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16. Abstract

As the proportion of highway needs that can be supported by fuel taxes declines, the attractiveness of toll funding rises. Public agencies and local authorities are examining their options and some states, notably Texas, have broadly increased the range of local toll-related options available. These entities need an analytical tool that will allow them to make realistic "first-cut screening" estimates at potential revenue, so they can make prudent determinations about the potential viability of a toll-supported option.

Most of the variables associated with revenue prediction are highly variable – corridor demand, diversion rate, and acceptable tolls. Sometimes only point estimates of these variables are available. But, it is imprudent to treat these factors as point estimates for simplicity of analysis, because such estimates can easily mask either a truly viable project or clearly questionable project.

This report documents the development of a spreadsheet analysis tool to provide a preliminary determination of the viability of a toll road or toll-supported project. The tool uses inputs typically available to TxDOT or local planning agencies and outputs measures representing various aspects of viability including economic measures, such as annual revenue or net present value. The project treats input and outputs as random variables, uses sensitivity analyses to identify critical variables, and develops probability distributions that improve the accuracy, reliability, and decision-making value of the toll study. The results of this project provide to TxDOT and local agencies a "first-cut screening tool" to be supplemented by investment-grade traffic and revenue studies if the findings warrant.

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ESTIMATING REVENUES USING A TOLL VIABILITY SCREENING TOOL

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DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration (FHWA) or the Texas Department of Transportation (TxDOT). This report does not constitute a standard, specification, or regulation. The engineer in charge was Wm. R. Stockton, P.E., (Texas, # 41188).

IMPORTANT NOTE TO USERS

The spreadsheet tool developed in this research is based on the Decision Tools® Suite from Palisade Corporation. Execution of this model requires purchase and installation of Palisade Corporation's Decision Tools suite of software containing the Microsoft Excel® add-in simulation macros that interface with Excel. The Decision Tools suite of software (macros that are loaded into Excel) must be installed on the user's computer. To execute this model, the @RISK® icon is selected. The loading process brings up Excel and installs the required macros. Then the model can be loaded similar to any other spreadsheet application.

The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

ACKNOWLEDGMENTS

This document represents the investigative and analysis phase of a research project involving the design, development, and testing of a static and simulation-based spreadsheet model to assist in the estimating of annual gross toll revenues and the equivalent net present value of those gross revenue estimates over a 40-year study period.

The authors appreciate the ongoing assistance and guidance of the project director, Roy Jarbeaux, of the Corpus Christi District, Texas Department of Transportation, as well as input from Diana Vargas and others in the Texas Turnpike Authority Division.

Special thanks are also due to the various TxDOT divisions and districts who have graciously contributed time and effort in providing test data and constructive feedback and review of the project, the software, and all associated official documents relating to this effort, including Phillip Russell, TTA, Program Coordinator; Andrew Griffith, RTI, Research Engineer and the Project Advisors: Martha Boyd, ELP; David Powell, TTA; Clay Smith, SAT; and Dan Wyly, ISD.

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CHAPTER 1: INTRODUCTION

As the proportion of highway needs that can be supported by fuel taxes declines, the attractiveness of toll funding rises. Public agencies and local authorities are examining their options and some states, notably Texas, have broadly increased the range of local toll-related options available. These entities need an analytical tool that will allow them to make realistic "first-cut screening" estimates at potential revenue, so they can make prudent determinations about the potential viability of a toll-supported option.

Most of the variables associated with revenue prediction are highly variable – corridor demand, diversion rate, and acceptable tolls – and can increase in variability with the length of the project. Sometimes only point estimates of these variables are available. But, it is imprudent to treat these factors as point estimates for simplicity of analysis, because such estimates can easily mask either a truly viable project or clearly bad project.

This report documents the development of a spreadsheet analysis tool to provide a preliminary determination of the viability of a toll road or toll-supported project. The tool uses inputs typically available to TxDOT or local planning agencies; it outputs measures representing various aspects of viability including economic measures, such as annual revenue or net present value. The project treats inputs and outputs as random variables, uses sensitivity analyses to identify critical variables, and develops probability distributions that improve the accuracy, reliability, and decision-making value of the toll study. The results of this project provide to TxDOT and local agencies a "first-cut screening tool," to be supplemented by investment-grade traffic and revenue studies if the findings warrant.

BACKGROUND

Toll financing of highway projects is becoming increasingly attractive in Texas. Current funding sources will support a declining proportion of the needs identified by the Texas Department of Transportation (TxDOT). Funding requirements for maintenance and construction continue to grow, while increasing fuel efficiency reduces fuel-tax revenues per vehicle-mile. In the face of growing financial limitations, the Texas Legislature has provided tolling options that are broader than ever in Texas.

The Texas Legislature has created the authority for regions to form Regional Mobility Authorities (RMAs) for the purpose of developing toll-supported highways where adequate local or state funding is not available. These RMAs may establish toll-supported facilities when such a facility is viable. Because the RMAs are not well-established toll authorities, the funds available to conduct toll-feasibility studies will be limited. Therefore, these new authorities need some capability to estimate, at least roughly, the feasibility of toll support for a prospective road project.

Similarly, the potential for toll support of state highways is receiving considerable attention within TxDOT. In the 1990s, TxDOT and the North Texas Tollway Authority (NTTA) coordinated to complete the President George Bush Turnpike (SH 190) in north Dallas. TxDOT had taken the project through design, environmental clearance, and right-of-way acquisition when it was transferred to NTTA. The vast majority of the $1 billion project was financed through bond sales, but the funding package also included a $135 million Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) loan through TxDOT. This type of "toll equity" financing has generated considerable interest and is envisioned as a likely model for some state projects and many potential RMA projects. Like the RMAs, the Texas Turnpike Authority (TTA) division of TxDOT does not have cash income to support numerous feasibility studies, but could benefit significantly from having sound analytical insight into the approximate viability of a toll project. That kind of analysis would allow TxDOT and the RMAs to answer two key questions:

- Is there a reasonable likelihood that a project will be self-supporting as a toll road?
- If not, what is the expected level of available toll support to use as a match for available public funds?

