Introducing StruPlan

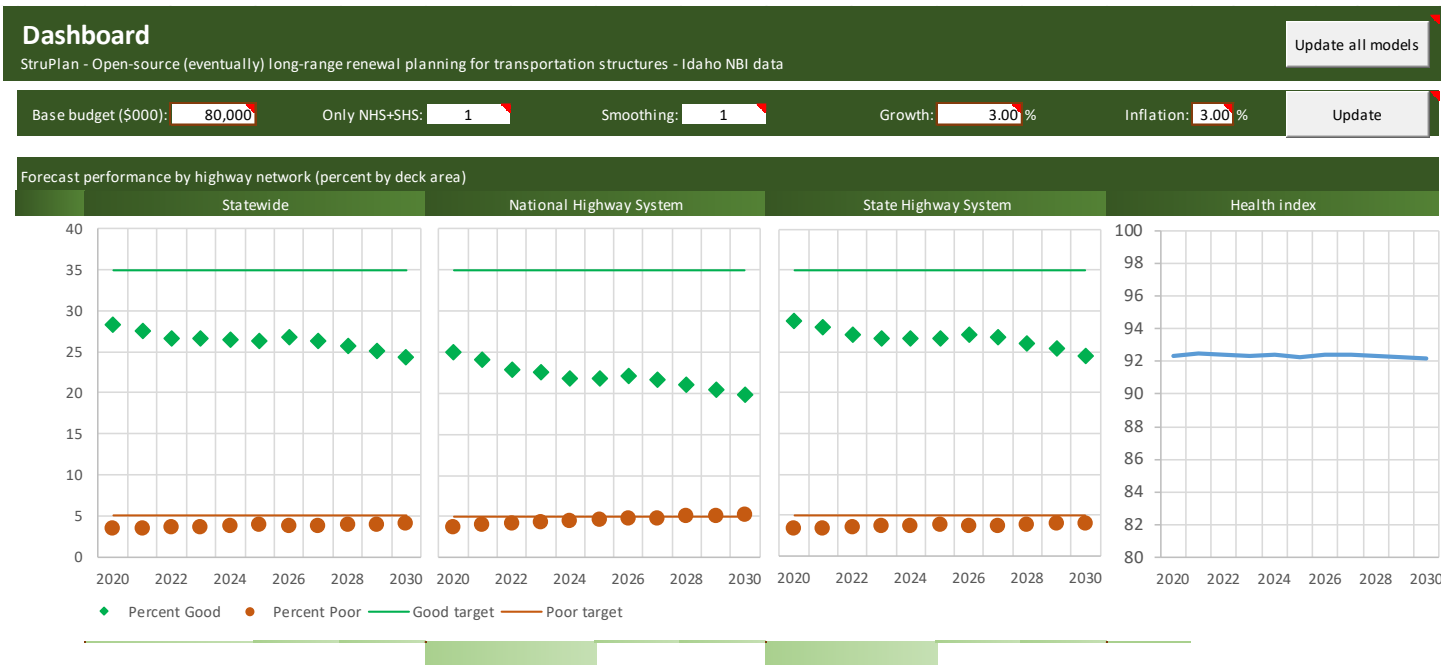
StruPlan is an open-source long-range renewal planning spreadsheet for transportation structures. Using bridge management system data and models, it produces a network level 10-year spending plan, with forecasts of condition and performance, based on an optimized selection of preservation, rehabilitation, and reconstruction activities. Parameters governing costs, deterioration, and treatment selection can be fine-tuned to fit the needs of each agency and program. All substantive calculations and results are readily visible on Excel worksheets, where they can be examined, tested, and modified. StruPlan is intended to be:

- A flexible and responsive tool to support transportation agency decision making;
- A learning tool for students, analysts, and developers who are new to life cycle cost analysis and bridge management systems; and
- A research tool for testing of new models and planning methods.

StruPlan can augment an agency's existing bridge management system by providing the transparency, analysis speed, and flexibility necessary for network-level decision support. It is meant to assist in the following business processes:

- Transportation Asset Management Plan (TAMP) development, to define state of good repair, 10-year performance targets, and 10-year spending plans;
- TAMP implementation, supporting tracking and adjustment of targets and spending plans proactively;
- Long-range needs analysis, and development of levels of service consistent with available resources, under scenarios and policies that minimize long-term cost;
- Capital budgeting and programming in cross-asset decision making processes, using priority-setting methods based on long-term social cost minimization;
- Development of preservation policies that minimize long-term costs, and application of those policies to specific structures.

