**Multi-Criteria Evaluation for Transportation Funding and Financing Alternatives**

**Angela J. Haddad**
The University of Texas at Austin
Department of Civil, Architectural and Environmental Engineering
301 E. Dean Keeton St. Stop C1761, Austin TX 78712, USA
Email: angela.haddad@utexas.edu

**Gina Blazanin**
The University of Texas at Austin
Department of Civil, Architectural and Environmental Engineering
301 E. Dean Keeton St. Stop C1761, Austin TX 78712, USA
Email: ginablazanin@utexas.edu

**Kenneth A. Perrine**
The University of Texas at Austin
Network Modeling Center, Center for Transportation Research
3925 W. Braker Ln., Stop D9300, Austin, TX 78759, USA
Email: kperrine@utexas.edu

**Chandra R. Bhat (Corresponding Author)**
The University of Texas at Austin
Department of Civil, Architectural and Environmental Engineering
301 E. Dean Keeton St. Stop C1761, Austin TX 78712, USA
Email: bhat@mail.utexas.edu
and
The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong

## ABSTRACT

Amid aging infrastructure and declining utility of traditional funding sources, it is vital that states secure innovative funding. This research analyzes the present and future funding landscape for the United States and specifically Texas, including the reliance on diminishing motor fuel tax and resistance to increasing it. Outcomes of this analysis are realized in an application that uses the Analytic Hierarchy Process to match infrastructure projects with the appropriate funding/financing mechanisms. These mechanisms and project characteristics are ranked according to academic and government sources. To the authors' knowledge, this level of comprehensiveness has not been previously implemented. Functions also exist for creating financial projections based upon user inputs and utilizing models from similar sources. While this database helps educate policymakers on use cases around innovative concepts, it can also assist in decision-making.


**Keywords:** Transportation funding, multi-criteria analysis, Analytic Hierarchy Process, innovative financing, revenue projections

## INTRODUCTION

Over the past 60 years, the U.S. population has doubled, yet much of the infrastructure that was built then still stands today, in relatively dilapidated condition. In particular, according to an American Society of Civil Engineers report (*1*), about 43% of our roadways are in poor or mediocre condition and need major maintenance. Nonetheless, state and local governments are hesitant to pass legislation to increase funding for the transportation sector, even if only to keep up with inflation rates. At the same time, states have the unique ability to create funding revenues that would work best for their populations. But, to do so, states need to have information on what mechanisms work best for their contexts and project considerations, which itself requires a more basic understanding of the factors that characterize these contexts and considerations. In this paper, we identify these factors and translate the findings related to these underpinning factors into an interactive database that can allow states to identify funding/financing mechanisms that may be most suitable for specific project scenarios. While the database development itself focuses on existing or potential Texas revenue sources, the revenue sources overlap well with those available in other states, making the database easily transferable. This database not only provides insights to legislators about funding possibilities, but also informs department of transportation (DOT) personnel about potential innovative financing mechanisms (including vehicle-miles-traveled or VMT fees, congestion pricing, credit enhancement tools, and fixed-income financing instruments such as bonds (*2*)) that can complement traditional funding mechanisms. (Although the terms *funding* and *financing* are often used interchangeably, they are separate concepts; the USDOT states that funding and financing are distinguished by whether the money paid for the project is revenue-based or debt-based.)

### Historical Funding/Financing in the Transportation Sector

For decades, DOTs have relied heavily on raising the motor fuel tax (MFT) to ensure sufficient revenue to fund the growing transportation infrastructure needs and overcome inflation and the improvement in vehicles' fuel efficiency. However, some states have kept rates constant for years. For example, Texas' MFT has remained at 20¢/gallon since 1991 (*3*), leading to an MFT revenue decline of 6% when accounting for inflation, despite a 49% increase in gasoline consumption between 1997 and 2016 (*4*). Texas legislators face severe public opposition to an MFT increase (*5*), a challenge faced in other states as well. Thus, the search for alternative funding sources has been an ongoing effort nationwide (*6–8*); many reports and committees have been created to introduce alternatives to the legislatures (*9*, *10*). Additionally, DOTs are developing transportation finance workforces to tackle these funding/financing challenges. Almost 30 states have established commissions for investigating funding gaps and suggesting mitigating strategies (*11*).

