorted by performance in the first year of the program horizon. The best 25% of the cells are coded green, the next 25% yellow, then orange, then red for the worst 25%. Thus, the areas of the pane that are reddest have the worst performance.

If a cell in any of the areas is blank, this indicates there are no bridges in that cell in the subset you selected. So if you selected district 1, for example, then only one column will be colored.

Bridges

Network-Level Analysis				<input checked="" type="checkbox"/> Show excluded bridges															
Bridges				<input type="checkbox"/> Show do-nothing bridges															
Please click the buttons at left to operate on each bridge																			
On/Off	Cand. Year	Bridge ID	Structure Name	State Hwy	Dist	Cost	Struc. Type	Func. Class	Major	Replac. Cost (\$1000)	TEV (\$1000)	Point TEV (\$1000)	CFV (\$1000)	Point CFV (\$1000)	Health Index	Point Health Index	Incr. Utility Cost		
On	2008	010032	US 41 NB OVER ALLIGATOR C	1	1	1	2	3	2	469	4347	0	4484	0	30.6	0.0	308.5		
On	2007	010033	US 41 NB OVER OYSTER CK.	1	1	1	2	3	2	182	3236	0	3168	0	36.1	0.0	18083.7		
On	2012	010035	EL JOBEAN BRIDGE EB	1	1	1	1	3	2	3124	24643	6	16801	6	68.2	100.0	46.3		
On	2008	010042	US-41 OVER SUNSET CANAL	1	1	1	2	3	2	623	8076	0	6302	0	85.5	0.0	232.3		
On	2009	010045	US 41 OVER MORNING STAR CANAL	1	1	1	2	3	2	866	9777	0	8428	0	86.2	0.0	167.1		
On	2007	010055	US 41 SB OVER ALLIGATOR C	1	1	1	2	3	2	524	5510	0	5124	0	33.0	0.0	18553.6		
On	2007	010056	US 41 SB OVER OYSTER CK	1	1	1	2	3	2	316	4093	0	3917	0	37.2	0.0	11395.1		
On	2007	010065	AIRPORT ROAD OVER I-75	1	1	1	1	4	2	830	8659	5611	7947	5273	31.8	34.0	5224.5		
On	2010	010066	S JONES LOOP RD/ I-75	1	1	1	1	6	2	1121	11800	7312	10782	6432	31.4	88.8	129.1		
On	2011	010063	I-75 SB/ALLIGATOR CREEK	1	1	1	1	1	2	1336	16448	8970	12584	6252	76.5	63.7	108.3		
On	2010	010070	I-75 NB /ALLIGATOR CREEK	1	1	1	1	1	2	1127	13718	7478	10603	5212	77.3	63.7	128.4		
On	2011	010071	I-75 SB OVER KINGS HIGHWAY	1	1	1	1	7	2	1183	8640	0	8414	0	37.4	0.0	122.4		
On	2010	010072	I-75 NB OVER KINGS HIGHWAY	1	1	1	1	7	2	1183	8643	0	8410	0	37.3	0.0	122.4		
On	2009	010073	I-75 SB / JONES LOOP RD	1	1	1	1	1	2	782	10424	5100	8392	4315	86.3	84.6	185.0		
On	2009	010074	I-75 NB / JONES LOOP RD	1	1	1	1	1	2	782	10431	5100	8435	4314	30.5	84.6	185.0		
On	2008	010078	I-75 SB/SANDY HARTMANS C	1	1	1	2	1	2	338	4388	0	4331	0	86.8	0.0	363.5		
On	2010	010080	I-75 SB/RIVERSIDE DR & RR	1	1	1	1	1	2	1011	7288	0	7039	0	36.6	0.0	143.2		
On	2010	010081	I-75 NB/RIVERSIDE DR & RR	1	1	1	1	1	2	1011	8134	0	7894	0	37.0	0.0	143.2		
On	2009	010082	I-75 SB / TUCKERS GRADE	1	1	1	1	1	2	788	10074	5273	8351	4757	88.3	30.2	183.6		
On	2009	010083	I-75 NB / TUCKERS GRADE	1	1	1	1	1	2	792	10083	5273	9022	4836	83.5	31.7	182.7		
On	2011	010093	US 17 OVER SHELL CREEK	1	1	1	2	2	2	1347	8897	0	7092	0	79.7	0.0	107.4		
On	2007	010095	US 17 SHELL CK N SLOUGH	1	1	1	2	2	2	465	4508	0	3841	0	85.2	0.0	6794.3		
On	2010	010098	SR 776 GOTTFRIED CREEK	1	1	1	1	10	2	1021	8580	0	7728	0	30.1	0.0	141.7		
On	2010	010099	SR 776 OVER ANDERSON CREEK	1	1	1	1	10	2	1384	76044	0	74230	0	39.6	0.0	441.1		

Whenever you make a change in the [Control Panel](#) to specify a subset of the bridge inventory to be analyzed, the NAT filters the list of bridges according to your criteria. You can see which bridges it selected on the Bridges worksheet. This worksheet presents one row per bridge, with a variety of data in the columns for each bridge. The features available here include:

- Click a bridge ID (third column) to see that bridge in the PLAT. If you don't have the PLAT workbook open, Excel will open it for you.
- Click a candidate year (second column) to see the bridge on the [Candidates](#) worksheet. This shows you the detailed results of the [network optimization](#) and how it affects this bridge.
- Click in the on/off column to determine individually which bridges are included in the analysis. This further reduces the size of the inventory subset you specified on the [Control Panel](#).
- Click a column heading to sort the list by that column. Click it again to reverse the order.
- You can use any feature of Excel to manipulate and analyze the list.
- [You can add, move, or remove columns in the list.](#)

The two checkboxes at the top of the worksheet shorten the list by excluding certain bridges. If you check "show excluded bridges", the list will include even the bridges you turned off in the on/off column. They still will not be included in the analysis, however. It is useful to be able to see these in case you want to turn any of them back on.