StruPlan does not replace a bridge management system (BMS), but adds new capabilities that current BMS either do not have, or that are prohibitively difficult, time-consuming, or inflexible in today's systems. It adds value to BMS.



Overview of capabilities

Data can be loaded into StruPlan using copy/paste, or imported from a source spreadsheet. The source file can be exported from a database or downloaded from the Federal Highway Administration (FHWA) web site. The model can work with any type of infrastructure that is inspected using an element and condition state system, in the same form as the AASHTO Manual for Bridge Element Inspection. Models are provided from published sources for bridge deterioration, life cycle cost, functional needs, scour risk, social cost, and federal Transportation Performance Management (TPM) measures. The quantitative parameters for these models are from published sources, and can be updated using data commonly found in BMS. Any aspect of the model can be enhanced using alternative sources or new research over time.

Through its analytical process, StruPlan produces the following basic outputs:

- Identification of the treatment on a given structure in a given year, that minimizes long-term cost, selected from four general approaches: do-nothing, preservation, rehabilitation, or reconstruction;
- Programmatic estimate of the initial cost of the treatment, including direct and indirect costs;
- Forecast condition with and without the treatment, in the form of health index and the federal TPM measures %Good and %Poor by deck area;
- Improvement in safety and/or mobility as a result of functional improvement and risk mitigation;
- Savings in social costs related to detours, crashes, and pollutant emissions;
- Total long-term agency and social cost savings for prioritization;
- Network summary of conditions, performance, and expenditures consistent with the optimized strategy under funding constraints.

All infrastructure management system models attempt to strike a balance among several important considerations, including transparency, execution time, cost, level of detail, realism, data requirements, performance metrics, and flexibility. StruPlan is designed to focus on speed, transparency, and flexibility. The level of detail and data requirements are kept minimal, consistent with the needs of a network level model. This is complementary to the more detailed models often found in bridge management systems. The functionality of StruPlan is confined to a few basic models that are most important at the network level:

- Data preparation
    - Importing of bridge and element data
    - Data clean-up, de-metrication, generic model selection to get started
- Modeling of planning metrics
    - Generation of element families (protective elements and their parents)
    - Long-term cost analysis and treatment selection
    - Forecasting of %Good and %Poor from element/state forecasts
    - Functional needs (safety, mobility, sustainability, risk)
- Support for planning decisions
    - Generation of annual work candidates
    - Prioritization within funding constraints
    - Forecasting of outcomes and spending plans

Element families

Bridge element inspection data include protective elements, such as wearing surfaces and coatings, and an association with a substrate element that is protected. StruPlan ties these elements together for long-term cost analysis, so the condition of protective elements contributes to long-term benefits and affects the choice of treatment. In addition, StruPlan models the potential effect of expansion joint seal condition on deterioration rates of other bridge elements.

Elements are combined into a smaller number of groups that share the same deterioration model, the same potential protective elements, and the same treatment characteristics. Each element group has a set of models:

- A long-term deterioration model in the form of a Markov model, the most common type of deterioration model in bridge management systems;
- A medium-term (10-year) deterioration model that is a hybrid of Weibull and Markov models, to make it age-sensitive;
- Protection factors that govern the effect of protective elements on the associated substrate elements;
- Long-term and medium-term unit cost models, expressed in a generic form that allows combining of dissimilar measurement units;
- Medium-term model of indirect (fixed) costs that are not dependent on bridge conditions;
- A model of treatment effectiveness.

If the imported data have bridges divided into structure units or spans, StruPlan performs its medium-term analysis also at this level of detail.

Long-term cost analysis

The long-term cost analysis in StruPlan simulates each element group and environment under a variety of scenarios of protective system effectiveness and initial treatment alternative. It is a network-level model that simulates an entire population of bridge elements and produces results in the form of unit long-term costs. Later in the medium-term model, the unit long-term costs are scaled to the size of each bridge and combined according to the forecast condition of the element and its protective elements.

