Users Manual

StruPlan

Open-source long-range renewal planning for transportation structures

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1. Introduction

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.

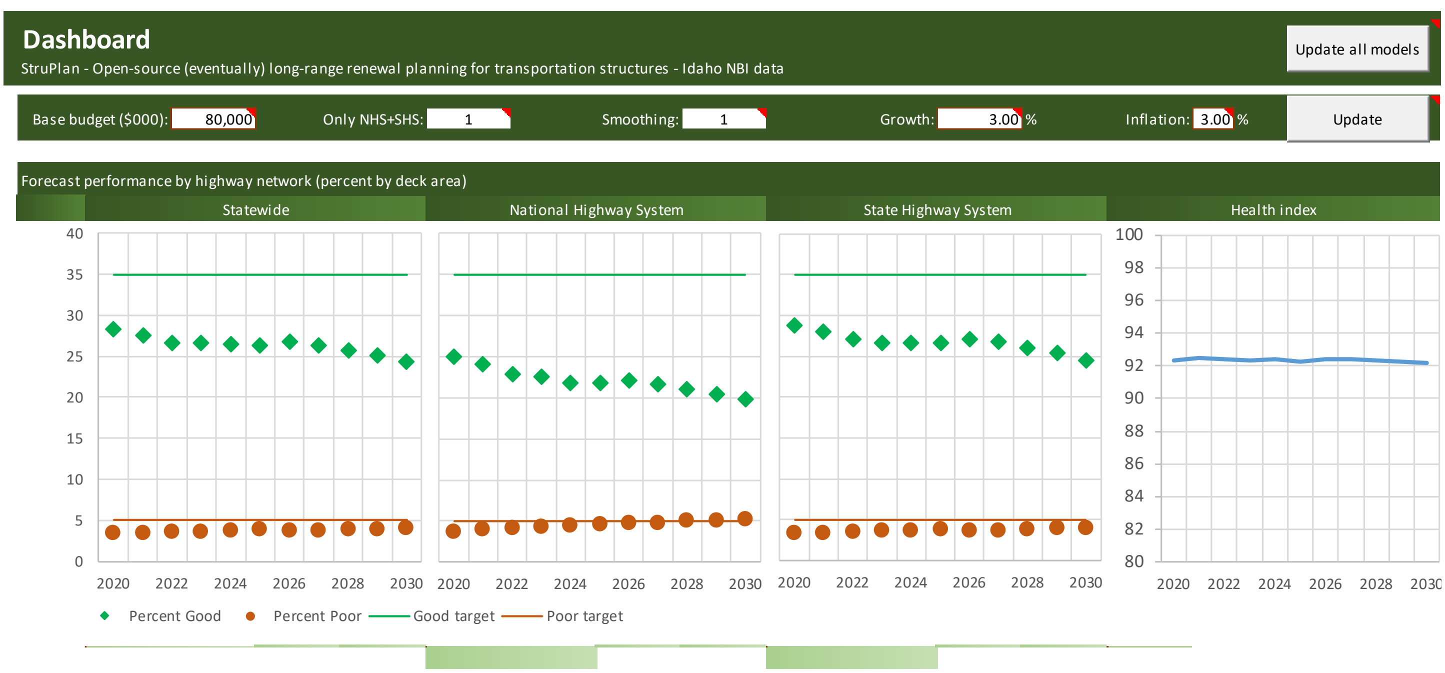


Figure 1. Dashboard display of medium-term condition forecasts

1.1 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 (AASHTO 2019). 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

1.2 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 (Mirzaei et al 2014);
- A medium-term (10-year) deterioration model that is a hybrid of Weibull and Markov models, to make it age-sensitive (Sobanjo and Thompson 2011);
- 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.

1.3 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.

1.4 Forecasting of %Good and %Poor

Federal TPM measures are relatively new (FHWA 2017), 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.

1.5 Functional needs and risk

Departments of Transportation in Florida (Thompson et al 1999, Sobanjo and Thompson 2004 and 2013), North Carolina (O'Connor and Hyman 1989), and Georgia (Garrow and Sturm 2013) 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 (AASHTO 2010) 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 (Thompson et al 2016).

1.6 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.

1.7 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.

1.8 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.

2. Using StruPlan

2.1 Using StruPlan for decision support

StruPlan is a spreadsheet-based planning model. Like any such model, it always shows a forecast of outcomes predicted by the model based on inputs that have been entered. Decision support functionality consists of making changes to the inputs, recalculating, and then evaluating the results. Keep making changes to the inputs to fine-tune the model until the results are satisfactory.

In the following discussion, and throughout this manual, it is recommended that you have your StruPlan file open, and follow along in the spreadsheet as you read the descriptions and instructions. You can have more than one worksheet visible at a time, and this is often useful. On the **View** ribbon in Excel, choose **New Window**.

Before you can use StruPlan for an annual planning cycle, it is important to ensure that the fundamental data requirements are up-to-date, especially bridge conditions and unit costs. See the **Getting Started** section for the step-by-step annual process.

Most of the use-cases discussed above can be performed on the **Dashboard** worksheet. Using the **Dashboard** is easy: adjust funding levels, click the **Update** button (it takes about 8 seconds), then evaluate the resulting conditions and expenditures. Repeat until satisfied.

Planning models always have inherent uncertainty. The way to handle this in a spreadsheet is to make changes in planning assumptions, to see how the outcomes are affected. You will need to use your judgment, and the judgment of your resident experts, to decide on the reasonableness of planning metrics and outcomes. Some of your models might be based on considerable research, and probably should not be changed without updating or improving the research. Other inputs are more heavily reliant on judgment.

Some of the inputs to StruPlan are especially reliant on judgment, and are most likely to be modified as a part of refining the model. These are shaded red in the **Worksheet Reference** chapter. It is recommended to focus on these inputs.

Unit costs and deterioration rates are especially likely to affect the model results. To help in making adjustments, a secondary dashboard, called **SensAge**, is provided. **SensAge** focuses on the **long-term model** for a given element group. It shows how the treatment selection varies with age at first treatment. For example, if you let an element deteriorate and do nothing to intervene for 40 years, what treatment (preservation, rehabilitation, or reconstruction) would be most cost effective then? You can make adjustments to unit costs, deterioration, and other model parameters to make the result more reasonable.

Use the **SensAge** worksheet to fine-tune your preservation strategy. Change the selection of element group at the top of the worksheet, and evaluate the treatment selections on the right side of the worksheet. Make changes to parameters on the **Group** worksheet as needed, and click the **Update LTCs** button (which typically takes less than 1 minute) until you are satisfied. Don't make changes that you or other experts would not think are reasonable. StruPlan does not enforce reasonableness – that's up to you.

All of the calculations in StruPlan are visible on the worksheets. You can examine any part of the model to help you understand what the model is doing and to evaluate reasonableness. You can modify the model if necessary. After you have made changes in the **Group** worksheet or any other part of the model, eventually you'll want to return to the **Dashboard** to see the effect on the overall program.

When you return to the **Dashboard** after making changes elsewhere, click the **Update All Models** button to ensure that all calculations in the entire file are up-to-date. This takes about 3 minutes to run.

2.2 Getting started

The StruPlan workbook and manual can be downloaded from **http://www.struplan.com**. It was developed using Microsoft Excel within Office 365, but does not rely on any features added to Excel since Office 2007. All timings in this manual were obtained on a vintage 2018 CoRe i7 64-bit Windows 10 computer using the 64-bit version of Excel, with an inventory of 1900 NHS and SHS bridges. The spreadsheet should be operable on any computer able to run Excel with VBA macros. Be sure Excel macro security is set to allow macros to run.

The file contains a small data set and a full set of default models to facilitate a quick start. You will want to insert your own bridge and element data, and customize model parameters, to fit your own circumstances. Figure 2 is a map of all the worksheets in the file. See the **Worksheet Reference** chapter for detailed information about the contents of each worksheet.

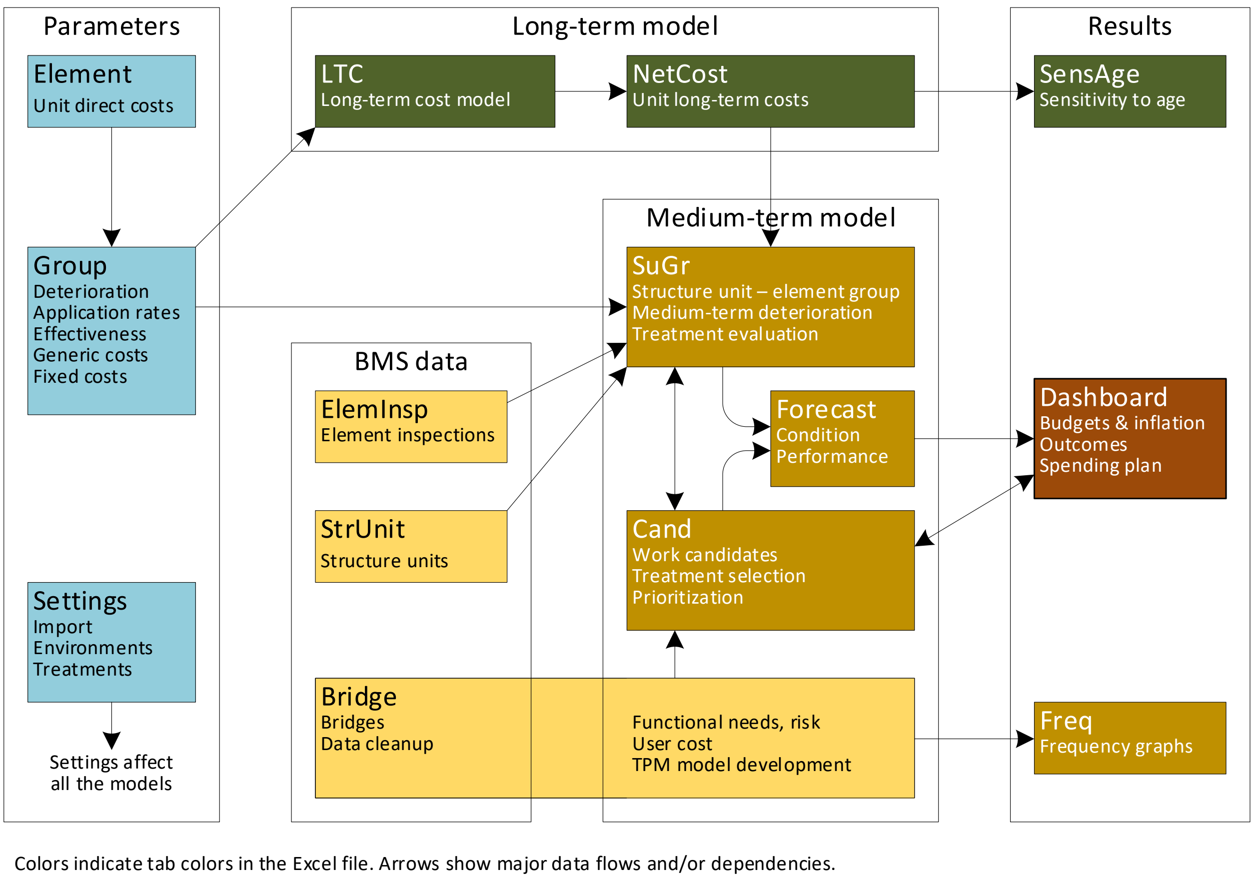


Figure 2. Map of StruPlan worksheets in the Excel file.

Conduct the following steps to set up the Excel file and begin working with the model:

1. Import BMS data. The leftmost columns in the **Bridge**, **StrUnit**, and **ElemInsp** tables must be provided. They can be copy/pasted into Excel from a data source such as an SQL query result table. Alternatively, StruPlan provides an **Import procedure**. See the **Worksheet Reference** chapter for detailed information about the data. The **Bridge** table contains bridge, roadway-on, and inspection data from the most recent element inspection, which should be the same inspection as what is provided on the **ElemInsp** worksheet.
2. The Bridge table has a group of **Data Cleanup** columns with formulas to impute missing data and make other changes to the raw bridge data. Check these columns to ensure their actions are appropriate for your agency's data. There are settings above the table that may need to be adjusted for your agency. Similarly, the **ElemInsp** table has a formula to clean up the environment number if needed.

3. Adjust the parameters on the **Settings** worksheet to fit the data and agency requirements. In particular, be sure the base year, overhead rate, and discount rate are correct. StruPlan comes with a generic national deterioration model based on FHWA's National Bridge Investment Analysis System. You can make this model faster or slower to improve the fit to your agency by adjusting the factors in the **Environments** table.
4. Adjust the element level unit costs on the **Element** worksheet to fit your agency. These costs should be similar to what is used in the agency's BMS.
5. Adjust the deterioration parameters on the **Group** worksheet, if your agency has done the research to develop deterioration models. These parameters should be similar to what is used in the agency's BMS.
6. Use the **SensAge** worksheet to check the reasonableness of the network level **long-term model** for all the element groups listed on the **Group** table that have nonzero populations. The **SensAge** worksheet shows the age ranges in which each of the four treatment categories yields least long-term cost. The parameters on the **Group** worksheet, or the other cost and deterioration parameters mentioned in previous steps, can be adjusted to improve reasonableness. After you change any of the parameters mentioned in this or previous steps, click the **Update LTCs** button on the **SensAge** worksheet to see the effect of the changes. This takes less than one minute.
7. In the upper right corner of the **Bridge** worksheet is the **Transportation Performance Management (TPM) model** for predicting %Good and %Poor from element data. See the **TPM Model** section for information on how this model works. Click the **Solve** button to update the model parameters to fit your inspection data. You can check the reasonableness of the best-fit model by consulting the graphs on the **Freq** worksheet.
8. Also on the top of the **Bridge** worksheet are several tables of parameters affecting the functional improvement model, including unit costs, a consumer price index for user costs, and level of service standards by functional class. These parameters should be adjusted as needed to fit your agency. Generally only the white-shaded cells should be changed. Other parameters in this area are determined from research projects and should not be changed unless further research has been conducted.
9. The **Cand** worksheet has a replacement cost threshold affecting whether rehabilitation projects are upgraded to replacement.
10. The **Dashboard** worksheet has budgetary parameters to define fiscal scenarios affecting the programming of work in the **medium-term model**. If you change any of these parameters, click the **Update** button to see the effect. This takes about 8 seconds.

StruPlan automatically updates all model results when new data are imported. If you paste or manually edit data, you'll need to click the **Update All Models** button on the **Dashboard** to force the models to update. This operation takes less than 3 minutes.

The best way to become comfortable with StruPlan is to run through all the above steps in a preliminary way first, to get models that should be somewhat close to your agency's situation. Then make a second pass to make further adjustments as needed in response to any issues you see with the results. If any results are far off, check the detailed intermediate results in all relevant worksheets for reasonableness. You can even make changes to worksheet formulas if needed to improve the output. The formulas that would most commonly be customized would be the data cleanup formulas on the Bridge table, and the treatment selection logic formulas on the **Cand** and **SuGr** tables. See the **Worksheet Reference** chapter for a detailed examination of every worksheet.

3. Planning models

3.1 Long-term model

An array of tables on the **LTC worksheet** makes use of data gathered on the **Group worksheet** to perform a purely network-level analysis of long-term costs. The model takes advantage of the fact that long-term costs of any individual element are linear with the current fraction in each condition state, provided that transition probabilities and real unit costs remain constant. This makes it possible to conduct the year-by-year Markov chain analysis generically for each condition state, using unscaled unit costs and resulting in an unscaled estimate of discounted unit long-term costs. Later for individual bridges it is unnecessary to repeat the long Markov chain calculation, since the same result can be had by multiplying the element condition state quantities by the unscaled unit long-term costs. This makes the model orders of magnitude faster.

Since different elements have different measurement units (square feet, linear feet, or each), the calculation is simplified by restating all unit costs in terms of $1000 of replacement value. This enables the grouping of elements regardless of their units. The preparation of these restated unit costs takes place on the **Group table**. Scaling of costs (initial and long-term) according to replacement value then takes place on the **SuGr table**.

The long-term cost analysis is conducted separately for each element group and environment, which are set at the top of the **LTC** worksheet. All parameters noted as coming from the **Group** worksheet vary by element group. Several scenarios of protective elements are calculated as discussed later in this chapter. These separate scenarios are not denoted in the subscripts of the following equations, to keep the notation simpler, since they are clear from context.

The subscript *t* in the following equations is the choice of initial **treatment**, from 1 to 4, denoting do-nothing, preservation, rehabilitation, and reconstruction respectively.

When referring to portions of tables in an Excel worksheet, we use the Excel notation of a table name followed by a column name or range of columns in square brackets. See the **Worksheet Reference** chapter for detailed information on each column of each table in each worksheet.

3.1.1 Element groups without protective systems

The calculation of long-term unit cost for treatment *t*, denoted LTC_t uses the following formulas when no protective elements are involved. The involvement of protective elements is discussed **further below**.

$$LTC_t = \sum_s Start_s SVC_{ts} + FixC_t + \sum_{y=Def+1}^{75} \left(\frac{1}{(1+d)^{(y-1)}} \times FC_y \right) + \frac{FC_{75}}{d} \times \frac{1}{(1+d)^{75}}$$

Where:

$Start_s$ = 1 if *s* is the starting condition state, or 0 otherwise.
Separate scenarios are calculated for each of the four possible starting condition states.

SVC_{ts} = Short-term unit variable cost for treatment *t* and state *s*, from **Group**[[PrVC1]:[RhVC4]].
Treatment *t* is assumed to occur at the start of year 1.
Separate scenarios are calculated for each possible treatment.
This unit cost is zero for do-nothing. For reconstruction, the entire cost is fixed.

$FixC_t$ = Fixed cost for treatment *t*, which is zero for do-nothing, from **Group**[[PrFix]:[RcFix]].

y = Year of the analysis, starting with 1. Costs are assumed to occur at the start of each year.

Def = Deferment period, usually 10 years, when no further costs are incurred after the initial cost.

d = Discount rate, from the **Settings** worksheet.

FC_y = Future cost in year *y*, as follows.

In the LTC_t formula, the first two terms are the initial variable and fixed costs for a unit of the element group, where the unit is standardized as $1000 of replacement value. The third term is the discounted sum of a sequence of annual costs, starting after the end of the deferment period and ending with year 75. The model is an ergodic Markov chain: sensitivity analysis has found that conditions converge by 75 years for all reasonable values of the deterioration model. The final term uses the converged year 75 conditions, and estimates the subsequent long-term costs as a perpetuity, which is then discounted to present value.

The calculation of future costs FC_y is done separately for each year, based on conditions forecast after application of a possible long-term treatment. No decision is made as to what type of treatment is applied, so it is represented generically as follows.

$$FC_y = \sum_s E_{ys}(App_s LVC_s(1 + OH) + LMC_s) + E_{y4} RiskC$$

Where:

E_{ys} = Fraction in state *s* in year *y* after the effect of the treatment, from **LTC**[[Effect1]:[Effect4]].

App_s = Application rate in state *s*, the fraction of state *s* that receives treatment each year, from **Group**[[App1]:[App4]].
Accounts for the fact that work is often delayed due to funding constraints and readiness.

LVC_s = Long-term variable cost of whatever work is done to state *s*, from **Group**[[VrCost1]:[VrCost4]].

OH = Overhead rate, from **Settings** worksheet.

LMC_s = Routine (unprogrammed) annual maintenance cost in state *s*, from **Group**[[MtCost1]:[MtCost4]].

$RiskC$ = Annual social cost of allowing state 4 to continue, from **Group**[DisProb] × **Group**[DisCost].

The condition after treatment, E_{ys}, is modeled as an average fraction of each condition state that is moved to condition state 1. First states 2 through 4 are calculated. If *t* > 1 (not do-nothing) and *y* = 1, then the effect of the short-term treatment t is used:

$$E_{ys} = S_{ys}(1 - STE_{ts})$$

Where:

S_{ys} = Condition, fraction in state *s* at the start of year *y*, from **LTC**[[State1]:[State4]].

STE_{ts} = Short-term effectiveness of treatment *t* in state *s*, from **Group**[[PrEff1]:[RhEff4]].
Reconstruction moves 100% to state 1.

If *y* > Deferment, then a generic long-term effectiveness is used:

$$E_{ys} = S_{ys}(1 - App_s LTE_s)$$

Where:

App_s = Application rate in state *s*, from **Group**[[App1]:[App4]].

LTE_s = Long-term effectiveness in state *s*, from **Group**[[Eff1]:[Eff4]].

In all other cases there is no treatment effect, so condition remains unchanged:

$$E_{ys} = S_{ys}$$

Condition state 1 is the fraction that is not in states 2 through 4.

$$E_{y1} = 1 - \sum_{s=2}^{4} E_{ys}$$

Condition starts in year 1 with 100% in whichever condition state the scenario is meant to address. After year 1, condition each year S_{ys} is computed from the condition after treatment in the previous year, using the Markov model.

$$S_{y1} = E_{(y-1)1} P_{11}$$

$$S_{y2} = E_{(y-1)1} \times (1 - P_{11}) + E_{(y-1)2} \times P_{22}$$

$$S_{y3} = E_{(y-1)2} \times (1 - P_{22}) + E_{(y-1)3} \times P_{33}$$

$$S_{y4} = E_{(y-1)3} \times (1 - P_{33}) + E_{(y-1)4}$$

Where:

S_{ys} = Condition, fraction in state *s* at the start of year *y*, stored in **LTC**[[State1]:[State4]].

$E_{(y-1)s}$ = Fraction in state *s* after treatment in year *y*-1, from **LTC**[[Effect1]:[Effect4]]. Modeled as if it occurs at the start of year *y*-1.

P_{ss} = Markov probability of remaining in the same condition state *s* after one year.

$$P_{ss} = 0.5\hat{}(\frac{1}{T_s \times EnvF})$$

Where:

T_s = Transition time, median time to move from state *s* to state *s*+1 if no action is taken. From **Group**[[TT1]:[TT3]].

$EnvF$ = Environment factor from **Environment**[Factor] on the **<u>Settings worksheet</u>**.

3.1.2 Element groups with protection

When a substrate element has protective elements associated with it, its transition probability is modified according to the condition of the protectors. Perfect condition of protectors gives the slowest rate of deterioration and the lowest long-term cost. Worst condition, or absence of a protector in a situation where it is expected, gives fastest deterioration and highest long-term cost. The long-term model recognizes up to two protectors, as follows:

P1 – Either wearing surface or protective coating, as configured in **Group**[P1].

P2 – Sealed expansion joint, as configured in **Group**[P2].

When protective systems are involved, the above equation for P_{ss} for the substrate element group incorporates them as follows:

$$P_{yss} = 0.5\hat{}(\frac{1}{T_s \times EnvF \times P1F_y \times P2F_y})$$

Where:

$P1F_y$ = Protection factor based on the condition of P1, or 1.0 if the element group doesn't expect P1.

$P2F_y$ = Protection factor based on the condition of P2, or 1.0 if the element group doesn't expect P2.

$$P1F_y = P1Max - (1 - \left(E_{y1}^{P1} + \frac{2}{3} \times E_{y2}^{P1} + \frac{1}{3} \times E_{y3}^{P1}\right)) \times (P1Max - P1Min)$$

Where:

$P1Max$ = Maximum protection factor for protector P1, from **Group**[PPMax].

$P1Min$ = Minimum protection factor for protector P1, from **Group**[PPMin].

E_{ys}^{P1} = Fraction in state *s* in year *y* after the effect of the treatment, from **LTC**[[Effect1]:[Effect4]].

The formula for P2 is similar to P1, except using the condition and parameters of protective element group P2. In this formulation the transition probability P_{yss} is now dependent on time, and the relationship of LTC_t to protective system condition is non-linear. Fortunately, if the extreme values of LTC_t are known for both protective systems, there is a simple and very close **approximation** that can be used for interpolating the value of LTC_t from the initial protection factor. This again makes it unnecessary to repeat the 75-year simulation for each bridge individually.

Because of the availability of this approximation, the long-term model considers just four protection scenarios, the permutations of best and worst protection for P1 and P2. Transition times for decks and steel elements in bridge management systems follow the convention that they are presented as if unprotected, or with worst protector condition. Therefore $P1Min$ is generally 1.0, and $P1Max$ is a larger number representing the increased transition time that comes with a fully-intact protective system. On the other hand, if expansion joints are absent, the protected elements are in their most benign situation, so $P2Max$ is 1.0. If a joint exists and its seal is failed, or it is an open joint, then $P2Min$ is a smaller number representing a decreased transition time.

To take advantage of the speed of Excel's multi-threaded recalculation, the **LTC** worksheet contains 48 copies of the long-term cost analysis, arranged in a grid. The 6 rows of the grid are the 2 protective systems followed by the 4 possible starting condition states. The 8 columns are the permutations of 2 extreme values of P1 and 4 possible treatments. This provides all of the scenarios needed for one permutation of group and environment, for element groups that are not protected with sealed joints. It produces one row in the **NetCost** table. A second set of scenarios is run for those groups that can be protected with sealed joints. See the **LTC worksheet** section for information on the structure and computational considerations for this worksheet.

3.1.3 Sensitivity to bridge age at first treatment

The **SensAge** worksheet provides a way to visualize the long-term cost calculations. It uses the models described above, for protected element groups, to forecast condition over a 200-year period, long enough to encompass the economic lifespan of most bridges. In each year, it considers all four treatment alternatives, as though nothing previously had been done to the bridge. In each year, it selects the treatment with least long-term cost.

A comparison of these costs, expressed as a benefit/cost ratio, is presented as a graph (Figure 3). In this example, which shows a concrete deck with wearing surface, do-nothing is optimal up to year 8. Then preservation becomes optimal up to year 24. Then rehabilitation becomes optimal up to year 49. After that, reconstruction is optimal.

The calculation of long-term cost LTC_{ty} on the **SensAge** worksheet uses the interpolation mentioned above to account for protective systems.

$$LTC_{ty} = \sum_s S_{ys} LTC_{ts}^{+} + Scale \times \left(\sum_s S_{ys} LTC_{ts}^{-} - S_{ys} LTC_{ts}^{+} \right) + \sum_s S_{ys}^{P1} LTC_{ts}^{P1} + \sum_s S_{ys}^{P2} LTC_{ts}^{P2}$$

Where:

S_{ys} = Substrate fraction in state *s* at the start of year *y*, from **SensAge**[[State1]:[State4]].

S_{ys}^{P1} = P1 fraction in state *s* at the start of year *y*, from **SensAge**[[P1S1]:[P1S4]].

S_{ys}^{P2} = P2 fraction in state *s* at the start of year *y*, from **SensAge**[[P2S1]:[P2S4]].

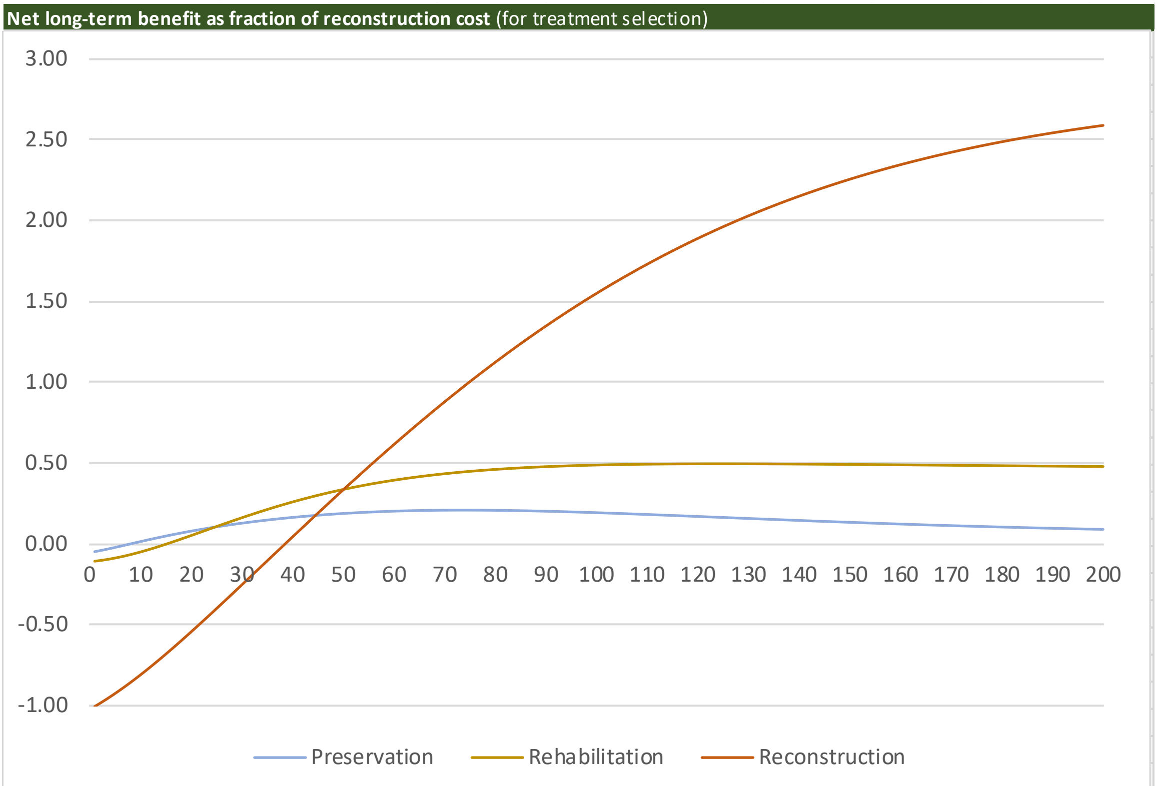


Figure 3. Example of treatment comparison on the SensAge worksheet.

LTC_{ts}^{+} = Substrate long term unit cost for treatment *t* and starting state *s*, under best protection scenario. From **NetCost**[[JBLTC1]:[JBLTC4]].