If you check "show do-nothing bridges", the list will show all bridges considered in the analysis, even the ones where no work was programmed.

If you have made any changes on the Control Panel or the [Configuration](#) worksheet that affect which bridges are selected, the Bridges worksheet will automatically reload next time you go to it. If you're in a hurry and don't want it to finish reloading, simply click the Cancel button on the "Working" dialog if it appears.

In addition to columns from the Pontis bridge, userbrdg, roadway, and inspevnt tables, a variety of calculated columns may appear in the worksheet. Here is a list of the possibilities.

include	Flag indicating whether to include the bridge in the analysis. Must be column A of the worksheet.
candyear	Year of the intervention. Must be column B of the worksheet.
brkey	Bridge key value, as identified in Pontis. Must be column C of the worksheet
platfile	Full path name of the PLAT file last used to generate candidates for this bridge
statehwy	Classification of on/off the state highway system (numbered in the order they appear on the Dashboard Control Panel, starting with 1)
district	Classification of district (numbered in the order they appear on the Dashboard Control Panel, starting with 1)
custodian	Classification of custodian (numbered in the order they appear on the Dashboard Control Panel, starting with 1)
structype	Classification of structure type (numbered in the order they appear on the Dashboard Control Panel, starting with 1)
funcclass	Classification of functional class (numbered in the order they appear on the Dashboard Control Panel, starting with 1)
major	1 for major structures, 2 for minor structures
replcost	Replacement cost of the bridge
tev	Total element value, in the health index computation
pnttev	Total element value of painted steel elements, in the health index computation
cev	Current element value, in the health index computation
pntcev	Current element value of painted steel elements, in the health index computation
health	Health index of the bridge
pnthealth	Health index of painted steel elements on the bridge
deck	NBI deck condition rating estimated for the first year of the program
supr	NBI superstructure condition rating estimated for the first year of the program
subs	NBI substructure condition rating estimated for the first year of the program
culv	NBI culvert condition rating estimated for the first year of the program
candtype	Name of the candidate as determined in PLAT
initcost	Initial cost of the intervention
agcyben	Agency benefit of the intervention
userben	User benefit of the intervention
lccben	Total life cycle benefit of the intervention
actcat	Action category of the most expensive component of the intervention
paint	Indicator of whether the bridge has any painted steel elements (yes/no)
utility	Value of the performance measure selected on the dashboard, for this bridge
iuc	Incremental utility/cost ratio

Tableau

Network-Level Analysis

Optimization Tableau

☒ Expanded

This worksheet is not intended to be edited and should not be referenced by formulas. Click any bridge ID to see its details.

2007 bridges	Action	Cost	CumCost	IUC	2008 bridges	Action	Cost	CumCost	IUC	2009 bridges	Action	Cost	CumCost	IUC	2010 bridges
810651	200	100	100	334.00	140024	100	26300	26300	11.24	750113	100	28900	28900	3.52	2300
810263	200	400	500	83.50	810407	100	52100	78400	3.33	100084	100	132800	161700	3.04	8103
810010	100	1300	1800	58.62	110078	100	28300	106700	8.08	250037	100	51900	213600	2.55	10015
110060	300	1000		52.10	120055	200	28000	134700	8.02	150133	600	876600	1090200	2.25	5000
813003	600	2600	4400	48.35	150604	300	142600	217300	7.33	150221	600	876600	1966800	2.25	10015
083001	100	13600		47.38	100582	100	24700	302000	7.63	110063	600	470500	2437300	2.24	6100
100028	100	419400	423800	47.21	330483	300	63000	365000	7.26	120063	600	5189300	7626600	2.24	6100
150046	600	543200	967000	40.48	330483	300	63000	428000	7.24	120310	600	285300	7911900	2.24	3200
340043	100	10100	371100	37.33	810732	300	41800	463800	7.23	130015	600	884000	8795900	2.23	1500
100337	300	3300	380400	37.27	160250	100	50400	520200	6.30	300054	600	793400	9589300	2.23	17011
160017	100	15800	396200	36.05	330487	300	41200	561400	6.88	150112	100	50500	9633800	2.22	3201
030086	100	33300		35.65	164506	300	123000	684400	6.85	150206	600	1130000	107700	2.22	1202
120138	100	18300	1014500	34.63	330486	300	41300	725700	6.83	830061	600	833100	116030	2.22	53011
813004	300	2700	1017200	34.19	160268	100	26400	752100	6.79	360341	600	266100	118630	2.22	0600
130004	600	193400	1216600	31.32	810583	300	39000	731100	6.79	160064	600	1064300	129340	2.22	7000
050031	100	300		31.22	330525	300	73400	870500	6.70	160063	600	1057900	139920	2.22	1202
120321	100	21200	1237800	31.03	120575	200	24200	834700	6.69	470014	600	654300	146460	2.22	0300
810785	100	2300	1240100	30.83	860625	200	44600	333300	6.63	030137	600	635700	152820	2.22	15011
810154	100	2300	1243000	30.41	810530	300	39000	378300	6.58	180105	600	434500	157160	2.22	5500
810002	100	1100	1244100	30.36	150485	200	30700	1069000	6.56	120068	600	5189300	209060	2.21	1206
030035	100	2300		30.22	100513	300	22500	1091500	6.36	170320	600	455200	213610	2.21	1502
100160	100	3100	1247200	30.19	170085	100	17900	1103400	6.35	120183	600	379700	217410	2.21	5200
120338	100	36600	1283800	29.39	150548	300	21900	1131500	6.23	100158	600	416300	221570	2.21	1500
120230	100	37000	1320800	29.74	150547	300	20900	1152200	6.21	120306	600	379700	225370	2.21	16011
330003	600	2460000	3780800	29.57	330434	300	16300	1169100	6.01	860563	600	2738100	252750	2.21	3600
080047	100	12400	3793200	29.44	860624	200	40800	1209300	5.90	370012	600	718700	253930	2.20	8700
810057	100	1500	3794700	29.40	160267	300	15000	1224900	5.88	120246	100	72800	260660	2.20	10011
300002	100	500		29.40	160238	200	43000	1267900	5.88	150141	600	475800	265420	2.20	15011
380014	100	1100		29.18	120553	200	154300	1422800	5.83	130054	600	604300	271470	2.20	2700
100063	100	1200	3795900	29.00	150543	300	10100	1432900	5.82	150165	600	215000	273620	2.20	0300
030026	100	22600		28.87	160251	100	33300	1472200	5.82	120048	600	512500	278740	2.19	3400
030102	100	2000		28.15	120554	200	128700	1600900	5.81	130032	600	512500	283870	2.19	1000
030088	100	700		28.11	160252	200	32300	1633800	5.71	120370	600	3152400	315390	2.18	1202
030089	100	121000		28.07	120555	200	34400	1655000	5.70	120371	600	3152400	345390	2.18	1202