Despite the increased efforts to investigate innovative funding alternatives and the dire need for more sustainable revenue sources, state legislation statistics indicate that 60% of funding proposals are rejected. Furthermore, an increased MFT remains the most popular revenue source in the U.S., corresponding to 40% of all the legislative funding proposals—but only six states have thus far approved indexed MFT increases. The growing popularity of electric vehicles (EV) has encouraged legislators to investigate EV fees, with eight successful and thirteen rejected attempts at legislation since 2015 (*12*). The resistance to mileage-based user fees remains significant, with only two instances of successful legislation in the past seven years. Meanwhile, VMT in the U.S. has risen from 2.57 trillion miles in 1998 to 3.2 trillion miles in 2018 (*10*).

Evidently, implementing new fee structures poses insurmountable obstacles for legislatures attempting to address the transportation infrastructure funding problem. Therefore, it is valuable to investigate alternatives and select ones that provide the most benefit for the least cost, while still considering the applicable values and goals of the government agency—as well as the plausibility of obtaining legislative approval of such a funding source. While prior research efforts have begun to address this problem, this research contributes to the identification of appropriate funding solutions using the Analytic Hierarchy Process (AHP) which is then embedded within a decision-making tool.

## LITERATURE REVIEW

Earlier literature focuses on characterizing funding methods in the context of their advantages and disadvantages, but these have been rather qualitative and *ad hoc* without a structured evaluation framework (*13*). An example of such a qualitative approach was implemented in 2004 in a round table of participants representing prominent transportation agencies with expertise in highway finance. They convened to reexamine long-term options for highway financing and found that general taxes are poor revenue sources to finance highway construction because they bear no direct relationship to highway use. The panel proceeded to identify alternative funding mechanisms' strengths and limitations but did not include any standardized evaluation criteria. The panel's approach was also employed in some studies (*10*, *14–16*). These studies consider alternative mechanisms' pros and cons in the context of sustainable funding generation, revenue potential, political viability, implementation, equity, and system impact considerations. However, the pure-qualitative approach, while accommodating important subjective elements, can also make decision-making challenging, especially given that the scholarly literature, as well as national and state-level reports, agree that decisions regarding funding alternatives constitute a complex multi-criteria problem (*13*). In this regard, many researchers have found that quantitative methods can provide important insights into the decision-making process, which can then be supplemented appropriately by subjective considerations. Toward this end, Indiana DOT (INDOT) used five criteria to assess potential funding mechanisms—revenue yield, ease of implementation, revenue predictability, public support, and business climate friendliness—each ranked on a three-point scale (*17*). Similarly, the Texas A&M Transportation Institute (TTI) relied on three-point based criteria, to inform policy decisions and determine how best to fund transportation infrastructure (*18*). Later NCHRP reports also evaluated revenue sources for public transportation investments using similar criteria and scores (*19*, *20*). While such efforts do provide a useful general guidance platform, they do not provide adequate and specific insights for selecting mechanisms based on agency needs (*18*). Besides, these criteria-based analyses do not go as far as to project future revenue, such as accomplished by the Joint Analysis using the Combined Knowledge (J.A.C.K.) model, the Transportation Revenue Estimator and Needs Determination System (TRENDS) model, and the INDOT revenue cost model, all described next.