LTC_{ts}^{-} = Substrate long term unit cost for treatment *t* and starting state *s*, under worst protection scenario. From **NetCost**[[JWLTC1]:[JWLTC4]].

LTC_{ts}^{P1} = P1 long term unit cost for treatment *t* and starting state *s*. From **NetCost**[[NBLTC1]:[NBLTC4]].

LTC_{ts}^{P2} = P2 long term unit cost for treatment *t* and starting state *s*. From **NetCost**[[NBLTC1]:[NBLTC4]].

Scale = Scale factor for excess long-term cost due to deteriorated protective systems (discussed below).

The three terms in the LTC_{ty} equation represent the substrate, P1 protective system, and P2 protective system, respectively. For element groups that are not protected by sealed joints, the third term is omitted and the sources of the substrate unit long term costs are **NetCost**[[NBLTC1]:[NBLTC4]] and **NetCost**[[NWLTC1]:[NWLTC4]].

Interpolation between best and worst protection is in proportion to the log of the protection factor. Sensitivity analysis research has shown that this approximation provides a close match – well within 1% - to a process where every bridge is simulated individually. Scale is computed as follows:

$$Scale = \frac{\log\left(P1F_y \times P2F_y\right) - MinScale}{MaxScale - MinScale}$$

Where:

$P1F_y$ = Protection factor based on the condition of P1, as described above.

$P2F_y$ = Protection factor based on the condition of P2, as described above.

$$MinScale = \log\left(P1Min \times P2Min\right)$$

$$MaxScale = \log(P1Max \times P2Max)$$

Where:

$P1Max$ = Maximum protection factor for protector P1, from **Group**[PPMax].

$P1Min$ = Minimum protection factor for protector P1, from **Group**[PPMin].

A similar calculation is performed on the **SuGr** worksheet to estimate long-term costs for individual bridges.

3.2 Medium-term model

In StruPlan, the medium-term is the period, typically 10 years, for which most agencies develop network level financial plans and transportation asset management plans. Over this time frame, deterioration modeling is important to ensure that sufficient funds are projected to satisfy emerging needs that might not yet be apparent. Also, certain types of projects can have very long lead times that may extend over most of this period. Agency strategies to anticipate and respond to impending funding shortages generally need to be planned and carried out over this time period.

3.2.1 Relationship between short-term and medium-term

A time frame of 5-10 years is sufficiently far in the future that it may not be possible, on specific bridges, to know precisely what kind of preservation work, if any, would be needed. However, it is necessary to know what the overall funding requirements will be, because it typically takes that long to make adjustments to revenue sources, especially when political support is required. StruPlan selects general work categories for each bridge in this time frame, but only for the purpose of making these medium-term financial projections more realistic. It must be understood that this does not represent a final selection. Agencies typically rely on their 4-year Statewide Transportation Improvement Plan (STIP) to communicate short-term bridge needs in terms of specific work on specific bridges. The agency's bridge management system (BMS), not StruPlan, should be relied upon for short-term project-level planning for the STIP.

3.2.2 Relationship between long-term and medium-term

Both long and medium time frames in StruPlan are intended to support network-level use cases as **discussed earlier**. The medium-term analysis corresponds to the time frame required for most of these use cases. However, the justification for most preservation and rehabilitation work is to save money over a longer time period, for the lifespan of the structure and beyond. The expression "cheaper in the long-run" is often used as a reason for keeping bridges in good condition and responding to relatively small defects in a timely way. The **long-term analysis** provides that context, enough information about future deterioration and costs to give a reasonable measure of tradeoffs inherent in the notion of "cheaper in the long-run".

Bridge preservation work is cost-effective in the long run in certain situations but not others. In particular, any time a crew visits a structure to make repairs, there is a substantial expenditure for mobilization and the maintenance of safe traffic flow. Fixed costs therefore are significant in StruPlan and cause the model to project a do-nothing response until the scale of a need, in terms of deterioration extent and long-term cost savings, is large enough to overcome the fixed cost. Once that fixed cost expenditure is committed, then it becomes economically attractive to take care of any other needs that can readily be met by the same intervention, even if those needs are not cost-effective in their own right as stand-alone projects. StruPlan takes this into account when projecting future conditions after work is done.

3.2.3 Treatment alternatives

Research by Florida DOT with the agency's work records found that interventions that improve a bridge's element conditions took place on average every 20 years (Sobanjo and Thompson 2001). FHWA for many years had a policy that it would not normally fund work more often than every ten years on a given bridge. While this policy has been relaxed, it is still common practice that work types needed more often than this are not programmed on a multi-year basis but are instead handled on a reactive basis by maintenance crews. Examples are pothole patching, vegetation and debris removal, and joint seal repairs. StruPlan does not explicitly plan these frequent actions, but instead includes an ongoing cost allowance for them, as a function of condition, in the long-term cost model. Bridges in good condition have lower annual maintenance costs.

What StruPlan does forecast is the more significant actions that take place no more often than once in a ten-year period, and require advance planning and multi-year programming. These are considered in four broad categories.

Do nothing. The default approach, if no other work is programmed, is to perform only routine maintenance. No cost and no improvement in condition are recognized for this alternative.

Preservation. Repairs to individual element groups on individual structure units (SuGrs) are considered at first independently, and then for the structure overall. Decks and painted steel elements are considered together with their protective elements. Typical unit costs are assumed to include incidental repairs to other elements.

Rehabilitation. When any of the primary element groups on the structure are found to be sufficiently deteriorated that rehabilitation yields the least long-term cost, then rehabilitation is considered as a treatment affecting the entire structure. Rehabilitation has more significant fixed costs than preservation and more ability to improve conditions on all elements of the bridge. It can in some cases include functional improvements to a structure that is not sufficiently deteriorated to justify reconstruction, but where potential social cost savings are substantial and the bridge is of a structure type where functional improvement is often feasible.

Reconstruction. This treatment may involve partial or complete replacement of the structure. It can be triggered either by very deteriorated conditions, where it minimizes long-term costs, or by substantial savings in social costs related to functional deficiencies or risk. In addition, if the cost of preservation or rehabilitation needs exceeds a certain percentage of replacement cost, the bridge is considered for complete replacement.

In each year of the ten-year medium term, StruPlan considers all four of these categories, first for each SuGr and then for each structure overall. It selects one of them as optimal, first considering long-term cost and then considering bridge-level concerns of functional deficiencies, risk, and cost. A matrix of work candidates is formed, of which the rows are structures and the columns are years 1 to 10. Each work candidate is evaluated for initial cost, long-term social cost savings, and forecast outcome after 10 years. This matrix then enters into the **priority-setting process**.

3.2.4 Initial cost

Cost estimates for work candidates are not meant to be suitable for design, or even for the STIP. They are meant to be an approximation of budgetary requirements for work that might occur any time in the next ten years. The methodology attempts to keep data requirements to a minimum while being unbiased but all-inclusive.

Agencies differ widely in their ability to develop unit cost metrics for planning purposes. It is assumed that bridge element quantity and condition data will be available, and that some indication of cost can be obtained. Some potential methodologies include:

- For work done by contract divide total cost (from contract documents or pay item records) by the total deteriorated quantity of elements driving the work, adding an allowance for non-contractual costs (e.g. engineering, supervision, etc.). Costs may have to be allocated among element groups when multiple elements are driving the work, or when units of measure may differ.
- For work done in-house, costs might be built up from resource consumption (labor, materials, equipment) with an allowance for overhead.
- Some agencies have cost allocation systems that can break down the work into broad categories that may be useful, such as deck repairs, or painting.
- Sometimes it may be difficult to identify which bridges are included in a contract. But if a network or geographic area can be identified for the contract, it may be possible to assume that bridge elements which improved in condition, and are not in any other contract, are the ones that received the work.
- Sometimes text-based descriptions of projects can be parsed using software, to make a useful classification of work. Florida's research is an example (Sobanjo and Thompson 2001).

These are primarily "top-down" methods that start from a reasonably precise estimate of total agency expenditure from an accounting or project management system, and allocate this money as closely as possible to available subtotals and then to specific bridges. They paper over a lot of differences among projects, which is acceptable for this sort of medium-term planning because comprehensiveness is more important than precision.

StruPlan organizes raw unit costs in the **Element** table, but then converts this right away to the **element group** level, and normalizes by replacement value, before the unit costs are used in any calculations. If an agency finds it easier to develop unit costs in some other form, such as by deck area and/or aggregated to element groups, it would be reasonably straight-forward to modify the **Element** and/or **Group** worksheets to change the methodology. All other worksheets look to the **Group** worksheet for the unit costs that they use in their formulas.

The method used in StruPlan for estimation of work candidate costs depends on the final selected treatment:

- Reconstruction of portions of a bridge, such as the deck or superstructure, are estimated as a purely fixed cost per $1000 of replacement value of the affected structure unit element groups. For total bridge replacement, it is an all-inclusive cost per deck square foot, multiplied by the existing deck area of the bridge.
- For rehabilitation, it is assumed that the most cost-effective treatment is applied to each structure unit/element group (SuGr). Costs of those treatments (discussed below) are summed over all the SuGrs on the structure. If functional improvement was found to be needed, feasible, and beneficial, then the improvement costs are estimated using an all-inclusive unit cost multiplied by deck area. This is added to the total SuGr cost.
- For preservation, it is assumed that the most cost-effective treatment is applied to each structure unit/element group (SuGr). No additional costs are applied for functional improvements.
- Do nothing always has zero cost in this model.

Detailed calculations of these costs can be found on the **SuGr** and **Cand** worksheets, and are described in the **Worksheet Reference** chapter of this document. SuGr cost is partially dependent on condition and partially a fixed cost as a fraction of replacement value, independent of condition. The same overhead rate used in the long-term cost calculation is also used in the medium-term fixed cost calculation, on the **Group** worksheet. A VBA procedure, as part of the network cost update, estimates the typical condition of each element group at ages that are typical for preservation or rehabilitation. A typical configuration would model preservation at age 20 years, and rehabilitation at age 40. The condition at these ages is multiplied by the unit variable costs, and then by the overhead rate, to yield a fixed cost per $1000 of replacement value. See the **Group** table in the Worksheet Reference for details.

3.2.5 Long-term social cost

The calculation of long-term cost LTC_{ty} on the **SuGr** worksheet uses the same interpolation as in the **long-term model** to account for protective systems.

$$LTC_{ty} = \sum_s S_{ys} LTC_{ts}^{+} + Scale \times \left(\sum_s S_{ys} LTC_{ts}^{-} - S_{ys} LTC_{ts}^{+} \right)$$

Where:

S_{ys} = Fraction in state *s* at the start of year *y*, from **SuGr**[[AYS1]:[AYS4]].

LTC_{ts}^{+} = Long term unit cost for treatment *t* and state *s*, under best protection scenario. From **NetCost**[[JBLTC1]:[JBLTC4]].

LTC_{ts}^{-} = Long term unit cost for treatment *t* and state *s*, under worst protection scenario. From **NetCost**[[JWLTC1]:[JWLTC4]].

Scale = Scale factor for excess long-term cost due to deteriorated protective systems (discussed below).

For element groups that are not protected by sealed joints, the sources of the unit long term costs are **NetCost**[[NBLTC1]:[NBLTC4]] and **NetCost**[[NWLTC1]:[NWLTC4]]. Interpolation between best and worst protection is in proportion to the log of the protection factor. Scale is computed as follows:

$$Scale = \frac{\log(PF_y) - MinScale}{MaxScale - MinScale}$$

Where:

PF_y = Protection factor based on the condition of the protecting elements, as described below.

$$MinScale = \log\,(P1Min \times P2Min)$$

$$MaxScale = \log\,(P1Max \times P2Max)$$

Where:

$P1Max$ = Maximum protection factor for protector P1, from **Group**[PPMax].

$P1Min$ = Minimum protection factor for protector P1, from **Group**[PPMin].

The treatment with the lowest long-term cost is selected for each SuGr. The total over all SuGrs on the bridge is used in calculating the agency benefits of work candidates.

3.2.6 Forecast condition

In the medium-term model, condition forecasts are computed for the first 10 years in 10 groups of columns of the **SuGr** worksheet. The columns are named using the year number as the first two digits of the column name, e.g. [02PF] as the protection factor in year 2. Condition starts in year 1 with the same fraction by state as in the most recent inspection. Element condition is aggregated into element groups using a weighted average by replacement value. After year 1, condition each year S_{ys} is computed from the condition after treatment (if any) in the previous year.

$$S_{y1} = E_{(y-1)1}P_{y11}$$

$$S_{y2} = E_{(y-1)1} \times \left(1 - P_{y11}\right) + E_{(y-1)2} \times P_{y22}$$

$$S_{y3} = E_{(y-1)2} \times \left(1 - P_{y22}\right) + E_{(y-1)3} \times P_{y33}$$

$$S_{y4} = 1 - S_{y1} - S_{y2} - S_{y3}$$

Where:

S_{ys} = Condition, fraction in state *s* at the start of year *y*, stored in **SuGr**[[yyS1]:[yyS3]].
Since the state 4 fraction isn't needed for deterioration calculations, it is not stored in the table.

$E_{(y-1)s}$ = Fraction in state *s* after treatment in year *y*-1, whose source depends on [SelYr], the year of treatment.
If [SelYr]=y-1, then it comes from **SuGr**[[Eff1]:[Eff4]], otherwise from **SuGr**[[xxS1]:[xxS3]] where x=y-1.

P_{yss} = Probability of remaining in the same condition state *s* in year *y*, from **SuGr**[[yyP11]:[yyP33]].

The medium-term model uses a Weibull model to forecast the onset of deterioration (Sobanjo and Thompson 2011). The model is age-dependent, so it depends on an estimate of the equivalent age of the element group, which is derived from earlier condition, either in the most recent inspection or after a previous treatment. The Weibull model makes the forecasts more realistic by reducing the rate of deterioration for elements in new condition. The transition probability for condition state 1 is computed as follows.

$$P_{y11} = \mathrm{EXP}(-(Age_y \,/\, \alpha_y)^{\beta} + ((Age_y - 1) \,/\, \alpha_y)^{\beta})$$

Where:

Age_y = Equivalent age, which is normally the previous year's age plus 1, stored in **SuGr**[yyEq].
For the first year after an inspection or treatment, equivalent age is:

$$Age_y = 1 + \alpha_y \times -\mathrm{LN}(E_{(y-1)1})^{1/\beta}$$

α_y = Scale factor for the Weibull model, stored in **SuGr**[yySc].

$$\alpha_y = \left(PF_y \times T_1 \ \times EnvF\right) / \ (\mathrm{LN}(2)^{1/\beta})$$

β = Shaping parameter of the Weibull model, from **Group**[Shape], a result of deterioration research, for example Sobanjo and Thompson (2011).

$E_{(y-1)1}$ = Fraction in state 1 after treatment in year *y*-1, whose source depends on [SelYr], the year of treatment. If [SelYr]=y-1, then it comes from **SuGr**[Eff1], otherwise from **SuGr**[xxS1] where x=y-1.

PF_y = Protection factor based on the condition of the protecting elements, as described below.

T_1 = Transition time, median time to move from state 1 to state 2 if no action is taken, from **Group**[TT1].

$EnvF$ = Environment factor from **Environment**[Factor] on the **Settings** worksheet.

The Weibull model computes state probabilities based on age, but here an equivalent transition probability is computed from the ratio of last year's state probability and this year's. The Florida research found that this way of framing the calculation avoids certain numerical problems, and also makes the Excel formulas simpler.

For condition states 2 and 3, the simpler Markov model is used. This is not directly age-dependent, but does rely on the forecast of protective system condition from the previous year, which in turn depends on the age-dependent Weibull model.

$$P_{yss} = 0.5\hat{}\left(\frac{1}{PF_y \times T_s \times EnvF}\right)$$

Where:

T_s = Transition time, median time to move from state *s* to state *s*+1 if no action is taken. From **Group**[[TT2]:[TT3]].

The protection factor PF_y plays a role in the forecasts of condition and long-term cost. An element group can have zero, one, or two protective systems. If present, each protector has a separate row in the **SuGr** worksheet and has its own calculations of initial cost, long-term cost, and condition. Without protective elements, the protection factor is merely 1.0, otherwise it is determined as follows.

$$PF_y = P1FY_{y-1} \times P2FY_{y-1}$$

Where:

$P1F_{y-1}$ = Protection factor based on the condition of P1 last year, or 1.0 if the element group doesn't have P1.

$P2F_{y-1}$ = Protection factor based on the condition of P2 last year, or 1.0 if the element group doesn't have P2.

$$P1F_{y-1} = P1Max - (1 - \left(E^{P1}_{(y-1)1} + \frac{2}{3} \times E^{P1}_{(y-1)2} + \frac{1}{3} \times E^{P1}_{(y-1)3}\right)) \times (P1Max - P1Min)$$

Where:

$P1Max$ = Maximum protection factor for protector P1, from **Group**[PPMax].

$P1Min$ = Minimum protection factor for protector P1, from **Group**[PPMin].

$E^{P1}_{(y-1)s}$ = Fraction in state *s* after treatment in year *y*-1, whose source depends on [SelYr], the year of treatment. If [SelYr]=y-1, then it comes from **SuGr**[[Eff1]:[Eff4]], otherwise from **SuGr**[[xxS1]:[xxS3]] where x=y-1..

The formula for P2 is similar to P1, except using the condition and parameters of protective element group P2.

As discussed above, annual forecast conditions are used in the estimation of work candidate initial costs and long-term costs. In later steps, they are also converted to TPM measures %Good and %Poor. The result is reported as an outcome after 10 years, and is also presented year-by-year in the **Forecast** worksheet and **Dashboard**. The section on **TPM model**, below, describes how the conversion takes place.

3.2.7 Priority-setting and funding constraints

The medium-term model creates on the **Cand** worksheet a matrix of work candidates, of which the rows are structures and the columns are years 1 to 10 in which the work might be done. Each work candidate is evaluated for initial cost, long-term social cost savings, and forecast outcome after 10 years. This matrix then enters into the priority-setting process.

In the context of priority setting, the decision to be made in each year on each structure is whether to implement the selected work candidate, or postpone the work for another year. If the work is postponed, condition deteriorates, thus increasing long-term cost, and another year of social costs are incurred. The benefit of deciding not to postpone, is the ability to avoid these excess costs. The cost of this decision is the reduction of funding available for other purposes, if the cost of the work candidate is programmed. So the benefit/cost priority criterion BC is calculated as follows.

$$BC = \frac{LTSC_{y+1} - LTSC_y}{IC_y}$$

Where:

$LTSC_y$ = Long-term social cost of the work candidate selected for year *y*, the sum of agency, user, and risk costs.

IC_y = Initial cost of the work candidate selected for year *y*.

The Excel RANK function is used for each year's column of work candidates to prepare a ranking of projects according to this criterion. Then a VBA function selects the highest-ranked work candidates until the year's budget is used up. This is repeated for each year of the medium-term. Once a bridge is programmed, it is set aside from the ranking and not considered further. After all years are programmed, the forecasting model prepares the **Forecast** worksheet to support condition graphs in the **Dashboard**. Condition state forecasts are converted to the federal TPM measures as described in the next section.

Any time the budget is modified on the **Dashboard** worksheet, the **Update** button can be clicked to make appropriate changes in the project selections and redo the forecast. This takes about 8 seconds.

3.3 TPM model

StruPlan converts certain forecasts of element condition to estimated probabilities of a Good or Poor rating according to federal Transportation Performance Management (TPM) definitions (FHWA 2017). TPM measures are necessary for Transportation Asset Management Plans and can be useful for tracking of performance targets when implementing these plans. FHWA designates a structure as Good if all of the applicable NBI component condition ratings (items 58, 59, 60, and 62) are at least 7. It designates a structure as Poor if any of the NBI component condition ratings are 4 or below.

StruPlan does not attempt to forecast NBI component ratings; it merely forecasts the probability that a structure is Good or Poor, a statistically much less demanding task.

Element condition state data are exponentially distributed, but TPM data are categorical at the bridge level (Good, Fair, or Poor). Several forms of predictive models are potentially compatible with these types of data, including the discrete choice logit models often used in transportation demand forecasting. One modeling approach that 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.

The **Bridge** table devotes its right-most set of columns to the development of TPM prediction models, using the most recent NBI component condition ratings and corresponding element inspections as input data. A maximum likelihood estimation process produces a set of Weibull model coefficients, stored in the **TPM** table at the top of the Bridge worksheet. These models are subsequently used on the **Cand** and **Forecast** tables to convert forecasts of future element conditions to forecasts of future %Good and %Poor.

This model is quite new and has not yet been widely applied. Therefore it should be regarded as experimental for the time being. Further research will help to refine and improve the model to ensure its usefulness to forecast outcomes and to aid in setting long-range performance targets (Thompson 2021).

The calibration process on the **Bridge** worksheet develops seven separate models. Percent Good and Percent Poor models, based on condition, are each developed for three networks:

NHS = NBI bridge on the National Highway System
SHS = State-maintained structure not included in NHS
Non = Structure not included in NHS or SHS

A seventh model is calibrated based on age rather than condition, for new structures on any network.

The calibration process begins by classifying each structure in a network, and its NBI component condition as Good or not Good, and Poor or not Poor. These binary choices are the dependent variables. Average element condition is computed, considering only primary elements (as configured on the **Group** table) and weighted by replacement value. The independent variable for the Good model, $GLog$, is a log transformation of the fraction in state 1.

$$GLog = \text{LOG10}(2 - S_1) \times (1/\text{LOG10}(2))$$

Where:

S_s = Fraction in condition state *s*.

The predicted probability of Good, $GPred$, is calculated from a Weibull model.

$$GPred = \text{TPM[Const]} + \text{TPM[Slope]} \times \text{EXP}(-(GLog/\text{TPM[Scale]}) \text{ ^ } \text{TPM[Shape]}))$$

All of the TPM coefficients are from the **TPM** table and are to be estimated using the maximum likelihood procedure. The accuracy of the prediction is quantified for each structure using a log likelihood function $GLike$.

$$GLike = [\text{Good}] \times \text{LN}(GPred) + (1 - [\text{Good}]) \times \text{LN}(1 - GPred)$$

A VBA procedure automates Excel's Solver tool to find the optimal values of the TPM coefficients that maximize the sum of $GLike$ over each network. Note that $GLike$ is a negative quantity, so maximizing it brings the total weighted spread between predicted and actual closest to zero. The **TPM** table computes a minimum sum of log likelihood as the prediction accuracy that would occur if the model has no predictive power at all, i.e. if the coefficients are all zero. A statistical property known as the p-Statistic estimates the probability that any correspondence between predicted and actual is only random chance. Therefore a good model is one where the p-Statistic is zero or very close to it. The Solver tool returns a code indicating whether it was able to find an optimal set of coefficients.

The model for Poor condition is very similar to the one for Good. The independent variable $PLog$ is:

$$PLog = \mathrm{LOG10}(1 + (S_4 + \mathrm{TPM[S3Wt]} \times S_3)) \times (1/\mathrm{LOG10}(2))$$

Unlike the Good model, this variable for Poor does not reverse the direction of the scale. Note that the relative weight given to condition state 3 is a model parameter that is determined in the same process as the rest of the parameters. The predicted probability of Poor, $PPred$, is:

$$PPred = 1 - (\mathrm{TPM[Const]} + \mathrm{TPM[Slope]} \times \mathrm{EXP}(-(PLog/\mathrm{TPM[Scale]})\ \hat{}\ \mathrm{TPM[Shape]})))$$

The log likelihood function $PLike$ is:

$$PLike = [\mathrm{Poor}] \times \mathrm{LN}(PPred) + (1 - [\mathrm{Poor}]) \times \mathrm{LN}(1 - PPred)$$

A seventh model forecasts the probability of Good, based on age rather than condition. This appears to be more accurate for structures that are new or newly-replaced. The same model is used for all three networks.

$$GPred = \mathrm{EXP}(-(Age/\mathrm{TPM[Scale]})\ \hat{}\ \mathrm{TPM[Shape]}))$$

The likelihood function is the same as in the condition-based Good model.

All seven models are calibrated using the same VBA procedure, which can be updated using the **Solve** button on the **Bridge** worksheet. It is unknown yet how consistent the TPM coefficients will be among agencies or over time. So currently it is recommended that this model be updated every time new bridge data are imported.

The **Freq** worksheet presents several graphs to aid in visualizing the relationship between element condition and TPM measures for the NHS models. Figure 4 is an example.

The TPM model is applied to forecast conditions on the **Cand** and **Forecast** worksheets. The calculations for this are identical to those described above, except the log likelihood functions are not needed.

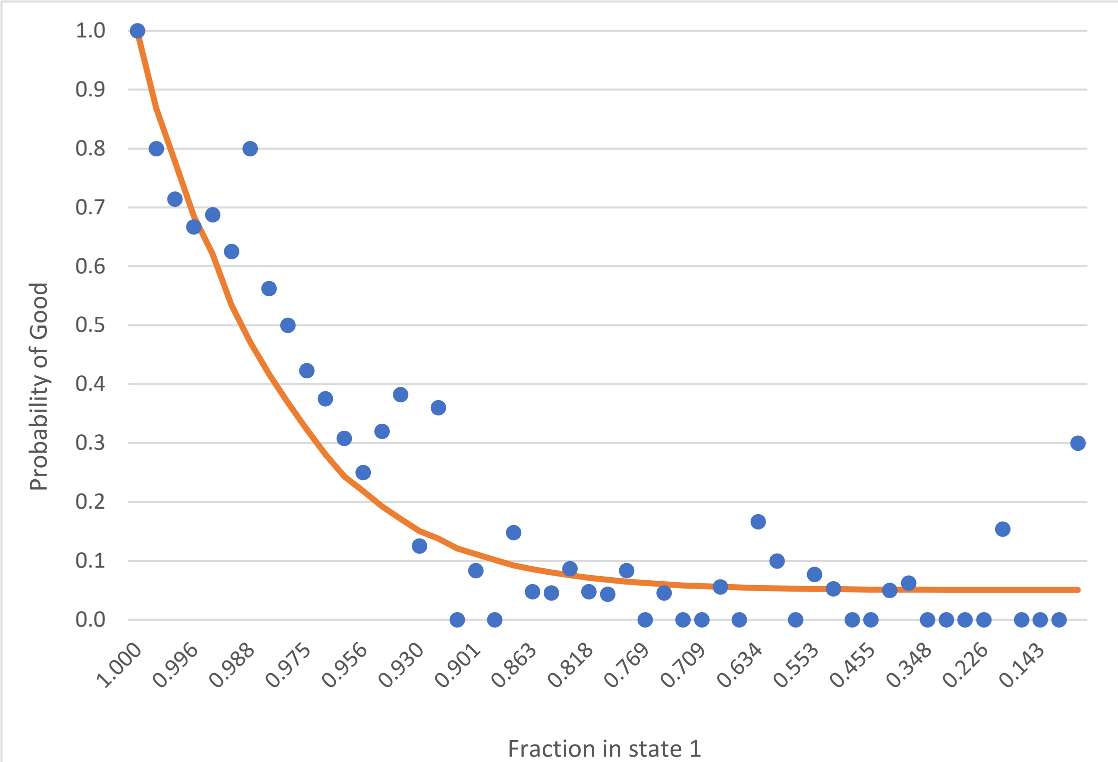


Figure 4. Probability of Good vs fraction in condition state 1.

4. Worksheet reference

The following sections describe in detail all of the worksheets in StruPlan. Much of this information can be found in notes, text, and formulas within the spreadsheet itself, but some may find the presentation here more useful or transparent for many purposes. Excel worksheet formulas can often be hard to read, especially when they contain logical branches for error-checking or exceptional conditions, such as avoiding division by zero. In the tables in this document, the formulas have been simplified by removing the exception-handling code, so the substantive calculations are more readable. Accompanying the tables are explanations helping to clarify how the worksheets are organized and why, connections to VBA code within the file, and guidance for those who would like to modify or customize the model.

In general StruPlan is organized to place as much substantive analysis code within worksheet formulas as possible, to make it visible and easy to modify. A small amount of VBA code is used, generally for two purposes:

- To re-use parts of the worksheet for multiple scenarios, thus reducing the size of the file and avoiding duplication;
- For calculations where a large table (such as ElemInsp) is summarized into another large table (such as SuGr). For this type of calculation VBA is much faster than Excel worksheet formulas.

Other than the preceding instance, in most cases Excel worksheet formulas are much faster than VBA code, sometimes by an order of magnitude. This is part of the reason why StruPlan can do in seconds what can take hours in most BMS. One reason for this is that Excel keeps track of the structure and status of calculations, and recalculates formulas only if any of their inputs change. Another reason is that Excel looks for parallel computation paths that can be assigned to separate threads of multi-threaded processors. A typical Core i7 computer used in engineering has 8 threads, and can perform 8 sets of calculations in parallel.

All of this happens automatically without requiring any extra work for the developer. However, careful organization of the spreadsheet can help Excel take maximum advantage of this capability. In particular, the use of tables and table formulas helps to ensure that the rows of a table can be recalculated in parallel.

StruPlan is an open spreadsheet, where any aspect can be modified or customized. The data item descriptions in the following sections are shaded to draw attention to the ones that would be updated most frequently. The colors are as follows.

- Items that would be updated often, such as budgets and unit costs, shaded red.
- Items that are imported annually from the BMS, or updated when importing new data, shaded yellow.
- Items that would be updated when adapting StruPlan to a new agency, or making policy changes, or completing research studies, shaded green.

Many agencies will want to add more reports to StruPlan, specific to their business needs. There is no limitation on adding new worksheets for this purpose. The tabular structure of most StruPlan results helps take maximum advantage of built-in data analysis features of Excel, such as pivot tables, that are often used for ad hoc analysis.

