# Development of Pontis User Cost Models for Florida

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## ABSTRACT

The Florida Department of Transportation (FDOT) has commissioned the University of Florida to perform a research study to develop user cost models for the Department's implementation of AASHTOWare™ Pontis™. The project features a literature review and survey, a thorough analysis of the sensitivity of Pontis to various user cost factors using Florida bridge data, gathering of additional data available within the Department, and analysis of the additional data. Because Pontis is already installed and operational, the research necessarily has a strong implementation component, working closely with the users of the system to ensure that the results can readily be put into practice. Among the products of the research will be some improved components of the user cost model, and a roadmap for the agency to supplement its existing data resources in the future to continue to improve the effectiveness of the models.

At its current stage, the project has developed an updated description of the mathematical form of the models, using a software testing methodology that may prove useful to any agency evaluating the reliability and suitability of new engineering or decision support software. The sensitivity analysis has identified the strengths and weaknesses of the model and established priorities for further investigation in the rest of the study. A request has been made to the Pontis Task Force for certain enhancements to allow Pontis to accept the improved components that Florida would like to develop.

## INTRODUCTION

The Florida Department of Transportation (FDOT) has commissioned the University of Florida, with subcontract support from Paul D. Thompson, to perform a research study to develop user cost models for the Department's implementation of AASHTOWare™ Pontis™ (*1*). The 24-month project, which began on October 1, 1997, features a literature review and survey, a thorough analysis of the sensitivity of Pontis to various user cost factors using Florida bridge data, gathering of additional data available within the Department, and analysis of the additional data. Because Pontis is already installed and operational in Florida, the research necessarily has a strong implementation component, working closely with the users of the system to ensure that the results can readily be put into practice. Among the products of the research will be some improved components of the user cost model, and a roadmap for the agency to supplement its existing data resources in the future to continue to improve the effectiveness of the models.

The user cost model in a Bridge Management System (BMS) has a strong effect on the outputs provided to decision-makers. Bridge program decisions frequently affect the level of service offered to the motoring public, by affecting bridge roadway geometrics, clearances, and load-carrying capacity. Deficiencies in these parameters cause certain vehicles to be forced to detour to longer routes, or may expose vehicles to a higher accident risk than bridges that have no such deficiencies. These effects on travel time and safety may be measured in terms of the value of the driver's time, vehicle operating costs, and accident costs. In a typical BMS application, the user cost implications of a decision may exceed the direct agency costs by a factor of 5 or more.

Pontis employs user cost models primarily to set priorities, since absolute need is established by the use of level-of-service standards. As a result, the magnitude of user costs has minimal effect on the Pontis outputs, as long as there is no systematic bias which affects one type of action or one type of bridge more than others. The focus, then, of this research is to develop user cost factors which lack systematic bias, even if there remains significant uncertainty in their magnitude. User cost factors with these characteristics can be determined and maintained economically with the resources available to FDOT, and will significantly enhance the value of Pontis in bridge program decision-making.

## ANALYSIS METHODOLOGY

A comprehensive search of TRIS, the Internet, and various libraries uncovered more than 70 articles and reports relevant to bridge user cost models, though most of the references were from outside the field of bridge management. A questionnaire was also sent to all 50 states to try to find ongoing studies that might not yet have been published. No such studies were found. Currently, nearly all bridge management systems with user cost modeling capability, including Pontis, rely on derivations from the model developed for North Carolina in the 1980s (*2*). Since FDOT has several relevant data sources of its own, it was desired to investigate the background literature to see if the models could or should be improved upon. Some highlights from the literature are described in later sections of this paper in the context of each component of the user cost model.

To provide a thorough test of the Pontis user cost model and analyze its sensitivity to uncertainty in data and model parameters, a reverse engineering approach was undertaken. This approach is similar to the software testing methodology now being developed under NCHRP Project 12-50. A Pontis simulation was prepared and executed, using a complete data set of Florida bridges on the state highway system, under controlled conditions that provided a clean data set of purely functional improvement needs.

The Florida database contains 6,384 bridges and 8,426 roadways on the state highway system. Of these roadways, 6,336 are on bridges, and 2,090 are under bridges. The simulation resulted in 950 functional needs on 941 bridges. The inputs and outputs of this simulation were transferred to a spreadsheet file. Within the spreadsheet, a model was created to mimic the expected behavior of the Pontis model, according to the Pontis documentation (*3*,*4*).

Differences between the spreadsheet model and the Pontis outputs were analyzed. This effort was aided by obtaining the source code of the user cost model logic portion of Pontis from its developer, Cambridge Systematics, Inc. In most cases, discrepancies were resolved by correcting the spreadsheet model to incorporate assumptions made in the Pontis software but not documented in the manuals. Later sections of this paper describe the hidden assumptions that were found, mostly related to the handling of missing values. Several minor software problems were discovered and brought to the developer's attention. Five of the 950 functional needs were removed from the data set because the reasons for discrepancies could not be determined. This resulted in a total of 945 cases on 938 bridges used in further analysis.