The network optimization model analyzes one year at a time. It starts with a list of possible investments on bridges that weren't already programmed in an earlier year. These investments are sorted by incremental benefit/cost ratio, then investments are programmed until the [budget](#) is exhausted. This is explained in more detail in the [optimization section](#) of this manual.

Intermediate results for each year of the analysis, presented in the same manner as the [optimization example](#), can be found on the Optimization Tableau worksheet. Yellow-highlighted investments are the ones that were programmed. White investments were considered but not programmed. When a white investment is followed by more yellow investments farther down the list, it means that a higher-cost investment was programmed on the same bridge. It will be one of the yellow investments shown lower in the list that same year.

The "Expanded" checkbox at the top of the worksheet controls how much information is displayed about each investment. If this box is cleared, only the bridge ID is shown and the worksheet then is narrower.

Click on any bridge ID to see that bridge on the [Candidates](#) worksheet.

Candidates

Network-Level Analysis

Candidates for bridge 940951

This worksheet is not intended to be edited and should not be referenced by formulas.

Initial cost of intervention																											
	2007	2008	2009	2010	2011	2012	2013	2014																			
1 Do nothing	0	0	0	0	0	0	0	0																			
2 Auto MRR&l	17800	24100	31000	36800	42300	3200	19300	21100																			
3 Auto replace	836800	836800	836800	836800	836800	836800	836800	836800																			
Gray interventions (if any) were disqualified by the screening criteria. See reasons for disqualification, below. Yellow highlighted candidate and year, if any, was selected by the network optimization.																											
Performance of intervention (percent)																											
	2007	2008	2009	2010	2011	2012	2013	2014																			
1 Do nothing	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00																			
2 Auto MRR&l	1.82	*	*	*	*	*	*	*																			
3 Auto replace	5.33	*	*	*	*	*	*	*																			
Performance is expressed as percent of the most desirable value																											
Incremental utility/cost ratio for qualified interventions																											
	2007	2008	2009	2010	2011	2012	2013	2014																			
1 Do nothing	---	---	---	---	---	---	---	---																			
2 Auto MRR&l	17.0506	*	*	*	*	*	*	*																			
3 Auto replace	0.72367	*	*	*	*	*	*	*																			
Change in utility divided by change in cost when upscoping from the next-less-expensive qualified candidate the same year																											
Reasons for disqualification																											
	2007	2008	2009	2010	2011	2012	2013	2014																			
1 Do nothing	0	0	0	0	0	0	0	0																			
2 Auto MRR&l	0	*	*	*	*	*	*	*																			
3 Auto replace	0	*	*	*	*	*	*	*																			
* Utility is not computed for years after an intervention is programmed. blank = intervention was screened out at the bridge level 0 = passed all screening criteria 1 = disqualified because utility was negative 2 = disqualified because a lower-cost intervention gave higher utility 3 = disqualified because another intervention gave a higher marginal utility for similar marginal cost 4 = filtered out by action category selections on the control panel																											
Detailed data: first interventions with performance forecasts																											
Year	Type	Prog Year	Cost	Utility	Ben/Cost	Life cycle benefits			Condition forecasts: NBI deck-spr-sub-culv; Bridge health index; Paint health index																		
						Agency	User	Total	2007	2008	2009	2010	2011	2012	2013	2014											
2007	1		0	0.00	0.000	0	0	0	467N	466N	366N	365N	365N	365N	365N	365N											
									35	33	32	30	28	26	25	24											
									37	36	34	33	31	29	28	27											
2007	2	2007	17800	1.82	17.051	-7200	0	-7200	467N	466N	366N	365N	365N	365N	365N	365N											
									35	35	33	32	30	28	27	26											
									37	36	37	36	34	32	31	29											
2007	3		836800	5.33	0.730	-706500	0	-706500	467N	667N	567N	566N	566N	465N	465N	465N											
									35	33	37	36	34	32	31	29											
									37	33	37	36	34	33	31	30											
2008	2		24100	1.12	0.000	-15400	0	-15400		466N	366N	365N	365N	365N	365N	365N											
										33	34	33	31	29	28	26											
										36	36	37	35	34	32	31											
2008	3		836800	5.33	0.000	-656500	0	-656500		466N	667N	567N	566N	566N	465N	465N											
										33	33	37	36	34	32	31											
										36	33	37	36	34	33	31											
2009	2		31000	0.18	0.000	-23600	0	-23600			366N	365N	365N	365N	365N	365N											
											32	33	32	30	28	27											
											34	36	37	35	34	32											
2009	3		836800	5.33	0.000	-611200	0	-611200			366N	667N	567N	566N	566N	465N											
											32	33	37	36	34	32											
											34	33	37	36	34	33											
2010	2		36800	-0.57	0.000	-33300	0	-33300				365N	365N	365N	365N	365N											