4.01 Dashboard worksheet – Network annual budget, forecast performance, and expenditures

The Dashboard supports the definition of planning scenarios, and presents the performance and expenditure outcomes that are predicted to result from any scenario. The following variables define the scenarios:

BaseBudget	Funding constraint in the first year, in BaseYear dollars. BaseYear is defined on the **Settings** worksheet.
OnlyNHSSHS	Set to 1 if prioritization and reports are to exclude structures not on the NHS or SHS.
Smoothing	Set to 1 to generate a more uniform annual allocation among networks and treatments.
GrowthRate	Real budget growth rate in percent per year.
Inflation	Inflation rate in percent per year.
Targets	Desired performance for each network. These provide baselines on the graphics but do not otherwise affect the analysis.

Click the **Update** button after changing any of these parameters, to update the graphs on this worksheet. The process takes about 8 seconds.

The **Update All Models** button rebuilds the **NetCost**, **SuGr**, **Cand**, and **Forecast** tables, updating all the models in StruPlan. This is useful after making significant changes to model parameters or formulas on any of the worksheets. It takes just over 3 minutes to execute.

4.01.1 DashPerf table - Forecast performance by highway network

All of the information in this table in columns [Stw-Good]:[Health] is computed as a weighted average of condition and performance from the **Forecast** table, selecting data consistent with the row and column labels. The OnlyNHSSHS flag affects the Statewide columns to omit structures that are neither NHS nor SHS. All averages are weighted by deck area.

Column	Description	Calculation
[Year]		Year starting with BaseYear to BaseYear+10.
[Stw-Good]	Condition %Good	Weighted average by deck area.
[Stw-Poor]	Condition %Poor	Weighted average by deck area.
[Stw-Safe]	Safety % Sufficient	Weighted average by deck area.
[Stw-Mobi]	Mobility % Sufficient	Weighted average by deck area.
[NHS-Good]	Condition %Good	Weighted average by deck area.
[NHS-Poor]	Condition %Poor	Weighted average by deck area.
[NHS-Safe]	Safety % Sufficient	Weighted average by deck area.
[NHS-Mobi]	Mobility % Sufficient	Weighted average by deck area.
[SHS-Good]	Condition %Good	Weighted average by deck area.
[SHS-Poor]	Condition %Poor	Weighted average by deck area.
[SHS-Safe]	Safety % Sufficient	Weighted average by deck area.
[SHS-Mobi]	Mobility % Sufficient	Weighted average by deck area.
[Health]	Health index	Weighted average by deck area.
[StwGoodTarg] **[StwPoorTarg]** **[NHSGoodTarg]** **[NHSPoorTarg]** **[SHSGoodTarg]** **[SHSPoorTarg]**	Targets	Copied from the Targets range to allow drawing of a straight line in the graphs to show the target conditions.

4.01.2 DashCost table - Planned expenditures by highway network and treatment

All of the information in this table in columns [Stw-Pres]:[SHS-Total] is summed from the **Forecast** table, selecting data consistent with the row and column labels. Costs are expressed in year-of-expenditure dollars.

Column	Description	Calculation
[Year]	Year	Year starting with BaseYear to BaseYear+10.
[Stw-Pres]	Statewide Preservation	Total cost of programmed work.
[Stw-Rehab]	Statewide Rehabilitation	Total cost of programmed work.
[Stw-Recon]	Statewide Reconstruction	Total cost of programmed work.
[Stw-Total]	Statewide Total	Total cost of programmed work.
[NHS-Pres]	NHS Preservation	Total cost of programmed work.
[NHS-Rehab]	NHS Rehabilitation	Total cost of programmed work.
[NHS-Recon]	NHS Reconstruction	Total cost of programmed work.
[NHS-Total]	NHS Total	Total cost of programmed work.
[SHS-Pres]	SHS Preservation	Total cost of programmed work.
[SHS-Rehab]	SHS Rehabilitation	Total cost of programmed work.
[SHS-Recon]	SHS Reconstruction	Total cost of programmed work.
[SHS-Total]	SHS Total	Total cost of programmed work.
[Budget]	Budget in year-of-expenditure dollars	BaseBudget * ((1+GrowthRate/100) ^ ([Year]-BaseYear))
[BuyPower]	Buying power in BaseYear dollars	[Budget] * ((1/(1+Inflation/100)) ^ ([Year]-BaseYear))
[ProjCnt]	Project count	Number of structures programmed

4.01.3 DashCount table – Count of projects by highway network and treatment

All of the information in this table in columns [Stw-Pres]:[SHS-Total] is counted from the **Forecast** table, selecting data consistent with the row and column labels.

Column	Description	Calculation
[Year]	Year	Year starting with BaseYear to BaseYear+10.
[Stw-Pres]	Statewide Preservation	Number of programmed projects.
[Stw-Rehab]	Statewide Rehabilitation	Number of programmed projects.
[Stw-Recon]	Statewide Reconstruction	Number of programmed projects.
[Stw-Total]	Statewide Total	Number of programmed projects.
[NHS-Pres]	NHS Preservation	Number of programmed projects.
[NHS-Rehab]	NHS Rehabilitation	Number of programmed projects.
[NHS-Recon]	NHS Reconstruction	Number of programmed projects.
[NHS-Total]	NHS Total	Number of programmed projects.
[SHS-Pres]	SHS Preservation	Number of programmed projects.
[SHS-Rehab]	SHS Rehabilitation	Number of programmed projects.
[SHS-Recon]	SHS Reconstruction	Number of programmed projects.
[SHS-Total]	SHS Total	Number of programmed projects.

4.02 Forecast worksheet – Forecast performance and cost by bridge and year

This worksheet supports the **Dashboard** by showing forecast conditions and costs each year over the medium-term period. The table, which is produced entirely by the VBA FinalForecast procedure, has one row for every year on every structure. Conditions are produced by aggregating the information on the **SuGr** worksheet when used in Mode 2 (Forecasting outcomes).

4.02.1 Forecast table - Forecast performance and cost by bridge and year

Column	Description	Calculation
[Bridge_ID]	Bridge ID	Bridge identifier from Cand[Bridge_ID].
[Year]	Prog year	Base year to 10 years later. Condition is at the start of each year.
[BrRow]	Bridge row	Index of related row in the Bridge table.
[NHS]	Nat'l hwy system	From Cand[NHS]
[SHS]	State hwy system	From Cand[SHS]
[Int]	Interstate	From Cand[Int]
[Dist]	District	From Cand[Dist]
[DeckArea]	Deck area sq.ft	From Cand[DeckArea]
[RpVal]	Repl value $000	Replacement value based on deck area, from Cand[RpVal]
[ADT]	Avg daily traffic	From Cand[ADT]
[NewAge]	Bridge age (yrs)	Bridge age taking into account possible replacement.
[Avg1] **[Avg2]** **[Avg3]** **[Avg4]**	Avg condition of primary elements	Fraction, by element replacement value, of all primary elements on the bridge in each condition state each year, aggregated from SuGr table. Primary elements are those that are associated with an NBI component in Group[NBI].
[GRow]	TPM row, Good model	Index of the associated row of the TPM table containing the applicable model parameters, for the Good model.
[GIx]	Cond index	Condition index used in the Good model, equal to [Avg1].
[GLog]	Log scale	Conversion of the condition index to a log scale: LOG10(2-[GIx]) × (1/LOG10(2))
[CondPred]	Predicted %Good condition-based	Prediction of the probability of Good using the condition-based Weibull model: TPM[Const] + TPM[Slope] × EXP(-(([GLog]/TPM[Scale]) ^ TPM[Shape])))
[AgePred]	Predicted %Good age-based	Prediction of the probability of Good using the age-based Weibull model: EXP(-(([Age]/TPM[Scale]) ^ TPM[Shape]))
[PRow]	TPM row, Poor model	Index of the associated row of the TPM table containing the applicable model parameters, for the Poor model.
[PIx]	Cond index	Condition index used in the Poor model: [Avg4] + TPM[S3Wt] × [Avg3]
[PLog]	Log scale	Conversion of the condition index to a log scale: LOG10(1+[PIx]) × 1/LOG10(2)
[Good]	Condition %Good	If [NewAge] <= 15 then [AgePred] else [CondPred]
[Poor]	Condition %Poor	100 × (if [NewAge]<=15 or [PIx]<0.0005 then 0 else 1 - (TPM[Const] + TPM[Slope] × EXP(-(([PLog] / TPM[Scale]) ^ TPM[Shape])))
[Safe]	Safety %Suff	From Cand[SafeDN] before treatment, Cand[ResSafe] after.
[Mobi]	Mobility %Suff	From Cand[MobDN] before treatment, Cand[ResMobi] after.
[Health]	Health index	Health index aggregated from SuGr table.
[Tmt]	Treatment class	From Cand[ResTmt]
[Cost]	Cost ($000)	From Cand[ResCost]

4.03 Cand worksheet – Investment candidate file

This worksheet gathers **SuGr** results, implements bridge-level treatment selection logic, and then prepares the treatment, cost, outcome, and benefit results for each year's work candidates. It stores this information for all ten years of the medium-term program, prioritizes the work candidates each year, and makes a selection of year and treatment for each structure. There is just one parameter to be set on this page:

RpLim   If preservation or rehabilitation cost exceeds this percent of replacement cost, then replace.

While all of the substantive logic is performed using Excel worksheet formulas, the worksheet relies on VBA code for certain functions: BuildCandidates to populate the table, gather data from the **SuGr** table, and save the annual work candidates; and Prioritize to apply budget constraints for each year and select the highest-priority candidates.

4.03.1 Cand table –Treatment selection, performance and cost outcomes

This table always contains the same structures as the **Bridge** worksheet. The columns [SGTmt]:[SGNote] are filled in by the VBA BuildCandidates procedure by aggregating data in the **SuGr** table. The cell named RpLim is the replacement threshold. A structure is replaced if its rehabilitation costs exceed this percent of replacement.

Column	Description	Calculation
[Bridge_ID]	Bridge ID	Bridge identifier from Bridge[Bridge_ID].
[BrRow]	Bridge row	Index of related row in the Bridge table.
[NHS]	NHS	From Bridge[NHS]
[SHS]	SHS	From Bridge[SHS]
[Int]	Interstate	From Bridge[Int]
[Dist]	District	From Bridge[Dist]
[DeckArea]	Deck sq.ft	From Bridge[DeckArea]
[RpVal]	Replace value	Replacement value based on deck area, from Bridge[RpVal]
[ADT]	ADT	From Bridge[ADT]
[Age]	Age (yrs)	From Bridge[Age]
[GPred]	Prob of Good	From Bridge[GPred]
[PPred]	Prob of Poor	From Bridge[PPred]
Data aggregated from the SuGr table		
[SGTmt]	Overall treatment	Highest treatment on primary elements. (Work on secondary elements can bump up the classification if more than one step above the rest of the bridge.)
[PCTmt]	Coating tmt	Highest treatment for coatings or coated elements.
[DkTmt]	Deck tmt	Highest treatment for deck elements.
[SpTmt]	Super tmt	Highest treatment for superstructure elements.
[SGCost]	Initial cost $000	Total initial cost from the SuGr worksheet.
[SGLTC]	Agency LTC $000	Total long-term cost from the SuGr worksheet.
[SGBen]	Benefit $000	Total long-term benefit from the SuGr worksheet.
[SGNote]	Remarks	Notes describing rehabilitation and reconstruction treatments on SuGrs.
Bridge level treatment selection logic		
[RpCost]	Initial cost $000 if reconstruction	Bridge[RpCost] × Bridge[RpVal] / 100, >= Settings!MinCost (Note: Costs on the bridge worksheet are expressed as % of replacement value.)
[RhCost]	Initial cost $000 if rehabilitation	Sum of functional improvement cost and SuGr cost. Bridge[RhFCost] × Bridge[RpVal] / 100 + [SGCost], >= Settings!MinCost
[PrCost]	Initial cost $000 if preservation	SuGr cost but no smaller than Settings!MinCost.
[RpBen]	Social benefit if Replaced $000	Sum of social benefit and SuGr benefit of replacement. Bridge[RcLong] × Bridge[RpVal] / 100 + [SGBen]

[RhBen]	Social benefit if rehabbed $000	Sum of social benefit and SuGr benefit of rehabilitation. Bridge[RhLong] × Bridge[RpVal] / 100 + [SGBen]
[UpgF]	Replace upgrade due to func need	Bridge needs rehab, but replacement gives added benefits > added costs. IF(AND([SGTmt]>=3,[RpBen]>[SGBen],[RpBen]-[RhBen]>[RpCost]-[RhCost]),1,0)
[Upg$]	Replace upgrade to save cost	Rehab cost is a high percentage of the replacement cost. IF([RhCost]>=[RpCost]*RpLim,1,0)
Forecasting of TPM measures		
[Avg1] **[Avg2]** **[Avg3]** **[Avg4]**	Avg condition of primary elements	Fraction, by replacement value, of all primary elements on the bridge in each condition state at the end of year 10. Primary elements are those that are associated with an NBI component in Group[NBI].
[NewAge]	Age in 10 years	Age of the structure at the end of the medium-term, accounting for possible replacement.
[GRow]	TPM row, Good model	Index of the associated row of the TPM table containing the applicable model parameters, for the Good model.
[GIx]	Cond index	Condition index used in the Good model, equal to [Avg1].
[GLog]	Log scale	Conversion of the condition index to a log scale: LOG10(2-[GIx]) × (1/LOG10(2))
[CondPred]	Predicted %Good condition-based	Prediction of the probability of Good using the condition-based Weibull model: TPM[Const] + TPM[Slope] × EXP(-((([GLog]/TPM[Scale]) ^ TPM[Shape])))
[AgePred]	Predicted %Good age-based	Prediction of the probability of Good using the age-based Weibull model: EXP(-((([Age]/TPM[Scale]) ^ TPM[Shape]))
[PRow]	TPM row, Poor model	Index of the associated row of the TPM table containing the applicable model parameters, for the Poor model.
[PIx]	Cond index	Condition index used in the Poor model: [Avg4] + TPM[S3Wt] × [Avg3]
[PLog]	Log scale	Conversion of the condition index to a log scale: LOG10(1+[PIx]) × 1/LOG10(2)
Final preparation of the work candidate		
[FinTmt]	Final treatment	If [UpgF] or [Upg$] then 4 else [SGTmt]
[FinCost]	Cost $000	IF([FinTmt]=1,0,IF([FinTmt]=2,[PrCost],IF([FinTmt]=3,[RhCost],[RpCost])))
[FinGood]	Condition %Good	If the [NewAge] is <= 15 then [AgePred] else [CondPred]
[FinPoor]	Condition %Poor	100 × (if [NewAge]<=15 or [PIx]<0.0005 then 0 else 1 - (TPM[Const] + TPM[Slope] × EXP(-((([PLog] / TPM[Scale]) ^ TPM[Shape])))
[FinSafe]	Safety %Suff	If SuGr!AltYear=11 or [FinTmt]<=2 or ([FinTmt]=3 and Bridge[RhSBen] <=0) or ([FinTmt]=4 and Bridge[RcSBen] <=0) then (If Bridge[DefWidth]=0 then 100 else 0) else 100
[FinMobi]	Mob'ty %Suff	If SuGr!AltYear=11 or [FinTmt]<=2 or ([FinTmt]=3 and Bridge[RhMBen] <=0) or ([FinTmt]=4 and Bridge[RcMBen] <=0) then (If Bridge[DefClear]=0 and Bridge[DefOLoad]=0 then 100 else 0) else 100
[FinLTC]	Agency LTC ($000)	[@SGLTC]
[FinSBen]	Safety benefit ($000)	IF([FinTmt]<=2,0,IF([FinTmt]=3, Bridge[RhSBen], Bridge[RcSBen]))×[RpVal]/100
[FinMBen]	Mobility benefit ($000)	IF([FinTmt]<=2,0,IF([FinTmt]=3, Bridge[RhMBen], Bridge[RcMBen]))×[RpVal]/100

[FinNote]	Remarks	IF([UpgF]=1,IF([Upg$]=1,"Upg/FN+$. ","Upg/FN. "),IF([[Upg$]]=1,"Upg/$. ",
		IF([FinTmt]=3,
		IF(Bridge[RhWiLUC] <>"","Widen. ","") &
		IF(Bridge[RhRaLUC] <>"","Raise. ","") &
		IF(Bridge[RhStLUC] <>"","Stren. ",""),""))) & [@SGNote]

4.03.2 Cand table – Annual work candidates

This section of the **Cand** table is repeated 10 times, showing work candidates for each year of the medium-term period. Column names end with a year from 1 to 10. Costs and benefits apply to the indicated treatment if it is implemented in the indicated year. Outcomes are forecast for the end of year 10. In the following table, definitions shown for year 1 are typical of all the other years.

Column	Description	Calculation
[Tmt1]	Treatment	Copied from [FinTmt]
[Cost1]	Cost ($000)	Copied from [FinCost]
[Good1]	Condition %Good	Copied from [FinGood]
[Poor1]	Condition %Poor	Copied from [FinPoor]
[Safe1]	Safety %Suff	Copied from [FinSafe]
[Mob1]	Mobility %Suff	Copied from [FinMobi]
[ABen1]	Agency Benefits ($000)	[FinLTC] subtracted from [FinLTC] for the next year
[SBen1]	Safety benefit ($000)	Copied from [FinSBen]
[MBen1]	Mobility benefit ($000)	Copied from [FinMBen]
[Note1]	Remarks	Copied from [FinNote]
[Ratio1]	Benefit cost ratio	([ABen1] + [SBen1] + [MBen1]) / [Cost1]) - ROW()/100000000 +ExtraGood*([@Good1]/100-[@GPred]) +ExtraPoor*([@PPred]-[@Poor1]/100) The second term is a tie-breaker to ensure that all B/C ratios are unique. Third and fourth terms are for smoothing the condition improvement.
[Rank1]	Rank	RANK.EQ([@Ratio1],[Ratio1],0)

4.03.3 Cand table – Do-nothing outcomes and final selections

This section provides outcome predictions at the end of year 10 if no treatment is selected in any year of the program. It then reports the results of the VBA Prioritize procedure, with attributes of the selected year and treatment.

Column	Description	Calculation
Outcomes if no treatment is selected		
[GoodDN]	Condition %Good	Copied from [FinGood]
[PoorDN]	Condition %Poor	Copied from [FinPoor]
[SafeDN]	Safety %Suff	Copied from [FinSafe]
[MobDN]	Mobility %Suff	Copied from [FinMobi]
Results after prioritization		
[ResYear]	Year	Year that was selected for the structure.
[ResTmt]	Tmt cat	Treatment that was selected in the selected year.
[ResCost]	Cost ($000)	Copied from [FinCost]
[ResGood]	Condition %Good	Copied from [FinGood]
[ResPoor]	%Poor	Copied from [FinPoor]
[ResSafe]	Safety %Suff	Copied from [FinSafe]
[ResMobi]	Mob'ty %Suff	Copied from [FinMobi]
[ResNote]	Remarks	Copied from [FinNote]

4.04 SuGr worksheet – Analysis of structure units and element groups

The most detailed calculations in StruPlan occur at the level of structure unit element groups (SuGrs), which are based on groups of element inspections on specific structures, linked to protective elements. This is where medium-term deterioration is modeled using a hybrid Markov/Weibull approach, year-by-year over 10 years. Four treatment categories (do-nothing, preservation, rehabilitation, and reconstruction) are modeled as initial costs, long-term costs, and effects on element condition. The medium-term forecasting is performed in two modes:

1. Generating candidates – Each possible treatment is evaluated in each year of the program. In each year, the treatment with least long-term cost is selected as the work candidate for the year. These results contribute to the annual lists of bridge work candidates that are stored on the **Cand** worksheet.
2. Forecasting outcomes – After an implementation year is selected for each bridge, based on prioritization under budget constraints, then the **SuGr** worksheet provides annual outcome forecasts that contribute to the bridge forecasts on the **Forecast** worksheet.

Mode is specified in a cell named Mode. In mode 1, the year to be analyzed is specified in a cell named AltYear.

Both of these modes are orchestrated by VBA code in the BuildCandidates and FinalForecast procedures respectively. The **SuGr** worksheet does not have any data entry, and is entirely created by VBA code in the BuildSuGrs procedure using data primarily from the **ElemInsp** table. Parameters required for the deterioration and initial cost calculations are obtained from the **Group** table. Long-term unit costs are obtained from the **NetCost** table, as a result of the **long-term model**.

VBA code in the BuildCandidates procedure controls interaction between the **SuGr** table and the **Cand** table to implement bridge-level treatment selection logic. When in mode 1 (generating candidates), the **SuGr** worksheet produces an initial treatment selection based on element-level concerns, which is then combined with bridge model results to reflect bridge-level concerns such as functional needs and risk. This may cause changes to the treatment selections, which are then fed back to the **SuGr** worksheet to affect the forecast of subsequent conditions.

4.04.1 SuGr table – Summary of aggregated ElemInsp data

Data in this section of the **SuGr** table are aggregated from **ElemInsp** data by the VBA procedure BuildSuGrs.

Column	Description	Calculation
[Key]	Lookup key	Concatenation of ElemInsp[StrUnit_ID] and ElemInsp[Group], uniquely identifies each row of the table.
[StrUnit_ID]	Structure unit	Structure unit identifier from ElemInsp[StrUnit_ID], matches StrUnit[StrUnit_ID].
[Group]	Elem group	Group code from ElemInsp[Group], matches Group[Group].
[Bridge_ID]	Bridge ID	Bridge identifier from ElemInsp[BRIDGE_ID], matches Bridge[BRIDGE_ID].
[Envt]	Envt	Environment code from ElemInsp[Envt], matches Environment[Class]. When the ElemInsp records associated with a SuGr do not all have the same value of ElemInsp[Envt], the BuildSuGrs procedure selects the one with the largest total replacement value.
[P1Grp]	Protect group 1	Group code of the first protective system, either a wearing surface or coating, if an associated element exists in ElemInsp and is allowed in Group[P1].
[P2Grp]	Protect group 2	Group code of the second protective system, a sealed joint, if the element exists in ElemInsp and is allowed in Group[P2].
[P1Key]	P1 lookup key	Concatenation of [StrUnit_ID] and [P1Grp], to identify the SuGr representing the first protective system.
[P2Key]	P2 lookup key	Concatenation of [StrUnit_ID] and [P2Grp], to identify the SuGr representing the second protective system.
[RpVal]	Replace value ($)	Total replacement value of all ElemInsps associated with the SuGr.
[00S1] **[00S2]** **[00S3]**	ElemInsp condition	Fraction in each condition state, average of associated ElemInsps, weighted by replacement value. (State 4 is not shown since it is not needed for subsequent calculations.)
[BrRow]	Bridge row	Index of related row in the Bridge table.
[CnRow]	Cand row	Index of related row in the Cand table.
[GrRow]	Group row	Index of related row in the Group table.
[EnRow]	Envt row	Index of related row in the Environment table.
[P1Row]	Protector P1 row	Index of the SuGr row representing the first protective system.
[P2Row]	Protector P2 row	Index of the SuGr row representing the second protective system.
[TT1] **[TT2]** **[TT3]**	Transition times (years)	Median residence time in the indicated state, looked up from Group[TT1] × Environment[Factor].
[Shape]	Weibull shape	Looked up from Group[Shape].
[P1Min] **[P2Min]**	Protection parameter	Looked up from Group[PPMin] for the protective SuGr.
[P1Rng] **[P2Rng]**	Protection param range	Looked up from Group[PPMax] - Group[PPMin] for the protective SuGr.
[00HI]	Health index	Health index calculated from average ElemInsp condition. [00S1] + (2/3)×[00S2] + (1/3)×[00S3].
[SelYr]	Treatment year	Year of program (1 to 10) in which the treatment is to be modeled. If Mode=1 then AltYear else lookup from Cand[ResYear].

4.04.2 SuGr table – Annual condition forecasts

This section of the table is repeated 11 times, showing forecast conditions for each year of the medium-term period. Column names start with a two-digit identification of the year, from 01 to 11. Conditions reported are forecast for the start of the year, just before any treatment that might be considered that year. Conditions reported for year 01 are the same as in columns [00S1]:[00S3]. Conditions reported for year 11 are at the end of the medium-term period (i.e. end of year 10).

To compute the estimated condition, a hybrid Markov/Weibull model starts with the previous year's condition of the SuGr and its P1 and P2 protecting SuGrs if applicable. If a treatment was modeled in the preceding year, then conditions start after completion of that treatment, which is still modeled as if completed at the beginning of the year.

In the following table, definitions shown for year 02 are typical of all the other years.

Column	Description	Calculation
[02PF]	Initial protection factor	Product of the protection factors of the two protecting elements as applicable. If the preceding year was the [SelYr], then get protector conditions after the treatment; otherwise, protector conditions are those at the start of the preceding year. [P1Min] + [P1Rng] × IF([SelYr]=1, INDEX([EffHI],[P1Row]), INDEX([01HI],[P1Row])) × [P2Min] + [P2Rng] × IF([SelYr]=1, INDEX([EffHI],[P2Row]), INDEX([01HI],[P2Row]))
[02Sc]	Scale factor	Scale factor used in the Weibull model. [02PF] × [TT1] / (LN(2) ^ (1 / [Shape]))
[02Eq]	Equivalent age (years)	SuGr age for the purposes of the Weibull model. This is recomputed based on condition in the year after a treatment. Otherwise, it is previous year's age plus 1. IF([SelYr]=1, 1+[02Sc] × ((-LN([Eff1])) ^ (1 /[Shape])), [01Eq]+1)
Same-state transition probability		
[02P11]	State 1	EXP(-(([02Eq] / [02Sc]) ^ [Shape]) + ((([02Eq] - 1) / [02Sc]) ^ [Shape]))
[02P22]	State 2	0.5 ^ (1 / ([02PF] × [TT2]))
[02P33]	State 3	0.5 ^ (1 / ([02PF] × [TT3]))
Forecast condition at the start of the year (fraction by state)		
[02S1]	State 1	IF([SelYr]=1,[Eff1],[01S1]) × [02P11]
[02S2]	State 2	IF([SelYr]=1,[Eff1],[01S1]) × (1-[02P11]) + IF([SelYr]=1,[Eff2],[01S2]) × [02P22]
[02S3]	State 3	IF([SelYr]=1,[Eff2],[01S2]) × (1-[02P22]) + IF([SelYr]=1,[Eff3],[01S3]) × [02P33]
[02HI]	Health index	[02S1] + (2/3)×[02S2] + (1/3)×[02S3]

4.04.3 SuGr table – Treatment selection, cost, and effect

This portion of the **SuGr** table models and compares four treatment categories – do nothing, preservation, rehabilitation, and reconstruction – and selects the treatment that minimizes long-term cost. The analysis is done separately for each year in the medium-term program, as determined by the values of cells Mode and AltYear.

After a preliminary decision about the optimal treatment for each SuGr, results are summarized in the **Cand** table, where functional need and risk considerations are incorporated and a final treatment decision is reached. These decisions are then brought back to the **SuGr** worksheet to determine the conditions following the treatment.

Unit costs (initial and long-term) are expressed in dollars per $1000 of element replacement value in the **Group** and **NetCost** tables. So it is necessary to multiple by replacement value to produce a dollar value of costs.

Column	Description	Calculation
[AYS1] **[AYS2]** **[AYS3]** **[AYS4]**	Condition at start of year	Lookup the appropriate year's conditions (e.g. [02S1], [02S2], [02S3] for year 2) based on [SelYr]. [AYS4] = 1-[AYS1]-[AYS2]-[AYS3]
[AYPF]	Prot factor	Lookup the year's protection factor based on [SelYr].
Initial cost of each treatment ($) (do-nothing costs zero)		
[InitCost2]	Preservation	[RpVal]/1000 × (Group[PrFix] + (SuGr[[AYS1]:[AYS4]] × Group[[PrVC1]:[PrVC4]]))
[InitCost3]	Rehabilitation	[RpVal]/1000 × (Group[RhFix] + (SuGr[[AYS1]:[AYS4]] × Group[[RhVC1]:[RhVC4]]))
[InitCost4]	Reconstruction	[RpVal]/1000 × Group[RcFix]
Long-term cost scaled to reflect the degree of protection		
[MinSc]	Min scale	LOG([P1Min]*[P2Min])
[MaxSc]	Max scale	LOG(([P1Min]+[P1Rng])*([P2Min]+[P2Rng]))
[Scale]	Scale factor	1 - (LOG([AYPF])-[MinSc]) / ([MaxSc]-[MinSc]))
[T1Row] **[T2Row]** **[T3Row]** **[T4Row]**	NetCost row for each treatment	Lookup associated row in NetCost based on environment, treatment, and group.