In order to establish priorities for improvements that FDOT might make to the user cost models, a sensitivity analysis was conducted. The spreadsheet was used instead of the actual Pontis software because it allowed the researchers to analyze the intermediate results of the model in depth. Each independent data item and each model parameter were varied independently through a range of values, according to the range of uncertainty in the value. Highlights of the sensitivity analysis are described with each portion of the model in the following sections.

## MODEL COMPONENTS

Benefits of functional improvements in Pontis are assessed in terms of user cost savings. When a deficient NBI approach alignment rating or travel way width exists on a bridge, road users are theoretically subject to higher accident risk. To evaluate a functional improvement or replacement which corrects the deficiency, the user cost model predicts a reduction in accident risk, which then is multiplied by an accident cost to yield a user cost savings. When a bridge has substandard vertical clearance or load capacity, certain trucks are unable to pass on or under the bridge and must detour, thus incurring higher labor costs and vehicle operating costs. The user cost model estimates the volume of detoured traffic and the resulting user cost, which would be avoided if the deficiency were corrected. The total user benefit of the functional needs in a project is therefore:

User benefit
$$B_r = W_c / 100 \times V_{ry}\left(BW_r + BR_r + BS_r\right) \quad (1)$$

Where: $W_c$ is the weight given to user cost benefits, in percent (Pontis cost matrix)
$V_{ry}$ is the forecast average daily traffic volume for the program year (calculated below)
$BW_r$ is the annual benefit of widening per unit average daily traffic (calculated below)
$BR_r$ is the annual benefit of raising per unit average daily traffic (calculated below)
$BS_r$ is the annual benefit of strengthening per unit average daily traffic (calculated below).

In the notation in all equations in this paper, subscripts indicate the level of resolution of the variable, or the entity that the variable describes. These are defined as follows:

- *b* indicates a bridge attribute (corresponds to bridge or inspection event table)
- *r* indicates a roadway attribute (corresponds to roadway table)
- *c* indicates a Cost Matrix parameter, linked to the bridge table by dim1val, dim2val, dim3val, dim4val
- *p* indicates a Policy Matrix parameter, linked to the bridge table by adtclass, dim2val, dim3val, dim4val
- *y* indicates a program year within the planning horizon.

When a bridge-level attribute is taken from the inspection event table, it is taken from the most recent inspection on the bridge. Approach alignment rating is the only attribute of this type. Variables without a subscript are systemwide parameters found in the Configuration Options table or the Improvement Model Parameters table. Florida uses the default definitions of the Pontis policy dimensions, which are as follows:

Dim1val—district in which the bridge is located
Dim2val—functional class of the roadway on the bridge
Dim3val—ownership of the bridge
Dim4val—national highway system (NHS) status of the roadway on the bridge
Adtclass—the traffic volume class of the roadway on the bridge.

Each of the components of this formula is described in the following sections. User cost savings tend to be very high in comparison to agency costs of functional improvements. For example, the Florida database exhibited functional needs with a total cost of $220 million and a total potential user cost savings of $1,040 million. In practice, nearly all transportation agencies exhibit decision-making behavior which undervalues user costs, relative to the user cost savings which would be estimated according to sound economic principles, as in Pontis. In order to more accurately model real decision-making behavior, Pontis includes the $W_c$ factor to simulate the typical agency's tendency to under-value user costs. The default value of this weight is, naturally, 100 percent. Since benefits are applied in Pontis primarily as a means of setting priorities, the relative differences in user cost savings among competing projects are more important than the absolute magnitude of the savings. Thus, the effect of the weight on priorities is small. However, the implication for the overall investment level in the bridge infrastructure is substantial.

## Traffic Volume Forecast

Traffic volume is explicitly represented in Equation (1) because it is the only part of the model that is sensitive to time during the simulation, for Florida's purposes. Other than traffic volume, the remainder of the model remains constant from one year to the next during the simulation. Pontis does allow level of service and design standards to vary by ADT class, which can change during the simulation. However, Florida is not using this feature.