This worksheet presents detailed information about the network level analysis as it affects one bridge. In the [network optimization](#), a screening process reduces the number of interventions to be considered and calculates an [incremental benefit/cost ratio](#) for priority-setting. The top set of tables shows the inputs and results of this stage.

In the bottom table you can see a listing of all the interventions considered and what happened to them. If one was programmed, it appears highlighted in yellow. Any that were screened out are shown in gray text. The table shows the performance that was predicted for the years following each intervention, as determined in the PLAT.

When you are viewing a bridge on this worksheet, you can click the Details button on the toolbar to see the same bridge in the PLAT.

Configuration

Network-Level Analysis

Configuration

This worksheet holds general inputs that control database access. It may be edited and referenced by formulas.

Model configuration	
US Customary units	TRUE
District	
Include non-state bridges	FALSE
First calendar year of program	2007
Years in program horizon	8
Major bridge deck area threshold	15000

Files and databases	
Default PLAT file	FDOT PLAT.xls
Pontis Connect String	DSN=Florida P43 2005;UID=Pontis;P'W'D=Pontis
PLAT Results Connect String	DSN=Florida PLAT Results

User preferences	
Advanced	FALSE
Auto update bridges worksheet	FALSE
Sort by clicking	TRUE

This worksheet sets various operational parameters governing the NAT and its models. You normally don't need to change anything on this worksheet unless you're a system [administrator](#). The model configuration parameters are generally a matter of agency policy, and the user preferences are for administrators who are [customizing](#) the system. Your system administrator can tell you what connection strings to use for accessing the Pontis database and the [PLAT Results Database](#).

Optimization Model

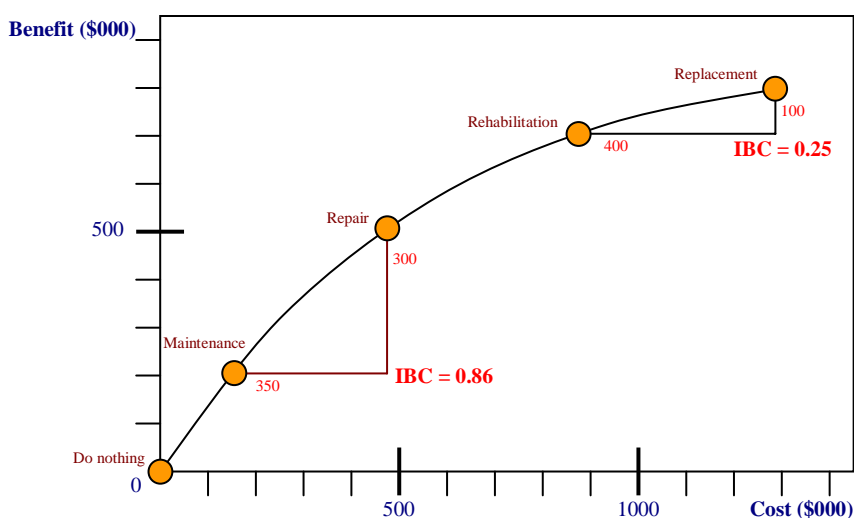
The problem of maximizing one objective subject to one constraint is known as the multiple-choice knapsack problem. The application described here is more particularly known as the capital budgeting problem. This is a famous problem in the operations research literature and has many possible solution methods. Exact solutions to the capital budgeting problem are surprisingly difficult to find, especially for a full-size state bridge inventory. But there is an approximate solution method that reliably produces solutions very close to the true optimum much more quickly than any exact method. This is called the [incremental benefit/cost \(IBC\) method](#). The speed of this method gives us a very user-friendly and responsive decision support tool.

An important aspect of the IBC method is that it produces near-optimal (and not guaranteed-optimal) solutions. It is possible in principle to take an IBC solution, investigate variations on it, and possibly come up with a somewhat better solution. However, the IBC method does offer a softer guarantee, that if the solution is not optimal, the maximum amount of sub-optimality (the additional total benefit that is possible but was not found) is limited to the benefit of the largest candidate selected. For a real-size problem, this is within the margin of uncertainty in the [budget constraints](#) and other inputs, so the small sub-optimality is considered acceptable as a practical matter.

The software algorithm used for computing the optimal program analyzes each year individually, prioritizing candidates according to the incremental benefit/cost ratio, which is the ratio of change in benefit divided by change in cost. Benefit is the improvement in the selected performance measure, relative to doing nothing, made possible by the added expenditure. Investments are programmed one at a time until the budget constraint is met. Bridges that are programmed in a given year are not considered for further action in later years. All of these steps are explained in more detail in the following sections.