[AYLTC1]
[AYLTC2]
[AYLTC3]
[AYLTC4]
	Long-term cost ($) of treatment alternatives	Settings!DNLTC × [RpVal]/1000 ×
		If [P2Row]=0 then
		SuGr[[AYS1]:[AYS4]] × NetCost[[NBLTC1]:[NBLTC4]] + [Scale] ×
		(SuGr[[AYS1]:[AYS4]] × NetCost[[NWLTC1]:[NWLTC4]] -
		SuGr[[AYS1]:[AYS4]] × NetCost[[NBLTC1]:[NBLTC4]])
		else
		SuGr[[AYS1]:[AYS4]] × NetCost[[JBLTC1]:[JBLTC4]] + [Scale] ×
		(SuGr[[AYS1]:[AYS4]] × NetCost[[JWLTC1]:[JWLTC4]] -
		SuGr[[AYS1]:[AYS4]] × NetCost[[JBLTC1]:[JBLTC4]])

Preliminary treatment selection		
[AYTmt]	Treatment	Select the lowest of [AYLTC1], [AYLTC2], [AYLTC3], [AYLTC4].
[AYCost]	Cost	Lookup from SuGr[[InitCost2]:[InitCost4]] based on [AYTmt].
[AYLTC]	LTC	Lookup from SuGr[[AYLTC1]:[AYLTC4]] based on [AYTmt].
[AYBen]	Benefit	[AYLTC1]-[AYLTC]
Bridge level treatment selection decisions		
[DNTmt]	Do nothing	If no primary elements have a cost-effective treatment, and no secondary elements are cost-effective above the preservation level, then do nothing on the bridge. There is no cost, benefit, or change in condition. If Cand[SGTmt] = 1 then 1 else 0

[PCTmt]	Coating rehab or recoat	If any painted steel elements require work, then also repaint the deteriorated area. This has no effect on cost or benefit (which are assumed to be included in steel element costs), but does affect the condition forecast. If ([Group] or [P1Grp] ="PC") and Cand[PCTmt] >=2 then 3 else 0
[WSTmt]	Deck overlay or redeck	If the deck requires rehab or replacement, then apply the same treatment to all associated elements (e.g. wearing surface, joints, railings, approach slabs). This doesn't change the overall treatment category of the bridge, nor the benefit, but does affect the condition forecast. If Group[RpDk]=1 and Cand[DkTmt]>=2) then Cand[DkTmt] else 0
[SJTmt]	Joint repair	Any time work is done on the bridge, ensure that expansion joint seals are repaired. (Expansion joint conditions don't, by themselves, trigger a project, but are incidental to other projects or performed as a maintenance task.) [Group]="SJ" and Cand[SGTmt]>=2 then 3 else 0
[RcSup]	Superstructure reconstruction	If the superstructure requires reconstruction, then also replace the deck and associated elements. This doesn't change the treatment category of the bridge, nor the benefits, but does affect the condition forecast. If Group[RpSp]=1 and Cand[SpTmt]=4 then 4 else 0
[RhUpg]	Upgrade to rehabilitation	If any of the primary element groups need rehabilitation, then model all conditions as if rehabilitated. This doesn't change the overall treatment category of the bridge, nor the costs or benefits, but does change the condition forecast. If [AYTmt]<=3 and Cand[SGTmt]=3 then 3 else 0
[RpUpg]	Upgrade to replacement	If the bridge was upgraded to a replacement due to cost or functional needs, then all elements are forecast to go to new condition. This doesn't change the benefits. The bridge is costed as a total bridge replacement. If Cand[UpgF]=1 or Cand[Upg$]=1 then 4 else 0
[FinTmt]	Final tmt	Select the highest of the treatments decided by the selection logic. IF([DNTmt]=1,1,MAX([AYTmt],SuGr[[PCTmt]:[RpUpg]]))
Condition immediately after treatment (assumed to be at start of year)		
[Eff1]	State 1	Fraction in state 1 depending on [FinTmt] as follows: 1: [AYS1] 2: [AYS1] + [AYS2]×Group[PrEff2] + [AYS3]×Group[PrEff3] + [AYS4]×Group[PrEff4] 3: [AYS1] + [AYS2]×Group[RhEff2] + [AYS3]×Group[RhEff3] + [AYS4]×Group[RhEff4] 4: 1
[Eff2]	State 2	Fraction in state 2 depending on [FinTmt] as follows: 1: [AYS2] 2: [AYS2] × (1 - Group[PrEff2]) 3: [AYS2] × (1 - Group[RhEff2]) 4: 0
[Eff3]	State 3	Fraction in state 3 depending on [FinTmt] as follows: 1: [AYS3] 2: [AYS3] × (1 - Group[PrEff3]) 3: [AYS3] × (1 - Group[RhEff3]) 4: 0
[EffHI]	Health index	[Eff1] + (2/3)×[Eff2] + (1/3)×[Eff3]

4.05 Freq worksheet – Correlation charts of federal performance measures

This worksheet supports the Transportation Performance Management (TPM) model on the **Bridge** worksheet, providing charts to illustrate the relationship between element conditions and TPM conditions. All of the graphs are populated by Excel worksheet formulas that summarize NHS data in the **Bridge** table. Blue dots are the actual population conditions, and the orange line is the best-fit Weibull model of the respective TPM measure. See the section **Bridge table – Estimation of federal TPM performance measures** below for more information on the data contributing to these graphs, and see the earlier chapter on the **TPM model** for background.

4.05.1 FreqGood table – Probability of Good vs fraction in state 1

This table groups bridges into bins according to element condition on a log scale, with bins designed to have roughly uniform populations to the extent possible. For the %Good model, element condition relies entirely on condition state 1.

Column	Description	Calculation
[Bin]	Bin number	Sequential from 1 to 51.
[Index]	Fraction state1	Average value of the condition index Bridge[GIx] in the bin.
[Pop]	Population	Number of bridges in the bin.
[Actual]	Actual Good	Actual fraction of the bin's bridges in Good condition (unweighted).
[Pred]	Predicted Good	Predicted fraction in Good condition, from Weibull model.

4.05.2 FreqPoor table – Probability of Poor vs weighted fraction in states 3 and 4

This table groups bridges into bins according to element condition on a log scale, with bins designed to have roughly uniform populations to the extent possible. For the %Poor model, element condition relies on condition states 3 and 4.

Column	Description	Calculation
[Bin]	Bin number	Sequential from 1 to 51.
[Index]	Fraction in 3,4	Average value of the condition index Bridge[PIx] in the bin.
[Pop]	Population	Number of bridges in the bin.
[Actual]	Actual Good	Actual fraction of the bin's bridges in Poor condition (unweighted).
[Pred]	Predicted Good	Predicted fraction in Poor condition, from Weibull model.

4.05.3 FreqRepl table – Probability of Good vs age

This table groups bridges into bins according to age, and focuses on bridges up to 15 years old.

Column	Description	Calculation
[Age]	Age in years	Age in years, 0 to 15.
[Frac]	Fraction state 1	Average value of Bridge[Avg1] in the bin.
[Pop]	Population	Number of bridges in the bin
[Actual]	Actual Good	Actual fraction of the bin's bridges in Good condition (unweighted).
[Pred]	Predict	Predicted fraction in Good condition, from Weibull model.

4.05.4 FreqPop table – Frequency chart of fraction in state 1

Simple frequency distribution of fraction in state 1, on a linear scale.

Column	Description	Calculation
[Bin]	Bin number	Sequential from 1 to 50.
[Frac1]	Fraction state 1	Fraction in state 1 in the bin.
[Count]	Population	Count in the bin.

4.06 Bridge worksheet – Functional needs, risk analysis, federal performance measures

The **Bridge** table accepts input data about individual structures, which may be imported, copy/pasted, or entered manually. These data are put through a cleanup process, then are used for analysis of functional needs, risk, social cost, and federal Transportation Performance Management (TPM) measures.

4.06.01 Bridge table – Input data

These data are all found in bridge management systems or FHWA NBI download files and are documented in the National Bridge Inventory Coding Guide (FHWA 1995). See the chapter on **Importing bridge data** for instructions on obtaining data. The following section, **Data cleanup**, contains formulas to handle missing values, conversion to US Customary units, and other cleanup tasks. These formulas can be augmented to accommodate common data problems that an agency may have. In particular, [CAT23], [DECK_AREA], [ON_OFF_SYS], [ROAD_SPEED], and [DET_SPEED] are often missing from input data sets, so formulas in the Data cleanup section provide reasonable substitutions.

Column	NBI item	Column name in FHWA download file
[BRIDGE_ID]	Bridge identifier 008	STRUCTURE_NUMBER_008
[DISTRICT]	District 002	HIGHWAY_DISTRICT_002
[FACILITY]	Facility carried 007	FACILITY_CARRIED_007
[BYPASSLEN]	Bypass length 019	DETOUR_KILOS_019
[CUSTODIAN]	Custodian 021	MAINTENANCE_021
[OWNER]	Owner 022	OWNER_022
[FUNCCLASS]	Functional class 026	FUNCTIONAL_CLASS_026
[YEARBUILT]	Year built 027	YEAR_BUILT_027
[LANES]	Lanes on 028A	TRAFFIC_LANES_ON_028A
[ADTTOTAL]	ADT 029	ADT_029
[ADTYEAR]	ADT year 030	YEAR_ADT_030
[DESIGNLOAD]	Design load 031	DESIGN_LOAD_031
[AROADWIDTH]	Approach width 032	APPR_WIDTH_MT_032
[OPPOSTCL]	Open closed 041	OPEN_CLOSED_POSTED_041
[SERVTYPON]	Service type on 042A	SERVICE_ON_042A
[SERVTYPUND]	Service type under 042B	SERVICE_UND_042B
[MATERIALMAIN]	Material main 043A	STRUCTURE_KIND_043A
[DESIGNMAIN]	Design main 043B	STRUCTURE_TYPE_043B
[MATERIALAPPR]	Material approach 044A	APPR_KIND_044A
[DESIGNAPPR]	Design approach 044B	APPR_TYPE_044B
[LENGTH]	Structure length 049	STRUCTURE_LEN_MT_049
[ROADWIDTH]	Road width 051	ROADWAY_WIDTH_MT_051
[DECKWIDTH]	Deck width 052	DECK_WIDTH_MT_052
[VCLROVER]	Vertical clearance 053	VERT_CLR_OVER_MT_053
[DKRATING]	Deck rating 058	DECK_COND_058
[SUPRATING]	Superstructure rating 059	SUPERSTRUCTURE_COND_059
[SUBRATING]	Substructure rating 060	SUBSTRUCTURE_COND_060
[CHANRATING]	Channel rating 061	CHANNEL_COND_061
[CULVRATING]	Culvert rating 062	CULVERT_COND_062
[ORLOAD]	Operating rating 064	OPERATING_RATING_064
[POSTING]	Posting 070	POSTING_EVAL_070
[WATERADEQ]	Waterway adequacy 071	WATERWAY_EVAL_071
[APPRALIGN]	Approach alignment 072	APPR_ROAD_EVAL_072
[INSPDATE]	Inspection date 090	DATE_OF_INSPECT_090

[NHS_IND]	NHS status 104	HIGHWAY_SYSTEM_104
[YEARRECON]	Year reconstructed 106	YEAR_RECONSTRUCTED_106
[TRUCKPCT]	Truck percent 109	PERCENT_ADT_TRUCK_109
[NBISLEN]	NBIS length 112	BRIDGE_LEN_IND_112
[SCOURCRIT]	Scour critical 113	SCOUR_CRITICAL_113
[ADTFUTURE]	ADT future 114	FUTURE_ADT_114
[ADTFUTYEAR]	ADT future year 115	YEAR_OF_FUTURE_ADT_115
[LOWEST_RATING]	TPM rating CAT23	LOWEST_RATING
[DECK_AREA]	Deck area CAT29	DECK_AREA
[ON_OFF_SYS]	SHS status	
[ROAD_SPEED]	Road speed mph	
[DET_SPEED]	Detour speed mph	

4.06.02 Bridge table – Data cleanup

This portion of the Bridge table provides data cleanup, converts metric data (as in NBI download files) to US Customary, and provides default values to fill in blanks. The formulas can be modified as needed to overcome any problems that may be found in each agency's data. The following parameters may be found above the table:

Metric	Flag indicating whether the input data are metric, set by the VBA import procedure.
MetricConv	Metric to US Customary conversion factors.
DefGrowth	Default traffic growth rate (%).
DefTruckPct	Default truck percent (%).
DetSpeedFactor	Detour speed factor.
MaxDetourLen	Maximum detour length (miles).

Column	Description	Calculation
[NHS]	National hwy sys	If [NHS_IND]=1 and [NBISLEN]="Y" then 1 else 0
[SHS]	State hwy system	If [ON_OFF_SYS]="" then If [OWNER]=01 then 1 else 0 else [ON_OFF_SYS]
[Dist]	District	[DISTRICT]
[Int]	Interstate	If [FUNCCLASS]=01 or 11 then 1 else 0
[DkCl]	Deck rating	If [DKRATING]<"0" or [DKRATING]>"9") then 10 else 1*[DKRATING]
[SpCl]	Superstr rating	If [SUPRATING]<"0" or [SUPRATING]>"9") then 10 else 1*[SUPRATING]
[SbCl]	Substr rating	If [SUBRATING]<"0" or [SUBRATING]>"9" then 10 else 1*[SUBRATING]
[CvCl]	Culvert rating	If [CULVRATING]<"0" or [CULVRATING]>"9" then 10 else 1*[CULVRATING]
[StCl]	Least component rating	Use [Cat23] if available, otherwise lowest of [[DkCl]:[SbCl]]
[StrTyp]	Structure type	If [CvCl]=10 then "Br" else "Cv"
[InspYear]	Inspection year	Converted from [INSPDATE], usually by taking the last 2 digits and adding 2000.
[DeckArea]	Deck area (sq.ft)	Use [DECK_AREA] if available, converting to US Customary if needed. Otherwise use [DkWid]×[BrLen], substituting [ApWid] for [DkWid] if needed.
[BrLen]	Bridge length (ft)	Convert metric to US Customary if needed.
[DkWid]	Deck width (ft)	Convert metric to US Customary if needed.
[ApWid]	Appr width (ft)	Convert metric to US Customary if needed.
[VClr]	Vert clear (ft)	Convert metric to US Customary if needed.
[OpRate]	Oper rating (ton)	Convert metric to US Customary if needed.
[RdWid]	Road width (ft)	Convert metric to US Customary if needed.
[Growth]	Traffic growth (%/yr)	([ADTFUTURE]/[ADTTOTAL]) ^ (1/([ADTFUTYEAR]-[ADTYEAR]))-1 Substitute DefGrowth if any of the inputs for this calculation are missing.
[ADT]	Avg daily traffic in base year	[ADTTOTAL]×((1+[Growth])^(BaseYear-[ADTYEAR]))
[Trucks]	Truck percent	[TRUCKPCT]/100, substitute DefTruckPct if missing.
[RdSpd]	Road speed mph	Use [ROAD_SPEED], or lookup from Standards[DefSpeed] if missing.
[DetSpd]	Detour spd mph	Use [DET_SPEED], or use [RdSpd]*DetSpeedFactor if missing.
[DetLen]	Detour length mi	Convert metric to US Customary if needed, limit to MaxDetourLen.

4.06.03 Bridge table – Functional deficiencies and mitigation

The models in this section of the **Bridge** table analyze bridge characteristics to quantify functional deficiencies. Agencies may wish to customize the logic for the deficiency and feasibility flags to fit their own policies. Florida DOT research provides the source for the accident risk model (Thompson et al 1999) and the truck detour model (Sobanjo and Thompson 2004).

Standards for level of service and for design are specified in the **Standards** table. In addition, the following cells have settings used in the formulas:

ShortBridgeThreshold	Maximum structure length to be considered a short bridge (feet).
ShortBridgeFactor	Factor applied to approach road width for level of service of short bridges.
ShortBridgeAddWidth	Minimum width that can be added to a short bridge (feet).

Column	Description	Calculation
[FCRow]	Functional class row	Index of matching row in the Standards table.
Level of service standards		
[LReqWid]	Required road width (ft)	Minimum road width for the bridge's functional class and number of lanes, according to level of service standards. [LANES] × Standards[LOSLaneWidth] + 2 × Standards[LOSShldWidth]
[ReqClear]	Required vertical clearance (ft)	Minimum vertical clearance for the bridge's functional class, according to level of service standards, looked up from Standards[LOSVertClr].
[ReqOLoad]	Required oper rating (tons)	Minimum operating rating for the bridge's functional class, according to level of service standards, looked up from Standards[LOSOpRating].
[Short]	Short bridge flag	If [BrLen] <= ShortBridgeThreshold then 1 else 0.
[SReqWid]	Required road width (ft) for short bridge	Minimum road width applicable to short bridges, based on approach road width. [ApWid] × ShortBridgeFactor
[NewWid]	Design road width (ft) for long bridge	Desired road width after widening or replacement, based on functional class and existing number of lanes, according to design standards. [LANES] × Standards[DesLaneWidth] + 2 × Standards[DesShldWidth]
Deficiency flags		
[DefWidth]	Deficiency flag for road width	If [SERVTYPON] is not 1,4,5,6,7,8 then 0, else if [Short] then if [RdWid] < [SReqWid] then 1 else 0 else if [RdWid] < [LReqWid] then 1 else 0
[DefClear]	Deficiency flag for vertical clr	If [SERVTYPON] is not 1,2,3,4,5,6,7,8 then 0 else if [VClr] < [ReqClear] then 1 else 0.
[DefOLoad]	Deficiency flag for oper rating	If [SERVTYPON] is not 1,4,5,6,7,8 then 0 else if [OpRate] < [ReqOLoad] then 1 else 0.
Feasibility flags		
[WideFeas]	Feasibility flag for widening	If [DefWidth]=1 and [DESIGNMAIN] from 01 to 08, or 19 then 1 else 0 Except if [Short] and [SReqWid]-[RdWid] < ShortBridgeAddWidth then 0.
[RaisFeas]	Feasibility flag for raising	If [DefClear]=1 and [DESIGNMAIN] from 01 to 06 or 08 to 10 then 1 else 0.
[StreFeas]	Feasibility flag for strengthening	If [DefOLoad]=1 and ([DESIGNLOAD]=9 or ([DESIGNLOAD] is 4,5,6 and [FUNCCLASS] is 07,08, 09,17,19)) then 1 else 0
Accident risk model		
[UrbArt]	Urban arterial coefficient	If [FUNCCLASS] is 14 or 16 then 886.0098 else-377.3701

[AlignDk]	Alignment and deck condition coefficient	If [DKRATING]<=6 and [APPRALIGN]<=6 Then 0.7899 else If [DKRATING]<=6 and [APPRALIGN]>6 Then 0.4531 else If [DKRATING]>6 and [APPRALIGN]<=6 Then 0.5031 else If [DKRATING]>6 and [APPRALIGN]>6 Then 0.3409
[OldNarw]	Narrowness of existing bridge	[LANES] / [RdWid]
[NewNarw]	Narrowness of new bridge	If [Short] then [LANES] / [SReqWid] else [LANES] / [LReqWid]
[OldAcc]	Est. crashes/year existing bridge	([UrbArt] + 0.7323 × [LANES] × [BrLen] / 3.2808399 (feet per meter) + [AlignDk] × [OldNarw] × [ADT]) / 1000
[RhAcc]	Est. crashes/year post rehab	If [WideFeas] then ([UrbArt] + 0.7323 × [LANES] × [BrLen] / 3.2808399 + If [APPRALIGN]<=6 then 0.5031 else 0.3409 × [NewNarw] × [ADT]) / 1000 else [OldAcc]
[RcAcc]	Est. crashes/year post reconstr	([UrbArt] + 0.7323 × [LANES] × [BrLen] / 3.2808399 + 0.3409 × [NewNarw] × [ADT]) / 1000
Truck height and weight detours		

[HtDet]	Height detours per year, existing bridge	[ADT] × [Trucks] × 365/100 ×
		If [FUNCCLASS] = 01 or 11 then
		If [VClr] < 9.65 then 100
		else if [VClr] < 13 then
		855.91 - 223.43 × [VClr] + 22.199 × [VClr] ^ 2 - 0.74236 × [VClr] ^ 3
		else if [VClr] < 14 then 1.0956E+56 × [VClr] ^ -48.683
		else if [VClr] <= 16.1 then 14.567 - 0.9046 × [VClr]
		else 0
		If [FUNCCLASS] <> 01 or 11 then
		if [VClr] < 7.3 then 100
		else if [VClr] < 13.5 then -26.275 + 34.692 × [VClr] - 2.3894 × [VClr] ^ 2
		else if [VClr] <= 14 then 138.86 - 9.886 × [VClr]
		else 0

[RhClr]	Rehab vertical clr	Looked up from Standards[DesVertClr]
[RhHtDet]	Height detours per year after rehabilitation	If [RaisFeas]=0 then [HtDet] else use same formula as [HtDet], using [RhClr] instead of [VClr]

[WtDet]	Weight detours per year, existing bridge	[ADT] × [Trucks] × 365/100 ×
		If [FUNCCLASS] = 01 or 11 then
		If [OpRate]×2000 < 10000 then 100
		else if [OpRate] ×2000 < 80000 then
		102.24 - 0.00008982 × [OpRate] ×2000
		- 0.000000014336 × ([OpRate] ×2000) ^ 2
		else if [OpRate] ×2000 <= 91100 then
		18.976 - 0.0002083 × [OpRate] ×2000
		else 0
		If [FUNCCLASS] <> 01 or 11 then
		If [OpRate]×2000 < 3700 then 100
		else if [OpRate]×2000 < 85000 then
		107.26 - 0.0019743 × [OpRate]×2000
		+ 0.0000000065265 × ([OpRate]×2000) ^ 2
		+ 0.000000000000022256 × ([OpRate]×2000) ^ 3
		else 0

Added deck area		
[RpDk]	Added deck sq.ft if replaced	[BrLen] × If [DefWidth]=1 then If [Short] then [SReqWid]-[RdWid] else [NewWid]-[RdWid] else 0
[WiDk]	Added deck sq.ft if widened	[BrLen] × If [WideFeas]=1 then If [Short] then [SReqWid]-[RdWid] else [NewWid]-[RdWid] else 0

4.06.04 Bridge table – Scour risk model

This section of the **Bridge** table implements a simplified scour model, intended to increase the priority for replacement if a bridge has deficiencies related to the risk of scour or flooding (Garrow and Sturm 2013). The model relies on data from the **Standards**, **Susceptibility**, and **ScourProb** tables. In addition, the following parameters are set in a table just above the **Bridge** table:

ScourDuration	Expected number of days that service is disrupted if a scour-related bridge closure occurs.
ScourThreshChannel	Threshold of channel rating (NBI 61) to consider scour benefits of replacement.
ScourThreshWater	Threshold of waterway adequacy (NBI 71) to consider scour benefits of replacement.
ScourThreshCriticality	Threshold of scour criticality (NBI 113) to consider scour benefits of replacement.

Replacement scour benefits are zero if channel rating, waterway adequacy, and scour criticality are all above their thresholds.

Column	Description	Calculation
[SubsCol]	Substructure condition index	Selected column of the Susceptibility table, based on substructure condition rating [SbCl].
[ChanRow]	Channel condition index	Selected row of the Susceptibility table, based on channel condition rating [CHANRATING].
[WatCol]	Waterway adequacy index	Selected column of the Standards table, based on waterway adequacy rating [WATERADEQ].
[SuscRow]	Susceptibility row index	Looked up from Susceptibility table based on [ChanRow] and [SubsCol].
[OverCol]	Overtopping frequency column index	Looked up from Standards table based on [FCRow] and [WatCol].
[ScourProb]	Scour disruption probability	Looked up from the ScourProb table based on [SuscRow] and [OverCol].
[ScrDet]	Annual scour detours	[ADT] × ScourDuration × [ScourProb]

It is possible to enhance the **Bridge** worksheet by adding more types of risk assessment, depending on the needs of each agency. Potential sources of relevant risk models include NCHRP Project 20-07(378) (Thompson et al 2016) and Florida DOT's bridge risk study (Sobanjo and Thompson 2013).

4.06.05 Bridge table – Summary of avoided social costs

This section of the **Bridge** table brings together the costs and benefits associated with correcting deficiencies related to function and risk. Currently the functional improvements that it considers are widening, raising, and strengthening; and the risk mitigation that it considers is for scour and flooding. The consequences it considers are crashes, travel time cost per hour, vehicle operating cost per mile, and the public health costs related to pollutant emissions (excluding carbon dioxide). The worksheet can be enhanced by adding more hazards or consequences.

All benefits of functional improvement and risk mitigation in StruPlan are modeled as annual avoided social costs. The model assumes that rehabilitation projects will correct deficiencies if their long-term benefit exceeds their cost, and assumes that reconstruction corrects all deficiencies. Costs and benefits are added to the rehabilitation and reconstruction projects associated with element condition, to give the total cost and priority of projects.

Above the **Bridge** table are general economic parameters for agency and user costs, which should be customized for each agency. Agency cost parameters are:

UnitReplCost	Cost per square foot for bridge replacement.
UnitWideCost	Cost per square foot for widening.
UnitRaisCost	Cost per square foot for raising.
UnitStrenCost	Cost per square foot for strengthening.

These agency costs include all indirect and overhead costs. StruPlan treats them as a reduction of the available budget if the project is selected.

The user cost methodology and metrics are based on the AASHTO Red Book (AASHTO 2010). In its current edition (as of this writing) all cost factors in the Red Book are expressed in year 2000 dollars. These therefore need to be updated to base year dollars using the Consumer Price Index (CPI). Currently the historical and most recent CPI can be found at **https://data.bls.gov/cgi-bin/surveymost?cu**. Choose "US city average, All items". This calculation is at the top of the **Bridge** worksheet, using the following cells:

RedBookYear	Cost year of Red Book unit costs, currently 2000.
CPI_RedBook	Value of the Consumer Price Index in the Red Book cost year, currently 172.2 for year 2000.
RedAccCost	Cost per accident in the AASHTO Red Book, page 5-24, currently $31,291. This figure is an average over all vehicle classes and accident types, assuming each accident involves only one vehicle. It excludes insurance reimbursement to avoid double-counting of costs.
RedHourCost	Travel time cost per hour from the AASHTO Red Book, page 5-4, currently $21.93. This figure uses the average over all occupations, computed as an opportunity cost.
RedMileCost	Vehicle operating cost per mile from the AASHTO Red Book, page 5-10, currently $0.149. This is based on the “large car” column and includes fuel, oil, maintenance, and tires.
RedVehOcc	Average vehicle occupancy is an estimate suggested by the AASHTO Red Book, but individual agencies may have developed their own estimates for transportation planning purposes.
CPI_Base	Value of the Consumer Price Index in the base year, currently 256.57 in 2020. This should be updated whenever the base year is changed.
UserAccCost	RedAccCost × CPI_Base/CPI_RedBook
UserHourCost	RedHourCost × CPI_Base/CPI_RedBook × RedVehOcc
UserMileCost	RedMileCost × CPI_Base/CPI_RedBook

Unit social cost of pollutant emissions is calculated in the [Emissn] column of the **Standards** table.

Column	Description	Calculation
Avoidable user impacts of functional deficiencies and risk		
[RhWiCr]	Crashes avoided by widening	Number of crashes per year as-is, minus number of crashes if widened. [OldAcc]-[RhAcc]
[RhRaHr]	Detour hours avoided by raising	Hours of truck travel saved per year with a higher vertical clearance. [DetLen]/[DetSpd] × ([HtDet]-[RhHtDet])
[RhRaMi]	Detour miles avoided by raising	Miles of truck travel saved per year with a higher vertical clearance. [DetLen] × ([HtDet]-[RhHtDet])
[RhStHr]	Hours avoided by strengthening	Hours of truck travel saved per year with a higher operating rating. [DetLen]/[DetSpd] × [WtDet]
[RhStMi]	Miles avoided by strengthening	Miles of truck travel saved per year with a higher operating rating. [DetLen] × [WtDet]
[RcCrash]	Crashes avoided by reconstruction	Number of crashes per year as-is, minus number of crashes if replaced. [OldAcc]-[RcAcc]
[RcHour]	Hours avoided by reconstruction	Hours of detours avoided per year if all clearance, weight, and scour deficiencies are removed by means of reconstruction. [DetLen]/[DetSpd] × ([HtDet]+[WtDet]+[ScrDet])
[RcMile]	Miles avoided by reconstruction	Miles of detours avoided per year if all clearance, weight, and scour deficiencies are removed by means of reconstruction. [DetLen] × ([HtDet]+[WtDet]+[ScrDet])
Agency costs as a percent of replacement value		
[RpVal]	Bridge replacement cost ($000)	Bridge-level costs (as opposed to element-level) are all scaled according to this bridge replacement cost. [DeckArea] × UnitReplCost/1000
[WideCost]	Widening cost	Cost (as percent of replacement value) of widening the bridge. [WideFeas] × [WiDk] × UnitWideCost/1000/[RpVal]×100
[RaisCost]	Raising cost	Cost (as percent of replacement value) of raising the bridge. [RaisFeas] × [DeckArea] × UnitRaisCost/1000/[RpVal]×100
[StrenCost]	Strengthening cost	Cost (as percent of replacement value) of strengthening the bridge. [StreFeas] × [DeckArea] × UnitStrenCost/1000/[RpVal]×100
Avoidable social cost as a percent of replacement value		
[RhWiAUC]	Annual social cost avoided by widening	Annual user cost (as percent of replacement value) avoided by widening. [WideFeas] × [RhWiCr] × UserAccCost/1000/[RpVal]×100
[RhRaAUC]	Annual social cost avoided by raising	Annual user cost (as percent of replacement value) avoided by raising. [RaisFeas] × ([RhRaHr]×UserHourCost + [RhRaMi]×(UserMileCost+Standards[Emissn])) /1000/[RpVal]×100
[RhStAUC]	Annual social cost avoided by strengthening	Annual user cost (as percent of replacement value) avoided by strengthening. [StreFeas] × ([RhStHr]×UserHourCost + [RhStMi]×(UserMileCost+Standards[Emissn])) /1000/[RpVal]×100
[RhWiLUC]	Long-term social cost avoided by widening	[RhWiAUC]×(1/Discount)
[RhRaLUC]	Long-term social cost avoided by raising	[RhRaAUC]×(1/Discount)
[RhStLUC]	Long-term social cost avoided by strengthening	[RhStAUC]×(1/Discount)

[RhLong]	Long-term social cost avoided by rehabilitation	[RhWiLUC] + [RhRaLUC] + [RhStLUC]
[RcSafe]	Annual safety benefit of reconstruction	Annual social cost of crashes (as percent of replacement value) avoided by reconstruction. [RcCrash] × UserAccCost/1000/[RpVal]×100
[RcMobi]	Annual mobility benefit of reconstruction	Annual social cost of detours (as percent of replacement value) avoided by reconstruction. ([RcHour]×UserHourCost + [RcMile]×(UserMileCost+ Standards[Emissn])) /1000/[RpVal]×100
[RcLong]	Long-term social cost avoided by reconstruction	[RcSafe]×(1/Discount) + [RcMobi]×(1/Discount)
Total cost-effective agency cost as a percent of replacement value		
[RhFCost]	Rehabilitation cost	Agency cost (as percent of replacement value) of functional improvements as a part of rehabilitation. Each type of improvement is included if its long-term benefits exceed its costs. If [RhWiLUC] > [WideCost] then [WideCost] else 0 + If [RhRaLUC] > [RaisCost] then [RaisCost] else 0 + If [RhStLUC] > [StrenCost] then [StrenCost] else 0
[RpCost]	Replacement cost	Agency cost (as percent of replacement value) of bridge replacement, including the cost of additional width to relieve safety deficiency. The cost of additional lanes is not included. (1 + [RpDk] / [DeckArea])*100
Total cost-effective social benefit as a percent of replacement value		
[RhSBen]	Annual safety benefit of rehabilitation	Annual social cost of crashes (as percent of replacement value) avoided by rehabilitation, recognized if the long-term benefits exceed the costs. If [RhWiLUC] > [WideCost] then [RhWiAUC] else 0
[RhMBen]	Annual mobility benefit of rehabilitation	Annual social cost of detours (as percent of replacement value) avoided by rehabilitation, recognized if the long-term benefits exceed the costs. If [RhRaLUC] > [RaisCost] then [RhRaAUC] else 0 + If [RhStLUC] > [StrenCost] then [RhStAUC] else 0
[RcSBen]	Annual safety benefit of reconstruction	Same as [RcSafe].
[RcMBen]	Annual mobility benefit of reconstruction	Same as [RcMobi].