In a normal multi-year simulation, the traffic volume variable, $V_{ry}$, is forecast by interpolation for the year of the project from Pontis roadway data items as follows:

Forecast average daily traffic

$$V_{ry} = 0 \qquad \text{if } V_{r0} \le 0 \tag{2}$$

$$V_{ry} = V_{r0} \qquad \text{if } V_{rn} \le 0 \text{ or } Y_{r0} \le 0 \text{ or } Y_{rn} \le Y_{r0} \text{ or } Y \le Y_{r0}$$

$$V_{ry} = V_{r0} \times \left( \frac{V_{rn}}{V_{r0}} \right)^{\left( \frac{Y - Y_{r0}}{Y_{rn} - Y_{r0}} \right)} \qquad \text{otherwise}$$

Where: $V_{r0}$ is the most recent actual traffic volume estimate (NBI item 29, adttotal in the roadway table)
$Y_{r0}$ is the year of most recent traffic volume estimate (NBI item 30, adtyear in the roadway table)
$V_{rn}$ is the forecast future traffic volume (NBI item 114, adtfuture in the roadway table)
$Y_{rn}$ is the year of forecast traffic volume (NBI item 115, adtfutyear in the roadway table)
$Y$ is the current year of the program simulation.

In most cases, Pontis interpolates the traffic volume for the current program simulation year based on a constant growth rate between the most recent ADT and the future ADT provided in the roadway table. If the most recent ADT is missing or zero, the effect is to turn off the entire user cost model. If any other variables needed for the traffic growth calculation are missing, the model uses the most recent ADT, adttotal, directly. However, if all variables except adtfutyear are present, Pontis estimates adtfutyear as adtyear plus the improvement model parameter DefaultADTchange. There were no cases in the Florida database where this latter refinement was applicable.

**Benefit of Widening**

Pontis estimates the user benefit of widening as the savings in accident costs. In the Florida database, widening needs represented 898 (95 percent) of the 945 cases, 83.5 percent of the costs, and 99.9 percent of the benefits of the full functional improvement program. The average user benefit of a widening project was $1.2 million per year. The method for estimating accident user costs in Pontis is derived from the North Carolina Bridge Management System, using the following formula:

Benefit of widening

$$BW_r = CA_c \left( R_r - R_r' \right) \tag{3}$$

Where: $CA_c$ the average cost per accident (Pontis cost matrix)
$R_r$ is an estimate of the current annual accident risk per vehicle (calculated below)
$R_r'$ is an estimate of the annual accident risk per vehicle after improvement (calculated below).

This result is calculated only for roadways on a bridge; it is zero for roadways under a bridge. It is also set to zero if $R_r < R_r'$.

As Equation (3) indicates, widening benefits are directly related to the average cost per accident. Since this unit cost factor is not yet known with great precision, there is a potentially wide range of benefit results. Values in the literature fall in the range from $10,000 to $40,000 per accident, with a Pontis default value of $37,600. Because of the high degree of uncertainty in this parameter and its importance to the model, it has high priority for further investigation.

The literature on traffic safety provides two different perspectives on the economic consequences of accidents, which have come to be known as the human capital approach and the willingness to pay approach. The human capital approach attempts to estimate the direct and indirect costs paid by society as a direct result of the specific accidents which have occurred. These costs include medical care, insurance and legal expenses, employer costs, lost productivity, property damage, and travel delay. In contrast, the willingness-to-pay approach estimates the amount of money the public would be willing to pay to avoid accidents. Implicitly, this cost includes intangibles such as pain and suffering, loss of enjoyment of life, inconvenience, and the premium associated with risk aversion. For bridge management, where the decision topic is the expenditure of public funds to prevent accidents, the willingness-to-pay approach would seem most suitable.

Among the most extensive studies of accident costs, Blincoe (*5*) found costs ranging from $2,855,000 per person for fatalities to $11,000 per person for minor injuries. These costs were developed under the willingness-to-pay approach in 1994 dollars. To be usable in a BMS, these costs may need to be converted to a cost per accident (rather than per injured person), in order to be compatible with an accident risk model. The North Carolina report (*2*) includes a reproducible methodology for generating unit costs from published sources.

Pontis does not distinguish among the types of accidents, so the costs of fatal, injury, and property damage accidents must be averaged together. There is evidence (*6*) that accidents related to narrow bridges are twice as likely to be fatal, compared to typical highway accidents. This is due to the finding that single-vehicle accidents have more than twice the percentage of fatal and incapacitating injuries as multi-vehicle accidents. Thus, the average accident cost should be weighted accordingly. No evidence has been found that other accident risk factors, such as alcohol and speed, affect bridge accidents differently from non-bridge highway accidents. However, icing may be related to higher accident risk on curved alignments in states with frequent freeze-thaw cycles. If an accident risk model can be developed for individual severity categories, then the increased severity of bridge-related accidents can be taken into account.

If data from historical sources or from the literature are used to develop a unit accident cost, the cost should be updated to program-year dollars. This is not strictly a matter of applying an inflation factor. As Blincoe (*5*) noted, between 1990 and 1994 the 16 percent increase in estimated accident costs was partly offset by a decrease due to increased safety of motor vehicles and roadways. This left a net 8.1 percent increase in the unit cost per accident. For bridges, the increasing use of modern parapet end treatments is especially significant.