Diminishing Marginal Returns

The [IBC method](#) relies on an economic concept called the Law of Diminishing Marginal Returns. This is a concept describing the economic relationships among alternative uses of the same investment capital. Each bridge has several alternative candidates with varying levels of investment and performance benefit. If [funding is constrained](#), it is desirable to find the highest-benefit use for the money. If more funding becomes available, then additional investment can be made in the same bridges to increase the benefit. If the benefits of the various alternative candidates on a bridge are plotted against costs, the curve shown below is a typical result. When interpreting this example, “benefit” is defined as the savings in life cycle cost of doing something, rather than doing nothing, or the improvement in condition or performance from doing something rather than doing nothing. If benefit is positive, this means that the discounted future cost savings exceeds the initial cost, or performance is improved. So any positive benefit is good.



In the example diagram, if the scope of work on the bridge is upgraded from Maintenance to Repair, the additional cost is \$350,000 and the additional benefit is \$300,000, for a marginal return, or incremental benefit/cost ratio (IBC) of 0.86. Similarly, if the scope of work is upgraded from Rehabilitation to Replacement, the cost increases by \$400,000 while the benefit increases by only \$100,000, for an IBC of 0.25.

This typical pattern, where each incremental investment produces a less-than-proportionate increase in benefits, is called the Law of Diminishing Marginal Returns. Under this rule, more expensive alternatives have progressively smaller IBC ratios. In other words, the first dollar gives the greatest benefit and the last dollar gives the smallest benefit. So in a program with a very high or unconstrained budget, the last alternative considered will be the one with a high additional cost but a small additional benefit. This will generally be the alternative with the smallest IBC ratio.

To understand why this curve must always be concave downward, imagine a situation where Repair costs are more than Rehabilitation. If this were true, then Rehabilitation would have higher benefits at lower cost, so it would always be a more economical choice. Because of the competition in any real bridge inventory among a large number of investments, any Candidate that has benefits too low, or costs too high, to fit the diminishing marginal returns curve, will be less attractive than other investments on the same bridge or other bridges. This is equivalent to saying that bridge maintenance projects behave like normal economic goods (rather than Giffen goods). Bridge maintenance models as they have been developed in practice, with discounting, will practically always behave mathematically like a normal good.

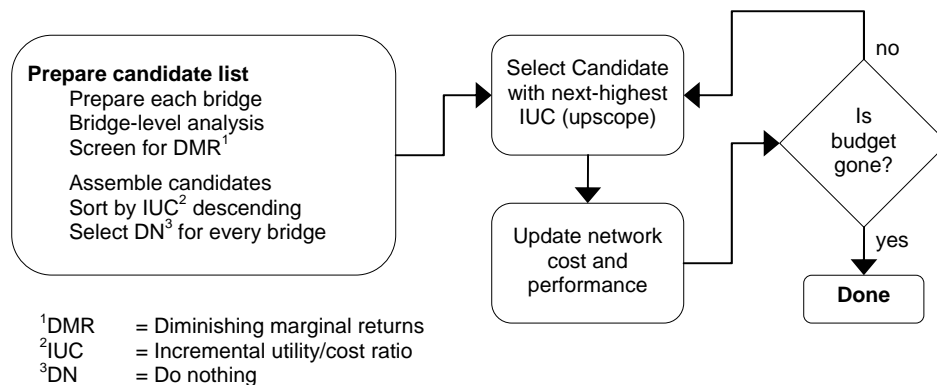
Incremental Benefit/Cost Algorithm

The IBC heuristic maintains a list of investment candidates sorted by the ratio of change in benefit, divided by change in cost. Benefit can be any [measure](#) that is additive over the entire bridge inventory, so an increase in benefit on one bridge also increases benefit by the same amount for the inventory as a whole. On each bridge, a set of alternative candidates is defined, starting with do-nothing at zero cost and zero benefit, and ending with total replacement at maximum cost and benefit. The rule of diminishing marginal returns is essential to the heuristic, so candidates failing to satisfy this rule are eliminated from consideration. The general steps of the heuristic are as follows:

1. Screen the candidates for [diminishing marginal returns](#) on each bridge.
2. Candidates of all bridges are combined into a list, sorted by decreasing IBC.
3. Select do-nothing for each bridge.
4. Process the candidate list in IBC-sorted order. At each stage the [budget constraint](#) is checked.
5. Each candidate replaces the previously-selected candidate on the same bridge, and then the total cost and performance are updated.
6. The heuristic stops after scanning through the complete list or earlier if the budget constraint is met.

In the version of the algorithm implemented in NAT, the final candidate programmed is the one that just equals or exceeds the budget. Thus, programmed expenditures may slightly more than the budget constraint. This keeps the algorithm from getting “hung up” on particularly large projects.

A flowchart of this algorithm appears below. The computationally-intensive part of the IBC heuristic is a sorting algorithm selected for computational efficiency based on the means of updating the candidate list.



As implemented in NAT, the algorithm actually continues past the point of determining programmed cost and performance, in order to determine the cost to satisfy a performance target, and the cost to maintain current performance.

Example of IBC Algorithm

The left side of the table below lists four bridges with a total of 10 alternative candidates (Alt). Each bridge has a do-nothing alternative labeled “0”, which has zero cost and benefit by definition. Life cycle cost (LCC) is calculated by the PLAT for each alternative. Benefit is the LCC of do-nothing minus the LCC of the alternative being considered. [Incremental benefit/cost ratio](#) (IBC) is the ratio of change in benefit divided by change in cost, relative to the next-less expensive alternative on the same bridge. By definition the do-nothing alternatives do not have an IBC because there is no less expensive alternative.