The genesis for the proposed project arose out of a specific TxDOT Houston District need. That need highlighted the potential value of a user-friendly toll viability screening tool. In 2002 TxDOT asked the Texas Transportation Institute (TTI) to examine a section of SH-99 (the Grand Parkway) near Houston to assess the feasibility of converting that facility to a toll road. A technical memorandum detailing the findings of that study concluded that toll revenues would support about 20 percent of the total project cost *(1)*. That brief study was conducted in a matter of a few weeks, but because it was unlike any previous work, it required considerable original work, especially in piecing together existing data to estimate potential traffic volumes and toll revenues. That study concluded that the debt coverage ratio for the proposed project was likely well below 0.5, making the project a most unlikely candidate for a toll road. At the time, TxDOT was not considering the project for toll equity financing, so that potential funding alternative was not explored. So, while a "go/no go" decision on a self-sustaining toll road was easily made using the data and tools available, the potential as a toll equity project was not nearly so easily concluded.

Having the capability to examine the toll viability question in a rapid turnaround manner would allow TxDOT to make very expeditious decisions about what role tolls should play in the project. This situation also demonstrated the potential value of TxDOT having an in-house capability to make a first-cut assessment of toll viability. But it also illustrated a vulnerability of these studies – dependence on point estimates of traffic volumes, diversion rates, and toll revenues.

Because toll road construction is funded (at least primarily) by the proceeds of revenue bonds, investors (purchasers of the bonds) want to be comfortable that the estimated revenues will be sufficient to service the debt of the bonds. Expertise to conduct "investment-grade" traffic and revenue studies, in which bond houses place considerable confidence, resides in a small handful of engineering consulting firms. Over the course of many years, these firms have developed capabilities and techniques that accord their analyses the level of confidence that major bond houses seek – that closely held expertise is not likely to change soon, certainly not with the outcome of the proposed research. The cost of an investment grade feasibility analysis is high enough, so there must be a good likelihood of feasibility before one is commissioned.

However, before TxDOT or any other entity can pursue an investment-grade project, there needs to be some analysis that indicates the role that tolls can play in a project. The TTI project referenced above used fairly simple spreadsheet models to estimate toll road costs and revenues, and thus predicted the potential viability of tolling that segment of the SH-99. Highlighted by that study were a few variables that are subject to considerable assumption(s) in the toll feasibility analysis. If those assumed values for these variables could be replaced with much more reliable probability distributions, then the results would be much more reliable and valuable.

PURPOSE

This spreadsheet tool is intended to allow the user to develop a reliable estimate of the toll revenue potential of a highway project. It allows for a comparison of revenues with expected costs, either as a net present value (NPV) for the project or on an annual basis. This latter feature is important for the obvious reason that bond repayment requires that a toll project cover debt service within a few years. But some of the other innovative funding techniques being considered by TxDOT, such as using toll revenues to pay for maintenance and operations, instead of capital costs, also require some level of understanding of annual revenues.

This tool complements TxDOT's existing methods, including the Preliminary Feasibility Tool (PFT) released in mid-2004. The PFT performs many functions that complement the toll viability screening tool (TVST), such as cost estimates and estimates of potential bond funding. The TVST complements the PFT by increasing the reliability of the preliminary revenue estimates.

SCOPE

The toll viability screening tool is applicable to all highway toll projects, though some of the input variables will change significantly depending on setting. For example, an urban project with similar toll projects in the region will differ considerably from a suburban project in the region with no toll roads, mostly because so little is known about the range of variability of public tolerance for tolling.

The scope of the more advance techniques imbedded in the tool is limited to revenue projections. Theoretically, the estimating principles that apply to revenues could be applied to costs as well. However, TxDOT has extensive experience in estimating costs so the efforts of this project were focused on revenues.

CHAPTER 2:
BACKGROUND AND LITERATURE REVIEW

In the mid-1990s, TTI prepared a series of reports for TxDOT that developed an evaluation procedure for the feasibility of private toll roads. Anticipating increased interest in privately funded toll roads for which TxDOT was responsible for evaluating and recommending to the Texas Transportation Commission, TxDOT wanted a uniform procedure for the evaluation process. In the final report, Glenn identified the following elements for the suggested guidelines (only major headings shown) *(2)* (Table 1):

Table 1. Recommended Elements of Toll Feasibility Study (*2*).

Project Description and Proposed Alignment	Integration with Existing Transportation Plans
Environmental Impacts	Traffic Forecasts
Financial Plan	Economic Impacts
Impact on U.S. – Mexico Trade Flow	Sensitivity Analysis

Glenn's variables included the complete range of expenses for the life cycle of the project. The results of his analyses will be helpful to the proposed project, as the general conditions of feasibility should be consistent between privately and publicly funded toll investments. Further, his analyses of the levels of sensitivity of dependent variables provide a sound starting point for the toll viability study.

Toll revenues are a function of toll road traffic volumes and toll rates. While accurately predicting traffic volume on a "free" (actually tax-funded) road is difficult, estimates for toll roads are much more challenging because of the impact of the tolls themselves. In general, to pay a toll, the traveler must perceive a benefit that is greater than the price of the toll itself. Travel time savings is typically used as a measure of benefit to most travelers. The monetary trade-off decision made by the traveler is: "Is the savings in time sufficient to justify the toll paid?" If the traveler perceives that the benefit is less than the toll paid, then he or she will use an alternative rather than the toll facility.

One approach to estimating that benefit is to multiply the "value of time" by the travel time saved, producing a monetary value – if that value is greater than the toll paid, then the traveler would use the toll road. However, the value of time is a distribution rather than a single value. Trip purpose, length of trip, available alternatives, total time savings, travel time reliability, disposable income, and other factors contribute to this distribution of value of time, making point estimates of potential revenues of limited worth. A model for estimating toll viability should be based on appropriate distributions of the value of time, without requiring the user to make complex decisions or calculations of the variables described above.