## Accident Risk

The parameters $R$ and $R'$ in Equation (3) can, in principle, be estimated from actual accident studies when they exist. However, no such studies were found in the literature or questionnaire. The North Carolina system offers an approximate way to estimate *R* based on bridge attributes as follows:

Current accident risk $$R_r = 365 \times 200 \times \left(3.28084 W_r\right)^{-6.5} \left[1 + 0.5 \frac{\left(9 - A_b\right)}{7}\right] \qquad (4)$$

Where: $W_r$ is the roadway width (curb to curb) in meters (Pontis roadway table, NBI item 51)

$A_b$ is the approach alignment rating (typically 2–9, Pontis inspection event table, NBI item 72).

If the approach alignment rating is missing, it is taken as zero. It would be more appropriate to take it as 9, so it does not add to the accident risk. In the 5 cases where this was an issue in the Florida database, this change would reduce the user cost by an average of 39 percent. If roadway width is less than zero, it is treated as zero. Some of the numeric constants in this formula are user-modifiable in Pontis, in the improvement model parameters table. They are defined as follows, with the Pontis parameter name given in parentheses:

- 365 is the number of days in a year (not customizable)
- 200 is a regression constant (AccRiscCoeff)
- 3.28084 is the constant Pontis uses to convert from meters to feet (not customizable)
- 6.5 is a regression constant (GAccRiskC)
- 0.5 is a model specification constant (not customizable)
- 9 is the highest approach alignment rating (GaccRiskB
- 7 is the range of allowed approach alignment ratings (GAccRiskB minus GAccRiskA).

The 200 and 6.5 are regression constants derived from the North Carolina study, so they should be modified only if another statistical analysis of accident data is conducted. The 0.5 constant arose because of the practice in North Carolina of assigning only even numbers for approach alignment ratings. It is not important to the model framework, but must be used with the North Carolina regression constants. The final two constants are artifacts of the NBI approach alignment scale, which ranges from 2 to 9. Assuming that FDOT uses the standard NBI definitions for this data item, there is no reason to change these constants.

Approach alignment ratings in the Florida database are heavily skewed toward the high end of the scale, with most bridges having a rating of 8. Only 7 bridges have ratings below 5. This makes overall user costs relatively insensitive to errors in the rating. On average, a 1-point change either way in approach alignment rating decreases total user costs by 4 percent in the Florida database. If all bridges in the data set had a rating of 2, the total user cost would increase by 21 percent.

The distribution of roadway widths in the Florida database is probably not unusual among the states, with most roadways in the 8–12 meter range. On average, the simulated widening in Pontis increased the roadway width by about 5 meters. The accident risk model is extremely sensitive to errors in the roadway width. An increase in roadwidth of 1 meter reduced user costs by an average of 92 percent, while a decrease of 1 meter increased user costs by a whopping 846 percent. The reason for this tremendous effect is the exponential form of the accident risk model in Equation (4) above. The large exponent makes the model very sensitive to even very small changes. For the same reasons, the accident risk model is extremely sensitive to the exponent in Equation (4). If the exponent is changed to 6.0, user costs increase by 261 percent. If the exponent is changed to 7.0, user costs decrease by 62 percent.

These considerations, combined with the overall importance of widening needs in the Florida database, make the accident risk model the highest priority for improvement. Florida does have a very good set of safety data which might be applied to this purpose. When developing new accident cost and risk models, it is important to be aware of the high percentage of accidents which are never reported. Blincoe (*5*) found that roughly half of all property-damage-only accidents, and more than 20 percent of all non-fatal injuries, are not reported to police.

When analyzing historical accident data, it is quite difficult to determine, from most police records, whether each accident is related to a bridge, especially if the bridge was not directly a part of the collision. In the absence of better information, Brinkman and Mak (*6*) recommend using any accidents within 500 feet of the bridge. It is possible to use a more sophisticated criterion than 500 feet, if speed and/or sight distance are known. In general, this distance should be based on the range within which driver behavior is affected.

Using the evidence presented in (*6*), it is likely that the accident risk in Florida is sensitive to the number of lanes, direction of traffic, functional classification, speed, approach roadway width, and traffic volume. The model used in Pontis is not sensitive to these variables, because the North Carolina study found counterintuitively that only roadway width and approach alignment significantly affected accident occurrence in their database. Therefore, the use of a new Florida data set might very likely result in a model having a much different set of explanatory variables.

The formula for accident risk after improvement is similar to Equation (4), but it depends on the width of the improved roadway.

Improved accident risk
$$R_r' = 365 \times 200 \times \left(3.28084 W_r'\right)^{-6.5} \left[1 + 0.5 \frac{\left(9 - A_b\right)}{7}\right] \tag{5}$$

Where: $W_r'$ is the improved roadway width (curb to curb) in meters (calculated below)
$A_b$ is the approach alignment rating (typically 2–9, Pontis inspection event table, NBI item 72).

