Part I

PROJECT AND NETWORK ACTIVITIES

Comparison of Pontis Bridge Project Recommendations to Programmed Work for Three U.S. Transportation Agencies

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ABSTRACT

The Pontis Bridge Management System (BMS) can provide an agency with direct recommendations for bridge maintenance and capital improvement projects. Recommendations are generated using bridge inventory and inspection data, needs generation models, and program development methods.

This paper presents the results of comparisons of Pontis project recommendations to the actual work performed by three agencies: Minnesota Department of Transportation (Mn/DOT), South Carolina Department of Transportation (SCDOT), and the New Jersey Turnpike Authority (NJTA). Each of the three agencies, programs works differently from the others, faces a different set of challenges, and uses Pontis differently within the agency. However, all three agencies have observed reasonable levels of correspondence between Pontis recommendations and actual work. Comparisons have been made between Pontis recommendations and actual work for replacements for Mn/DOT and SCDOT, and for maintenance work for NJTA.

INTRODUCTION

Since its initial development in 1989, the Pontis® BMS has had a significant impact on bridge management in the U.S. First developed through the support of the Federal Highway Administration (FHWA), and now as a product of the American Association of State Highway and Transportation Officials (AASHTO), Pontis is a complete bridge management system. It supports functions including collecting bridge inventory and inspection data; formulating network-wide preservation and improvement policies for use in evaluating the needs of each bridge in a network; and developing recommendations for what projects to include in an agency's capital plan for deriving the maximum benefit from limited funds.

One metric of the usefulness of a BMS is the degree to which its project recommendations conform to the set of projects actually performed by the agency. Ideally, an agency's BMS should make project recommendations that are consistent with agency policy, and the projects actually performed by the agency should be similar to

those recommended by the BMS. However, significant differences may exist between BMS recommendations and actual work as a result of: a lack of sufficient data in the BMS; inaccurate BMS models; differing objectives being sought in the BMS versus actual practice; and/or other technical and institutional factors.

This paper presents the results of comparisons of Pontis project recommendations to the actual work performed by three agencies: Mn/DOT, SCDOT, and the NJTA. These represent three of the over 40 agencies using Pontis. The following sections present an overview of Pontis, comparison of Pontis recommendations to the bridge program for each of the agencies, and a set of conclusions drawn from the comparison.

PONTIS OVERVIEW

Figure 1 illustrates the framework Pontis uses in recommending projects for an agency's capital or maintenance program. Inspection and cost data are used to help develop and update a preservation policy, the set of maintenance actions recommended for each state of each environment in which each bridge element may exist. The preservation policy is used as input to the program simulation, together with user-specified improvement costs and policies, the agency's budget, and other parameters. In the program simulation Pontis develops bridge-by-bridge project recommendations, and sums the needs, recommended work and other metrics across all bridges in a network to produce network-level results.

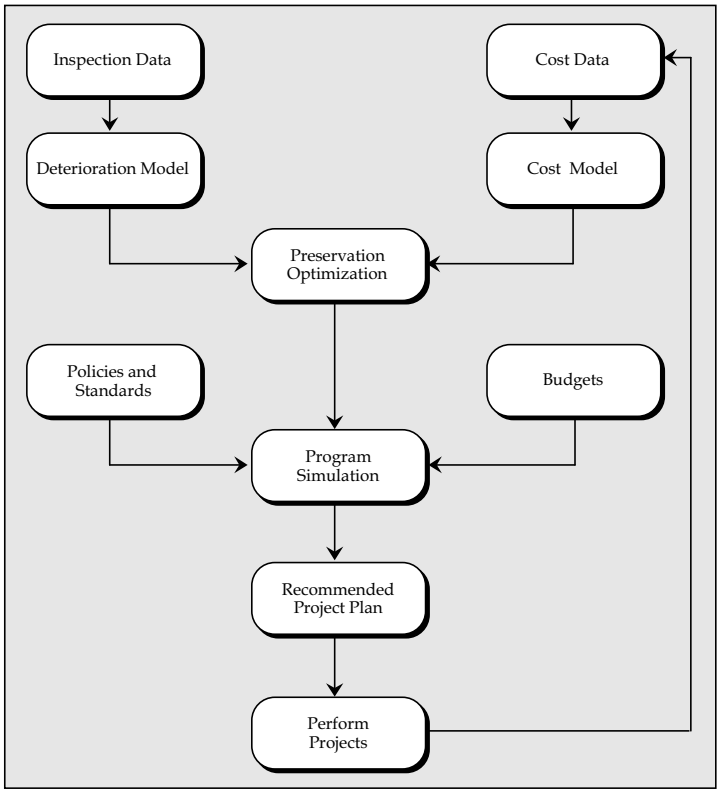

Figure 1: Pontis modeling framework.