The importance of other, less direct factors cannot be overlooked. For example, the SR-91 Express Lanes in Orange County, California, experience toll road use that is not insignificant during times of day when the adjacent free lanes are operating in free-flow conditions *(3)*. The operating staff concludes that factors other than pure travel time savings contribute to the travelers' decisions to use the toll lanes, such as perceived improved safety and much higher travel time reliability.

Projected traffic volumes throughout the life of the typical revenue bond road project (20-30 years) are subject to substantial variability. Well-developed regional planning models provide an estimate of roadway volumes at various time horizons, but those estimates are typically point estimates of the expected mean traffic volume. Further, the planning models do not typically provide any confidence intervals that describe to the analyst or decision maker some sense of how broadly distributed the expected volumes might be, and this variation could be a significant factor in decision-making.

Li et al. used stated preference surveys of travelers on I-635 and the Dallas North Tollway to develop estimates of price elasticity of demand *(4)*. The situational context of this study is different from most potential RMA projects, but in principle represents similar factors – drivers are choosing (in a survey) between a non-toll trip and a faster, more reliable toll trip. From their study, the authors conclude that the deduced value of time is between \$3 and \$6, considerably below any local wage rate, suggesting that other factors play a significant role in the traveler's decision to use a toll facility. The project developed a toll evaluation tool, based on some assumed and empirical estimates of driver response to toll and time savings. The authors conclude that the tool has promise, but requires additional refinement. As with the other previous research, the results of the Dallas study provide an excellent starting point for the proposed research.

Thus the estimation of toll revenues, as a function of volumes and tolls, is actually a complex interaction of traffic, travel time savings, value of time, and tolls, each with its own distribution and each interacting with one or more other variables. Although the interaction is complex, it produces a much more robust result for decision-making, and appropriate application of background probability distributions makes task of making reasonable estimates of toll revenues straightforward.

A 1998 study by Orozco and McCullough examined the experience of the broad development of toll facilities in Mexico during the 1990s, with a goal of improving the accuracy and reliability of estimating the variables that affect gross toll revenues *(5)*. The study developed a traffic forecasting model based on travel distance, travel time, and user costs, but unlike Glenn, limited the variables considered. Using the empirical data from the developed toll roads to describe elasticity, the authors prepared adjustments to the mathematical functions for traffic forecasting. They noted that usage, and therefore toll revenues from passenger cars, was considerably more elastic than for trucks, which had generally lower diversion rates than cars and buses. Although the study was based on a limited sample of Mexican toll roads, the principles and mathematical relationships developed will be another useful element of the proposed study.

CHAPTER 3:
IMPORTANT TERMS AND CONCEPTS

SIMULATION

Simulation is the art and science of moving a defined modeled system through time in order to observe and record changes manifest by risk and uncertainty. Simulation is a statistical process that generates artificial data from a model and displays the summary data in a meaningful format.

VARIABLES

Variables are the basic elements of a model that hold important values that make up or describe the situation being modeled. Users define variables, but the software program holds cell locations at their assumed values.

CERTAIN OR UNCERTAIN

If a given variable is known with a high degree of confidence, that variable is termed "deterministic." If the variable in question can assume a range of values not expertly known to the decision maker, that variable is termed "stochastic" or "uncertain." If a variable is stochastic in nature, the user will assign a reasonable probability distribution to model the possible outcome of that variable for a given iteration of the model. For the model described herein, users can define stochastic variables by placing an assumed distribution function in a cell.

INDEPENDENT OR DEPENDENT

Independent variables are unaffected by the values that other variables assume within a model. A dependent variable is a variable whose value is determined by one or more of the other variables defined in the model. Dependent variables change within the model as the other variables change.

INPUT/OUTPUT VARIABLES

Any model requires the combination of input variables, which in turn determine the value of output variables. Output variables represent variables that are of keen interest to the decision maker and will change with changes in one or more of the variables that define the output variable.

HOW SIMULATION "WORKS"

Simulation works by selecting values for all of the variables that are assumed to be uncertain in nature and calculating an outcome for one or more of the output variables of interest and storing the value. This is termed an *iteration.* Then another iteration is performed, recalculating the stochastic variables and saving the result for the designated output variable. Any reasonable number of iterations can be performed, and the resultant value of the output variable is saved in a temporary file. At the conclusion of the simulation, all of the resultant values of the output variable can be viewed either in tabular or graphical form.

For the model presented herein, a simulation software package from Palisade Corporation is used in conjunction with Excel. The specific software package is termed "@RISK" and is a set of pre-written macros that load into Excel. It is then possible to define a given cell within Excel to be a probability distribution. Currently, @RISK supports over 25 different probability distributions and possesses unique and powerful capabilities to graphically display results relating to the designated output variables.

Application of the Triangular Distribution

The important concept built into the simulation model is that the analyst inputs three values for the input parameters for this section. As discussed in the Introduction, the objective of this project was to construct a simulation model that assumes that relevant input parameters are treated as random variables. With this point in mind, the current version of the model is based on a relevant probability distribution that represents a reasonable operating definition of most of the input variables. The current simulation model describes many of the input variables by a *triangular distribution*.

The triangular distribution requires three input values from the analyst: a minimum perceived value, a mean value, and a maximum value. Rather than inputting a single value (representing a point estimate or a constant) the analyst suggests a range of values from a low value, an average value, and a maximum value. The current model makes extensive use of the triangular distribution, as it represents a reasonable distribution to represent input values. There are other candidate distributions that could be applied, but this model is restricted to the triangular distribution.

Equation (1) gives the probability distribution function for the triangular distribution:

$$f(x) = \frac{2(x - a)}{(b - a)(c - a)} \tag{1}$$

where:

a = the minimum value,
b = the most likely value, and
c = the maximum value.

For example, to estimate the total corridor Average Daily Traffic (ADT) for a project at time t = 1, the analyst feels (subjective in part) that the minimum value is an ADT of 15,000, the average or most likely ADT is around 20,000, but the maximum value could be as high as 22,000. Using the @RISK triangular distribution generator, Figure 1 shows a graphical representation of this estimate.