The J.A.C.K. and TRENDS models are Texas-specific tools that were developed to perform revenue projections. The J.A.C.K. model combines revenue predictions and "what-if" scenarios related to vehicle registration fees, MFTs, proposition bonds, and other agency revenues (*21*). The model inputs and assumptions include population, vehicle registration, fuel economy, inflation, and tax rates. The evaluation of this model concluded that revenue projections are most sensitive to the accuracy of the population and fuel economy estimates (*21*). TRENDS is another web-based tool developed by TTI in 2012 to provide a comprehensive financial forecasting tool for Texas transportation agencies (*22*). The tool makes assumptions regarding transportation needs, population growth, fuel efficiency, inflation, and gas taxes. User inputs include the selection of population growth and fuel efficiency scenarios, as well as fees and tax increases. Then, the model outputs tables and graphs of forecasted revenues and expenditures throughout the analysis period. The revenue sources considered in this tool include MFT, indexed MFT, vehicle registration fee, alternative fuel fee, and VMT fee (*22*). Another state-specific tool is INDOT's framework that projects revenues while considering evasion rates and implementation costs. The outcome is a comprehensive cash flow diagram presenting the estimated net revenue that each mechanism generates. The framework is publicly available as an Excel-based tool, allowing users to test different scenarios and the effects of the various inputs on revenues (*23*). While these three models provide good examples of revenue projection capabilities, they leave out an important piece of the puzzle: the ability to explore other criteria (such as political viability, implementation, equity, and revenue predictability) that affect the viability of an alternative and develop a transparent methodology that assigns relative weights (priorities) to the suite of criteria based on importance within the context of a multi-criteria decision mechanism.

Finally, we identified two studies that implement a decision-making framework through assigning importance weights to the criteria, instead of being solely based on numeric or verbal evaluation of each criterion. The first is the numeric scoring approach proposed by the National Surface Transportation

Infrastructure Financing Commission (NSTIFC) in 2009. The committee developed guiding principles to evaluate future funding/financing mechanisms based on five criteria categories and relevant sub-criteria:

- Funding Stream Considerations (the overall revenue-raising potential, sustainability, and flexibility of the funding approach);
- Implementation and Administration Considerations (the political and legal viability of a mechanism, the ease and cost of initial implementation, and enforcement requirements);
- Economic Efficiency and Impact Considerations (the ability of the mechanism to promote efficient use of the transportation system);
- Equity Considerations (the user-pay principle and equity across groups); and
- Applicability to Other Levels of Government (the applicability of particular funding methods to the federal, state, and local government levels) (*24*).

The study then assigned quantitative weights to the criteria based on its members' opinions about the relative importance of individual criteria (*24*). Criteria related to revenue stream considerations had the highest importance and represented 31% of the weight. This was followed by implementation considerations weighing 27.5%, economic efficiency and impact representing 24.5% of the weight, and equity considerations, which were given 17% of the weight (*24*). Pulipati et al., the second study to assign importance weights, also conducted a multi-criteria analysis to select transportation revenue strategies for Texas (*13*). This study is the closest to our current effort since the researchers used a multi-criteria decision analysis (MCDA) method called "PROMETHEE" to rank funding alternatives based on criteria weights elicited through Delphi surveys targeting subject matter experts. Compared to the NSTIFC study, the weights corresponding to revenue generation and ease of implementation criteria were reduced to 24% and 18%, respectively. On the other hand, the study gave a higher weight of 25% to equity considerations, as compared to the 17% assigned by the NSTIFC study. Finally, the authors conclude that such a systematic approach can improve the decisions of policymakers and they recommend this methodology to other DOTs (*13*).

Most of the criteria compete for significance and therefore necessitate the establishment of priorities among state officials to better inform their decisions (*13*, *24*). This concept is further researched within the database application presented by this paper. Unlike earlier studies which required interviewing SMEs to acquire data on the weights that should be assigned for each criterion, our work streamlines this process by assigning importance weights on a project-by-project basis. Additionally, our work allows for a versatile approach that dynamically updates the decision weights as a function of the project at hand rather than using the constant weights provided in previous studies. Furthermore, while previous efforts strictly focused on either implementing a multi-criteria approach or financial projections to evaluate new revenue sources, this study provides both perspectives simultaneously to ensure a holistic framework.