Annual conditions and costs in the long-term are forecast year-by-year over 75 years using a Markov Chain. Sensitivity analysis research with these models has shown that conditions converge to a steady state within 75 years under any realistic set of deterioration and cost parameters. After 75 years, the remaining long-term costs are estimated using a perpetuity model. All costs are discounted to present value using an agency-specified discount rate.

The results of all scenarios of element group, protection effectiveness, and treatment are gathered in a single table of network unit long-term cost factors, which is the main product of the StruPlan long-term model. A sensitivity analysis worksheet helps the analyst to visualize the effect of bridge age on the selection of treatment.

Forecasting of %Good and %Poor

Federal TPM measures are relatively new, and do not yet have proven forecasting models. Since reliable deterioration models are based on element level data, it is desirable to have a model that builds on element forecasting to predict the federal measures. Element condition state data are exponentially distributed, but TPM data are categorical at the bridge level (Good, Fair, or Poor). One modeling approach that is compatible with these forms of data and has worked well in research so far, is a Weibull survival model. This model relates the fraction in condition state 1 to the probability of being in Good condition; and likewise links states 3 and 4 to Poor condition.

StruPlan includes worksheet formulas and a VBA module to use maximum likelihood estimation, built on Excel's Solver tool, to develop best-fit parameters of these Weibull models. The procedure is simple but gives useful forecasts. It should be regarded as experimental so far, until more agencies have experience with it.

Functional needs and risk

Departments of Transportation in Florida, North Carolina, and Georgia have done a significant amount of research on bridge functional deficiencies and risk. The models are simple but very useful because they rely on data that are readily available in BMS.

To analyze the effects of clearance and load restrictions, the models estimate the fraction of truck traffic exceeding any given level of height or weight. To analyze the effects of substandard width or approach alignment, the models estimate the relative increase in crashes. For scour, the models estimate the probability of bridge failure. All of these were derived by researchers through field data collection and historical research. The AASHTO Red Book provides economic parameters to estimate the user cost savings if deficiencies are corrected, considering costs of accidents, travel time, and vehicle operations. Public health costs related to excess pollutant emissions (not including carbon dioxide) are also estimated.

Generation of annual work candidates

Analysis at the most detailed level is conducted at the level of structure units and element groups, or SuGrs for short. Each treatment alternative is evaluated for initial cost and long-term cost, in each year of the 10-year period. The calculation uses the results of the network level unit long-term cost model, selecting the treatment with least long-term cost. These results are summed to the bridge level, and there are combined with the results for functional needs and risk. Configurable treatment selection logic in some cases upgrades the work candidate to rehabilitation or replacement based on the type of work needed and its cost.

The final bridge-level treatment decision is returned to the SuGr-level model to make a final forecast of condition outcomes at the end of the 10-year period. At the bridge level, a final determination is made of initial cost, benefit, and outcomes. These are saved for each possible implementation year.

Prioritization within funding constraints

In the priority-setting model, work candidates compete for a limited budget, which is usually much smaller than the total cost of the candidates. Priority is determined using an incremental benefit/cost ranking, where the benefit of programming a given project in a given year is the avoided long-term cost that would otherwise be incurred if the work had to be delayed until the following year. Bridges which are not selected will deteriorate, increasing the long-term agency cost, and will also continue to incur excess user costs, if any.

Each bridge is selected just once during the ten-year period for a capital project. Routine maintenance activities, usually not programmed on a multi-year basis, are included in the long-term cost calculation and not identified individually. Agencies can use the model to investigate budgetary scenarios, taking into account inflation and real growth, if any.

Forecasting of outcomes and spending plans

After application of a budget constraint and prioritizing, StruPlan summarizes the resulting condition and performance outcomes, and the necessary expenditures to achieve those outcomes. Outcomes are reported in terms of the federal TPM measures (%Good and %Poor) and health index. Expenditures are forecast for preservation, rehabilitation, and reconstruction. To support the structure that is common in Transportation Asset Management Plans, separate forecasts and expenditures are provided for the National Highway System and the State Highway System.

Status

StruPlan is in pilot testing through 2020. General release free of charge is planned for early 2021 under a BSD zero-clause (public domain equivalent) license.