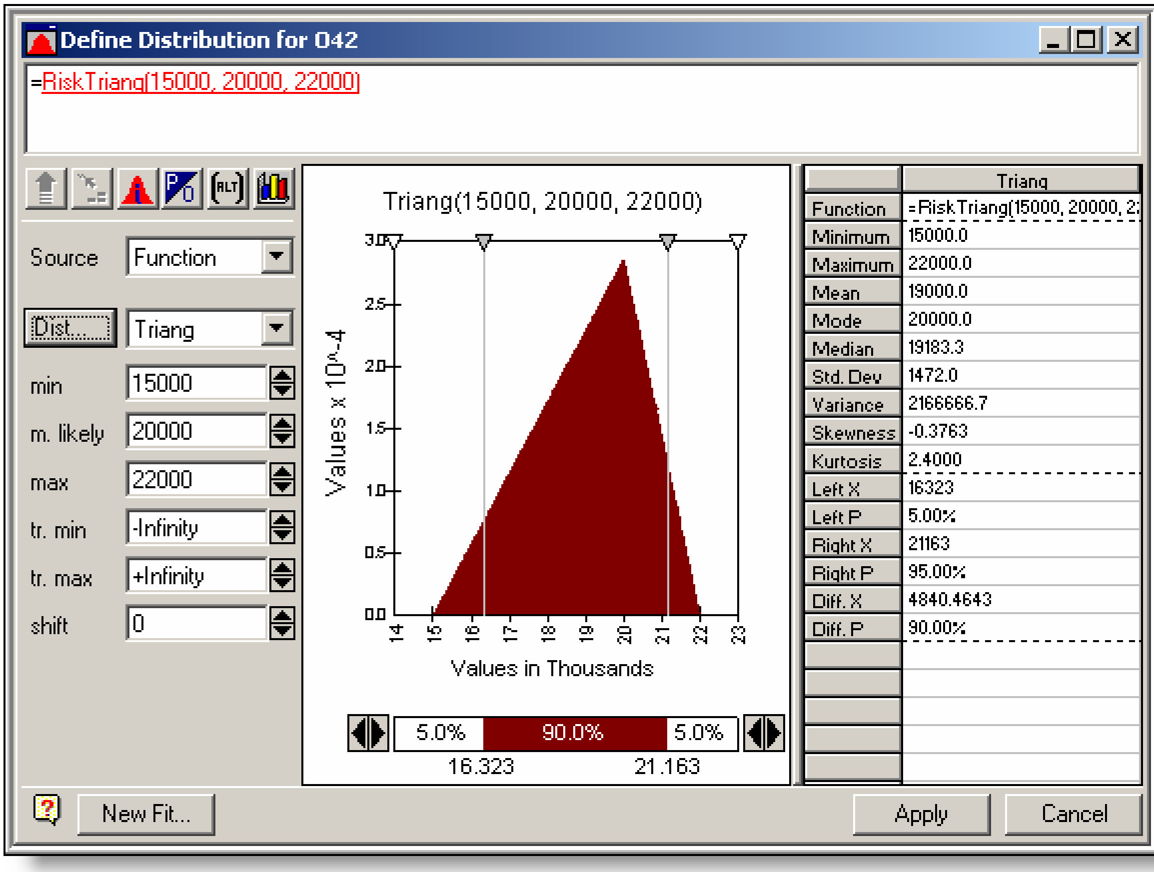

Figure 1. Example of a Triangular Distribution to Estimate ADT.

A useful feature of the @RISK probability function is the ability to visualize percentiles of the distribution. @RISK provides a default spread showing the lower 5 percent and the upper 5 percent of the assigned distribution given the input parameters. In the example shown in Figure 1 above, the lower 5 percent value is 16,323 meaning 95 percent of the values will occur above 16,324 vehicle per day (VPD). At the upper end, the 95th percentile is represented by 21,163 VPD.

The analytical mean value of this particular distribution is 19,000 VPD even though the analyst suggested that the "most likely" value is 20,000 VPD. Figure 1 shows that this particular distribution is not symmetrical. This is due to the fact that the analyst suggested three values such that the most likely value (20,000 VPD) is not in the middle of the spread. There is nothing wrong with this notion! If this is what the analyst feels best represents the spread of the data, then "so be it." Mathematically, the mean (μ) of a triangular distribution is given by:

$$F \; ' \; \frac{(a+b+c)}{3} \tag{2}$$

For the example shown above, the mean is:
(15,000 + 20,000 + 22,000)/3 = 19,000 (VPD).

The theoretical variance is:

$$\sigma^2 = \frac{a^2 + b^2 + c^2 - ab - ac - bc}{18} \tag{3}$$

$$\sigma^2 = \frac{15,000^2 + 20,000^2 + 22,000^2 - (15,000)(20,000) - (15,000)(22,000) - (20,000)(22,000)}{18}$$

= 2,166,784 VPD^2. The standard deviation is the square root of the variance and is 1472 VPD.

Thus, the analyst's initial three estimates translate into a mean value of 19,000 VPD with an associated standard deviation of 1472 VPD. Knowledge of the associated variance and corresponding standard deviation provides a measure of the associated risk for estimating the initial ADT value. Throughout the remainder of the traffic input section, extensive use of the triangular distribution is applied.

Note: If empirical data suggest or the analyst desires to model with other distributions (beta, truncated normal, etc.) then certain calculation cells must be redefined to suit individual assumptions.

In addition to baseline data, users are required to enter *three estimates* for most of the critical input parameters. The model assumes application of the triangular distribution to "best" describe uncertainty. The three estimates required for the stochastic parameters are:

- a **minimum** expected value for the parameter in question,
- a **most likely** expected value for the parameter in question, and
- a **maximum** expected value for the parameter in question.