Note that the model assumes no change to the approach alignment rating due to widening. Thus, the approach alignment contribution to accident risk is the same in both the current and improved cases. The improved roadway width depends in part on the length of the bridge. For long bridges, the width depends on design standards for lane and shoulder width. For short bridges, the improved width also may depend on the approach road width.

Improved road width
$$W_r' = \max\left(SW_r, LW_r\right) \quad \text{if } L_b < 60 \text{ and } W_r < SW_r \tag{6}$$
$$W_r' = LW_r \quad \text{otherwise}$$

Where: $SW_r$ is the design width (meters) if the bridge is short (calculated below)
$LW_r$ is the design width (meters) if the bridge is long (calculated below)
$L_b$ is the bridge length (meters, Pontis bridge table, NBI item 49)
60 is the length threshold (meters, Pontis improvement model parameter MaxWidenLength).

Design width if short $$SW_r = 0.9\ AW_r \quad (7)$$

Where: $AW_r$ is the approach road width (meters, Pontis roadway table, NBI item 32)
0.9 is the width deficiency factor (Pontis improvement model parameter WidthDefFactor).

Design width if long $$LW_r = LN_r \times DLW_p + 2 \times DSW_p \quad (8)$$

Where: $LN_r$ is the number of lanes (Pontis roadway table, NBI item 28)
$DLW_p$ is the design lane width (meters, Pontis policy matrix)
$DSW_p$ is the design shoulder width (meters, Pontis policy matrix).

A total of 671 of the 898 roadways identified for widening had lengths less than or equal to 60 meters.

Since Equations (4) and (5) both use the same exponential form, it might be expected that the model is quite sensitive to the parameters governing improved roadway width. In fact, the effect is extremely small. Reducing the design lane width from 3.7 meters (about 12 feet) to 3.3 meters (less than 11 feet) reduces benefits by only 0.01 percent.

The main reason for this is that the benefit is determined by subtracting the accident risk after improvement from the accident risk before improvement. Since the model is exceedingly sensitive to road width, the accident risk after improvement is much smaller than the accident risk before, by a factor averaging about 4,500. This implies that the improvement virtually eliminates excess accident risk, which is reasonable enough for the purposes of the model.

Pontis has an acc_risk column in the roadway table, intended to hold an externally calculated value for accident risk. This column is not populated in Florida. A review of the source code indicates that this item is probably not used by Pontis.

## Benefit of Raising

The Florida database has 45 cases of raising, accounting for 11.7 percent of the cost but only 0.06 percent of the benefits of the full functional improvement program. The average benefit of a raising project was $14,000 per year. Pontis calculates the vehicle operating cost and travel time cost associated with traffic on a detour route, and assumes that this entire cost is saved if a functional improvement is undertaken. Only trucks are assumed to be affected. Raising is considered only for roadways under a structure. The project benefit is then:

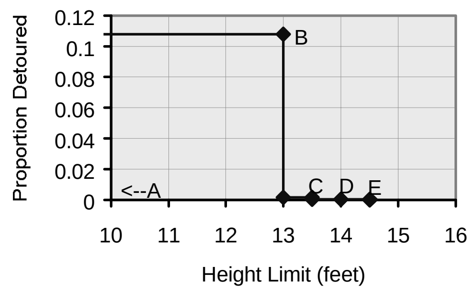
Benefit of raising $$BR_r = 365 \times DC_r \times PT_r / 100 \times PH_r / 100 \quad (9)$$

Where: $DC_r$ is the detour cost per truck for this roadway (calculated below)
$PT_r$ is the percentage of the traffic stream occupied by trucks (Pontis roadway table, NBI item 109)
$PH_r$ is the percentage of trucks which are detoured by the bridge (calculated below).

If the truck percentage is missing or zero, it is given the value of the improvement model parameter DefaultTruckPct, whose default value is 5 percent. This affected 21 of the 45 cases of raising in Florida.

Pontis calculates the detoured percentage of trucks by comparing the vertical clearance field (vclrinv in the roadway table, NBI item 10) against a stepwise linear graph of the distribution of truck heights in the traffic stream. The following table and graph show the default values developed for California. For easier reading, the default values are shown on the graph in feet. However, the values in Pontis are expressed in meters as in the table.

| Point | Height Limit (m) | Percent Detoured |
|---|---|---|
| A | ≤ 0.00 (ClrDetoursThreshA) | 0.000 (ClrDetoursFracA) |
| B | ≤ 3.96 (ClrDetoursThreshB) | 10.810 (ClrDetoursFracB) |
| C | < 4.11 (ClrDetoursThreshC) | 0.180 (ClrDetoursFracC) |
| D | < 4.27 (ClrDetoursThreshD) | 0.050 (ClrDetoursFracD) |
| E | < 4.42 (ClrDetoursThreshE) | 0.027 (ClrDetoursFracE) |
| | ClrDetoursThreshE | 0.000 (ClrDetoursDefault) |




States may customize this model by modifying any or all of the breakpoints in the improvement model parameters table.