These candidates can be placed in priority order by sorting by IBC. The right side of the table shows the result. The right-most column of this table is the cumulative cost of the four-bridge program as each increment of funding is added, if investments are selected in order of IBC. Please note that cumulative values are not just the cumulative sum of the cost column. This is because when we determine the cumulative amount of money for the bridge network and select any candidate for a bridge on the list, we also need to de-select the previously selected candidate for that bridge. For example, if Alt #2 of Bridge #1 is added to the program (seventh row of the table), then the \$700,000 cost of Alt #2 is added, but this replaces Alt #1, whose \$200,000 cost is subtracted. This is a net increase in cost of \$500,000 which increases the cumulative value from \$600,000 to \$1,100,000.

If no funding is available, do-nothing must be selected for all four bridges, so the total program cost is zero. If \$1.7 million is available, there is enough money to perform Alt #1 on Bridges #2-3, and there is also enough to up-scope Bridge #1 to Alt #2. Also, because the algorithm allows one additional expenditure to use up and possibly slightly exceed the budget, it will up-scope Bridge #3 to Alt #2. If \$2.6 million is available, then there is also enough money to perform the work on Bridge #4.

Candidates grouped by bridge

Bridge	Alt	Cost	LCC	Benefit	IBC
1	0	0	2400	0	--
1	1	200	2000	400	2.00
1	2	700	1400	1000	1.20
2	0	0	3000	0	--
2	1	500	2550	450	0.90
3	0	0	2600	0	--
3	1	400	2000	600	1.50
3	2	600	1850	750	0.75
4	0	0	1900	0	--
4	1	800	1340	560	0.70

All economic quantities in \$000s

Sorted by IBC

Bridge	Alt	IBC	Cost	Cum
1	0	--	0	0
2	0	--	0	0
3	0	--	0	0
4	0	--	0	0
1	1	2.00	200	200
3	1	1.50	400	600
1	2	1.20	700	1100
2	1	0.90	500	1600
3	2	0.75	600	1800
4	1	0.70	800	2600

At any given budget level, total benefits are maximized by following this priority list, within a reasonable level of uncertainty.

The NAT shows these same internal results of the optimization in the [Tableau](#) worksheet.

Performance Measures

The primary purpose of the Network Analysis Tool is to determine the maximum level of inventory performance achievable at any given level of funding. The [budget constraint](#) is intended to be easily manipulated by the user to analyze sensitivity to funding uncertainty. Performance may be measured in several ways, depending on the purpose of the analysis. If physical condition is the only concern, then [NBI ratings](#) and/or [health index](#) are most appropriate. For a broader measure of performance that includes the direct effect of bridges on road users and the value of preventive maintenance opportunities, it is best to use [life cycle cost](#).

All performance measures are calculated individually by bridge in the PLAT, then communicated to NAT through the [PLAT Results Database](#). Then NAT performs the further computations to aggregate performance over multiple bridges.

Performance is calculated by the NAT for any inventory subset selected on the [Control Panel](#). If the choice of performance measure or the composition of the network subset are changed by clicking in the Control Panel area of the [Dashboard](#), all the tables and graphs on the dashboard are updated immediately. The Dashboard also has a [time-series graph](#) and table to enable comparisons of performance between different parts of the inventory.

Percent Good/Excellent

For statewide program management purposes, the primary objective to be maximized by the NAT is the percentage of structures on the State Highway System having a condition rating of either excellent or good, either for the lowest of deck, superstructure, or substructure ratings; or for the culvert rating. This is interpreted as the percent whose lowest NBI condition rating is at least 6.

In order to predict this performance measure into the future as a result of programming decisions, the Federal Highway Administration's NBI Translator Program (distributed with Pontis) is used to convert predicted element conditions into predicted NBI condition ratings. This conversion is performed within PLAT and then communicated to NAT via the PLAT Results Database. Deck, superstructure, substructure, and culvert condition ratings can also be plotted separately in the [time-series graph](#) on the Dashboard.

Health Index

The Health Index was first proposed by the California Department of Transportation as a type of weighted average condition measure for a bridge or any subset of an inventory. It includes all condition states, weighting each element by its failure cost or by some other appropriate weight. This gives emphasis to elements that have the biggest economic impact on bridge functionality. Prioritization by health index gives the same results as “worst-first” prioritization, which understates the importance of preventive maintenance on the better condition states. As a measure of current inventory condition, however, the Health Index is a consistent way to reduce the voluminous data in an element inspection into a simpler quantity that can be compared across bridges and over time. The Health Index is computed as follows:

$$\text{Health Index} \quad HI = \frac{CEV}{TEV} \times 100$$

$$\text{Current Element Value} \quad CEV = \sum_e C_{ef} \sum_i^{N_e} Q_{ei} \left(1 - \frac{i-1}{N_e-1}\right)$$

$$\text{Total Element Value} \quad TEV = \sum_e C_{ef} \sum_i^{N_e} Q_{ei}$$

where C_{ef} is the failure cost for element e

Q_{ei} is the quantity of element e in condition state i

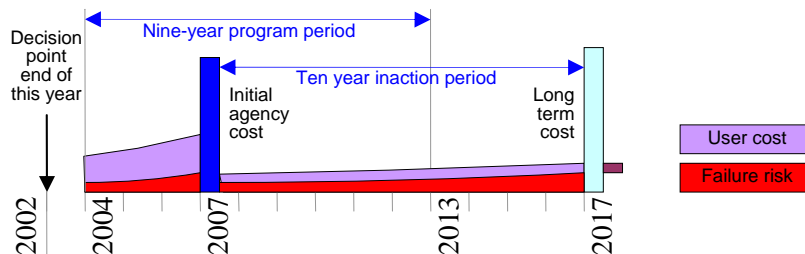
N_e is the number of condition states in element e

At the network level, health index is computed by separately accumulating CEV and TEV over the entire inventory, then performing the HI computation only for the inventory as a whole. This gives greater emphasis to bridges with higher replacement costs.