Sensitivity Analysis and Tornado Diagrams

The toll viability screening tool provides additional valuable information to the decision maker through its capability of performing sensitivity analyses. Due to the variability of the parameters involved in the revenue estimates, it is critical to know what issues really impact the outcomes to an extent that may change the final decision. By knowing what variables make the most difference, the decision maker can focus his or her attention on these crucial variables that drive the outcomes.

One way to visualize the impact of crucial variables in the outcomes is by plotting the result of a sensitivity analysis in a "tornado diagram." A tornado diagram is generated automatically by TVST or by selecting the "Tornado" tab in the graph window menu. This diagram allows comparison of sensitivity analysis for many input variables at once. The input variable that impacts the output the most is shown at the top of the diagram. Input variables are ranked based on how strong their influence is on the output. The model uses a regression analysis technique to quantify this influence by calculating a rank order correlation value associated with each input. A complete positive correlation between the variables is represented by a value of 1: when the input value increases, the output value also increases.

Figure 2 illustrates the usefulness of a tornado diagram in visualizing the results of a sensitivity analysis. From the top to the bottom of the diagram, the input variables are ranked based on the rank order correlation value.

In this particular case, the tornado diagram shows the growth rate in corridor for a two-axle vehicle at the opening year as the variable that has the highest correlation value (0.794). This means that the growth rate in corridor for a two-axle vehicle has the greatest impact on the revenue, followed by the toll revenue days (0.397), volume of a two-axle vehicle (0.319), estimated toll diversion rate (0.197), and estimated traffic growth for a three-axle vehicle (0.191).

Therefore, the decision maker must pay more attention to the estimates of these input variables than the others. In this case, the decision maker would likely want to invest time and resources in verifying the estimate of traffic growth rate for two-axle vehicles at the opening year, as significant changes in that estimate will have more impact than any other on the output variable. If the analyst improves on the quality ranges or estimates of the input variables, the model should be rerun.

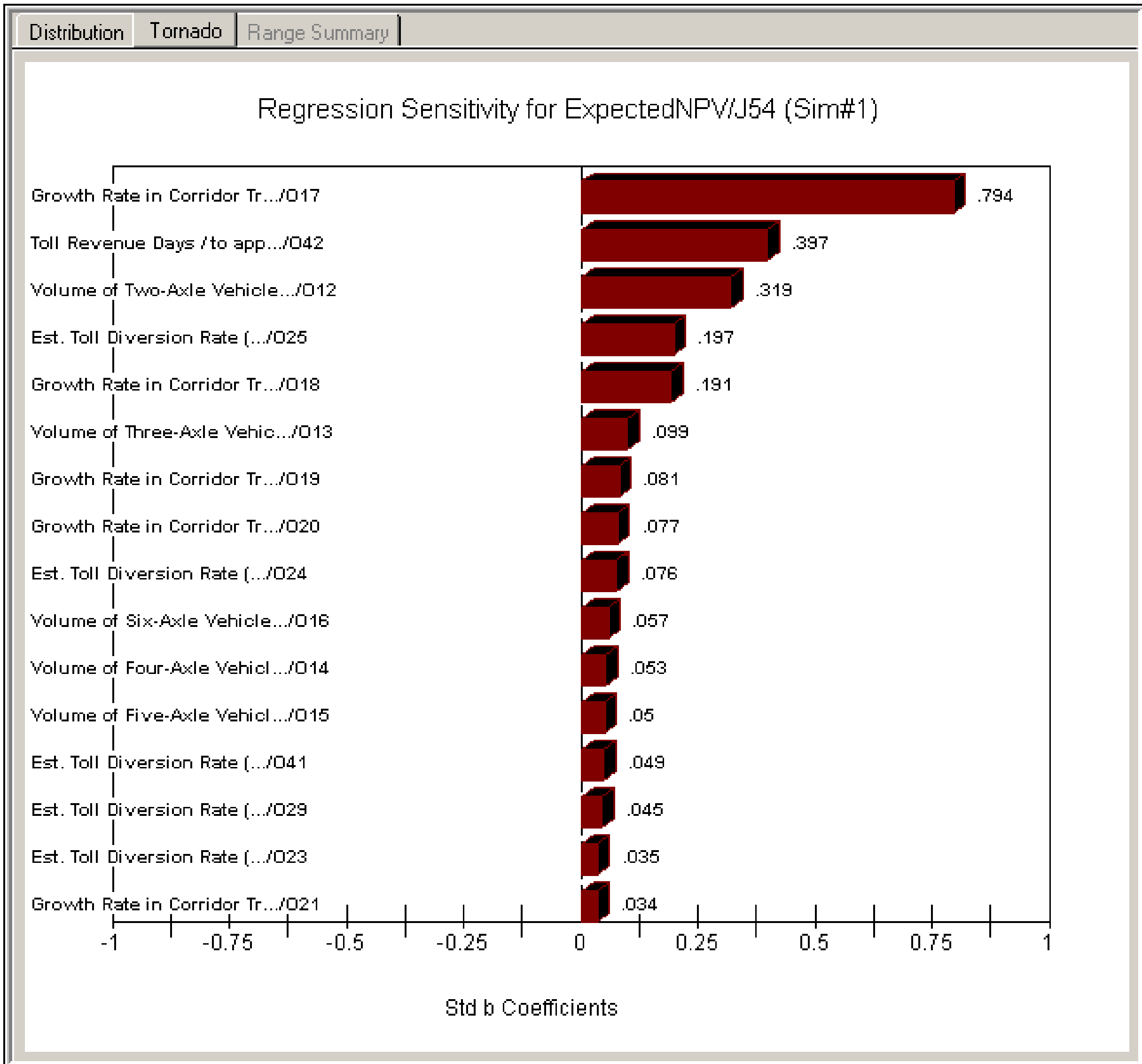

Figure 2. Tornado Diagram to Visualize the Results of Sensitivity Analysis.

USING TRAVEL TIME SAVINGS AS A BASIS TO ESTIMATE INITIAL TOLL RATE

It is axiomatic to state that travelers use toll roads when the value of using the toll road equals or exceeds the cost. In reality the value of using the toll road is largely in the perception of the traveler and, therefore, quite difficult to estimate reliably. However, some basic assumptions can be made that will help the analyst identify the range of tolls that may be most appropriate for a particular project.