In the Florida data set, 8 bridges are under threshold A, 5 under threshold B, 31 under threshold C, and 1 under threshold D. Out of these 45 bridges, 21 are within 2 cm of a threshold, so there is significant exposure to the sensitivity of the threshold values. On average, an increase of 2 cm in vertical clearance reduced the raising benefit by 65 percent, while a decrease of 2 cm increased benefits by only 1 percent. The lack of symmetry is largely an artifact of the small sample size. However, the high sensitivity exhibited in the first case is because of a large discontinuity in the step function at point B. Only one bridge crossed the threshold (moving from 3.96 meters to 3.98), but its user cost increased by a factor of 60. Such discontinuities are a common problem with step functions and are probably unavoidable with this form of model. The use of a piecewise linear or curvilinear model might reduce the sensitivity. However, in real life there is a large dropoff in the truck height distribution near the legal height limit, which in Florida is 13 feet 6 inches.

The literature review provided no helpful data to develop a new height distribution. The Permits Office at FDOT does have a good data set for trucks above the legal height limit.

## Benefit of Strengthening

The Florida database has only 3 cases of strengthening, reflecting the fact that the state has a very small percentage of posted bridges compared to most other states.

Strengthening accounted for 4.8 percent of the cost but only 0.03 percent of the benefits of the full functional improvement program. The average benefit of a strengthening project was $93,000 per year. Pontis calculates the vehicle operating cost and travel time cost associated with traffic on a detour route, and assumes that this entire cost is saved if a functional improvement is undertaken. Only trucks are assumed to be affected. Strengthening is considered only for roadways on top of a structure. The benefit is then:

Benefit of strengthening $$BS_r = 365 \times DC_r \times PT_r / 100 \times PW_b / 100 \quad (10)$$

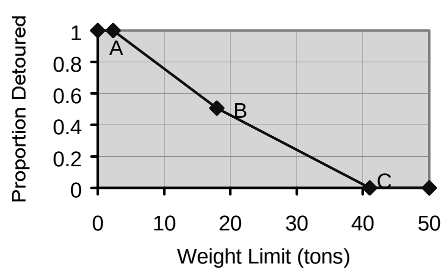
Where: $DC_r$ is the detour cost per truck for this roadway (calculated below)
$PT_r$ is the percentage of the traffic stream occupied by trucks (Pontis roadway table, NBI item 109)
$PW_b$ is the percentage of trucks which are detoured by the bridge (calculated below).

If the truck percentage is missing or zero, it is given the value of the improvement model parameter DefaultTruckPct, whose default value is 5 percent. This affected 2 of the 3 cases of strengthening in Florida.

Pontis calculates the detoured percentage of trucks by comparing the operating rating field (orload in the bridge table, NBI item 64) against a piecewise linear graph of the distribution of truck weights in the traffic stream, as shown below. The agency determines the x-coordinates for the breakpoints at the top and bottom of the graph, and the x,y coordinates for the breakpoint in the center. The example below is drawn with the Pontis default values, which were developed for California in 1991. As an example of reading the graph, the center breakpoint specifies that a bridge with an 18 ton weight limit will detour 50.425 percent of the trucks. The table below left shows the default values and names of the customizable parameters in the improvement model parameters table.

| Point | Weight Limit (tons) | Percent Detoured |
|---|---|---|
| A | 2.3 (StrDetoursMinThresh) | 100.0 |
| B | 18.0 (StrDetoursCornerX) | 50.425 (StrDetoursCornerY) |
| C | 41.0 (StrDetoursMaxThresh) | 0.0 |

Between point A and zero, all trucks are detoured.
At or below zero, no traffic is detoured.
Above point C no traffic is detoured.




It is possible that some fraction of trucks exceeds the operating rating but ignores any posting signs present. Also, many states post bridges at levels different from the operating rating. The model makes no assumptions about these factors, since it describes only the percentage of trucks that are actually detoured at each operating rating level.

All three Florida bridges needing strengthening fall between points B and C in the piecewise linear function contributing to Equation (10). Operating ratings of deteriorated bridges are known with less certainty than clearances, so a larger variation was investigated. An increase of 5 tons in operating rating on these three bridges decreased user costs by 30 percent, while a decrease of 5 tons increased user cost by 35 percent. The piecewise linear function used in Equation (10) has discontinuities that are far less severe than a step function. The effect on user cost is therefore much smoother and more intuitive.

The literature review provided no usable sources of truck weight data, but available FDOT weigh-in-motion data may provide suitable models.

**Benefit of Replacement**

The sensitivity analysis data set for Florida did not include any replacement projects, since these were filtered out. However, the user cost model for replacement benefits is very similar to the combined effect of all of the separate functional improvements. An analysis of the source code reveals just a few differences as discussed in this section.