Preservation Model

The preservation model recommends a policy for what maintenance, repair and rehabilitation (MR&R) actions to take in each state for each *condition unit* that may exist on a structure, where a condition unit is defined as a combination of a bridge element and environment. Figure 2 illustrates how a structure may be decomposed into structure units (often referred to as spans) and condition units in Pontis. Each condition unit may exist in up to one of five discrete states. For each state there may be up to three feasible maintenance actions.

The preservation policy for a condition unit is determined by formulating a Markov decision model with an infinite time horizon, discounted future costs, and the objective of minimizing discounted long-term agency costs. The model is converted into a linear program and solved using the Simplex method, as has been described in general in the operations research literature (*1*), and in detail for Pontis (*2*).

Program Simulation

The results of the preservation optimization, along with additional data on the agency's budget, and the agency's policies and standards, are used as inputs to the program simulation. The program simulation recommends preservation and improvement projects, within a specified budget, for each bridge in the network for a specified number of years.

Figure 3 is a flow chart of the steps in the program simulation. For each year of the simulation Pontis generates a list of project alternatives for each bridge, sorts the list

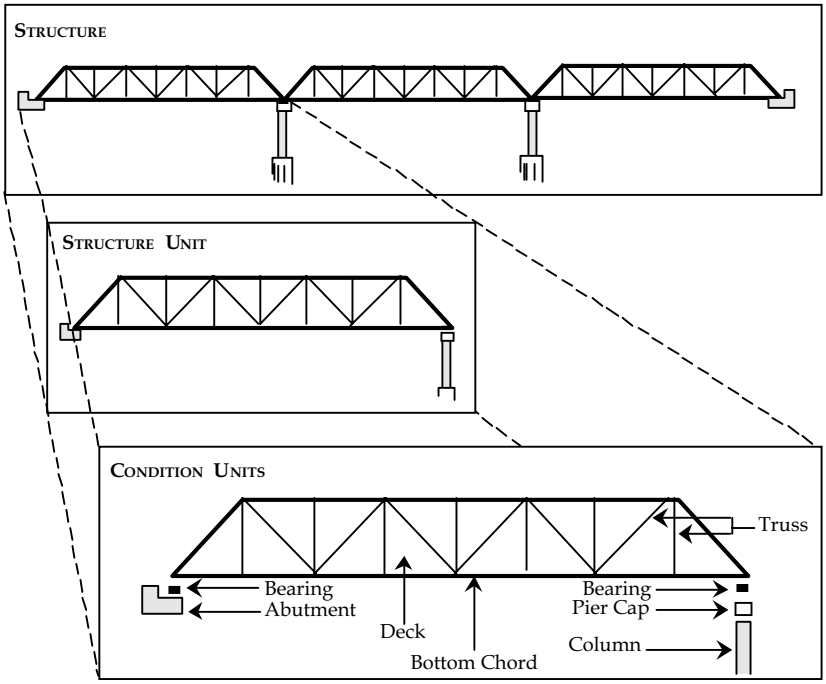

Figure 2: Decomposition of a structure in Pontis.