Researchers note that toll rate setting is typically approached on a "per mile" basis. That approach is useful for planning or analytical purposes, but the traveler is more likely to view the cost as a total cost per trip than as a rate per mile. With that as an assumption, researchers can proceed to prepare a rough comparison of cost and "value."

Planning models typically use the "utility" of a travel alternative as the basis for comparing multiple alternatives. The utility will include relevant costs and benefits, such as toll and travel time savings. It is generally recognized that other factors besides cost and travel influence user choice, such as travel time reliability and perceived safety. As those are very difficult to quantify, the measurable parameters will suffice for the current analysis.

Researchers posit that the "typical" toll corridor user will be attracted to the toll road if the following condition is met:

Travel time savings (minutes) H Value of time ($/min) > Total toll

Travel time savings refers to the difference in the estimated typical travel time on the toll road and the non-toll alternative. These two alternative travel times should be fairly easy to estimate given the length of the two routes, the estimated operating speed on the two routes, and the number of stops (e.g., traffic signals).

Value of time is a more difficult quantity to estimate, as the research in that area is not complete, especially as it relates to values specific to Texas travelers. As is probably evident, the value of one person's time is likely to differ considerably from that of another person, especially if the two travelers have very different incomes. Further complicating the subject estimate is the fact that each person, regardless of income, may have a different value of time on separate trips, depending on the purpose of the trip. Trips that have significant consequences associated with late arrival, such as trips to catch a plane or to daycare where late fees apply, are likely to be high value trips, whereas those of a more leisurely purpose, such as recreational or weekend shopping, may have a lower value for each traveler. So the value of time is actually a multi-dimensional distribution, rather than a single value, which does not make the estimation process any simpler or any less important. For purposes of estimating trip value, it is reasonable to use TxDOT's standard value of time estimate of $17.50, which can be updated annually by multiplying by the consumer price index.

Example: A proposed freeway toll route of 12 miles will be an option for a surface street route of 12 miles with six signalized intersections. A conservative estimate of time to traverse the toll route is 12 minutes (assuming 60 mph speed), while the travel time on the alternate route is probably closer to 18 minutes (12 miles at 45 mph plus 20 seconds per intersection). Therefore, the time savings is 18 – 12 = 6 minutes.

Using the standard estimate of the value of time ($17.50/hour), the time savings of 6 minutes would be valued at $1.75 ($0.29/min H 6 min). This suggests that a typical traveler would choose the toll road if the trip toll was not more than $1.75, which means the per-mile rate was about $0.145. This hypothetical toll rate is somewhat higher than TxDOT's typical analysis ($0.12 per mile), but it is not out of line with per-mile rates on some segments of the Harris County and North Texas toll roads. This simple analysis suggests that the analyst would want to consider rates around $0.15 as part of the range of tolls on the project.

Note that the conclusions on toll rates are very sensitive to the assumed values of time. The estimate used was based on the "per auto" value of $17.50 per hour. The "per person" default rate of $14.00 would yield a time savings value of $1.40 (instead of $1.75), so the inferred per-mile rate would be $0.12. This analysis shows that the analyst must consider a range of possibilities to develop a meaningful result.

BASE TOLL DIVERSION RATES

In the planning and assessment of toll projects, a key decision variable that could affect financial viability is the toll rate that is chosen and assigned to each vehicle classification. The toll rate serves as a key driver of revenue since, all other things being equal, the higher the toll rate charged each vehicle, the higher should be the projected revenues generated and consequently the higher the project's valuation. For this reason, any assessment of a given project's overall financial viability should be made within a context of specific toll rates proposed to determine that viability.

Researchers anticipate that any toll road viability study would likely include the investigation of several different toll rates to determine how each individually would affect total project revenues. To accommodate an analyst who wishes to examine the impact that different levels of toll charges would have on valuation, the TVST has been designed to allow up to five different toll rates to be trialed during a single simulation run. Figure 3 illustrates the data entry estimates for two-axle vehicles.

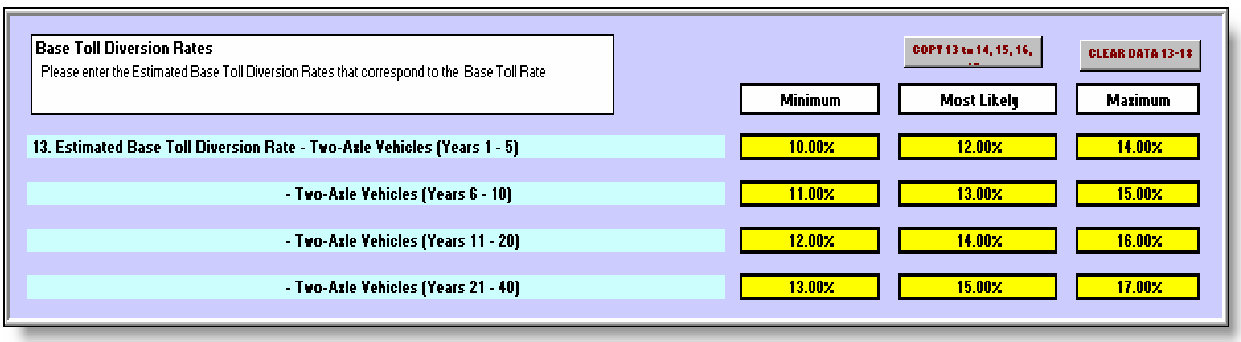

Figure 3. Specimen Data Entry for Toll Diversion Rates-Two-Axle Vehicles.

The model permits estimates for years 1-5, 6-10, 11-20, and 21-40. Three percentage estimates are required: minimum, most likely, and maximum. Elements 13-17 establish the estimated percentages of all vehicle classes that *probably* would elect to take the toll option. Again, these are estimates of future outcomes and possess significant variability and uncertainty.