4.06.06 Bridge table – Estimation of federal TPM performance measures

This portion of the **Bridge** table is concerned with estimation of federal TPM (Transportation Performance Management) performance measures %Good and %Poor (FHWA 2017). The calculations are used in an **automated procedure** to estimate a set of Weibull models to convert forecasts of element conditions to forecasts of %Good and %Poor by deck area. In this way the forecast federal measures are made sensitive to investment levels and policies configured in the StruPlan model.

This model is quite new and has not yet been widely applied. Therefore it should be regarded as experimental for the time being. Further research will help to refine and improve the model to ensure its usefulness to forecast outcomes and to aid in setting long-range performance targets.

Each row in the **Bridge** table is associated with a network: NHS, SHS, or Non as defined below. Two models are developed for each network, for %Good and %Poor. A third model, applicable to all bridges, is concerned with newly-replaced bridges regardless of network. A VBA procedure ComputeBridgePrimaryConditions populates the columns [Avg1] to [Avg4] with an average of element conditions computed for primary elements (i.e. elements that are associated with an NBI component in **Group**[NBI]). This is updated any time new bridge data are imported, and the user can manually update the calculation using the **Update All Models** button on the **Dashboard** worksheet.

Each bridge is classified, based on its most recent NBI component ratings, as either Good, Poor, or neither. Worksheet formulas implement a Weibull model to try to predict the probability of Good or Poor based on the average element conditions. Graphs of predicted vs actual, organized into bins for clarity of presentation, are on the **Freq** worksheet. Worksheet formulas in the **Bridge** worksheet calculate a log likelihood function, a negative value indicating the accuracy of the prediction for each bridge.

A VBA module modTPM contains a set of procedures that automate the Excel Solver tool to try to find the set of Weibull model parameters that maximize the total likelihood that variability in the actual %Good or %Poor is explained by the model based on element conditions. Parameters and statistics of the Weibull models are found in the **TPM** table, which is immediately above these **Bridge** table columns. The **Solve** button in the **TPM** table executes these VBA procedures to find the best-fit Weibull model. See the separate chapter on the **TPM model** for more information on how it is estimated and used.

Column	Description	Calculation
[Valid]	Has valid data	1 if the bridge has both a valid element condition summary and a valid NBI component rating; 0 otherwise.
[Netwk]	Network	Indicates the portion of the inventory for which the bridge is applicable. NHS = NBI bridge on the National Highway System SHS = State-maintained structure not included in NHS Non = Structure not included in NHS or SHS
[Good]	Actual Good	1 if the bridge is classified as Good, 0 otherwise.
[Poor]	Actual Poor	1 if the bridge is classified as Poor, 0 otherwise.
[Avg1] **[Avg2]** **[Avg3]** **[Avg4]**	Primary element condition	Fraction, by replacement value, of all primary elements on the bridge in each condition state. Primary elements are those that are associated with an NBI component in Group[NBI].
Probability of Good, based on element condition		
[GRow]	TPM row, Good model	Index of the associated row of the TPM table containing the applicable model parameters, for the Good model.
[GIx]	Cond index	Condition index used in the Good model, equal to [Avg1].
[GLog]	Log scale	Conversion of the condition index to a log scale: LOG10(2-[GIx]) × (1/LOG10(2))

		(Note that this reverses the direction of the scale, so the highest [Avg1] yields the lowest [GLog] and vice versa.)
[GBin]	Frequency bin	Assignment of a bridge to a bin for the frequency plot on the Freq worksheet: If not NHS then 0, else TRUNC(SQRT([GLog])*50)+1
[GPred]	Predicted %Good	Prediction of the probability of Good using the Weibull model: TPM[Const] + TPM[Slope] × EXP(-(([GLog]/TPM[Scale]) ^ TPM[Shape])))
[GLike]	Log likelihood	Negative number reflecting the accuracy of the prediction: [Good] × LN([GPred]) + (1-[Good]) × LN(1-[GPred])
Probability of Poor, based on element condition		
[PRow]	TPM row, Poor model	Index of the associated row of the TPM table containing the applicable model parameters, for the Poor model.
[PIx]	Cond index	Condition index used in the Poor model: [Avg4] + TPM[S3Wt] × [Avg3]
[PLog]	Log scale	Conversion of the condition index to a log scale: LOG10(1+[PIx]) × 1/LOG10(2) (Unlike the Good model, this does not reverse the direction of the scale.)
[PBin]	Frequency bin	Assignment of a bridge to a bin for the frequency plot on the Freq worksheet: If not NHS then 0, else MIN(TRUNC(([PLog]^0.28)*70)+1,51) Note that this is scaled to give a more uniform plot.
[PPred]	Predicted %Poor	Prediction of the probability of Poor using the Weibull model: 1-(TPM[Const] + TPM[Slope] × EXP(-(([PLog]/TPM[Scale]) ^ TPM[Shape]))))
[PLike]	Log likelihood	Negative number reflecting the accuracy of the prediction: [Poor] × LN([PPred]) + (1-[Poor]) × LN(1-[PPred])
Probability of Good, based on age		
[RpRow]	TPM row, replacement model	The bottom row of the TPM table has this model.
[Age]	Age (years)	MaxInspYear - [YEARBUILT]
[RpPred]	Predict %Good	Prediction of the probability of Good using the Weibull model: EXP(-(([Age]/TPM[Scale]) ^ TPM[Shape]))
[RpLike]	Log likelihd	Negative number reflecting the accuracy of the prediction: [Good] × LN([RpPred]) + (1-[Good]) × LN(1-[RpPred])

4.06.07 Standards table – Levels of service, design standards, flood overtopping frequency, emissions

This table provides a variety of modeling parameters that are dependent on the functional classification of the roadway on a structure. They set the level of service standards for determination of functional deficiency, the design characteristics of an improved structure, a classification of overtopping frequency based on NBI item 71 (waterway adequacy), and social cost estimates reflecting the public health costs of pollutant emissions.

Data in the columns from [DefSpeed] to [DesVertClr] can be customized to the needs of specific agencies, which will affect the number of functional needs generated, and the magnitude of user costs that might be saved if a functional need is addressed by rehabilitation or replacement.

Column	Description	Calculation
[Func]	Functional class	See federal coding guide for definitions.
[Name]	Functional class	See federal coding guide for definitions.
[DefSpeed]	Default speed	Assumed traffic speed if not in the bridge management system (mph).
[LOSLaneWidth]	Level of service Lane width	Lane width (ft) used in determining the required traveled way width to satisfy level of service standards.
[LOSShldWidth]	Level of service Shoulder width	Shoulder width (ft) used in determining the required traveled way width to satisfy level of service standards.
[LOSVertClr]	Level of service Vertical clear	Minimum vertical clearance (ft) to satisfy level of service standards.
[LOSOpRating]	Level of service Operating rating	Minimum operating rating (tons) to satisfy level of service standards.
[DesLaneWidth]	Design Lane width	Lane width (ft) after replacement or widening.
[DesShldWidth]	Design Shoulder width	Shoulder width (ft) after replacement or widening.
[DesVertClr]	Design Vertical clear	Vertical clearance (ft) after replacement or raising.
[Wat0] **[Wat1]** **[Wat2]** **[Wat3]** **[Wat4]** **[Wat5]** **[Wat6]** **[Wat7]** **[Wat8]** **[Wat9]** **[Wat10]**	Overtopping frequency category	Overtopping frequency category, an integer from 1 to 5, for scour model. Classification based on functional class and waterway adequacy (NBI 71). See Garrow and Sturm (2013) for a discussion of the scour likelihood model, which is the source of all data in these columns.
[OrigEmis]	Emission social cost 2000$	Public health costs of pollutant emissions, not including carbon dioxide, reported in year 2000 dollars. These metrics come from the FHWA Highway Economic Requirements System (FHWA 2005). HERS costs by vehicle type are converted to fleet average using FHWA VMT statistics (FHWA 2015).
[Emissn]	Emission social cost in base year dollars	[OrigEmis] × CPI_Base / CPI_RedBook CPI_Base is the Consumer Price Index in the base year CPI_RedBook is the Consumer Price Index in year 2000.

4.06.08 Susceptibility table – Scour susceptibility

This table categorizes a structure's susceptibility to scour based on channel condition and substructure condition. See Garrow and Sturm (2013) for a discussion of the scour likelihood model, which is the source of all data in this table.

Column	Description	Calculation
[Chan]	NBI channel condition rating (NBI 61)	See federal coding guide for definitions.
[Subs0] **[Subs1]** **[Subs2]** **[Subs3]** **[Subs4]** **[Subs5]** **[Subs6]** **[Subs7]** **[Subs8]** **[Subs9]** **[Subs10]**	Scour susceptibility	Each column is a category of substructure condition rating (NBI 60). See federal coding guide for definitions. Scour susceptibility is a classification from 1 to 11.

4.06.09 ScourProb table – Likelihood of service disruption due to scour

This final step of the scour likelihood model estimates the probability of service disruption based on scour susceptibility and overtopping frequency. See Garrow and Sturm (2013) for a discussion of the scour likelihood model, which is the source of all data in this table.

Column	Description	Calculation
[Suscp]	Scour susceptibility	Integer from 1 to 11 as determined in the Susceptibility table.
[Otop1] **[Otop2]** **[Otop3]** **[Otop4]** **[Otop5]**	Probability of service disruption	Each column is a category of overtopping frequency as determined in the Overtopping Frequency section of the Standards table.

4.06.10 TPM table – Estimation of federal performance measure probabilities

TPM (Transportation Performance Management) contains model coefficients, constraints, and diagnostics related to the forecasting of the federal %Good and %Poor bridge condition measures. It supports formulas in the **TPM section** of the **Bridge** worksheet for maximum likelihood estimation of a Weibull model to predict %Good and %Poor from element level conditions. It also supports the **Cand** and **Forecast** worksheets where the federal measures are forecast for individual bridges as a result of work candidates.

All of the data in this table are either calculated by formulas, or set by the Excel Solver tool, which is executed via the **Solve** button. Data in the columns from [S3Wt] to [Shape] can optionally be entered manually to explore the model solution space or to suggest starting values for Solver. See the separate chapter on the **TPM model** for more information on how this table is used. Note that certain rows in the table may be empty if the file does not contain any structures to which the model would apply.

Column	Description	Calculation
[Netwk]	Network	Indicates the portion of the inventory for which the table row is applicable. NHS = NBI bridge on the National Highway System SHS = State-maintained structure not included in NHS Non = Structure not included in NHS or SHS Repl = Age-based model used with newly-replaced bridges (any network)
[Model]	Model	Good or Poor TPM model.
[Key]	Lookup key	Unique lookup key for each row of the table.
Model coefficients		
[S3Wt]	State 3 weight	Relative weight given to condition state 3 (compared to state 4) when computing the condition index for the %Poor model. Not used in any of the other models.
[Const]	Constant	Constant term in the Good and Poor Weibull models.
[Slope]	Slope	Slope coefficient in the Good and Poor Weibull models.
[Scale]	Scale	Scale coefficient in all the Weibull models.
[Shape]	Shape	Shape parameter in all the Weibull models.
Model constraints		
[NetAct]	Actual condition	Actual percent of inventory deck area, for bridges designated by [Netwk], in the condition designated by [Model], based on NBI component condition ratings.
[NetPre]	Predicted condition	Predicted percent of inventory deck area, for bridges designated by [Netwk], in the condition designated by [Model], based on NBI component condition ratings.
[BesAct]	Actual for best cond	Actual percent of deck area in Good condition, for bridges having a condition index (for the Good model) of 1.0. Not used in Poor or Repl models.
[BesPre]	Predicted for best cond	Predicted percent of deck area in Good condition, for bridges having a condition index (for the Good model) of 1.0. Not used in Poor or Repl models.
[WorAct] **[WorPre]**	Worst condition	Not currently used.
Model diagnostics		
[Count]	Count	Number of bridges in the indicated network (not used in Repl model).
[UnWt]	Unweighted condition	Unweighted percent of bridges in the indicated condition.
[Result]	Resulting log likelihood	Sum of log likelihood function for the model.
[Min]	Minimum log likelihood	Minimum value of the log likelihood function, if the model has no explanatory power.
[p-Stat]	p-statistic	Indication of model explanatory power.
[Code]	Solver code	Result code returned by Excel's Solver.
[Msg]	Message	Interpretation of success or failure based on Solver code.

4.07 StrUnit worksheet – Structure units

Some agencies divide bridges into spans or structure units, each having a separate list of elements. This can provide a more precise work plan since the element composition of a bridge and condition can vary along the length of a bridge. In some states only large complex bridges are divided up in this way, while other states have all multi-span bridges divided using this feature. For data imported or copy/pasted from a bridge management system, this table is required even if the agency does not take advantage of it. NBI data sets downloaded from the FHWA web site do not have this feature, so the StruPlan **import procedure** prepares a dummy table to take its place.

4.07.1 StrUnit table – Structure units

Column	Description	Calculation
[BRIDGE_ID]	Bridge identifier	Must agree with a bridge in Bridge[Bridge_ID].
[StrUnit_ID]	Structure unit	Unique structure unit identifier. If the agency doesn't use this feature, Bridge_ID may be substituted. However, this column must still be unique in the StrUnit table.

4.08 ElemInsp worksheet – Element inspections

This worksheet provides the main element-level input to StruPlan. Generally the information is meant to come from a bridge management system, or from FHWA's web site. See the **Import table** or the chapter on **Importing bridge data** later in this document for instructions on preparing an import data set. StruPlan requires element inspection data for most of its functionality. One parameter is set at the top of the page:

DefEnvt	Default environment if imported data do not have a valid environment code

4.08.1 ElemInsp table – Element inspections

The columns from [PON_ELEM_INSP_GD] to [ELEM_QTYSTATE4] can be imported, copy/pasted, or entered manually. Rows can be added or deleted from the table as needed. When element data are downloaded from the FHWA National Bridge Inventory web site, certain columns expected by StruPlan are not provided. The StruPlan **data import procedure** fills in default values for these columns.

Column	Description	Calculation
[PON_ELEM_INSP_GD]	ElemInsp GUID	Unique identifier for rows in the pon_elem_insp table of BrM. Not found in NBI download files, so in that case StruPlan uses Bridge_ID.
[BRIDGE_ID]	Bridge identifier	Agency identifier for rows in the pon_elem_insp table of BrM. NBI download column STRUCNUM. Must agree with one row in Bridge[Bridge_ID].
[StrUnit_ID]	Structure unit identifier	Identifier of the structure unit to which the element inspection belongs. Not found in NBI download files, so StruPlan provides a dummy value. Must agree with one row in StrUnit[StrUnit_ID].
[PARENT_PON_ELEM_INSP_GD]	Parent GUID	For protective elements, unique identifier of the element inspection record that it protects. Not found in NBI download files so in that case StruPlan creates a dummy value.
[ELEM_KEY]	Element number	NBI download column EN, must agree with one Element[ElemKey].
[ELEM_PARENT_KEY]	Parent element	NBI download column EPN, must agree with one Element[ElemKey].
[ENVKEY]	Environment	Environment class, expected to be an integer from 1 to 4. Not found in NBI download files.
[ELEM_QTYSTATE1]	Quantity state 1	Quantity in condition state 1, in element units
[ELEM_QTYSTATE2]	Quantity state 2	Quantity in condition state 2, in element units
[ELEM_QTYSTATE3]	Quantity state 3	Quantity in condition state 3, in element units
[ELEM_QTYSTATE4]	Quantity state 4	Quantity in condition state 4, in element units
[ElRow]	Element def'n	Formula for matching row in Element table.
[GrRow]	Group row	Formula for matching row in Group table.
[BrRow]	Bridge row	Formula for matching row in Bridge table.
[SURow]	Structure unit	Formula for matching row in StrUnit table.
[EnRow]	Environment	Formula for matching row in Environment table.
[PaRow]	Parent ElemInsp	Formula for parent row in ElemInsp table.
[Group]	Element group	Formula to identify the group to which the element belongs.
[Envt]	Cleanup envt	Assigns a default value from DefEnvt if a record does not have an environment class found in the Environment table.
[Qty]	Total quantity	Sum of the four condition state quantities.
[Val1]	State 1	[ELEM_QTYSTATE1] / [Qty] × [RpVal]
[Val2]	State 2	[ELEM_QTYSTATE2] / [Qty] × [RpVal]
[Val3]	State 3	[ELEM_QTYSTATE3] / [Qty] × [RpVal]
[Val4]	State 4	[ELEM_QTYSTATE4] / [Qty] × [RpVal]
[RpVal]	Total	Establishes element replacement value, which is used for scaling of element-based costs throughout StruPlan. [Qty] × Element[RcCost] × (1+Overhead)

4.09 SensAge worksheet – Sensitivity to age at first treatment

This worksheet simulates a 200-year time series of Markov deterioration of a related family of element groups, consisting of a substrate and up to two protective systems. The first protector is either a wearing surface or coating, and the second is a sealed expansion joint. The information in **Group**[P1] and **Group**[P2] determines what is possible. In each year, the model considers four possible treatments and computes initial costs and long-term costs for each. It selects the one with lowest long-term cost and indicates the result with a numeric code and color in the [Tmt] column. It compares the treatments in time series graphs on the right-hand side of the worksheet.

The graphical presentation of network level tradeoffs is helpful in evaluating the reasonableness of model inputs. Parameters on the **Group** worksheet can be changed if necessary to improve reasonableness. To specify a scenario to analyze, set the values in the following cells:

SA_Group	Element group, must be one of the codes listed in **Group**[Group].
SA_Joints	Can be 0 or 1. Value of 1 is valid only if a group code is specified in **Group**[P2].
SA_Envt	Normally an integer from 1 to 4, matching **Environment**[Class].
StartCond	Initial conditions for the simulation. Normally 100% in state 1.

Before computing the columns in the table, a few input values are gathered and prepared just above the table:

MedYr	Looked up from **Group**[[TT1]:[TT3]] for substrate element group.
P1MedYr	Looked up from **Group**[[TT1]:[TT3]] (for corresponding protector).
P2MedYr	Looked up from **Group**[[TT1]:[TT3]] (for corresponding protector).
P1SameProb	0.5 ^ (1/P1MedYr).
P1NextProb	1 – P1SameProb.
P1MinProt	Looked up from **Group**[PPMin].
P1MaxProt	Looked up from **Group**[PPMax].
P2SameProb	0.5 ^ (1/P2MedYr).
P2NextProb	1 - P2SameProb.
P2MinProt	Looked up from **Group**[PPMin].
P2MaxProt	Looked up from **Group**[PPMax].
SuVal	Network-wide replacement value ($M) of the parent element group from **Group**[RpVal]
P1Val	Replacement value ($M) of the first protective element group
P2Val	Replacement value ($M) of the second protective element group
MinScale	LOG(P1MinProt×P2MinProt).
MaxScale	LOG(P1MaxProt×P2MaxProt).

The element group values SuVal, P1Val, and P2Val are used for scaling of the three element groups when computing initial costs and long-term costs per $1000 of replacement value. Protective elements can protect more than one substrate element group. Therefore, the network-wide replacement value of protectors is allocated to substrate element groups according to each parent element group's value.

If you make changes in any of the input data or formulas in the long-term model, click the **Update LTCs** button to ensure that all long-term models are up-to-date. This typically takes less than one minute to run.

4.09.1 SensAge table – Long-term condition and cost forecast

Column	Description	Calculation
[Year]	Year	Year of the simulation, 1 to 200
[State1] **[State2]** **[State3]** **[State4]**	Substrate condition	For [Year]=1, start with conditions in StartCond (usually 100% state 1). For subsequent years: [State](S,[Year]-1) × ProbSS(S,[Year]-1) + [State](S-1,[Year]-1) × ProbSS(S-1,[Year]-1) where S is the condition state to be computed. Note [State] is taken from previous year. ProbSS is the transition probability modified by protection factors. taken from [[Prob11]:[Prob44]] in previous year.
[P1S1] **[P1S2]** **[P1S3]** **[P1S4]**	Protection 1 condition	For [Year]=1, start with conditions in StartCond (usually 100% state 1). For subsequent years: [State](S,[Year]-1) × P1SameProb(S) + [State](S-1,[Year]-1) × P1NextProb(S-1) where S is the condition state to be computed. Note [State] is taken from previous year.
[P2S1] **[P2S2]** **[P2S3]** **[P2S4]**	Protection 2 condition	For [Year]=1, start with conditions in StartCond (usually 100% state 1). For subsequent years: [State](S,[Year]-1) × P2SameProb(S) + [State](S-1,[Year]-1) × P2NextProb(S-1) where S is the condition state to be computed. Note [State] is taken from previous year.
[P1Prot]	Protection factor P1	If P1MaxProt=0, 1, P1MaxProt-(1-([P1S1]+(2/3)*[P1S2]+(1/3)*[P1S3]))*(P1MaxProt-P1MinProt))
[P2Prot]	Protection factor P2	If P2MaxProt=0, 1, P2MaxProt-(1-([P2S1]+(2/3)*[P2S2]+(1/3)*[P2S3]))*(P2MaxProt-P2MinProt))
[Prot]	Protection factor total	[P1Prot] × [P2Prot]
[Prob11] **[Prob22]** **[Prob33]** **[Prob44]**	Modified transition probability	0.5 ^ (1/(EnvtFactor × MedYr × [P1Prot] × [P2Prot])) [Prob44] = 1.0.
[Scale]	Protection scale factor	Used for interpolating long-term cost between best and worst protection. 1-IF(MinScale=MaxScale,1,(LOG([Prot])-MinScale)/(MaxScale-MinScale))
[CostT1] **[CostT2]** **[CostT3]** **[CostT4]**	Initial cost ($/$000)	Initial cost if the indicated treatment takes place in the year indicated. Treatments T1 thru T4 are DN, Pres, Rehab, and Recon respectively. (SensAge[[State1]:[State4]] × NetCost[[Init1]:[Init4]] × SuVal+ SensAge[[P1S1]:[P1S4]] × NetCost[[Init1]:[Init4]] × P1Val+ SensAge[[P2S1]:[P2S4]] × NetCost[[Init1]:[Init4]] × P2Val) / (SuVal+P1Val+P2Val) where NetCost[[Init1]:[Init4]] comes from the row specified by SA_Group, SA_Joints, and SA_Envt, for the indicated treatment, for the substrate, P1, or P2 as needed.
[LTCT1] **[LTCT2]** **[LTCT3]** **[LTCT4]**	Long-term cost ($/$000)	Long-term cost if the indicated treatment takes place in the year indicated. Treatments T1 thru T4 are DN, Pres, Rehab, and Recon respectively. If SA_Joints=0 or the substrate element group is not protected by sealed joints: ((SensAge[[State1]:[State4]] × NetCost[[NBLTC1]:[NBLTC4]] + [Scale] × (SensAge[[State1]:[State4]] × NetCost[[NWLTC1]:[NWLTC4]] - SensAge[[State1]:[State4]] × NetCost[[NBLTC1]:[NBLTC4]])) × SuVal + SensAge[[P1S1]:[P1S4]] × NetCost[[NBLTC1]:[NBLTC4]] × P1Val) / (SuVal+P1Val) Otherwise: ((SensAge[[State1]:[State4]] × NetCost[[JBLTC1]:[JBLTC4]] + [Scale] × (SensAge[[State1]:[State4]] × NetCost[[JWLTC1]:[JWLTC4]] - SensAge[[State1]:[State4]] × NetCost[[JBLTC1]:[JBLTC4]])) × SuVal +

		SensAge[[P1S1]:[P1S4]] × NetCost[[NBLTC1]:[NBLTC4]] × P1Val + SensAge[[P2S1]:[P2S4]] × NetCost[[NBLTC1]:[NBLTC4]] × P2Val) / (SuVal+P1Val+P2Val) where NetCost[[Init1]:[Init4]] comes from the row specified by SA_Group, SA_Joints, and SA_Envt, for the indicated treatment, for the substrate, P1, or P2 as needed. In the above, [Scale] is used to interpolate between best and worst protection.
[PrTBC]	Scaled net benefit	([LTCT1]-[LTCT2])/[CostT4], used in the graph at upper right of worksheet
[RhTBC]	Scaled net benefit	([LTCT1]-[LTCT3])/[CostT4]
[RcTBC]	Scaled net benefit	([LTCT1]-[LTCT4])/[CostT4]
[Tmt]	Lowest-cost treatment	Indicates with an integer 1 to 4 the treatment with lowest value in [[LTCT1]:[LTCT4]].

4.10 NetCost worksheet – Network level cost results

StruPlan prepares a table of network level estimates of long term cost per $1000 of element replacement value, using a **life cycle cost analysis** from the **LTC** worksheet. By preparing these metrics in advance, StruPlan makes it unnecessary to simulate 75 years of deterioration and costs separately for each bridge, thus saving an enormous amount of execution time. The results in this table are used in the **SensAge** worksheet for sensitivity analysis, and in the **SuGr** worksheet to generate work candidates for each structure unit element group.

All of the information in this worksheet is generated by the VBA UpdateNetCosts procedure, which may be executed by clicking the **Update LTCs** button at the top of the **SensAge** worksheet. The procedure iterates through all possible combinations of environment, element group, and presence of sealed joints, updating the **LTC** worksheet for each scenario and then capturing the results of the long-term cost analysis. The whole process typically takes less than one minute.

4.10.1 NetCost table – Unit long-term costs by environment, treatment, and element group

This table holds the results of the long-term cost analysis for every possible scenario. Each row of **NetCost** corresponds to one row in **LTC_Results**. Each row in **NetCost** contains the results of one scenario without sealed expansion joints, and may have a second scenario with sealed joints if the corresponding element group is marked as potentially protected by sealed joints in **Group**[P2].

Column	Description	Calculation
[Key]	Lookup key	Concatenation of environment class, treatment abbreviation, and group code, for matching to rows in SuGr table.
[EnRow]	Environment	Matching row in the Environment table.
[TrRow]	Treatment	Matching row in the Treatment table.
[GrRow]	Element group	Matching row in the Group table.
[Init1] **[Init2]** **[Init3]** **[Init4]**	Unit initial cost ($/$000)	Copied from LTC[[Init1]:[Init4]]
[NBLTC1] **[NBLTC2]** **[NBLTC3]** **[NBLTC4]**	Unit long-term cost ($/$000)	Results for structure units without joints with best protective element condition. Copied from LTC[[BLTC1]:[BLTC4]].
[NWLTC1] **[NWLTC2]** **[NWLTC3]** **[NWLTC4]**	Unit long-term cost ($/$000)	Results for structure units without joints with worst protective element condition. Copied from LTC[[WLTC1]:[WLTC4]].
[JBLTC1] **[JBLTC2]** **[JBLTC3]** **[JBLTC4]**	Unit long-term cost ($/$000)	Results for structure units with sealed joints with best protective element condition. Copied from LTC[[BLTC1]:[BLTC4]].
[JWLTC1] **[JWLTC2]** **[JWLTC3]** **[JWLTC4]**	Unit long-term cost ($/$000)	Results for structure units with sealed joints with worst protective element condition. Copied from LTC[[WLTC1]:[WLTC4]].

4.11 LTC worksheet – Long-term cost calculations

This worksheet performs the long-term cost calculation generically for a selected element group and environment. For element groups that can be protected by sealed expansion joints, scenarios are evaluated with and without the protection. A VBA procedure cycles through all the scenarios and gathers the results on the **NetCost** worksheet. All cost calculations are expressed in dollars per $1000 of element replacement value, and are later scaled according to the size of each bridge.

Long-term costs in StruPlan are used as a means of comparing treatment alternatives. Therefore each scenario starts in the first year with a choice of treatment, either do nothing, preservation, rehabilitation, or reconstruction. This is followed by a deferment period (typically 10 years), when no work is programmed and zero cost is incurred. This is followed by a long period when a standardized allowance is made for subsequent annual costs, dependent on condition. No assumption is made about the timing of subsequent actions; rather, each year is considered equally likely.

The long-term cost calculation is a long Markov chain, where each year's condition depends on condition in the year before. To minimize computational time, the worksheet is arranged into eight parallel chains, enabling Excel to assign the calculations to the eight processor threads available on computers commonly used by civil engineers. Excel automatically recognizes the opportunity for parallel processing and optimizes execution time. Testing has shown that execution time is one-eighth of what it would otherwise be, because of this arrangement.

One summary table at the top of the worksheet gathers results from an array of 48 tables below it, arranged in eight columns of 6 tables each. Each table contains a Markov chain of 75 years, modeling deterioration and the effect of possible treatments.