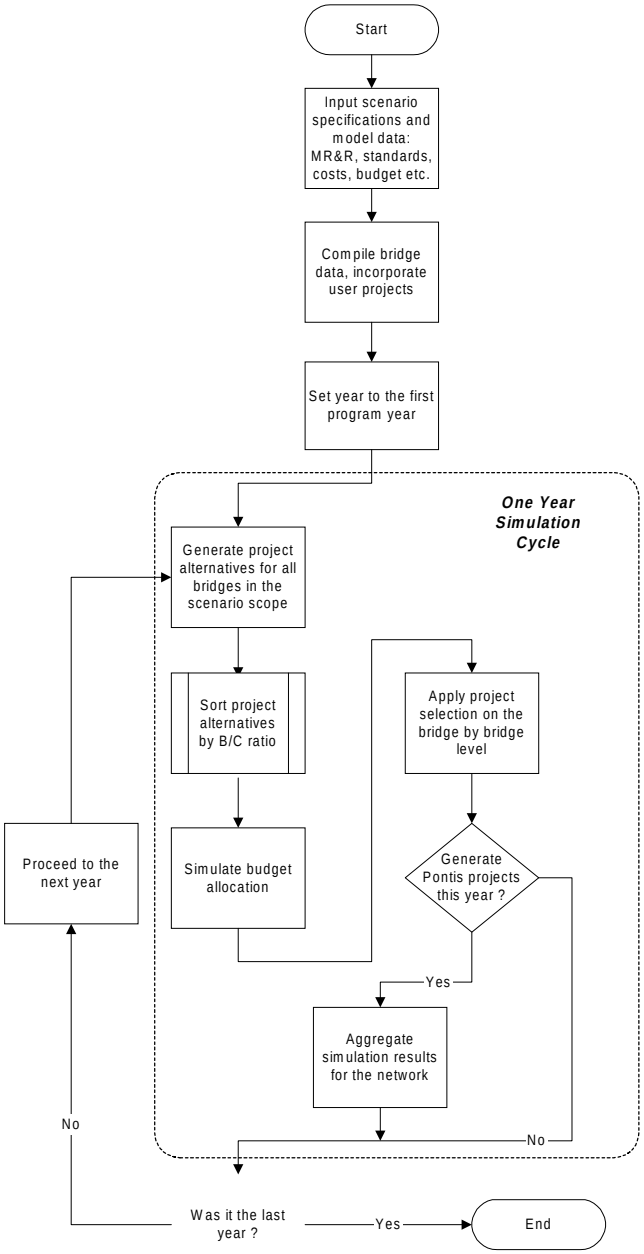

Figure 3: Flowchart of the program simulation.

of projects, and selects projects in decreasing order of incremental benefit-cost ratio. Project alternatives may include preservation projects, generated through applying the preservation policy, improvement projects (widening, raising, strengthening or replacing a structure), user-defined projects, and/or a combination of these.

The overall objective of the simulation is to maximize benefits, subject to a budget constraint and a number of other constraints. For preservation projects, benefits are defined as the savings in agency costs that results from performing the recommended work in the current year, rather than deferring work for a year. For improvement projects,

user benefits are calculated by estimating the travel time savings, vehicle operating savings and savings in accident costs for a candidate bridge improvement.

Besides the agency's budget, a number of additional simulation constraints may be specified to help generate projects that reflect the real-world conditions under which agencies operate. These include:

- **Minimum project cost.** Work is deferred until future years if the sum of the costs of recommended actions on a structure is less than this value.
- **Minimum action cost.** Individual preservation actions are deferred if their cost is less than this value.
- **Deferment years.** After a project has been performed on a structure, work may be deferred for a specified number of years.
- **Replacement threshold.** If the cost of preservation actions for a structure exceeds a specified percentage of the replacement costs, a replacement alternative is triggered. However, this alternative is suppressed if the candidate replacement project fails to meet certain other criteria.

The simulation generates project recommendations for each structure in a network for each program year simulated. Pontis aggregates the project-level results to derive network-level results of needs, recommended work, and projected benefits of doing the recommended work. Pontis also stores the project-level results for use in project planning.

ANALYSIS AND RESULTS OF COMPARING PONTIS RECOMMENDATIONS WITH AGENCY PROGRAMS

The available literature specifically related to Pontis generally either describes the overall design of the project, focuses on some of the details of its models, or discusses network level results obtained using the product (*3–6*). Only recently, since agencies have begun to complete the initial work required to determine the elements in the bridge inventories, conduct element inspections, and generate project-level results in Pontis, has it been possible to make a meaningful comparison between detailed Pontis results and agency work. The following paragraphs present comparisons of Pontis and agency-generated project-level recommendations for the three agencies participating in the study.

Minnesota Department of Transportation

For the Minnesota Department of Transportation (Mn/DOT), comparisons were made between bridges recommended for replacement by Mn/DOT staff and by Pontis for one district. The district used was Mn/DOT District 1, located in the northeastern part of Minnesota and including the City of Duluth. The district is responsible for 600 trunk highway bridges, with 179 on highways with an Annual Daily Traffic (ADT) value of over 5,000 vehicles per day.