When a bridge is replaced, Pontis recognizes the benefits of widening for all roadways on and under the bridge. All roadways are assumed to have the approach alignment rating of the bridge before the project, and all are assumed to have an approach alignment rating of 9 after the project. With these refinements, the user cost formulas are the same as formulas (3)–(8) above.

Pontis assumes that bridge replacement eliminates all operating rating deficiencies. As a result, the project benefit includes the benefit of strengthening, calculated in the same way as described above in formula (10).

Pontis assumes that vertical clearance deficiencies are removed for all roadways on and under the bridge when the bridge is replaced. This properly handles the cases where bridges have restricted vertical clearance on the roadway on top of the structure, such as thru-truss bridges. Florida has 8 bridges in its inventory which have roadways-on with vertical clearances of 14.5 feet or less.

The replacement benefit model for height-related detours in Pontis is formulated to allow for the possibility that, when both height and weight restrictions exist, certain trucks may be affected by both restrictions.

Repl. height benefit

$$BR_r = 365 \times DC_r \times PT_r / 100 \times \left[ \left(1 - PW_b / 100\right) \times PG_b / 100 \times PH_r / 100 \right] \qquad (11)$$

Where: $DC_r$ is the detour cost per truck for this roadway (calculated below)

$PT_r$ is the percentage of the traffic stream occupied by trucks (Pontis roadway table, NBI item 109)

$PW_b$ is the percentage of trucks which are detoured by the bridge due to weight (same as above)

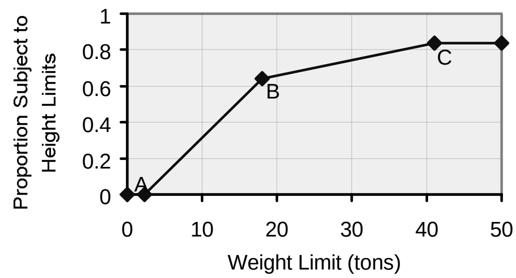
$PH_r$ is the percentage of trucks which are detoured by the bridge due to height (same as above)

$PG_b$ is the percentage of those trucks not detoured by the weight limit, which are potentially subject to height restrictions (explained below).

The proportion of those trucks not detoured by weight limits, which are potentially subject to height restrictions, is given as a piecewise linear graph, as shown below. When the weight limit is below the first breakpoint, it is assumed that all traffic is detoured anyway, so height limits are not considered for any trucks. When the weight limit is above the last breakpoint, a constant fraction of the traffic stream is assumed to be potentially subject to height limits. With the default values shown, this fraction is less than 1 because, when this model was developed for California, only duals and tractor-trailers were considered for height restrictions.

| **Point** | **Weight Limit (tons)** | **Percent Subject to Height Limits** |
|---|---|---|
| A | 2.3 (MinDualTTST) | 0.0 |
| B | 18.0 (DualTTSTxA) | 64.30 (DualTTSTyA) |
| C | 41.0 (DualTTSTxB) | 83.57 (DualTTSTyB) |

Below point A no traffic is subject to the height limits.
Above point C the proportion remains constant at DualTTSTyB.




There is a subtle logical inconsistency in the use of $PH_r$ in the raising and replacement models. In the raising model, $PH_r$ is a percentage of the entire truck traffic stream which is detoured, since the percentage detoured by weight restrictions is zero. In the replacement model, on the other hand, $PH_r$ is a percentage of only the lighter-weight duals and tractor-trailers. The $(1 - PW_b)$ term restricts $PH_r$ to lighter-weight vehicles, and the $PG_b$ term restricts $PH_r$ to only duals and tractor-trailers.

Part of this inconsistency can be removed by setting all the percentages in the $PG_b$ model to 100, so the definition of $PH_r$ is not limited to duals and tractor-trailers. There is no easy way, however, to remove the effect of $(1 - PW_b)$. Fortunately for Florida, the number of bridges with both operating rating of 41 tons or less, and roadway-on vertical clearance of 14.5 feet or less, is zero. Thus, in all cases where $PH_r$ is more than zero, $(1 - PW_b/100)$ is 1 and no inconsistency exists.

Considering the Pontis user community as a whole, it would be worthwhile to consider eliminating the $PG_b$ factor and simplifying the definition of $PH_r$ to conform to its usage in the strengthening model. This could cause some minor double-counting of benefits in cases where both clearance and weight restrictions exist on the roadway on top of a bridge, but the number of cases where this is a problem is likely to be small in most states. The benefit of the change would be to make the user cost model smaller, more consistent, and more understandable.

## Detour Cost

Each time a truck is detoured, it experiences vehicle operating costs associated with the added detour distance, and travel time costs associated with the added detour time. Pontis uses a model of these factors for raising, strengthening, and replacement.