A separate health index is computed for painted steel elements. This makes it possible to use the NAT to develop a program focused solely on painting.

Life Cycle Benefit

PLAT computes a life cycle cost for every intervention using models of initial cost, action effectiveness, deterioration, functional needs, user costs, and other factors. These models are fully described in the PLAT Users Manual. They are based on a life cycle activity profile shown schematically in the diagram below.



Each type of cost is defined in the table below. If any Candidate is compared with the possibility of doing nothing, the operative question is: will the investment of initial costs (blue) be more than offset by savings in future costs (violet, red, light blue, and purple).

Agency life cycle costs		User life cycle costs	
Direct cost (blue)	Cost directly related to the quantity of scope items	Accident cost (violet)	Expected value of user costs due to excess accident risk, because of narrow bridge roadway
Indirect cost (blue)	Maintenance of traffic, mobilization, and engineering costs	Delay cost (violet)	Expected value of user costs due to height or weight restrictions, or moveable bridge openings
Near-term risk (red)	Possibility of "failure," needing emergency repairs if deteriorated conditions are not remedied	Work zone user cost	Not currently used, will eventually be the user delay cost due to construction work
Long-term cost (light blue)	Total life cycle costs beyond the end of the model, based on ending conditions	Long-term cost (purple)	Remaining user costs beyond the end of the model
Total agency LCC	Sum of the above, all discounted	Total user LCC	Sum of the above, all discounted

These cash flows are discounted to the decision point of the analysis using net present value analysis. Each cost item is discounted (reduced in value) by an amount that depends on how far in the future it occurs. Naturally if a cost needs to be incurred, we prefer to put it off as long as possible, because then it matters less to us. The discount factor represents how much less it matters for each year that we can delay the cost.

Total life cycle cost is computed for every candidate, including do-nothing, for every possible implementation year. Life cycle benefit of an intervention is then computed as the life cycle cost of doing nothing that year minus the life cycle cost of the intervention. It is then the savings in life cycle cost achieved by doing something rather than doing nothing.

Administration

It is recommended that the Excel workbook be administered as a custom reporting program for purposes of deployment and security. It reads from the Pontis database and the [PLAT Results Database](#), and produces results to be read or printed by the end-user. It does not write anything back to any database.

A small amount of data (mainly network subset choices, budget constraints, and performance targets, all specified on the [Dashboard](#)) are created within the workbook and may be saved by the end-user in an Excel .XLS file in the local file system. These data are updated often as a program is refined. Like most Excel files, these should have a normal level of security, protected by the local machine's Windows login procedure and regular backups.

Deployment is recommended to occur once per year. The most convenient way, for administrative purposes, is to provide an Excel template .XLT file in a centralized location accessible to all the users. Each user should launch the system by first launching Excel, then using File – New to create the Excel workbook from the template. If desired, a Windows short-cut to the template can be provided, to ensure that a fresh copy of the system is always loaded. If the user attempts to use File-Save to save changes to the file, Excel automatically prompts for a file location and name. The template can be made read-only in the file system so it cannot be modified.

You can modify the Word document containing the Users Manual, and create a new Acrobat file from it. The Acrobat file must be named “Florida NAT Users Manual.pdf”. Use print driver settings that produce a bookmark pane and create hyperlinks. When you click the Users Manual button on the toolbar, the software searches first in the network templates path, then the local templates path, and finally in the directory containing the workbook (if it was previously saved), looking for this file. Your local templates path is the one that appears first when you save an Excel file as a template, or when you create a new Excel workbook from a template.

A [deployment checklist](#) has been prepared to assist in designing an orderly deployment process. It is recommended that a regular process be undertaken to ensure data quality. See [Data Management](#) for information on the data used in the network analysis tool.

The worksheets in the system are designed to be [modified](#) by advanced users. Such modifications can be gathered and deployed to all users in the subsequent release.

Deployment Checklist

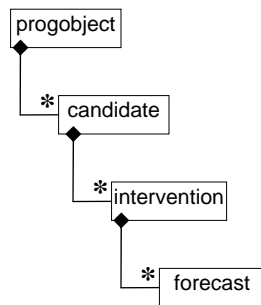
The following steps should be completed each year to update the network analysis tool and deploy it to all users in headquarters and district offices. To access the Excel worksheets containing administrative data and analytical inputs, you will need to click the Advanced mode button on the [toolbar](#). This turns off worksheet protection and exposes the worksheet tab bar, providing access to all the worksheets in the system.

- ☐ Refer to the PLAT Users Manual and complete the deployment checklist there, to ensure there is one working PLAT workstation. You will need to run the PLAT batch process to initialize all your bridges in the [PLAT Results Database](#). NAT requires that the PLAT Results Database first be populated with analysis results before it will produce meaningful outputs.
- ☐ Identify a clean copy of the latest NAT Excel template and Users Manual, incorporating any software updates and refinements made in the past year. Ensure that testing of the software is completed.
- ☐ Check and update the information on the [Configuration](#) worksheet, including everything in the Model Configuration and Files and Databases sections. You must provide an ODBC connection string for both the Pontis database and the PLAT Results database.
- ☐ Finalize the Excel template for deployment.
 - If the [Dashboard](#) is in Advanced mode, click the Advanced Mode toolbar button to put it in normal mode.
 - Save the file as an Excel template, along with the Users Manual, in the Office network templates directory.
 - Set the file's read-only bit.
 - Remove and archive the old template.
- ☐ Notify end-users of the new release. If necessary, send them a new shortcut file pointing to the new template.