PRICE ELASTICITY ESTIMATES

While it might be desirable to trial higher toll rates as a means to generate greater revenue, one must consider an additional factor in any such analysis. While higher toll rates do generate higher revenues from the traveling public who choose to pay them, it is also true that higher toll rates generally reduce the desirability of toll segments to more discretionary travelers and therefore precipitate a reduction in the overall volume of traffic. This phenomenon of higher toll rates effecting an overall reduction in traffic volume (although not necessarily a reduction in toll revenues) is known as the *price elasticity of demand*.

This concept is not only supported by general economic principles but also, at least in the short run, by research on existing toll roads in Texas and in other states. While all toll projects could expect to see a reduction in traffic volumes to some extent as a result to higher toll rates, the degree to which the elasticity principle applies among individual projects and therefore the degree to which an increase in toll rates will affect a project's overall valuation will likely vary among projects, depending on such factors as availability of alternate routes, demographics, geography, and other specifics related to the perceived utility that a given toll road provides.

As a consequence of the reality of the impact of price elasticity, the TVST incorporates the effects of the price elasticity principle into adjustments made in toll rates by reducing traffic volumes in accordance with price elasticity variables. In other words, as prices are increased from a base level price set by the analyst, revenues are recalculated from reduced traffic volumes caused by the corresponding increase in price. Figure 4 illustrates the data input for the acceptable range of the price elasticity parameter.

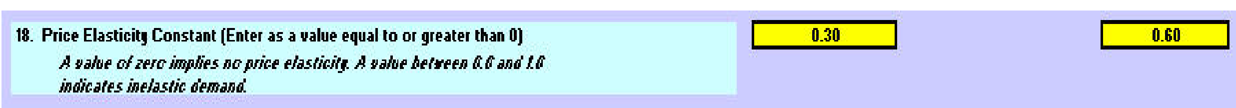

Figure 4. Data Input for Price Elasticity.

For the example, a range of 0.30 to 0.60 has been entered. Research on this topic indicates that these two values represent realistic values for future diversion adjustments brought about by increasing toll rates over time.

The model then simulates the price elasticity constant for a given year from this input range using a uniform distribution (equally likely outcomes). The mean value for this parameter is displayed as shown in the model (Figure 5).

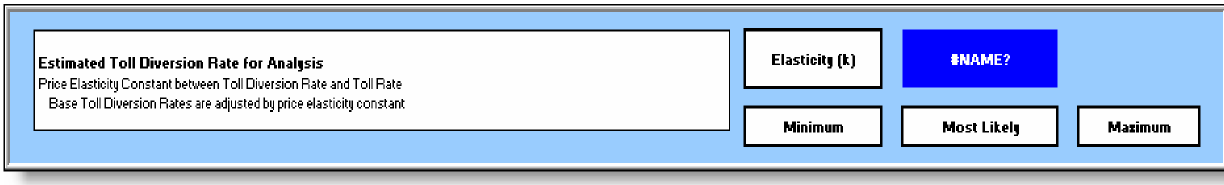

Figure 5. Calculated Elasticity Parameter.

The remaining blue calculation cells (elements 19-23) are summary cells that display calculated values based upon the previous inputs. The user can review the values and check for consistency and reasonableness of the values. Changes can be made in the prior cells to achieve desired user values.

If the user does not desire to include price elasticity, he or she simply enters a “0” for both the minimum and maximum elasticity coefficient. Otherwise, the user enters minimum and maximum values based upon subjective judgment. A suggested range from the user is 0.2 to 0.6.

CHAPTER 4:
OVERVIEW OF THE MODEL

OVERVIEW OF THE MODEL

The toll analysis model is a Microsoft Excel-based spreadsheet model combined with Palisade Corporation's Decision Tools suite of macro add-ins. Extensive use is made of the @RISK macro sets, which permit the simulation of specified spreadsheet cell variables. The resulting analysis generates simulated data sets (artificial data) from which graphical displays of the variability of the designated output variables may be observed. Figure 6 illustrates an overview of the designed model.