In the past the district has used measures such as NBI condition and appraisal ratings, deficiency status, sufficiency ratings, maintenance reports, and in-field evaluation

by inspectors and engineers to select bridges for replacement. Priority for projects is determined by both bridge condition, and external factors such as the timing of other road and bridge projects in the area of the bridge, but not by any projections of future deterioration.

In 1998, District 1 staff developed a 20-year plan for their bridge replacement and improvement program for the years 2001 to 2020. The 20-year plan listed the district's recommended bridge replacement projects for the years 2002 to 2013. Replacements were only planned through 2013 due to uncertainty in conditions beyond that time. For purposes of the comparison with Pontis results, bridge replacement projects that were scheduled to be completed from 1998 to 2000 were combined with the list from the 20-year plan to form a list of 64 bridge replacements planned for District 1.

A Pontis program simulation was run for the district using known funding levels for the years 1998 to 2000 and estimated funding levels for 2001 to 2013. The Pontis simulation resulted in a total of 36 recommended replacements.

Table 1 summarizes the comparison of planned bridge replacements for Mn/DOT District 1 with the Pontis results. Of the 64 projects recommended by the district for replacement, 19 (30%) of the projects also are recommended by Pontis for replacement. Forty-five other projects (70%) were selected by the district for replacement but were not recommended for replacement by Pontis. Of these 45, 30 of the projects (67%) were selected by Pontis for other MR&R work, including 8 bridges which had 3 MR&R projects recommended in a span of 10 years, and 2 bridges which had 2 MR&R projects recommended in a span of 5 years. These 10 bridges with MR&R projects being recommended in rapid succession indicate bridges in poor condition, which are

Table 1: Mn/DOT Summary Results

Description	Number of Structures	Percent of Total
Structures Recommended for Replacement by Pontis		
Programmed	19	53%
Not Programmed	17	47%
Total, All Recommended	**36**	**100%**
Structures Recommended for Replacement by Pontis, High B/C Ratio Only[a]		
Programmed	15	79%
Not Programmed	4	21%
Total, All Recommended with High B/C Ratio	**19**	**100%**
Structures Programmed for Replacement		
Replace. Recommended by Pontis, High B/C Ratio	15	23%
Replace. Recommended by Pontis, All B/C Ratios	19	30%
Replace or Major Maint. Recommended by Pontis	29	45%
No Replace or Major Maint. Recommendation	35	55%
Total, All Programmed	**64**	**100%**

[a] A B/C ratio (measured as annual user benefits/project cost) of 0.06 was used as a cutoff.

deteriorating fairly quickly and would typically be recommended for replacement rather than repair. If the recommended maintenance work for these 10 bridges is up-scoped to replacement and included in the total, then 29 (45%) of bridges were recommended for replacement by both the district and Pontis.

Although only 19 of the 36 replacements recommended by Pontis appear in the district plan, 15 of the top 19 projects are included in the plan, if the projects are ordered by decreasing benefit/cost (B/C) ratio.

In summary, the comparison of Pontis results to the Mn/DOT program for District 1 indicates that Pontis recommends replacement or major maintenance for 45% of the bridges in the actual replacement program. Of the bridges recommended for replacement by Pontis, 53% of the total, and 79% with a high B/C ratio, are in the District 1 replacement program. Although there is a reasonable level of correspondence between Pontis recommendations and the actual plan, there are nonetheless significant differences between the Pontis recommendations and actual results, primarily as a result of the following factors:

- In a Pontis simulation, deterioration of bridge elements over time is modeled, so some of the replacements recommended over a 20-year period are made for bridges that are currently in good condition. However, assumptions about deterioration were not explicitly made in developing the actual Mn/DOT plan.
- The District 1 plan was developed considering additional factors not addressed in Pontis, such as the timing and locations of work planned for other assets in the district.
- It appears that the Pontis models are more likely to recommend maintenance over replacement than a program that results from following traditional Mn/DOT practice. This is an issue that Mn/DOT intends to research further, in order to better determine the best long-term approach. However, the initial results suggest that, whereas Pontis may recommend a series of major maintenance actions on a single structure over several years, in practice it is more practical to lump maintenance needs from different years together, and consider whether it is then more cost-effective to replace the structure.