Detour cost per truck $$DC_r = CV_c \times D_r + CT_c \times \frac{D_r}{DS_r} \quad (12)$$

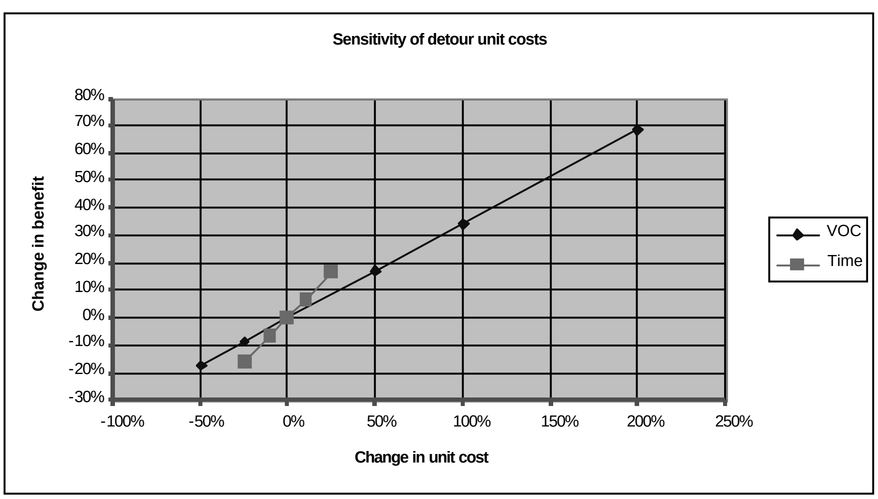
Where: $CV_c$ is the average vehicle operating cost per km of detour (Pontis cost matrix)
$CT_c$ is the average travel time cost per hour of detour (Pontis cost matrix)
$D_r$ is the detour distance for the roadway in km (Pontis roadway table, NBI item 19)
$DS_r$ is the speed on the detour route, kph (Pontis roadway table, not in NBI).

Since detour speed is not an NBI data item, many agencies lack this information. When missing, Pontis estimates the detour speed by factoring the roadway speed (Pontis roadway table), using the improvement model parameter DetspeedFactor. The default value of this factor is 80 percent. Since roadway speed, also, is not an NBI item, Pontis has a set of default speed values DefaultRoadspeedFCnn, where nn is the roadway functional class, in the improvement model parameters table. Since these defaults are very rough, it is better to collect the actual detour speed or at least the bridge roadway speed, if possible.

The Florida database lacks both the detour speed and the road speed, so it uses the DefaultRoadspeedFCnn parameters. Only functional classes 09, 11, 14, 16, 17, and 19 have roadways with raising or strengthening needs. The agency intends to collect a complete set of posted speed data in its first round of Pontis inspections, now underway.

Detour unit costs per hour and per kilometer affect both raising and strengthening costs. In the Florida data set, 34 percent of the detour cost is vehicle operating cost, and 66 percent is travel time cost. Since the two cost factors are added together, the model is naturally about twice as sensitive to travel time cost as it is to vehicle operating cost, as indicated in the graph. However, since the cost of travel time is known with more certainty than the cost of vehicle fuel and maintenance, the effect of uncertainty might be about the same for the two factors.

In the literature, truck operating costs per kilometer range from 19 cents to 31 cents. However, the range narrows considerably when the studies are adjusted to the same set of assumptions. The most recent and up-to-date source of these data is the Highway Economic Requirements System (HERS) (*7*), whose estimates would likely be in the 10–20 cent range after adjusting for Florida conditions. The Pontis default value is currently 25 cents.



Estimates in the literature for hourly truck travel time costs range from $17.34 to $34.79, with the most common values in the range of $21 to $25. The HERS study again is the most usable source of this information. The Pontis default is currently $19.34. Florida does not have its own direct source of these unit cost factors.

## CONCLUSIONS

At the current (January 1999) stage of the study, FDOT has determined its priorities for user cost model development, and has completed an inventory of available data sources. The accident risk model has been found to be clearly of highest priority. The next step is to analyze the available data to determine whether improved models can be developed. A request has been made to the Pontis Task Force to provide a means by which the improved models can be connected to the software.

In a related activity, FDOT is investigating the possibility of adding a user cost model for movable bridge openings. This would be useful in establishing priorities for replacement of the state's large inventory of more than 80 movable bridges.

In September 1998, FDOT began a parallel project to develop agency cost models for Pontis. This 24-month project will use data from the literature and from FDOT historical data to develop unit costs for preservation, functional improvements, and replacement.

As a highly decentralized state, FDOT has advanced its implementation of Pontis by gradually gaining the support of its independent-minded districts. With strong district support for the inspection process, and strong headquarters support for the analytical process, FDOT is positioning itself for long-term success of its bridge management system.

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