The eight columns of tables, which Excel assigns to separate processor threads, address scenarios of four treatments (DN, Pres, Rehab, and Recon) for each of two levels of protection (Best and Worst). Worksheets that use the results (**SensAge** and **SuGr**) select the appropriate treatment and interpolate between best and worst protection based on the condition of protecting elements, if any. If wearing surfaces or coatings are absent on a bridge, then worst protection is assumed for the P1 protecting element. If joints are absent, then best protection is assumed for the P2 element.

The first row of tables calculates a protection factor for wearing surfaces or coatings, for element groups having one of those possible protecting elements. Generally a bridge with no such protection, or protection in worst condition, has a protection factor of 1.0. Better protection yields a higher protection factor and therefore slower deterioration.

The second row of tables calculates a protection factor for sealed expansion joints. Joints in best condition, or bridges without joints, have a protection factor of 1.0. Joints in worse condition have a lower protection factor and faster deterioration.

The third through sixth rows of tables calculate long-term costs for the selected element group, conditional on each of the four possible condition states. State 1 yields the lowest long-term cost, and state 4 yields the highest cost. As individual bridges are analyzed in the **SuGr** worksheet, long-term cost is a linear combination of the four condition states, based on the condition of the element group on each structure unit.

Names are assigned to the 48 tables to represent their position in the worksheet. After the prefix "LTC_", the next two characters are "Be" for the best protection scenario, or "Wo" for worst protection. The next characters designate the treatment: "DN", "Pres", "Rehab", or "Recon". The final two characters designate the row: P1 and P2 for the protection factor rows, then S1, S2, S3, and S4 for the substrate condition states. For example, **LTC_BePresS2** is the table for best protection, preservation treatment, starting with condition state 2.

To simplify maintenance of this worksheet, the Excel worksheet formulas in the tables are designed to enable the use of copy/paste to update most of the tables after any changes are made. In the first row, make any needed changes in the **LTC_BeDNP1** table, then copy the table and paste it seven times across the row to replace the tables there. In the second row, make any needed changes in the **LTC_BeDNP2** table, then copy the table and paste it seven times across the row to replace the tables there. In the third row, make any needed changes in the **LTC_BeDNS1** table, then copy the table and paste it 31 times across the row and then downward to the three rows below it, to replace the tables there. Behavior of each table is governed by the Start column on the right-hand edge of the worksheet, and the Protect, Tmt, and State rows on the bottom of the worksheet. In the following sections of this document, these range names appear in certain formulas to affect the calculations in the tables.

4.11.1 LTC_Results table – Gathering of unit long-term costs from the matrix of models

This table provides a centralized place to summarize the final results of the 48 tables below it. The following table indicates the sources for each column. The **LTC_Results** table is the only table on this worksheet that is referenced outside the worksheet, and only by the VBA procedure UpdateNetCosts that generates the **NetCost** table. The following cells, all at the top of the **LTC** worksheet, are populated by UpdateNetCosts as it iterates through all the possible scenarios and fills in the NetCost table:

LTC_Group	Element group, must be one of the codes listed in **Group**[Group].
LTC_Joints	Can be 0 or 1. Value of 1 is valid only if a group code is specified in **Group**[P2].
LTC_Envt	Normally an integer from 1 to 4, matching **Environment**[Class].

The cell named Deferment specifies the number of years after year 1, when no costs are to be incurred. This should be at least the length of the short-term analysis period, generally 10 years. Standardized long-term costs are incurred starting in year Deferment+1.

All unit costs are expressed in dollars per $1000 of element replacement value.

Column	Description	Source
[Treatment]	Treatment	DN, Pres, Rehab, or Recon
[Init1] **[Init2]** **[Init3]** **[Init4]**	Unit initial cost ($/$000)	LTC_BeDNS1, LTC_BePresS1, LTC_BeRehabS1, LTC_BeReconS1 LTC_BeDNS2, LTC_BePresS2, LTC_BeRehabS2, LTC_BeReconS2 LTC_BeDNS3, LTC_BePresS3, LTC_BeRehabS3, LTC_BeReconS3 LTC_BeDNS4, LTC_BePresS4, LTC_BeRehabS4, LTC_BeReconS4
[BLTC1] **[BLTC2]** **[BLTC3]** **[BLTC4]**	Unit long-term cost ($/$000): Best protection	LTC_BeDNS1, LTC_BePresS1, LTC_BeRehabS1, LTC_BeReconS1 LTC_BeDNS2, LTC_BePresS2, LTC_BeRehabS2, LTC_BeReconS2 LTC_BeDNS3, LTC_BePresS3, LTC_BeRehabS3, LTC_BeReconS3 LTC_BeDNS4, LTC_BePresS4, LTC_BeRehabS4, LTC_BeReconS4
[WLTC1] **[WLTC2]** **[WLTC3]** **[WLTC4]**	Unit long-term cost ($/$000): Worst protection	LTC_WoDNS1, LTC_WoPresS1, LTC_WoRehabS1, LTC_WoReconS1 LTC_WoDNS2, LTC_WoPresS2, LTC_WoRehabS2, LTC_WoReconS2 LTC_WoDNS3, LTC_WoPresS3, LTC_WoRehabS3, LTC_WoReconS3 LTC_WoDNS4, LTC_WoPresS4, LTC_WoRehabS4, LTC_WoReconS4

4.11.2 LTC_BeDNP2 tables – Protection factors for best and worst protective systems by treatment

Two sets of rows each have eight tables to calculate protection factors. The tables starting with **LTC_BeDNP1** calculate protection factors for wearing surfaces or protective coatings, for element groups that have them. The tables starting with **LTC_BeDNP2** calculate the protection factor for sealed expansion joints, supporting scenarios that consider the effect of seal condition. Also in this second row of tables are columns [Prob11] to [Prob33], which combine the two protection factors and modify the substrate transition probabilities to account for changes in protector condition as the protective elements deteriorate.

The following information documents the second set of tables. The **LTC_BeDNP1** tables are similar except that they do not contain the [Prob11] to [Prob33] columns. Prior to the calculations in the table, the worksheet accesses and prepares the relevant modeling parameters, as follows:

MedYr	Looked up from **Group**[[TT1]:[TT3]] for substrate element group.
P2MedYr	Looked up from **Group**[[TT1]:[TT3]] (for corresponding protector) × EnvtFactor.
P2SameProb	0.5 ^ (1/P2MedYr).
P2NextProb	1 - P2SameProb.
P2LTEffect	Looked up from **Group**[[App1]:[App4]] × **Group**[[Eff1]:[Eff4]].
P2STEffect	Looked up from **Group**[[PrEff1]:[RhEff4]].
P2MinProtect	Looked up from **Group**[PPMin]
P2MaxProtect	Looked up from **Group**[PPMax]

Column	Description	Calculation
[Year]	Year	Year of the long-term time frame, 1 to 75.
[State1] **[State2]** **[State3]** **[State4]**	Condition at start of year	For [Year]=1, start in 100% state 1 if best-protection scenario (Protect="Best"), or 100% state 4 if worst protection scenario. For subsequent years: [Effect](S,[Year]-1) × P2SameProb(S) + [Effect](S-1,[Year]-1) × P2NextProb(S-1) where S is the condition state to be computed. Note [Effect] is taken from previous year. Deterioration is after previous treatment (if any) up to the start of current year. [State4] = 1-[State1]-[State2]-[State3]
[Effect1] **[Effect2]** **[Effect3]** **[Effect4]**	Condition after treatment	Modeled as just after the start of the year. [Effect2] (similar for [Effect3] and [Effect4]): If [Year] = 1, Then If Tmt="DN" then [State2] else [State2]*(1-P2STEffect)), Else If [Year] <= Deferment then [State2] else [State2]*(1- P2LTEffect) [Effect1] = 1-[Effect2]-[Effect3]-[Effect4]
[Prob11] **[Prob22]** **[Prob33]**	Modified transition probability	Substrate transition probability modified with protection factors. 0.5 ^ (1/MedYr(S)) × [Prot](for protector P1, same year) If protected by joints, multiply by [Prot] for protector P2.
[Prot]	Protection factor	If P2MaxProt=0 or blank then 1 else P2MaxProt - (1-([Effect1]+(2/3)×[Effect2]+(1/3)×[Effect3]))×(P2MaxProt-P2MinProt))

4.11.3 LTC_BeDNS1 tables – Long-term cost for substrates by treatment and starting state

Four rows of eight tables calculate the long-term cost of the selected substrate element group. These calculations are also performed for protective element groups, separately from their substrates. Each row of tables computes a separate starting condition state. Later on the **SuGr** worksheet when considering a given structure unit element group in a forecast condition, the four estimates of long-term cost are combined according to the fraction in each condition state.

Prior to the calculations in the table, the worksheet accesses and prepares the relevant modeling parameters, as follows:

Discount	From **Settings**!Discount
Overhead	From **Settings**!Overhead
LTEffect	Looked up from **Group**[[App1]:[App4]] × **Group**[[Eff1]:[Eff4]].
STEffect	Looked up from **Group**[[PrEff1]:[RhEff4]].
LTVarCost	Looked up from **Group**[[App1]:[App4]] × **Group**[[VrCost1]:[VrCost4]] × (1+Overhead) + **Group**[[MtCost1]:[MtCost4]].
STVarCost	Looked up from **Group**[[PrVC1]:[RhVC4]].
FixCost	Looked up from **Group**[[PrFix]:[RcFix]].
RiskCost	Looked up from **Group**[DisProb] × **Group**[DisCost].

Column	Description	Calculation
[Year]	Year	Year of the long-term time frame, 1 to 75.
[State1] **[State2]** **[State3]** **[State4]**	Condition at start of year	For [Year]=1, start with 100% in the indicated starting state (Start). For subsequent years: [Effect](S,[Year]-1) × ProbSS(S,[Year]-1) + [Effect](S-1,[Year]-1) × ProbSS(S-1,[Year]-1) where S is the condition state to be computed ProbSS looked up from LTC_BeDNP2[[Prob11]:[Prob33]], preceding year (transition probability modified by protection factors) [State4] = 1-[State1]-[State2]-[State3]
[Effect1] **[Effect2]** **[Effect3]** **[Effect4]**	Condition after treatment	Modeled as just after the start of the year. [Effect2] (similar for [Effect3] and [Effect4]): If [Year] = 1, Then If Tmt="DN" then [State2] else [State2]*(1-STEffect)), Else If [Year] <= Deferment then [State2] else [State2]*(1- LTEffect) [Effect1] = 1-[Effect2]-[Effect3]-[Effect4]
[Agcy]	Annual agency cost	For [Year]=1, use the short-term variable and fixed costs for the selected treatment: [[State1]:[State4]] × STVarCost + FixCost For [Year] from 2 to Deferment, the cost is zero. For subsequent years use the long-term costs: [[State1]:[State4]] × LTUnitCost
[Risk]	Annual risk cost	[State4] × RiskCost
[Social]	Annual discounted social cost	([Agcy] + [Risk])*(1/((1+Discount)^([Year]-1)))

By year 75, condition and costs reach a steady state. The calculation for [Social] is repeated one more time for year 76, and then divided by Discount to estimate subsequent long-term cost as a perpetuity. This is added to the sum of the [Social] column to yield the reported long-term cost.

4.12 Group worksheet – Element group parameters and cost calculations

This worksheet contains most of the important modeling parameters for calculations based on element data, including deterioration, long-term cost analysis, and short-term cost estimation. In StruPlan, the **long-term analysis** simulates 75 years of deterioration and costs, with a perpetuity adjustment to allow for costs even beyond 75 years. The **medium-term analysis** is typically the same time period as the Transportation Asset Management Plan, or 10 years.

Implicit in StruPlan is a set of treatment category definitions, which are more quantitative than definitions found in other sources (such as the FHWA Preservation Guide) and more oriented toward the needs of asset management analysis. The treatment categories are modeled as follows:

- Do nothing or maintenance-only – Deterioration rates and maintenance costs assume that only unprogrammed or cyclical maintenance work is performed, such as filling of potholes, clearing of brush, and mitigation of safety hazards. The costs are recognized only in the long-term model (for comparison of long-range outcomes) and not in the medium-term model (where they are assumed to be paid from a separate operating budget).
- Preservation – Treatments are driven by element conditions and assumed to apply to elements individually. Usually only condition states 2 and 3 are affected by preservation, with the exception that protective elements (wearing surfaces, coatings, and sealed joints) can be repaired if in state 4. Fixed costs are recognized for the elements needing work, and are relatively low.
- Rehabilitation – Treatments are driven by element conditions but assumed to apply to the bridge as a whole. A rehab project addresses all the needs on a bridge on all elements, and may include the total replacement of protective elements. Rehabilitation can affect all elements and condition states, and has a higher fixed cost than preservation.
- Reconstruction – This treatment can be based on element condition if the costs of alternative treatments (preservation or rehabilitation) are relatively high compared to the replacement cost. Replacement can also be driven by functional needs or risk. Cost does not depend on condition, so is modeled as a fixed cost in the short term. All projects are modeled as in-kind replacement with no change in structure type or number of lanes. All elements are restored to new condition, and functional and risk mitigation deficiencies are corrected.

Since StruPlan is an open spreadsheet, it can be modified if necessary to change any of these definitions. However as a reminder, StruPlan is intended as a network level analysis, so definitions are intentionally more general and less detailed, with reduced data requirements, compared to a full-scale bridge management system analysis.

The Group worksheet has several embedded notes providing more information about certain items. Most significant is the handling of sealed or unsealed expansion joints. The software generates associations between joints and element groups that can be protected (and thus experience slower deterioration) if the joints are fully sealed. Open joints are modeled in the same way as joints whose seals are in condition state 4 Poor joint seal condition causes faster deterioration of protected element groups in the model.

Another important note concerns group XX. This group represents elements that may occur in the bridge data but which are not to be considered in the model. The software does not create SuGrs for elements in group XX.

In the short-term model, fixed costs play an important role. For example, they prevent the model from generating very small projects, because such projects would have high costs relative to their small benefits. The long-term model, however, is purely network level and therefore must treat all costs as variable because it does not distinguish individual structures. Fixed costs are computed by applying an overhead factor to variable cost. For the short-term model, this calculation is based on condition at a given age where preservation or rehabilitation would occur. Two settings govern this:

PrYear – Age at which preservation is assumed, used only in setting fixed cost.

RhYear – Age at which rehabilitation is assumed, used only in setting fixed cost.

4.12.1 Group table – Deterioration, application rates, effectiveness, unit variable and fixed costs

The yellow-shaded columns in the table are those that would be most commonly changed when adapting StruPlan to a new agency or updating model parameters based on agency research. The initial columns from [Group] to [P2] might be changed for applications that require more distinctions among elements, where deterioration rates or costs might differ in a more fine-grained manner among elements. In general, the parameters set in each row of the **Group** table are applied to every element belonging to that group.

The columns from [MtCost1] to [RhVC4], and [PrFix] to [RcFix] use formulas to estimate cost factors, computed from element level unit costs. These formulas can be modified if desired to change the cost structure, for example to change the relative costs of preservation vs rehabilitation, or the amount allocated to fixed costs.

Many of the columns available for data entry in the **Group** table affect the network level long-term cost calculation reported in the **NetCost** table. Therefore the **NetCost** table is updated automatically any time data are changed in the **Group** table. If you change any formulas, click the **Update** button to re-generate the **NetCost** table.

Column	Description	Calculation
[Group]	Element group	An abbreviated code used in grouping elements that have similar deterioration rates and cost structure. Each row must have a unique code. The code is used to identify models for the SuGr, ElemInsp, SensAge, NetCost, LTC, and Element tables. In most cases the suggested codes are two characters, the first representing a material and the second a bridge component. For certain applications, longer codes might be useful, for example to distinguish multiple protective coating systems that have different costs or deterioration rates, to correspond with agency-defined elements. Protective elements have more specific requirements: • Protective coatings must begin with PC, e.g. "PC1", "PC2" etc. • Wearing surfaces must begin with WS. • Sealed joints must begin with SJ and open joints with OJ.
[Sort]	Sort order	Generally a sequential numbering of rows in the order desired for most purposes. This allows the rows to be temporarily sorted in a different order and then restored to their default order.
[NBI]	NBI component	Corresponding NBI component most commonly associated with the element group. Must be Dk, Sp, Sb, Cv, or blank. If blank, the element group is not considered in estimating the federal %Good and %Poor.
[RpDk]	Replace with deck	Enter a 1 for element groups that are typically replaced if the deck is replaced, zero or blank otherwise.
[RpSp]	Replace with superstructure	Enter a 1 for element groups that are typically replaced if the superstructure is replaced, zero or blank otherwise.
[Name]	Group name	Name of the element group.
[P1]	Protector 1	Generally this should be WS, PC, or blank. If a Group has a type of protective element indicated in this column, then a protective element is expected in the modeling. If absent, the Group is modeled as though a protective element could be added, and this gives it the benefit of slower deterioration.
[P2]	Protector 2	P2 is a model of expansion joints. Indicate in this column which Group should be assumed as the default sealed joint which might be installed in place of an open joint; or leave blank if a sealed joint would not protect the elements in the Group. If a bridge has no joints present, this is modeled as the best protection with no joint seal deterioration, Protection Factor (PF)=1. If a sealed joint is present, it may deteriorate and this adds to long-term cost, with PF<1. If an open joint is present, this is modeled as a sealed joint in worst condition (PF at its lowest value less than 1). The model assumes that a seal

		or water diversion device could be added to an open joint to make it behave as a sealed joint.
[P1Row]	P1 row	Formula to determine the row of the Group table where the model describing the P1 protective system can be found. (This will still be correct even if the table is sorted.)
[P2Row]	P2 row	Formula to determine the row of the Group table where the model describing the P2 protective system can be found. (This will still be correct even if the table is sorted.)
[PPMin]	Minimum protection parameter	Used only for protective element groups, blank otherwise. Should generally be <= 1.0 for sealed joints, and = 1.0 for wearing surfaces and coatings. When no joint is present, groups marked with P2=SJ are modeled as having best protection. When OJ is present, this is modeled as SJ in worst condition, under the assumption that a seal or other protection could be added to the joint.
[PPMax]	Maximum protection parameter	Used only for protective element groups, blank otherwise. Should generally be = 1.0 for sealed joints, and >= 1.0 for wearing surfaces and coatings.
[TT1] **[TT2]** **[TT3]**	Transition times	Median time in years to transition from the indicated condition state to the next-worse condition state (or median residence time in the indicated state).
[Shape]	Weibull shape parameter	Shaping parameter of the Weibull model, which if >1.0 causes a slowing of Markovian deterioration for newer or newly-replaced elements.
[App1] **[App2]** **[App3]** **[App4]**	Application rates	The average percent of each condition state that receives treatment in any one year, in the long-term model. This accounts for the fact that funding constraints, project lead times, and other practical matters cause a delay in implementing corrective action.
[Eff1] **[Eff2]** **[Eff3]** **[Eff4]**	Effectiveness	The average percent of each condition state that is restored to condition state 1 by a treatment (conditional on a treatment being applied), in the long-term model.
[CostFac]	Cost factor	Multiplier for element costs, used in sensitivity analysis. Normally based on Settings!SensCost, but can be set individually by element group.
[DisProb]	Disruption probability	Probability, in any one year, that transportation service will be disrupted (posting, closure, safety or mobility impacts), to the extent that an element is in condition state 4. Used in the long-term model.
[DisCost]	Disruption cost	Cost that is incurred by the agency, road users, and society if service is disrupted due to poor conditions. Used in the long-term model.
[Count]	Bridge count	Number of bridges containing an element in this group. SUMIF(Element[Group],[Group],Element[Count])
[RpVal]	Replacement value	Element quantity times element replacement unit cost, summed over all bridge elements in the group. This is a total cost including overhead. SUMIF(Element[Group],[Group],Element[RpVC])×(1+Overhead)×[CostFac]
[MtCost1] **[MtCost2]** **[MtCost3]** **[MtCost4]**	Maintenance unit cost	Annual maintenance cost of being in each state, part of the network level long-term cost calculation, in dollars per $1000 of replacement value. [CostFac]×SUMIF(Element[Group],[Group],Element[MtVC2])/[RpVal]×1000
[VrCost1] **[VrCost2]** **[VrCost3]** **[VrCost4]**	Long-term unit variable cost	This is the average unit cost incurred by the agency if a preservation or repair action is taken on elements in the group, in dollars per $1000 of replacement value. On each bridge, the fraction in each state is multiplied by the unit cost for that state and the replacement value to estimate the project dollars. [CostFac]×SUMIF(Element[Group],[Group],Element[PrVC2])/[RpVal]×1000

[PrVC1] **[PrVC2]** **[PrVC3]** **[PrVC4]**	Short-term unit variable cost: preservation	Unit cost, expressed in dollars per $1000 of replacement value, if a preservation treatment is applied, by condition state. Used in the short-term model.
[RhVC1] **[RhVC2]** **[RhVC3]** **[RhVC4]**	Short-term unit variable cost: rehabilitation	Unit cost, expressed in dollars per $1000 of replacement value, if a rehabilitation treatment is applied, by condition state. Used in the short-term model.
[PrEff1] **[PrEff2]** **[PrEff3]** **[PrEff4]**	Short-term treatment effect: preservation	The average percent of each condition state that is restored to condition state 1 by a preservation treatment (conditional on a treatment being applied), in the short-term model.
[RhEff1] **[RhEff2]** **[RhEff3]** **[RhEff4]**	Short-term treatment effect: rehabilitation	The average percent of each condition state that is restored to condition state 1 by a rehabilitation treatment (conditional on a treatment being applied), in the short-term model.
[PrSt1] **[PrSt2]** **[PrSt3]** **[PrSt4]**	Preservation condition	Typical condition (fraction by state) when a preservation action is applied. This is calculated by the VBA SetFixedCostConditions procedure, based on conditions taken from the SensAge worksheet in the year specified in the PrYear cell (typically year 20). Used in the short-term model to estimate typical fixed costs of a project.
[RhSt1] **[RhSt2]** **[RhSt3]** **[RhSt4]**	Rehabilitation condition	Typical condition (fraction by state) when a rehabilitation action is applied. This is calculated by the VBA SetFixedCostConditions procedure, based on conditions taken from the SensAge worksheet in the year specified in the RhYear cell (typically year 40). Used in the short-term model to estimate typical fixed costs of a project.
[PrFix]	Unit fixed cost: preservation	Portion of preservation project costs that are not dependent on deteriorated quantity, expressed in dollars per $1000 of replacement value. Calculated as typical preservation conditions, times variable cost of preservation, times the overhead rate.
[RhFix]	Unit fixed cost: rehabilitation	Portion of rehabilitation project costs that are not dependent on deteriorated quantity, expressed in dollars per $1000 of replacement value. Calculated as typical rehabilitation conditions, times variable cost of rehabilitation, times the overhead rate.
[RcFix]	Unit fixed cost: reconstruction	Since reconstruction costs are not dependent on condition, the reconstruction cost is the condition state 4 rehab cost (assumed to be element replacement) increased by the overhead rate, expressed in dollars per $1000 of replacement value.

4.13 Element worksheet – Element definition and cost parameters

Most StruPlan formulas work with data aggregated to the element group level. The **Elements** table provides the classification of elements into groups. It also provides the initial calculations that are used to convert raw element units of measure into generic costs per $1000 of element replacement value. This provides a reasonable way of overcoming the differences among elements in their measurement units, to simplify calculations.

4.13.1 Element table – Element grouping, unit costs, conversion to standardized costs

Data in columns [ElemKey] to [RpVUC] are typically copy/pasted from a bridge management system, but many agencies calculate them externally using data gathered from work accomplishment records.

The replacement value [RpVC] calculated in this table is the primary basis for allocating all element-based costs throughout StruPlan. This is consistent with StruPlan's intended role as a financial planning model for structural asset management.

All elements that occur in the ElemInsp table should be defined in the Element table, to assign them to a group and to provide appropriate unit costs. If an ElemInsp refers to an element number that is not defined in the Element table, the software ignores it. You can explicitly mark elements as unused by assigning them to group XX, a special group that StruPlan recognizes and suppresses. For example, an element for "utilities on bridge" is one that some agencies might track but which they normally would not want to include in the model.

If you enter or paste any data in this table, be sure to click the **Update LTCs** button on the **SensAge** worksheet to regenerate the unit long term costs, or the **Update All Models** button on the **Dashboard**.

Column	Description	Calculation
[ElemKey]	Element number	Must agree with values used in ElemInsp[ELEM_KEY]
[Name]	Name	
[Units]	Units	
[Group]	Element group	Must agree with one value of Group[Group]
[MtVUC2]	Maint cost 2	Maintenance variable cost per element unit in state 2
[MtVUC3]	Maint cost 3	Maintenance variable cost per element unit in state 3
[MtVUC4]	Maint cost 4	Maintenance variable cost per element unit in state 4
[PrVUC2]	Repair cost 2	Repair variable cost per element unit in state 2
[PrVUC3]	Repair cost 3	Repair variable cost per element unit in state 3
[PrVUC4]	Repair cost 4	Repair variable cost per element unit in state 4
[RpVUC]	Replace cost	Replacement variable cost per element unit
[Count]	ElemInsp count	COUNTIF(ElemInsp[ELEM_KEY],[ElemKey])
[Quantity]	Total quantity	SUMIF(ElemInsp[ELEM_KEY],[ElemKey],ElemInsp[Qty])
[MtVC2]	Maint 2 value	[MtVUC2] × [Quantity]/1000
[MtVC3]	Maint 3 value	[MtVUC3] × [Quantity]/1000
[MtVC4]	Maint 4 value	[MtVUC4] × [Quantity]/1000
[PrVC2]	Repair 2 value	[PrVUC2] × [Quantity]/1000
[PrVC3]	Repair 3 value	[PrVUC3] × [Quantity]/1000
[PrVC4]	Repair 4 value	[PrVUC4] × [Quantity]/1000
[RpVC]	Replace value	[RpVUC] × [Quantity]/1000

4.14 Settings worksheet – General settings and parameters

This worksheet provides general parameters used throughout the StruPlan model. Notes are embedded in the worksheet to help guide the entry of parameter values. Aside from the tables discussed in the following sections, the following general parameters are defined:

- BaseYear – first year for which projects are planned.
- Overhead - Percentage added to direct costs to account for indirect costs such as mobilization, traffic control, engineering, etc.
- Discount - Time value of money, the benefit of delaying a cost by one year (excluding inflation).
- SensCost – Adjustment factor for element-based costs, used in sensitivity analysis on the Group worksheet.
- SensDNLTC – Adjustment factor for do-nothing long-term costs, used in sensitivity analysis on the SuGr worksheet to scale benefits up or down.
- MinCost – Minimum project cost, ensures that very small bridges still have a realistic floor on project costs.
- ExtraGood – Small increase in priority for increase in %Good, for smoothing of condition.
- ExtraPoor – Small increase in priority for reduction in %Poor, for smoothing of condition.

An inflation rate is used only on the Dashboard worksheet, so it is entered there with budget constraints.

4.14.1 Environment table – Environment factors affecting deterioration

Inspectors classify each element inspection into an environment class to characterize climate and operating conditions that may affect the rate of deterioration. StruPlan supports up to 4 classes. When importing data the model picks one environment for each structure unit based on highest element replacement value. Models are generated only for environments that have non-zero populations.

If the unclassified count at the top of the table is greater than zero, check the **ElemInsp** table for [ENVKEY] values that are not defined in the Class column. Usually they should be integers from 1 to 4.

Column	Description	Calculation
[Class]	Class	Generally environment classes should be numbered 1 to 4.
[Factor]	Factor	The environment factor is applied to transition times to make deterioration faster or slower. A factor of 1 leaves the transition time unchanged; a factor less than 1 makes deterioration faster; a factor greater than 1 makes deterioration slower. Use this factor to adjust deterioration rates upward or downward for sensitivity analysis or to reflect agency-specific climate or operating conditions.
[Count]	Count	Formula to count the number of ElemInsp rows associated with each environment class.

4.14.2 Treatment table – Treatment definitions

StruPlan is configured to distinguish among four treatment categories that correspond to federal Transportation Asset Management Plan reporting requirements. The treatment parameters on the **Group** worksheet, and the treatment selection logic on the **Cand** and **SuGr** worksheets, effectively provide definition for the treatment categories. This logic can be modified to change the meaning of any treatment. The **Treatment** table provides long and short names for each treatment.

Column	Description	Calculation
[Name]	Treatment name	Descriptive name of the treatment
[Abbr]	Abbreviation	Abbreviated name that is used where space is tight.

4.14.3 Import table – Import history

StruPlan provides a VBA procedure to import data from an external file. Within the VBA development environment, the modules modMain and modImport contain a set of procedures to conduct various tasks supporting importation of data, including:

- Prompting a user to browse for a file pathname (Browse button);
- Finding a specified Excel workbook, worksheet, table, column, or range;
- Importing an Excel table (Import button); and
- Filling in certain missing data.

To import data, it is necessary to prepare a Raw Data File, an Excel workbook file containing two or three worksheets of data: **Bridge**, **StrUnit** (optional), and **ElemInsp**. Each of these worksheets must contain a table of data by the same name, containing the columns indicated as input data on the like-named worksheets of StruPlan. If the **StrUnit** worksheet is omitted, the StruPlan import procedure will prepare a dummy table containing the same number of rows as the **Bridge** table. Imported data replace the rows that are already on each worksheet.

The data for these worksheets can be obtained from a BMS database using an SQL query. For the **Bridge** table, the query would join the bridge table with the most recent inspection event and the roadway on the structure. The query result can then be exported, or copy/pasted into an empty workbook or directly into StruPlan. Another way to obtain the data is to download bridge and element inspection data from FHWA's web site, where data are available from every state. See the chapter on **Importing bridge data** for instructions.

As much as possible missing data in the Raw Data file should be cleaned up before importing. The **Bridge** table has a set of data cleanup columns where formulas can be provided to accomplish some common tasks such as conversion from metric to US customary units. These formulas can be modified, or additional columns added, to handle any necessary manipulations of the raw data.