South Carolina Department of Transportation

SCDOT maintains approximately 8,200 state-owned structures. Prior to using Pontis, SCDOT lacked a formal process for determining what bridges required replacement. However, a general emphasis was placed on using the Sufficiency Rating as a guide to what structures were in need of replacement. In 1995 a list of bridge replacements was prepared for the program years of 1995–1997, independent of Pontis, for a special bridge bond program that emphasized replacement of state-owned structures off of the federal aid system. By focusing on structures off of the federal aid system, the program tended to identify low-ADT bridges for replacement.

A preliminary analysis of the 1995–1997 program indicated that Pontis recommended replacement for approximately 40% of the bridges on the replacement list, though the bridges recommended for replacement by Pontis tended to have lower priority on the list. The results of the analysis led to increased acceptance of Pontis results within SCDOT.

Since 1998 (starting with the 2000 program), replacement lists have been prepared using Pontis together with engineering judgement and other data. The procedure SCDOT has adopted includes the following steps:

- **Step 1:** Use Pontis to generate an initial project list.
- **Step 2:** Send initial project list to districts for review.
- **Step 3:** Analyze results of Step 1 and 2.
- **Step 4:** Develop a preliminary bridge project ranking and programming list.
- **Step 5:** Develop the final bridge project ranking and programming list.

Table 2 presents the results of the SCDOT program development procedure for the 2000 program. As indicated in the table, Pontis recommended a total of 498 replacements. This resulted from a program simulation run with a high budget. The list of candidate replacements was sorted in order of decreasing cost/benefit ratio and sent to SCDOT district offices for review. The list of 498 was narrowed to 31 bridges based on the review. An additional 4 bridges not recommended for replacement were added for one or more of the following reasons:

- In certain cases, maintenance actions that were recommended rather than replacement were infeasible, or were being conducted frequently enough that it was considered more cost-effective to replace the structure.
- In certain cases there were site-specific conditions, not considered in Pontis, that necessitated replacement of a structure.
- Route management considerations (bringing all structures on a route up to the same standards) required selected replacements not recommended by Pontis.

Overall, the final list shows a high degree of correlation with the Pontis recommendations. For instance, if the list of Pontis recommendations is sorted in order of decreasing B/C ratio, and then the bridges in the list are ranked from 1 to 498, the average rank of the 31 bridges included in the program is 82. Thus, on average, the bridges included in the SCDOT replacement program were in the top 20% of the list of Pontis-recommended replacements.

Table 2: SCDOT Summary Results

Description	Number of Structures	Percent of Total
Structures Recommended for Replacement by Pontis		
Programmed in Year 2000	31	6%
Not Programmed in Year 2000	467	94%
Total, All Recommended	**498**	**100%**
Structures Programmed for Replacement in Year 2000		
Replacement Recommended by Pontis	31	89%
Replacement Not Recommended by Pontis	4	11%
Total, All Programmed	**35**	**100%**

Though a detailed comparison of pre-2000 replacements with the Year 2000 program was not performed, the available evidence suggests that the average ADT for structures included in the replacement program increased (to 4,393 vehicles for the 2000 program), as did the average bypass length for replaced structures (to 6 miles). This is a general indication that SCDOT priorities are shifting to place a greater emphasis on maximizing user benefits by replacing structures with higher traffic levels and/or requiring significant truck detours, rather than just those with the lowest Sufficiency Rating.

New Jersey Turnpike Authority

The NJTA has begun using Pontis to develop maintenance recommendations for approximately 500 structures. Prior to using Pontis, the agency relied on expert opinion to prioritize bridges to be included in annual deck, painting and structure repair (including substructure elements, joints and bearings) contracts. The procedure followed involved reviewing inspection reports, generating a list of structures for field checking and further consideration, using engineering judgement to arrive at a short list, followed by more detailed inspections to determine which of those to include in the annual maintenance contracts.

For the 1999 fiscal year, two of the Authority's three major maintenance contracts encompassing deck-related work, Contract Numbers R-1332 and R-1333, were considered. Together these contracts include maintenance work on 34 structures (not including three major structures that are not stored in the Pontis database), and were developed independently of Pontis. For comparison with these contracts, Pontis program simulations were run with budgets set to the contract amounts for each contract, and with the simulation scope narrowed to deck-related work only.