Data management

NAT uses data from both the Pontis database and the PLAT Results Database. However, the PLAT Results Database is the source of all the data used in its analysis. Pontis data are used only in the [Bridges](#) worksheet for reporting information about the subset of bridges being analyzed.

When customizing the Bridges worksheet, you can choose any Pontis data items from the bridge, userbrdg, roadway, and inspevnt tables. These are reported on the worksheet but never modified.



The entity-relationship diagram at left shows the four tables in the PLAT Results Database, and how they relate to each other. A program object (probject) is currently the same thing as a bridge, but in the future it can be expanded to other types of transportation assets.

The candidate table contains the names of PLAT candidates, which are shown on the left side of the Candidate Pane on the PLAT Dashboard. An Intervention is one Candidate applied in one implementation year, represented by one cell in the Candidate Pane. A Forecast record contains the forecast performance that would occur in a given year as a result of a given Candidate.

In most cases, the PLAT Results database should be set up on a network server so it can be accessed from all PLAT workstations that will need to update the network level analysis.

Normally it is not necessary to set up password protection for the PLAT Results Database, beyond the access control for its server, since it is not used by any other application and the data are easily re-generated by PLAT.

If desired, you can integrate the PLAT Results database with your Pontis database. Use the provided Microsoft Access database as a model for table and column definitions. Be sure to set up a cascading delete referential integrity constraint as is done in the Access database. Then on the PLAT Configuration worksheet, the PLAT Results Database connect string would be the same as the Pontis connect string. The two connections are never open at the same time.

NAT outputs data only to its internal worksheets, and not to any external files or databases.

Customizing Worksheets

Generally only the [Bridges](#) worksheet is intended to be user-customizable. You can add or subtract columns on the worksheet, including additional Pontis data items and a large selection of calculation results, mostly from the [PLAT Results database](#).

To add, delete, or modify columns in the Bridges worksheet, you need to make use of several rows that normally are hidden. Follow these steps:

- Click the Advanced mode button on the toolbar to go into Advanced mode if not already there. The worksheet tabs will appear at the bottom of the screen.
- Click the “[Config](#)” worksheet tab, find the item named “Sort by clicking,” and set its value to FALSE. Doing this will enable you to select and edit the column headings.
- Click the Bridges worksheet tab. If it starts updating from the database, you don’t have to wait for it to complete. Just click the Cancel button on the “Please wait...” box if it appears.
- Select rows 4 through 9 by click-dragging the row numbers at the far left.
- Right-click the selection and choose Unhide. The worksheet will then appear as below.

	A	B	C	D	E	F	G	H	I	J	K	L
1	Network-Level Analysis											
2	Bridges											
3												
4	Please click the buttons at left to operate on each bridge											
5												
6	calc	calc	calc	bridge		calc	calc	calc	calc	calc	calc	calc
7	inclu	and yes	brkey	strucname		state	dist	cust	struc	func	major	rep
8												
9	On	Cond	Bridge ID	Structure Name	State	Dist	Cust	Struc	Func	Class	Major	Rep
	Diff	Year			Hwy			Type				Cost
												(\$1000)
												TEV
												(\$1000)
10	On	2009	010032	US 41 NB OVER ALLIGATOR C	1	1	1	2	3	2		469
11	On	2007	010033	US 41 NB OVER OYSTER CK.	1	1	1	2	3	2		182
12	On	2011	010042	US-41 OVER SUNSET CANAL	1	1	1	2	3	2		623
13	On	2013	010045	US 41 OVER MORNING STAR CANAL	1	1	1	2	3	2		866
14	On	2007	010055	US 41 SB OVER ALLIGATOR C	1	1	1	2	3	2		524
15	On	2007	010056	US 41 SB OVER OYSTER CK	1	1	1	2	3	2		316
16	On	2007	010065	AIRPORT ROAD OVER I-75	1	1	1	1	4	2		830
17	On	2012	010073	I-75 SB / JONES LOOP RD	1	1	1	1	1	2		782
18	On	2012	010074	I-75 NB / JONES LOOP RD	1	1	1	1	1	2		782
19	On	2009	010078	I-75 SB/SANDY HARTMANS C	1	1	1	2	1	2		338
20	On	2014	010080	I-75 SB/RIVERSIDE DR & RR	1	1	1	1	1	2		1011
21	On	2014	010081	I-75 NB/RIVERSIDE DR & RR	1	1	1	1	1	2		1011
22	On	2013	010082	I-75 SB / TUCKERS GRADE	1	1	1	1	1	2		788
23	On	2013	010083	I-75 NB / TUCKERS GRADE	1	1	1	1	1	2		792
24	On	2007	010035	US 17 SHELL CK N SLOUGH	1	1	1	2	2	2		465
25	On	2014	010038	SR 776 GOTTFRIED CREEK	1	1	1	1	10	2		1021
26	On	2007	030001	RESERVOIR GATE CANAL	1	1	1	2	1	2		968

Row 8 is always blank, to ensure that Excel recognizes row 9 as column headings. Rows 6 and 7 are table and column names that determine what data are loaded.

To insert a column, right-click an Excel column heading (the letter at the very top), and choose Insert. Fill in the database table and column names in rows 6 and 7 of the new column, and be sure to provide a label in row 9 for the column heading. The remainder of the column can remain blank. Excel automatically formats the cells correctly, including underlining the column heading. You can add a left or right border to your column or make other format changes, if desired, using the Excel features on the Format menu.

You can also edit or delete columns. However, you may not change or delete columns A through C, which are used by the software for navigation.

The software also provides a number of calculated data items, identified with “calc” as the table name, that you can use as columns in the worksheet. These columns are shown with the [Bridges](#) worksheet.