StruPlan can be modified to add more formats, to import into additional StruPlan tables, or to import from additional types of source data stores. If you write VBA code for an additional data import capability, add a row to the Import table to provide a location for a filename (or URL), a date/time when the data were last imported, and buttons to browse for an external file and to launch the import code. You can use the ImportRawData procedure in the VBA modImport module as an example of the necessary code.

Column	Description	Calculation
[Type]	File type	Indicates the type of file that can be imported using the buttons in this row. Currently only a "Raw data" format is supported. This feature provides room for future expansion to import other types of data if needed.
[File]	File pathname	A path can be typed in manually, or can be set using the Browse button.
[Date imported]	Date/time imported	The VBA Import procedure sets this column when it completes its work.
[Browse]	Browse button	Click this button to browse for a file to be imported.
[Import]	Import button	Click this button to import the selected file.

5. Importing bridge data

Bridge data can be input to StruPlan by importing, or by using copy/paste. Using StruPlan's built-in VBA procedure to import data is recommended, since this ensures that appropriate columns are selected and updates all of the models using the new data. Data can be obtained from FHWA's National Bridge Inventory web site or from a bridge management system database. Both methods are discussed in this chapter.

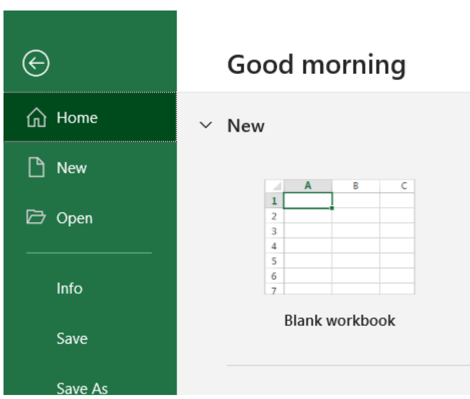
5.1 Importing NBI data

Any state's NBI bridge and element data can be downloaded from FHWA's web site and then imported into StruPlan. Initially bridge data are downloaded in a .txt file, and element data are downloaded in a .zip file which contains an .xml file. Excel commands are used to then import both files into the same .xlsx file on separate worksheets named **Bridge** and **ElemInsp** respectively. You will want to save this Raw Data File as a backup so you can readily re-import your data later if needed. A command in StruPlan is used to import the Raw Data File into a StruPlan workbook.

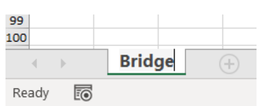
NBI data sets do not have structure units, which are used in bridge management systems to organize bridge conditions into multiple element lists representing separate spans or structure design types (e.g. main and approach segments). The StruPlan Import procedure will automatically create a dummy **StrUnit** table in StruPlan if the Raw Data File does not contain one.

Step 1: Prepare the Raw Data File

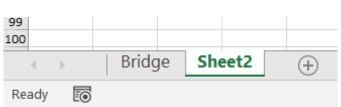
1.1 Launch Excel and create a new blank workbook file. One way to do this is File -> New -> Blank workbook.

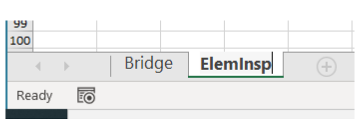


1.2 The first worksheet tab will be named "Sheet1" Double-click this name and change it to **Bridge**.



1.3 If there is no Sheet2 tab, click the plus sign to add it. Then change its name to **ElemInsp**.

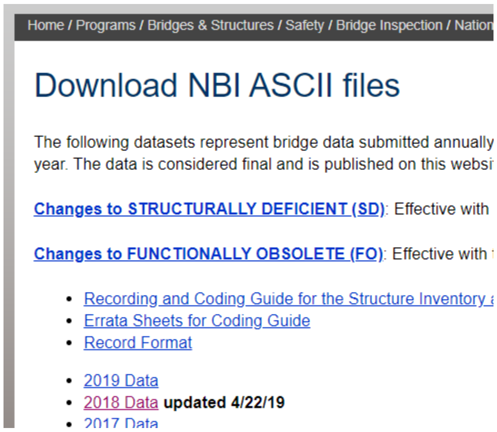


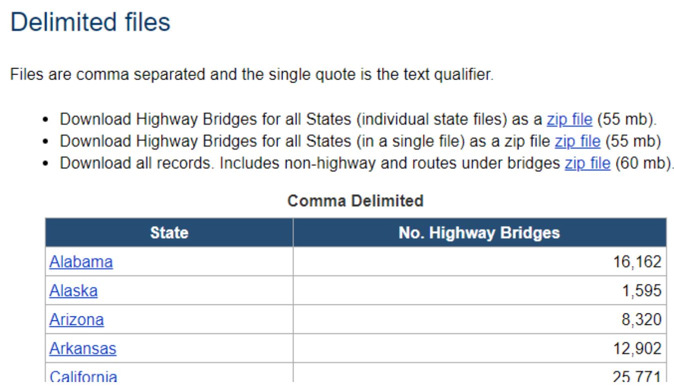


1.4 Save your new Raw Data File. One way to do this is File -> Save As. Give the file a name such as "NBI 2019 Raw Data File.xlsx".

Step 2: Download and import the NBI bridge table

2.1 In your web browser, visit FHWA's web site at **https://www.fhwa.dot.gov/bridge/nbi/ascii.cfm**. Click the link for the latest year of data. Then click the link labeled "Delimited Files." Then click the link for your state.

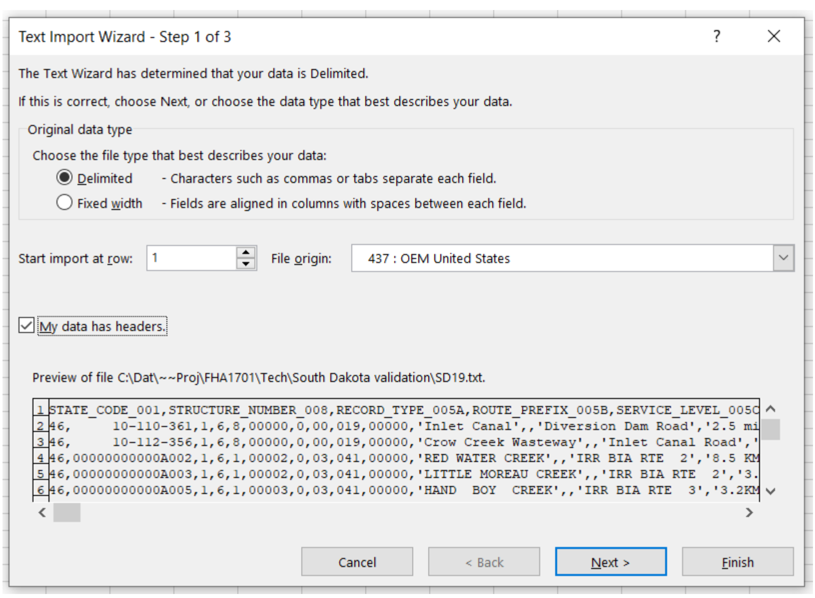




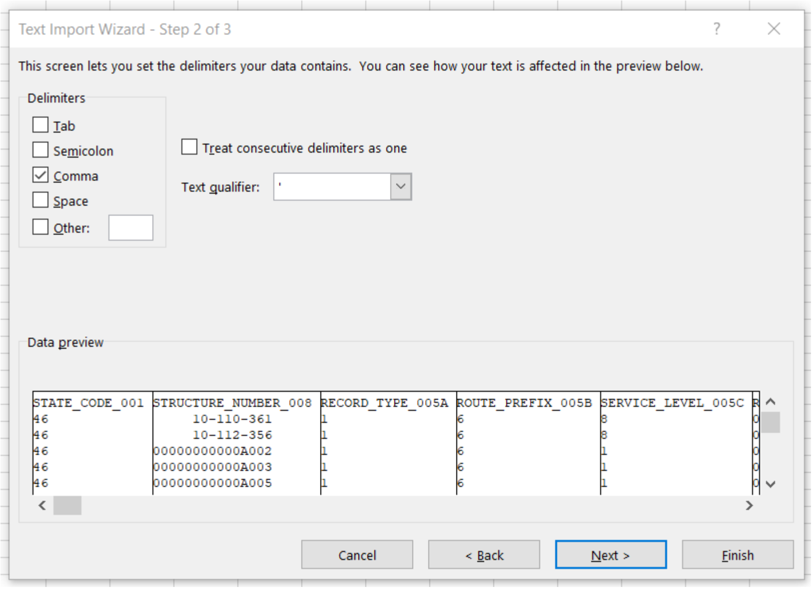
2.2 Right-click "Proceed to Data" and select "Save linked content as …". Save the file in the same folder as the Raw Data File that you prepared earlier. This will be a .txt file.

2.3 In Excel go to the **Bridge** worksheet in your Raw Data File. Go to File -> Open -> Browse. Select "All files (*.*)" from the file type drop-down. Browse to the .txt file that you saved in the previous step, and click Open.

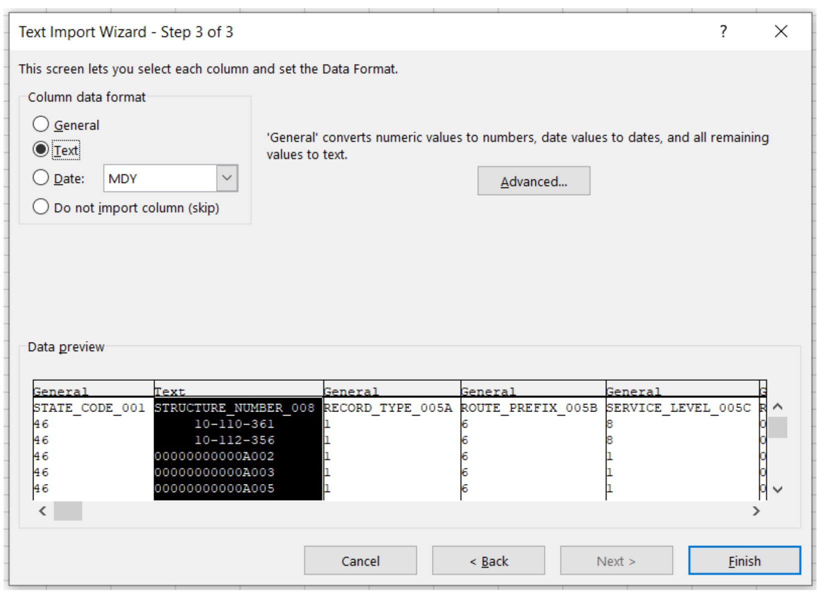
2.4 Excel will present the first step of the Text Import Wizard. Choose "Delimited" and "My data has headers." Then click Next.



2.5 In the second step of the Text Import Wizard, choose "Comma" as the delimiter, and single quote as the Text qualifier.

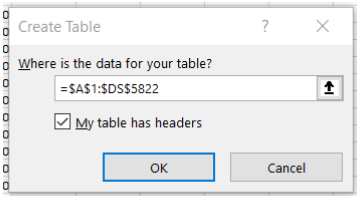


2.6 The Text Import Wizard divides up your data into columns and takes a guess at the data type of each column. Sometimes its guess is wrong. So now you need to go carefully through the columns to ensure that certain columns are designated to be Text. Click the second column, which is "STRUCTURE_NUMBER_008". Then in the upper part of the wizard choose Text. Do the same for each of the following NBI items: 002, 007, 021, 022, 026, 031, 041, 042A, 042B, 043A, 043B, 044A, 044B, 058, 059, 060, 061, 062, 070, 071, 072, 090, 104, 112, 113, LOWEST_RATING. Then click Finish.

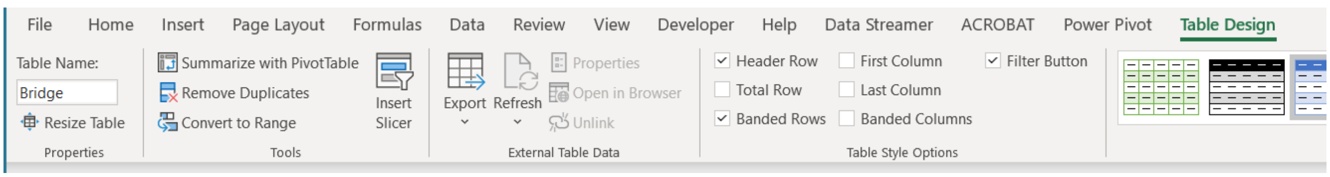


A couple of notes about this step: The NBI contains a large number of categorical data items that appear to be numeric but are normally interpreted as text. Often they have leading zeroes which are significant. Only a subset of these are used in StruPlan and listed in the preceding paragraph. You may want to mark additional columns as Text if you plan to use your Raw Data File for purposes other than StruPlan or if you plan to add more data items to StruPlan. Also note that one of the items to be marked as Text is the inspection date, item 090. This is intentionally marked as Text and not Date. StruPlan uses only the right-most two digits of this date (representing the year of inspection).

2.7 Now convert the imported data into an Excel data table. First click any cell within the data (e.g. cell A1) then Insert -> Table. Excel should automatically determine the relevant range of cells. Ensure that "My table has headers" is checked. Then click OK.



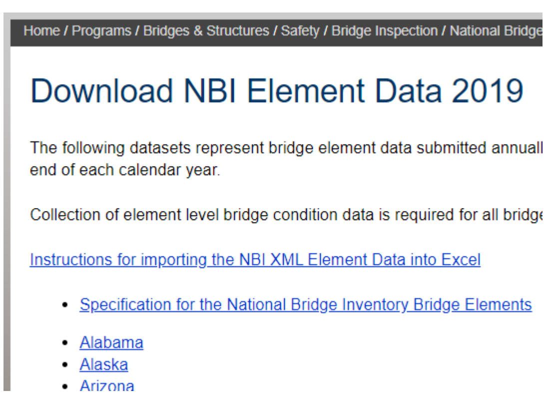
2.8 Excel will add a "Table Design" tab to the ribbon at the top of the screen, and the first item on this ribbon is "Table Name". By default Excel names your new table "Table1", but you should change it to **Bridge**.



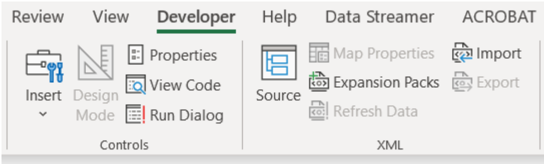
2.9 The preceding steps will result in a table of data in a new temporary Excel file, with the entire table selected. Type Ctrl-C to copy the entire table, then in your Raw Data file, click cell A1 on the Bridge worksheet and type Ctrl-V to paste the table. Then save your Excel Raw Data File. You do not need to save the temporary file that the Text Import wizard had created.

Step 3: Download and import the NBI element table

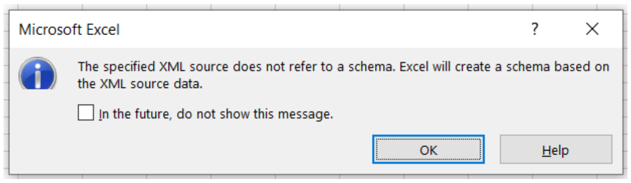
3.1 In your web browser, visit FHWA's web site at **https://www.fhwa.dot.gov/bridge/nbi/element.cfm**. Click the link for the latest year of data, which should be the same year as for the bridge data in the previous step. Then click the link for your state. Save the file in the same folder as the Raw Data File that you prepared earlier. This will be a .zip file. Extract the .xml file from the zip file.



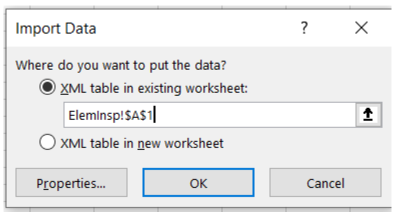
3.2 In Excel go to the **ElemInsp** worksheet in your Raw Data File. Select the Developer tab. If it is not available, you can add it in File -> Options -> Customize Ribbon. In the XML section of the Developer ribbon, select Import.



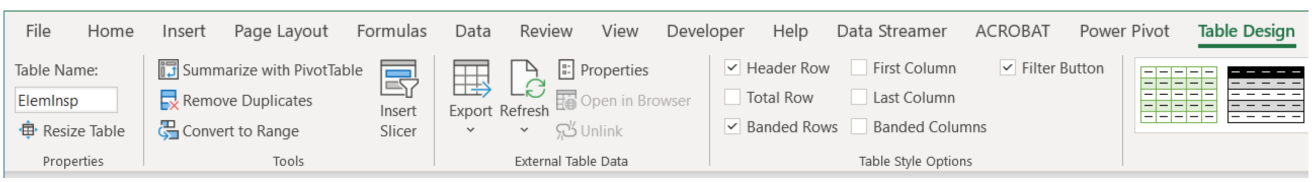
3.3 Browse to the .xml file that you extracted earlier, and click Import. An informational message will pop up. Just click OK.



3.4 Click in cell A1 of the **ElemInsp** worksheet. Then click OK.



3.5 Excel's Import procedure takes care of setting the correct data types and creating a data table. Excel will add a "Table Design" tab to the ribbon at the top of the screen, and the first item on this ribbon is "Table Name". By default Excel names your new table "Table2", but you must change it to **ElemInsp**.



3.6 Save your Raw Data File.

Step 4: Remove unneeded rows (optional)

Depending on your goals for using StruPlan, you may want to remove data rows that are not needed for your analysis. For example, most agencies using StruPlan for preparation of a Transportation Asset Management Plan would want to include only NBI-qualified bridges on the National Highway System (NHS), and might optionally include structures on the State Highway System if they have element data for these structures. An easy way to filter the data might be as follows:

4.1 On the **Bridge** table, type a new column heading immediately to the right of the table (in row 1, leaving no blank columns in between), naming it something like "Selected". Just under this in row 2, type a formula that gives a value of 1 if the row is to be selected, and 0 otherwise. For example, the following formula produces a 1 if a bridge has a non-zero number of elements, and is either owned by the state highway agency or is an NBI-qualifying NHS bridge (regardless of ownership):

```
=IF(
    AND( COUNTIF(ElemInsp[STRUCNUM],[@[STRUCTURE_NUMBER_008]])>0,
         OR([@[OWNER_022]]="01",
             AND([@[BRIDGE_LEN_IND_112]]="Y",[@[HIGHWAY_SYSTEM_104]]="1"))),
1,0)
```

DR	DS	DT
LOWEST	DECK_AI	Selected
7	147.62	0
4	119.9	0
5	166.14	0

Sort the table from smallest to largest on the new Selected column, then delete all the rows that have a value of 0 in this column. You can then delete the Selected column.

4.2 You can follow a similar procedure on the **ElemInsp** table to delete any rows that do not have a corresponding Bridge row, using this formula. Sometimes the structure number in the NBI bridge table doesn't match the one in the element table, most commonly because of leading zeroes. This formula will uncover that problem.

```
=IF(COUNTIF(Bridge[STRUCTURE_NUMBER_008],[@STRUCNUM])=1,1,0)
```

4.3 If it is important to you to make the Raw Data File as small as possible, you can delete columns from both the Bridge and ElemInsp tables that are not used in StruPlan. See the sections of this manual for the **Bridge** and **ElemInsp** tables for listings of columns that StruPlan requires. Bear in mind, however, that the StruPlan Import procedure that you will be using in the next step ignores any data columns that it doesn't require.

4.4 Be sure to save your Raw Data File after completing this step.

Step 5: Import the Raw Data File into StruPlan

StruPlan has a built-in VBA procedure to import **Bridge**, **StrUnit**, and **ElemInsp** data from a Raw Data File. The procedure deletes bridges that may have already been in the StruPlan file. It creates a dummy **StrUnit** table if needed, and also provides a few columns in the **ElemInsp** table that are not found in NBI element files. After importing a new data set, StruPlan updates all of its models to incorporate the new data.

Bear in mind that the Import procedure does not import any of the model parameters on the **Settings**, **Element**, **Group**, **Bridge**, or **Dashboard** worksheets. See the **Getting Started** chapter for more information about these data requirements.

5.1 In a StruPlan workbook, go to the **Settings** worksheet. Update the Base Year and System Name as appropriate for the new data that you plan to import. Save the file with an appropriate file name, e.g. "StruPlan 1.3 SD-NBI.xlsm". This must be a macro-enabled Excel file, so the file extension is ".xlsm".

5.2 In the **Import** table in the **Settings** worksheet, click the cell under the "Browse…" column heading. Select the Raw Data File that you prepared in the earlier steps.

5.3 In the **Import** table in the **Settings** worksheet, click the cell under the "Import…" column heading. This will import the required data from the Raw Data File and update the model calculations. It doesn't matter if the Raw Data File is open or closed when the button is clicked, but if open, be sure it is saved. The process takes less than 3 minutes.

5.2 Importing bridge management system data

Importing data from a bridge management database is best performed by personnel having some basic knowledge of the agency's database and the tools for accessing it, including knowledge of Structured Query Language (SQL). While the process can be completed in less than a day, there are enough options, potential security hurdles, and things that can go wrong, that the learning curve can be much longer.

StruPlan does not automatically connect to bridge management databases, but can be configured to do so using Excel's data import wizard, which can be accessed by selecting Data -> Get Data -> From Database or Data -> Get Data -> From Other Sources -> From ODBC. This process uses Microsoft's built-in Power Query Editor to transform incoming data into the desired format. Most agencies have other query tools or report writers that can also perform this operation.

The present chapter describes a somewhat simpler method that may be easiest for personnel who are able to use an SQL command line interface to their bridge management system database, but either do not regularly employ query tools or would prefer to have more direct control of the data flows. The method creates a Raw Data File, an Excel .xlsx file containing three worksheets named **Bridge**, **StrUnit**, and **ElemInsp**, which are each created using an SQL statement documented here. The intermediate step of preparing a Raw Data File makes the process more transparent and provides an opportunity to view and manipulate the data before importing into StruPlan. You will want to save this Raw Data File as a backup so you can readily re-import your data later if needed. A command in StruPlan is used to import the Raw Data File into a StruPlan workbook, or Copy/Paste can be used to copy the three tables into StruPlan.

Even if the Power Query Editor or another query tool are used, it will still be necessary to perform tasks that substantially duplicate what is described here, to ensure that incoming data are in the correct format.

Step 1: Prepare the Element table in StruPlan (optional)

When you first download StruPlan from StruPlan.com, it comes configured for the elements defined in the AASHTO Manual for Bridge Element Inspection. These can be found in the **Element table**. If you keep the Element table as it is, StruPlan will ignore all your agency-defined elements. However, you can configure StruPlan to recognize agency-defined elements and associate them with an element group for modeling. This can be done using the following steps.

1.1 Launch your SQL query command line program and connect to your bridge management database.

1.2 Copy and paste the following SQL query into the command line, then execute it.

```
SELECT ELEM_KEY,ELEM_LONGNAME,ENGLISHUNIT,COUNT(*) as Population FROM
(SELECT d.ELEM_KEY,d.ELEM_LONGNAME,m.ENGLISHUNIT,
(SELECT dd.ELEM_KEY FROM PON_ELEM_DEFS dd WHERE dd.PON_ELEM_DEFS_GD=
   (SELECT ee.PON_ELEM_DEFS_GD FROM PON_ELEM_INSP ee
   WHERE ee.PON_ELEM_INSP_GD=e.PARENT_PON_ELEM_INSP_GD)) as ELEM_PARENT_KEY,
e.ELEM_QTYSTATE1,e.ELEM_QTYSTATE2,e.ELEM_QTYSTATE3,e.ELEM_QTYSTATE4
FROM PON_ELEM_INSP e, PON_ELEM_DEFS d, METRIC_ENGLISH m,
(SELECT b.BRIDGE_GD, i.INSPEVNT_GD, b.BRIDGE_ID
FROM BRIDGE b,INSPEVNT i, ROADWAY r
WHERE i.BRIDGE_GD=b.BRIDGE_GD and r.BRIDGE_GD=b.BRIDGE_GD
and i.INSPEVNT_GD=
   (SELECT MAX(j.INSPEVNT_GD) FROM INSPEVNT j WHERE j.BRIDGE_GD=b.BRIDGE_GD and
   (SELECT COUNT(*) FROM PON_ELEM_INSP e, PON_ELEM_DEFS d
   WHERE e.INSPEVNT_GD=j.INSPEVNT_GD and e.PON_ELEM_DEFS_GD=d.PON_ELEM_DEFS_GD
   and e.ELEM_QTYSTATE1+e.ELEM_QTYSTATE2+e.ELEM_QTYSTATE3+e.ELEM_QTYSTATE4>0
   and d.ELEM_KEY<1000)>0
and j.INSPDATE=
   (SELECT MAX(k.INSPDATE) FROM INSPEVNT k WHERE k.BRIDGE_GD=b.BRIDGE_GD and
   (SELECT COUNT(*) FROM PON_ELEM_INSP e, PON_ELEM_DEFS d
   WHERE e.INSPEVNT_GD=k.INSPEVNT_GD and e.PON_ELEM_DEFS_GD=d.PON_ELEM_DEFS_GD
   and e.ELEM_QTYSTATE1+e.ELEM_QTYSTATE2+e.ELEM_QTYSTATE3+e.ELEM_QTYSTATE4>0
   and d.ELEM_KEY<1000)>0))
and r.ON_UNDER='1' and (b.ON_OFF_SYS='1' or (b.NBISLEN='Y' and r.NHS_IND='1'))
and b.LENGTH>0 and (b.DECK_AREA>0 or b.DECKWIDTH>0 or r.AROADWIDTH>0)) c
WHERE e.INSPEVNT_GD=c.INSPEVNT_GD and d.ELEM_PAIRCODE=m.PAIRCODE
and e.PON_ELEM_DEFS_GD=d.PON_ELEM_DEFS_GD
) x
WHERE ELEM_KEY<1000 and (ELEM_PARENT_KEY<1000 or ELEM_PARENT_KEY is null)
and ELEM_QTYSTATE1+ELEM_QTYSTATE2+ELEM_QTYSTATE3+ELEM_QTYSTATE4>0
GROUP BY ELEM_KEY,ELEM_LONGNAME,ENGLISHUNIT
ORDER BY ELEM_KEY
```

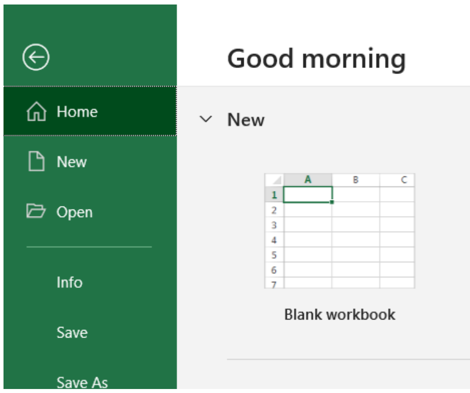
This query makes a listing of all of the elements found in your element inspection data, and provides a count of the estimated number of rows that will end up in your **ElemInsp table**. In fact, most of this query is identical to the **ElemInsp query discussed in Step 5** below, and can be modified in the same ways if needed.

This syntax is correct for Microsoft SQL Server databases but might differ in other databases. The table and column names agree with AASHTOWare Bridge Management (BrM) release 6+ but might differ in other bridge management systems. Each row must have a unique value in the BRIDGE_ID column. In older versions of BrM you may need to replace BRIDGE_GD with brkey, and make other similar changes for compatibility with the older database.

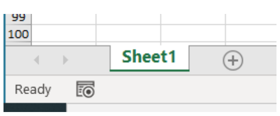
1.3 Compare the list of elements with your **Element table**. Add to your element table any elements that you wish to handle within StruPlan. Any elements that you omit will be ignored. Be sure to assign each element to an appropriate Group, as listed in the **Group table**. You can add more groups if necessary. If you decide to omit any elements entirely, you can modify the queries as discussed in **Step 5**.

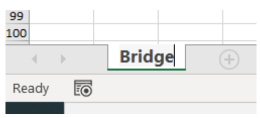
Step 2: Prepare the Raw Data File

2.1 Launch Excel and create a new blank workbook file. One way to do this is File -> New -> Blank workbook.

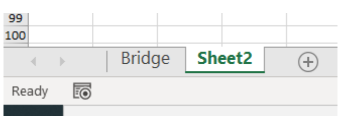


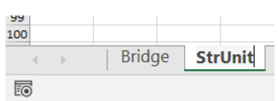
2.2 The first worksheet tab will be named “Sheet1” Double-click this name and change it to **Bridge**.



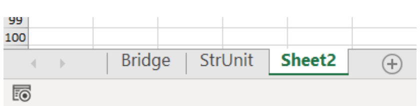


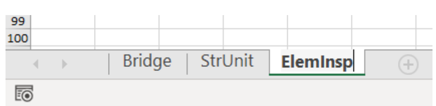
2.3 If there is no Sheet2 tab, click the plus sign to add it. Then change its name to **StrUnit**.





2.4 If there is no Sheet3 tab, click the plus sign to add it. Then change its name to **ElemInsp**.





2.5 Save your new Raw Data File. One way to do this is File -> Save As. Give the file a name such as “BMS 2019 Raw Data File.xlsx”.

Step 3: Prepare the Bridge table

3.1 Launch your SQL query command line program and connect to your bridge management database. Make sure that your query program is configured to export column headings when exporting query result files. If you are using Microsoft SQL Server Management Studio, go to Tools -> Options -> Query Results -> SQL Server -> Results to Grid. Check "Include column headers when copying or saving results", then click OK. The new setting won't affect any existing query tabs, so you'll need to open new ones and/or restart the program.