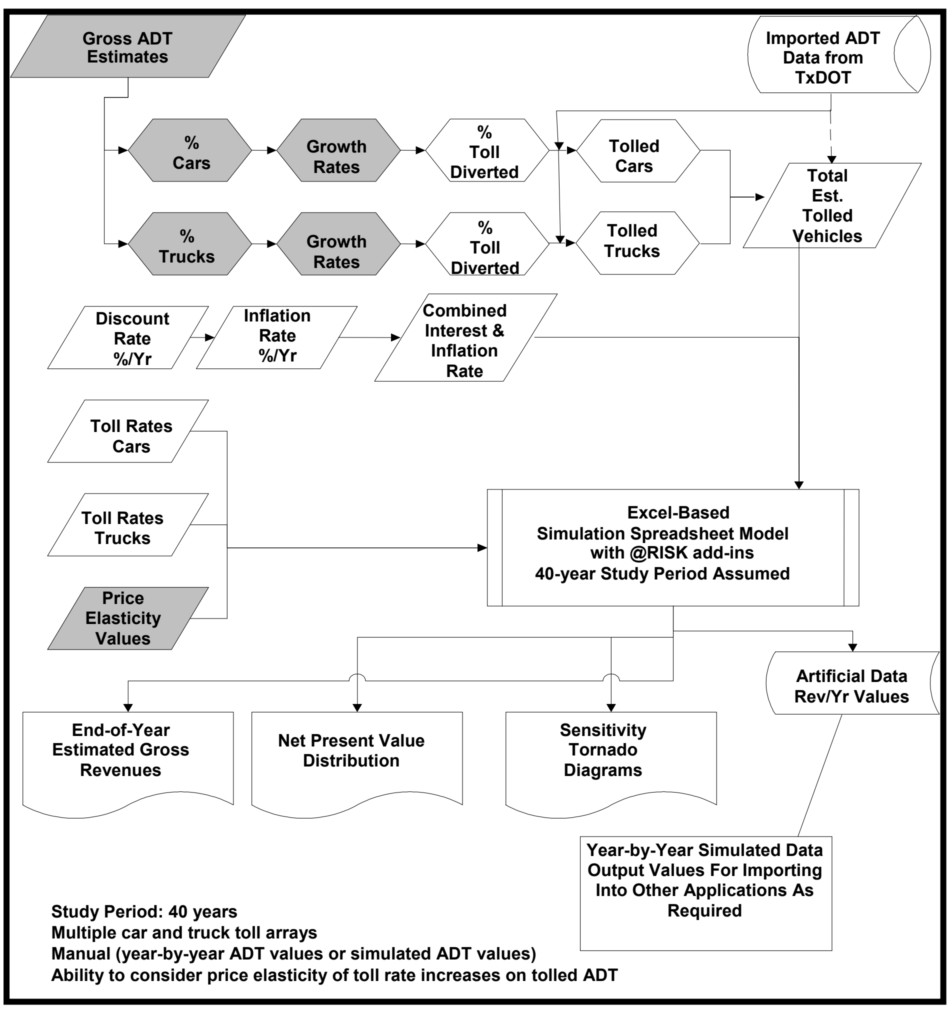

Figure 6. Overview of the Model's Logic.

The first element of the model is the development of the number of tolled vehicles by classification, which the analyst can obtain three ways. Two techniques use ADT data and convert those estimates to the number of tolled vehicles. One technique involves manual entry of externally generated data (typically from the local Metropolitan Planning Organization [MPO] or the Transportation Planning and Programming [TPP] Division of TxDOT). If forecast data do not exist, the analyst can enter locally generated estimates of opening year volumes combined with user-selected growth rates. Either ADT estimate is then adjusted to achieve an estimate of total tolled vehicles, by year. Thirdly, in some cases, analysts may have access to estimates of tolled vehicles, which allows the bypassing of some of these steps.

Following the entry of interest and inflation rates, the model requires beginning toll rates by vehicle classification and an estimate of the anticipated price elasticity. There are techniques provided in the user's guide to assist the analyst in estimating both initial toll rates and elasticity. An estimate of elasticity is important primarily because the analyst will have the option of entering up to five separate starting toll rates for comparison. The elasticity factor recognizes that an increase in the toll rate will typically cause some users to choose not to use the toll road, so the increase in revenue is not linear.

As mentioned previously, use of the triangular distribution is recommended for all of the inputs that are treated as random variables (shaded shapes in Figure 6). This distribution takes advantage of the analyst's familiarity of the most likely, minimum, and maximum values for each variable. While the actual distribution of these variables is not likely to be triangular, at this level of analysis, the assumption of a triangular distribution is convenient and well within reason.

KEY ELEMENTS OF THE MODEL

This section of the report highlights some of the key elements of the toll viability screening tool itself. A description of the inputs to the model is followed by a description of the outputs. All of these elements are described in more detail in the user's guide that accompanies the software package.

Inputs

All of the inputs should be readily available to the analyst. If some of them are not available, the analyst can make reasonable assumptions without much risk because the built-in sensitivity analysis will identify the critical assumptions. If a "reasonable assumption" is shown to be critical, then the analyst can invest more time and resources into obtaining better input data. If the sensitivity analysis indicated that the original assumption has little impact on the output, then the analyst has not wasted effort.

General Project Information

These inputs are names or characteristics of the project, as well as estimates of relevant financial factors:

- facility name, opening year – both self-explanatory;
- total length of tolled project, segments and timing of segments that make up total length – toll projects may be implemented in phases; these inputs allow the analyst to more accurately portray the schedule and, therefore, the revenue;
- number of lanes – self-explanatory;
- maximum ADT per lane – this parameter caps the amount of traffic that can be considered for revenue generation, particularly in out years when compound growth could cause the total vehicles to reach unrealistic levels;
- interest rate per year, inflation rate per year – self-explanatory; and
- estimated time savings, assumed value of time for vehicles using toll road – while not explicitly included in the modeling, they are valuable in assessing the toll potential.

Traffic Data Input

These inputs are the analyst's estimates of traffic for the analysis period and the impact that tolling will have on traffic:

- daily volume of vehicles for up to five vehicle classifications (minimum, most likely, maximum, [MMLM] – initial volumes;
- growth rate for ADT by vehicle classification (MMLM) – self-explanatory;

- base toll diversion rates (MMLM) for several year ranges – allows analyst to consider whether the toll road will become more or less attractive over time; and
- minimum and maximum price elasticity.

Toll Data Input

These inputs are those that directly describe toll rates and assumptions on toll collection:

- equivalent toll revenue days – self-explanatory,
- up to five candidate initial toll rates – self-explanatory, and
- frequency of toll rate increase – self-explanatory.

Outputs

The outputs of the model provide numerical and graphical descriptions of traffic, revenue, NVP of revenue, and rank order analysis of critical assumptions:

- toll diverted ADT summary – total number of tolled vehicles;
- traffic and revenue summary – expected toll road traffic, annual revenue and NPV by project year, including graphs;
- summary of revenue analysis – NPV of project revenues and 90 percent confidence intervals on project revenues for each of the candidate initial toll rates;
- histograms of annual revenue and NPV; and
- tornado diagrams showing input variable sensitivity.

CLOSING REMARKS

The research conducted in this project represents a first step in the journey to put useful analytical tools in the hands of the practitioner. Replacing point estimates with simple distributions and using simulation to calculate thousands of possible combinations significantly improves the reliability of the outputs and gives the decision maker some estimates of confidence interval for the resulting revenue estimates. With continued use, practitioners will no doubt make many improvements to this model or to the techniques used to generate inputs and interpret outputs. Such improvements should be shared through professional papers and short courses.

There remains a significant body of research to be done, especially into traveler response to tolls. Two issues briefly touched in this project are the willingness to pay tolls, which determines toll road usage, and price elasticity, which describes the traveler response to changes in toll levels. TxDOT should pursue both in order to make important advances in the ability to predict toll revenue.

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