Table 3 below summarizes the comparison of Pontis recommendations with actual work programmed by the agency. As indicated in the table, maintenance work was recommended by Pontis for a total of 101 structures. Of these, 73 were evaluated by the Authority's design engineer for work in either Contract R-1332 or R-1333, independent

Table 3: NJTA Summary Results

Description	Number of Structures	Percent of Total
Structures Recommended for Deck Maintenance by Pontis		
Programmed	15	13%
Recommended for Further Consideration	73	63%
Not Recommended for Further Consideration	28	24%
Total, All Recommended	**101**	**100%**
Structures Programmed for Deck Maintenance		
Maintenance Recommended by Pontis	15	44%
Maintenance Not Recommended by Pontis	19	56%
Total, All Programmed	**34**	**100%**

of the Pontis results. Further, 15 of the Pontis-recommended structures were included in either Contract R-1332 or R-1333.

Overall the correlation between Pontis recommendations and actual work was considered reasonable. The list of Pontis recommendations correlated particularly well with the list of bridges identified for further consideration. The differences between Pontis recommendations and actual work are believed to result primarily from the following factors:

- Pontis element-level inspections are visual inspections only, but visual inspections of deck wearing surfaces can be misleading. In the detailed analysis the history of work done on the deck, soffit, and other factors were considered, in addition to the visual inspections.
- In the case of 9 of the 15 structures for which work was scheduled, but not recommended by Pontis, the structure was near another structure included in the program, and it was considered most cost-effective to work on both structures concurrently. Pontis does not consider proximity and work staging in its recommendations, but these are important factors on routes with heavy traffic.
- Although the unit cost of deck maintenance actions was considered accurate in Pontis, in practice a number of actions not included in the unit cost figure are included in deck maintenance work, such as replacing joints. Ideally, the NJTA would be able to specify that Pontis up-scope its recommendations to include other such activities where appropriate.

CONCLUSIONS

In each of the three agencies included in this study, there is a reasonable correlation between Pontis recommendations and actual work. The results suggest that agencies that have accumulated a complete set of element-level inspections can use Pontis to generate a baseline list of candidate bridge replacements or maintenance projects. However, an agency's actual bridge plan can be finalized only by applying engineering judgement to the Pontis-generated list, determining actual work items and costs at the bridge level.

A number of improvements should be made to the Pontis BMS to enable it to make project recommendations that better match agency practice. The results point to a series of conclusions with respect to how the Pontis program simulation should be enhanced, and how the project planning process in Pontis should be improved.

Enhancements to the Pontis Program Simulation

Comparing Pontis recommendations to actual agency work provides a great deal of insight with regard to how the Pontis program simulation could be enhanced to generate project recommendations closer to those that would be adopted by an agency. Enhancements that should be made to the product include:

- **Recognize physical linkages between elements in making project recommendations.** A key feature of the preservation model in Pontis is that each

condition unit is considered independently. Rules should be added to the program simulation algorithm causing particular combinations of action types and element categories to trigger other actions on other element types.

- **Up-scope projects based on common sense considerations.** Given the high fixed cost incurred in performing maintenance work on a bridge, once the decision has been made to perform maintenance, agencies typically try to satisfy all maintenance needs on the structure, not just the needs that Pontis might identify. The program simulation should be modified to allow users to specify a set of rules for painting and major rehabilitation to account for such common sense considerations.
- **Improve simulation of user projects.** User projects can be entered into Pontis, but the program simulation is aware of a user project only in the year in which it is scheduled. The Pontis program simulation should handle user projects better, recognizing planned future projects (especially replacements), and then suppressing work prior to scheduled work accordingly.

All of these enhancements have been proposed for inclusion in the next major Pontis product release.

Improvements in Project Planning

The authors found it more convenient to manipulate Pontis recommendations outside the product than to use the Pontis project planning screens. A number of improvements should be made to the Project Planning Module in Pontis to improve its usability:

- **Allow for moving projects from one scenario to another.** In Pontis all project recommendations are associated with a particular program scenario, and cannot be moved from one to another. It is critical to be able to do so, in order to build a program that represents the agency's actual plan.
- **Allow for less detailed project descriptions.** In Pontis, maintenance projects specify actions at the state and condition unit level. Pontis recommendations are generated at that level, but agency projects generated externally to Pontis are not. The product should be able to accept project specification at a less detailed level.
- **Convert planned projects into completed actions.** Pontis includes the Action Log Module for recording completed actions, but this facility is independent of the Project Planning Module, resulting in double entry of project data if an agency uses the product as designed. Users should be able to change a project's status from planned to completed rather than reentering project data.

All of these improvements have been proposed for inclusion in the next major Pontis product release.

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