3.2 Copy and paste the following SQL query into the command line, then execute it.

```
SELECT
b.BRIDGE_ID,b.DISTRICT,b.FACILITY,r.BYPASSLEN,b.CUSTODIAN,b.OWNER,r.FUNCCLASS,
b.YEARBUILT,r.LANES,r.ADTTOTAL,r.ADTYEAR,b.DESIGNLOAD,r.AROADWIDTH,i.OPPOSTCL,
b.SERVTYPON,b.SERVTYPUND,b.MATERIALMAIN,b.DESIGNMAIN,b.MATERIALAPPR,b.DESIGNAPPR,
b.LENGTH,r.ROADWIDTH,b.DECKWIDTH,b.VCLROVER,i.DKRATING,i.SUPRATING,i.SUBRATING,
i.CHANRATING,i.CULVRATING,b.ORLOAD,b.POSTING,i.WATERADEQ,i.APPRALIGN,
year(i.INSPDATE) as INSPDATE,r.NHS_IND,b.YEARRECON,r.TRUCKPCT,b.NBISLEN,i.SCOURCRIT,
r.ADTFUTURE,r.ADTFUTYEAR,b.DECK_AREA,b.ON_OFF_SYS,r.ROAD_SPEED,r.DET_SPEED
FROM BRIDGE b,INSPEVNT i, ROADWAY r,
(SELECT DISTINCT BRIDGE_GD,INSPEVNT_GD FROM
(SELECT e.BRIDGE_GD,e.INSPEVNT_GD,d.ELEM_KEY,
(SELECT dd.ELEM_KEY FROM PON_ELEM_DEFS dd WHERE dd.PON_ELEM_DEFS_GD=
   (SELECT ee.PON_ELEM_DEFS_GD FROM PON_ELEM_INSP ee
   WHERE ee.PON_ELEM_INSP_GD=e.PARENT_PON_ELEM_INSP_GD)) as ELEM_PARENT_KEY,
e.ELEM_QTYSTATE1,e.ELEM_QTYSTATE2,e.ELEM_QTYSTATE3,e.ELEM_QTYSTATE4
FROM STRUCTURE_UNIT s, PON_ELEM_INSP e, PON_ELEM_DEFS d, PON_ENVT_DEFS v,
(SELECT b.BRIDGE_GD, i.INSPEVNT_GD, b.BRIDGE_ID
FROM BRIDGE b,INSPEVNT i, ROADWAY r
WHERE i.BRIDGE_GD=b.BRIDGE_GD and r.BRIDGE_GD=b.BRIDGE_GD
and i.INSPEVNT_GD=
   (SELECT MAX(j.INSPEVNT_GD) FROM INSPEVNT j WHERE j.BRIDGE_GD=b.BRIDGE_GD and
   (SELECT COUNT(*) FROM PON_ELEM_INSP e, PON_ELEM_DEFS d
   WHERE e.INSPEVNT_GD=j.INSPEVNT_GD and e.PON_ELEM_DEFS_GD=d.PON_ELEM_DEFS_GD
   and e.ELEM_QTYSTATE1+e.ELEM_QTYSTATE2+e.ELEM_QTYSTATE3+e.ELEM_QTYSTATE4>0
   and d.ELEM_KEY<1000)>0
and j.INSPDATE=
   (SELECT MAX(k.INSPDATE) FROM INSPEVNT k WHERE k.BRIDGE_GD=b.BRIDGE_GD and
   (SELECT COUNT(*) FROM PON_ELEM_INSP e, PON_ELEM_DEFS d
   WHERE e.INSPEVNT_GD=k.INSPEVNT_GD and e.PON_ELEM_DEFS_GD=d.PON_ELEM_DEFS_GD
   and e.ELEM_QTYSTATE1+e.ELEM_QTYSTATE2+e.ELEM_QTYSTATE3+e.ELEM_QTYSTATE4>0
   and d.ELEM_KEY<1000)>0))
and r.ON_UNDER='1' and (b.ON_OFF_SYS='1' or (b.NBISLEN='Y' and r.NHS_IND='1'))
and b.LENGTH>0 and (b.DECK_AREA>0 or b.DECKWIDTH>0 or r.AROADWIDTH>0)) c
WHERE e.INSPEVNT_GD=c.INSPEVNT_GD and e.STRUCTURE_UNIT_GD=s.STRUCTURE_UNIT_GD
and e.PON_ELEM_DEFS_GD=d.PON_ELEM_DEFS_GD and e.PON_ENVT_DEFS_GD=v.PON_ENVT_DEFS_GD
) x
WHERE ELEM_KEY<1000 and (ELEM_PARENT_KEY<1000 or ELEM_PARENT_KEY is null)
and ELEM_QTYSTATE1+ELEM_QTYSTATE2+ELEM_QTYSTATE3+ELEM_QTYSTATE4>0) bb
WHERE b.BRIDGE_GD=bb.BRIDGE_GD and i.BRIDGE_GD=b.BRIDGE_GD and r.BRIDGE_GD=b.BRIDGE_GD
and i.INSPEVNT_GD=bb.INSPEVNT_GD and r.ON_UNDER='1'
ORDER BY b.BRIDGE_ID
```

This query accomplishes several important things:

- Joins the bridge, inspection event, and roadway tables, omitting any bridges that do not have a qualifying record in all three tables.
- Lists all of the data items required for the Bridge table of StruPlan. The order of column names in the select statement is not significant. Columns may be omitted if necessary, and extra columns may be added.
- Inspection event records are qualified only if they have at least one corresponding element inspection having an element number less than 1000 (i.e. defect records are excluded). See the **ElemInsp query discussion in Step 5**, below, for more information on qualified element inspection records and how the query might be modified.
- Only the most recent inspection event on each bridge is used. If more than one record have the same inspection date, the inspection event's globally-unique identifier (GUID) is used as a tie-breaker.
- Only the roadway-on record is used from the roadway table.
- Bridges are qualified if they are NBI-qualified bridges on the National Highway System, or if they are on the state highway system. You can choose to limit or expand these criteria to include other structures in your database. If your agency uses different criteria to identify the State Highway System, you can modify this part of the query accordingly. Be sure to modify the other queries discussed in this section also.
- For the inspection date, only the year is used in StruPlan.

The inner subquery bb (shaded yellow) is nearly the same as the **ElemInsp query discussed below**. The subquery has the effect of selecting only bridges referenced in the ElemInsp table. This is not necessarily a StruPlan requirement. However, since most of the analysis in StruPlan is concerned with elements, bridges without elements can participate only in the minor parts of the model concerned with functional deficiencies and risk. StruPlan can also accommodate structures lacking a roadway-on, such as tunnels or high-mast light poles. In this case the agency would need to review the models and data to ensure suitability for these non-bridge structures.

An alternative is to use a simpler query and then filter unused bridges within Excel, in the manner discussed in the **earlier section on importing NBI data**. This could be a good option in cases where manual editing of the ElemInsp table is necessary for other reasons anyway, or where structures without elements are to be included. An example of the simpler query is:

```
SELECT
b.BRIDGE_ID,b.DISTRICT,b.FACILITY,r.BYPASSLEN,b.OWNER,r.FUNCCLASS,b.YEARBUILT,r.LANES,
r.ADTTOTAL,r.ADTYEAR,b.DESIGNLOAD,r.AROADWIDTH,i.OPPOSTCL,b.SERVTYPON,b.MATERIALMAIN,
b.DESIGNMAIN,b.MATERIALAPPR,b.DESIGNAPPR,b.LENGTH,r.ROADWIDTH,b.DECKWIDTH,b.VCLROVER,
i.DKRATING,i.SUPRATING,i.SUBRATING,i.CHANRATING,i.CULVRATING,b.ORLOAD,b.POSTING,
i.WATERADEQ,i.APPRALIGN,year(i.INSPDATE) as INSPDATE,r.NHS_IND,b.YEARRECON,r.TRUCKPCT,
b.NBISLEN,i.SCOURCRIT,r.ADTFUTURE,r.ADTFUTYEAR,b.LOWEST_RATING,b.DECK_AREA,b.ON_OFF_SYS,
r.ROAD_SPEED,r.DET_SPEED,b.BRIDGE_GD,i.INSPEVNT_GD
FROM BRIDGE b,INSPEVNT i, ROADWAY r
WHERE i.BRIDGE_GD=b.BRIDGE_GD and r.BRIDGE_GD=b.BRIDGE_GD and r.ON_UNDER='1'
ORDER BY b.BRIDGE_ID
```

This query produces a much bigger table because it includes multiple inspections on each bridge. It therefore would require considerable editing since StruPlan requires each bridge to have only one inspection. One way to filter it is, in Excel, remove rows where INSPEVNT_GD does not appear in the ElemInsp table.

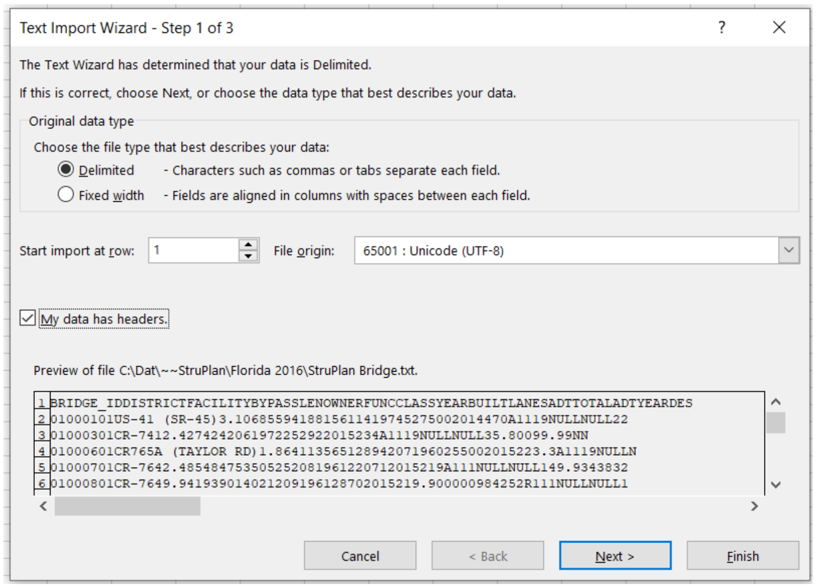
Note that this simpler query includes two columns, BRIDGE_GD and INSPEVNT_GD, which do not appear in the StruPlan Bridge table. In its import procedure discussed in **Step 6**, StruPlan ignores any extra columns that appear in the Raw Data File.

This syntax is correct for Microsoft SQL Server databases but might differ in other databases. The table and column names agree with AASHTOWare Bridge Management release 6+ but might differ in other bridge management systems. Each row must have a unique value in the BRIDGE_ID column.

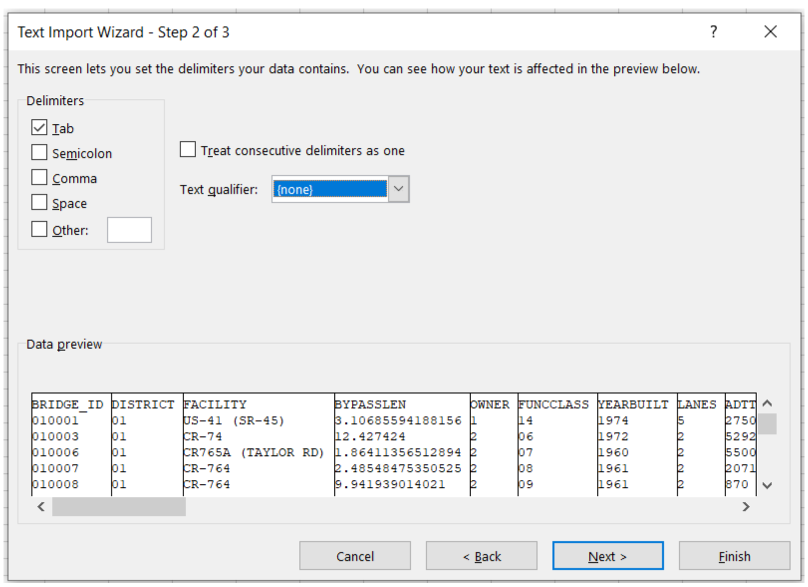
3.3 Export the result of this query to a tab-delimited text file. In Microsoft SQL Server Management Studio, click anywhere in the grid displaying the query result, type Ctrl-A, then right-click and choose “Save Results As…”.

3.4 In Excel go to the **Bridge** worksheet in your Raw Data File. Go to File -> Open -> Browse. Select “All files (*.*)” from the file type drop-down. Browse to the .txt file that you saved in the previous step, and click Open.

3.5 Excel will present the first step of the Text Import Wizard. Choose “Delimited” and “My data has headers.” Then click Next.

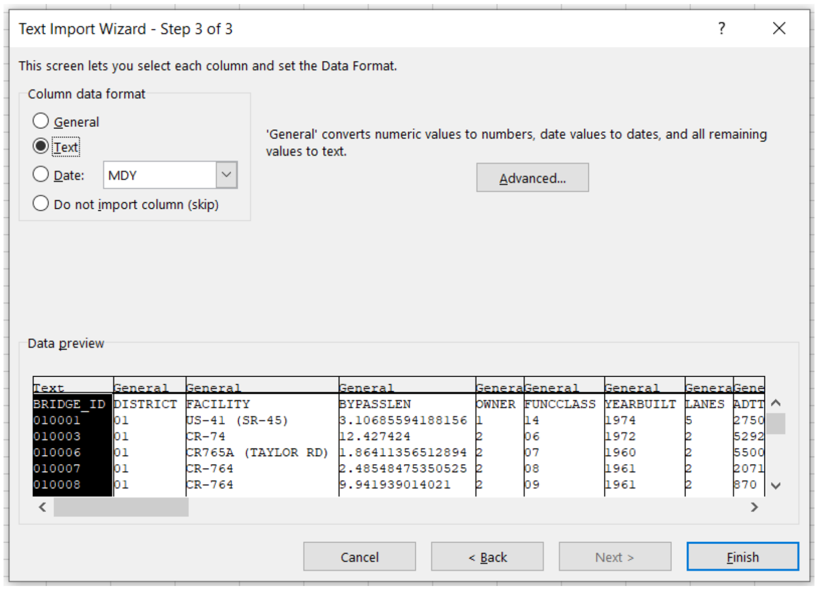


3.6 In the second step of the Text Import Wizard, choose “Tab” as the delimiter, and “(none)” as the Text qualifier.



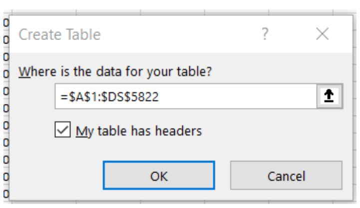
3.7 The Text Import Wizard divides up your data into columns and takes a guess at the data type of each column. Sometimes its guess is wrong. So now you need to go carefully through the columns to ensure that certain columns are designated to be Text. Click the first column, which is “BRIDGE_ID”. Then in the upper part of the wizard choose Text. Do the same for each of the following columns: DISTRICT, FACILITY, CUSTODIAN, OWNER, FUNCCLASS, DESIGNLOAD, OPPOSTCL, SERVTYPON, SERVTYPUND, MATERIALMAIN, DESIGNMAIN, MATERIALAPPR, DESIGNAPPR,

DKRATING, SUPRATING, SUBRATING, CHANRATING, CULVRATING, POSTING, WATERADEQ, APPRALIGN, INSPDATE, NHS_IND, NBISLEN, SCOURCRIT, and ON_OFF_SYS. Then click Finish.

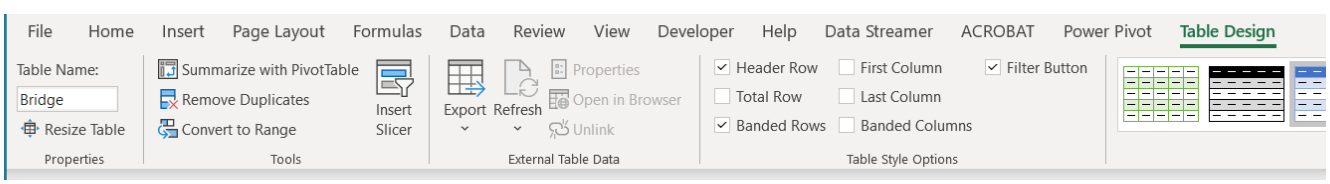


A couple of notes about this step: The NBI contains a large number of categorical data items that appear to be numeric but are normally interpreted as text. Often they have leading zeroes which are significant. Only a subset of these are used in StruPlan and listed in the preceding paragraph. You may want to mark additional columns as Text if you plan to use your Raw Data File for purposes other than StruPlan or if you plan to add more data items to StruPlan. Also note that one of the items to be marked as Text is the inspection date, item 090. This is intentionally marked as Text and not Date. StruPlan uses only the right-most two digits of this date (representing the year of inspection).

3.8 Now convert the imported data into an Excel data table. First click any cell within the data (e.g. cell A1) then Insert -> Table. Excel should automatically determine the relevant range of cells. Ensure that “My table has headers” is checked. Then click OK.



3.9 Excel will add a “Table Design” tab to the ribbon at the top of the screen, and the first item on this ribbon is “Table Name”. By default Excel names your new table “Table1”, but you should change it to **Bridge**.



3.10 In SQL Server, an exported query result has the word “NULL” in any cell containing null data. Use Excel’s Replace command (Ctrl-H) to change all occurrences of NULL to blanks.

3.11 The preceding steps will result in a table of data in a new temporary Excel file, with the entire table selected. Type Ctrl-C to copy the entire table, then in your Raw Data file, click cell A1 on the Bridge worksheet and type Ctrl-V to paste the table. Then save your Excel Raw Data File. You do not need to save the temporary file that the Text Import wizard had created.

Step 4: Prepare the StrUnit table

4.1 Copy and paste the following SQL query into the command line, then execute it.

```
SELECT DISTINCT BRIDGE_ID, StrUnit_ID FROM
(SELECT e.PON_ELEM_INSP_GD,c.BRIDGE_ID,
concat(c.BRIDGE_ID,'|',s.STRUNITKEY) as StrUnit_ID,
e.PARENT_PON_ELEM_INSP_GD,d.ELEM_KEY,
(SELECT dd.ELEM_KEY FROM PON_ELEM_DEFS dd WHERE dd.PON_ELEM_DEFS_GD=
   (SELECT ee.PON_ELEM_DEFS_GD FROM PON_ELEM_INSP ee
   WHERE ee.PON_ELEM_INSP_GD=e.PARENT_PON_ELEM_INSP_GD)) as ELEM_PARENT_KEY,
v.ENVKEY,e.ELEM_QTYSTATE1,e.ELEM_QTYSTATE2,e.ELEM_QTYSTATE3,e.ELEM_QTYSTATE4
FROM STRUCTURE_UNIT s, PON_ELEM_INSP e, PON_ELEM_DEFS d, PON_ENVT_DEFS v,
(SELECT b.BRIDGE_GD, i.INSPEVNT_GD, b.BRIDGE_ID
FROM BRIDGE b,INSPEVNT i, ROADWAY r
WHERE i.BRIDGE_GD=b.BRIDGE_GD and r.BRIDGE_GD=b.BRIDGE_GD
and i.INSPEVNT_GD=
   (SELECT MAX(j.INSPEVNT_GD) FROM INSPEVNT j WHERE j.BRIDGE_GD=b.BRIDGE_GD and
   (SELECT COUNT(*) FROM PON_ELEM_INSP e, PON_ELEM_DEFS d
   WHERE e.INSPEVNT_GD=j.INSPEVNT_GD and e.PON_ELEM_DEFS_GD=d.PON_ELEM_DEFS_GD
   and e.ELEM_QTYSTATE1+e.ELEM_QTYSTATE2+e.ELEM_QTYSTATE3+e.ELEM_QTYSTATE4>0
   and d.ELEM_KEY<1000)>0
and j.INSPDATE=
   (SELECT MAX(k.INSPDATE) FROM INSPEVNT k WHERE k.BRIDGE_GD=b.BRIDGE_GD and
   (SELECT COUNT(*) FROM PON_ELEM_INSP e, PON_ELEM_DEFS d
   WHERE e.INSPEVNT_GD=k.INSPEVNT_GD and e.PON_ELEM_DEFS_GD=d.PON_ELEM_DEFS_GD
   and e.ELEM_QTYSTATE1+e.ELEM_QTYSTATE2+e.ELEM_QTYSTATE3+e.ELEM_QTYSTATE4>0
   and d.ELEM_KEY<1000)>0))
and r.ON_UNDER='1' and (b.ON_OFF_SYS='1' or (b.NBISLEN='Y' and r.NHS_IND='1'))
and b.LENGTH>0 and (b.DECK_AREA>0 or b.DECKWIDTH>0 or r.AROADWIDTH>0)) c
WHERE e.INSPEVNT_GD=c.INSPEVNT_GD and e.STRUCTURE_UNIT_GD=s.STRUCTURE_UNIT_GD
and e.PON_ELEM_DEFS_GD=d.PON_ELEM_DEFS_GD and e.PON_ENVT_DEFS_GD=v.PON_ENVT_DEFS_GD
) x
WHERE ELEM_KEY<1000 and (ELEM_PARENT_KEY<1000 or ELEM_PARENT_KEY is null)
and ELEM_QTYSTATE1+ELEM_QTYSTATE2+ELEM_QTYSTATE3+ELEM_QTYSTATE4>0
ORDER BY BRIDGE_ID,StrUnit_ID
```

This query produces a listing of structure units containing just a BRIDGE_ID and a StrUnit_ID, where the latter is the concatenation of the BRIDGE_ID and the structure unit key. Each row must have a unique value in the StrUnit_ID column. This query is nearly identical to the **ElemInsp query discussed in the next section**, selecting all the structure units that are referenced in the ElemInsp table. See the next section for a more detailed explanation of the parts of the query.

An alternative is to use a simpler query and then filter unused structure units within Excel, in the manner discussed in the **earlier section on importing NBI data**. This could be a good option in cases where manual editing of the ElemInsp table is necessary for other reasons anyway. An example of the simpler query is:

```
SELECT b.BRIDGE_ID, concat(b.BRIDGE_ID,'|',s.STRUNITKEY) as StrUnit_ID
FROM BRIDGE b, STRUCTURE_UNIT s
WHERE b.BRIDGE_GD=s.BRIDGE_GD) t
```

This syntax is correct for Microsoft SQL Server databases but might differ in other databases. The table and column names agree with AASHTOWare Bridge Management 6+ but might differ in other bridge management systems.

4.2 Follow all of the remaining parts of **Step 3** to populate the **StrUnit** table in the Raw Data File. Both columns must be designated as Text.

Step 5: Prepare the ElemInsp table

5.1 Copy and paste the following SQL query into the command line, then execute it.

```
SELECT * FROM
(SELECT e.PON_ELEM_INSP_GD,c.BRIDGE_ID,
concat(c.BRIDGE_ID,'|',s.STRUNITKEY) as StrUnit_ID,
e.PARENT_PON_ELEM_INSP_GD,d.ELEM_KEY,
(SELECT dd.ELEM_KEY FROM PON_ELEM_DEFS dd WHERE dd.PON_ELEM_DEFS_GD=
      (SELECT ee.PON_ELEM_DEFS_GD FROM PON_ELEM_INSP ee
      WHERE ee.PON_ELEM_INSP_GD=e.PARENT_PON_ELEM_INSP_GD)) as ELEM_PARENT_KEY,
v.ENVKEY,e.ELEM_QTYSTATE1,e.ELEM_QTYSTATE2,e.ELEM_QTYSTATE3,e.ELEM_QTYSTATE4
FROM STRUCTURE_UNIT s, PON_ELEM_INSP e, PON_ELEM_DEFS d, PON_ENVT_DEFS v,
(SELECT b.BRIDGE_GD, i.INSPEVNT_GD, b.BRIDGE_ID
FROM BRIDGE b,INSPEVNT i, ROADWAY r
WHERE i.BRIDGE_GD=b.BRIDGE_GD and r.BRIDGE_GD=b.BRIDGE_GD
and i.INSPEVNT_GD=
      (SELECT MAX(j.INSPEVNT_GD) FROM INSPEVNT j WHERE j.BRIDGE_GD=b.BRIDGE_GD and
      (SELECT COUNT(*) FROM PON_ELEM_INSP e, PON_ELEM_DEFS d
      WHERE e.INSPEVNT_GD=j.INSPEVNT_GD and e.PON_ELEM_DEFS_GD=d.PON_ELEM_DEFS_GD
      and e.ELEM_QTYSTATE1+e.ELEM_QTYSTATE2+e.ELEM_QTYSTATE3+e.ELEM_QTYSTATE4>0
      and d.ELEM_KEY<1000)>0
and j.INSPDATE=
      (SELECT MAX(k.INSPDATE) FROM INSPEVNT k WHERE k.BRIDGE_GD=b.BRIDGE_GD and
      (SELECT COUNT(*) FROM PON_ELEM_INSP e, PON_ELEM_DEFS d
      WHERE e.INSPEVNT_GD=k.INSPEVNT_GD and e.PON_ELEM_DEFS_GD=d.PON_ELEM_DEFS_GD
      and e.ELEM_QTYSTATE1+e.ELEM_QTYSTATE2+e.ELEM_QTYSTATE3+e.ELEM_QTYSTATE4>0
      and d.ELEM_KEY<1000)>0))
and r.ON_UNDER='1' and (b.ON_OFF_SYS='1' or (b.NBISLEN='Y' and r.NHS_IND='1'))
and b.LENGTH>0 and (b.DECK_AREA>0 or b.DECKWIDTH>0 or r.AROADWIDTH>0)) c
WHERE e.INSPEVNT_GD=c.INSPEVNT_GD and e.STRUCTURE_UNIT_GD=s.STRUCTURE_UNIT_GD
and e.PON_ELEM_DEFS_GD=d.PON_ELEM_DEFS_GD and e.PON_ENVT_DEFS_GD=v.PON_ENVT_DEFS_GD
) x
WHERE ELEM_KEY<1000 and (ELEM_PARENT_KEY<1000 or ELEM_PARENT_KEY is null)
and ELEM_QTYSTATE1+ELEM_QTYSTATE2+ELEM_QTYSTATE3+ELEM_QTYSTATE4>0
ORDER BY BRIDGE_ID,StrUnit_ID,ELEM_KEY,ELEM_PARENT_KEY
```

Subquery c (shaded yellow) selects the most recent inspection on each bridge, excluding inspections that have no qualifying elements. If two inspections have the same date, the GUID is used as a tie-breaker. For this purpose qualifying elements are those which have a non-zero total quantity and an element number less than 1000, assuming that larger element numbers are defect records.

Subquery c also excludes bridges that have no roadway-on, bridges that are neither on the National Highway System nor state-maintained, and bridges whose deck area cannot be determined. This query can be modified if desired to increase or decrease the number of bridges considered.

StruPlan can accommodate bridges lacking elements. However, since most of the StruPlan analysis is concerned with elements, bridges lacking them can generate only needs related to functional deficiencies or risk. StruPlan can also accommodate structures lacking a roadway-on, such as tunnels or high-mast light poles. In this case the agency would need to review the models and data to ensure suitability for these non-bridge structures.

On protective system elements, the green subquery producing ELEM_PARENT_KEY provides an element number for the substrate being protected. Subquery x (shaded red) then assembles all of the columns needed for the ElemInsp worksheet. The outer query (unshaded) further filters this data set to exclude four-digit element numbers (assumed to be defect records) and elements that have zero quantity. It is acceptable to include agency-defined elements, but be sure the **Element table** of StruPlan includes all elements that occur in the data, as discussed in **Step 1**.

The clause "ELEM_KEY<1000", which occurs three times in the above query, can be modified to exclude other elements that you do not wish to model in StruPlan. To exclude element 900, for example, you can change the clause to "(ELEM_KEY<1000 and ELEM_KEY<>900)". Alternatively, you can include element 900 in the StruPlan **Element table**, but then assign it to the Group XX, which StruPlan automatically ignores.

This syntax is correct for Microsoft SQL Server databases but might differ in other databases. The table and column names agree with AASHTOWare Bridge Management 6+ but might differ in other bridge management systems.

5.2 Follow all of the remaining parts of **Step 3** to populate the **ElemInsp** table in the Raw Data File. The following columns must be designated as Text: PON_ELEM_INSP_GD, BRIDGE_ID, StrUnit_ID, and PARENT_PON_ELEM_INSP_GD. Remember to change all the cells containing NULL to blanks.

Step 6: Import the Raw Data File into StruPlan

StruPlan has a built-in VBA procedure to import **Bridge**, **StrUnit**, and **ElemInsp** data from a Raw Data File. The procedure deletes bridges that may have already been in the StruPlan file. After importing a new data set, StruPlan updates all of its models to incorporate the new data.

Bear in mind that the Import procedure does not import any of the model parameters on the **Settings**, **Element**, **Group**, **Bridge**, or **Dashboard** worksheets. See the **Getting Started** chapter for more information about these data requirements. It is especially important to add element definition rows to the Element table for agency-defined elements that appear in the ElemInsp table.

6.1 In a StruPlan workbook, go to the **Settings** worksheet. Update the Base Year and System Name as appropriate for the new data that you plan to import. Save the file with an appropriate file name, e.g. "StruPlan 1.3 SD-NBI.xlsm". This must be a macro-enabled Excel file, so the file extension is ".xlsm".

6.2 In the **Import** table in the **Settings** worksheet, click the cell under the "Browse…" column heading. Select the Raw Data File that you prepared in the earlier steps.

6.3 In the **Import** table in the **Settings** worksheet, click the cell under the “Import…” column heading. This will import the required data from the Raw Data File and update the model calculations. It doesn’t matter if the Raw Data File is open or closed when the button is clicked, but if open, be sure it is saved. The process takes less than 3 minutes.

6.4 Check the data clean-up and conversion formulas on the Bridge worksheet to ensure that these are correct for your data. In particular, make sure the cell named “Metric” is 1 if your data is metric, and 0 if US Customary. Also check the SHS column to ensure that its definition for State Highway System bridges is correct for your agency. If you activate the Filter button on Excel’s Data tab, you can use Excel’s auto-filtering features to inspect columns in the tables to look for error values or other unexpected results. Examples of common issues:

- Bridges with deck area or deck width of zero.
- Bridges that are neither on the NHS or SHS, but lack a TPM model in the “Non” network.

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