## OUTLINE OF DATABASE FRAMEWORK

This paper develops a modeling approach, implemented in the form of a database application, to assist transportation agencies with mapping out future funding/financing plans and effectively communicating their findings with legislators and the public. To our knowledge, no attempts have been made to evaluate the appropriateness of funding/financing mechanisms regarding specific project applications. Providing alternative definitions customized to project characteristics is more desirable than a general concept by supporting a more consistent and realistic comparison of the alternatives to each of the criteria.

The study goals are implemented in a database via two modules: (a) Appropriateness and (b) Projections. The Appropriateness module ranks the different strategies based on economic, implementation, equity, and other parameters identified by the NSTIFC, INDOT, and TTI. The Projections module predicts revenue streams and tests the revenue generation potential of different policies. The outcomes of the database provide a comprehensive indication of the performance of each alternative as part of specific project investments, unlike previous studies that tend to limit the evaluation to a specific set of criteria and generalizing the results for all project types.

A multi-step methodology was implemented to achieve a dynamic MCDA framework whose recommendations are sensitive to changes in the characteristics of the project being funded:

1. Define a set of funding/mechanisms and their evaluation criteria.
2. Assign a performance score for each alternative on each criterion using a five-point scale.
3. Develop a framework to convert a set of project-specific inputs, including budget, significance, construction duration, investment timing, sustainability and equity goals, and business density, into a smaller set of coherent variables, capturing the major features of the project that could be later related to the selection of financing mechanisms.
4. Develop a procedure to translate the effect of project characteristics on the importance of each criterion. This procedure involves eliciting expert opinions regarding the importance of evaluation criteria for four project scenarios corresponding to different characteristics and determining a score for each characteristic. These opinions are then extrapolated for other projects having different characteristics scores by piecewise linear interpolation.
5. Apply AHP to determine the best-performing strategies depending on revenue generation as well as the other parameters previously discussed.
6. Develop revenue projection models to produce revenue stream diagrams. The Projections module considers population, vehicle ownership, employment, inflation, and other relevant economic inputs and assumptions—similar to the efforts previously conducted in TTI's TRENDS models and INDOT Revenue Cost Model but extended further.

The Appropriateness and Projections modules are integrated into the FUNding Decision (FUND) database—an Access-based application developed to support the selection of funding mechanisms for specific projects. Using that framework, FUND ranks funding/financing mechanisms based on characteristics of a hypothetical project as provided through a series of questions. The methodology of the process and the AHP calculations are further explained in the next section. While this methodology is designed to be implemented by any DOT, this study focuses on the case of TxDOT for whom the FUND database was developed.

## METHODOLOGY

### MCDA and AHP Concept

MCDA methods have been developed to support decisions that involve conflicting criteria, and provide a systematic evaluation process that is transparent and repeatable, capable of eliciting expert opinions, and better understood by the public and policymakers. Broniewicz and Ogrodnik (2020) recognized over 58 articles that employ MCDA in the field of transportation over the last 20 years (*25*). Based on their review, they concluded that the AHP is the most popular MCDA method for solving complex and unstructured problems through a systematic logical analysis.

AHP involves pairwise comparisons between criteria and options to facilitate the selection of the best alternative (*26*). It provides a mathematical framework for decomposing and structuring complex problems and involves six main steps: (a) structuring, (b) prioritizing through pairwise comparisons, (c) obtaining a priority vector for decision criteria, (d) computing the matrix of option (alternative) scores, (e) checking for consistency in the preference judgments, and (f) ranking the options. AHP is explained in detail in several MCDA books such as (*26*).

### Implementation of the Appropriateness Module

One of the main objectives of this study is to implement AHP within a decision-making framework that ranks funding/financing mechanisms according to their appropriateness to fund user-specified projects with specific characteristics. This objective is achieved through a three-component framework that captures the characteristics of the transportation infrastructure project at hand through a set of questions, conveys the

AHP problem structuring, and combines project characteristics and AHP definitions through a computational process to determine the appropriateness score of each mechanism. **Figure 1** provides an overview of the major components of the framework developed in this study to rank financing mechanisms using AHP; each component is discussed in detail in the next sections. The solid-colored boxes in **Figure 1** represent the main outcome of each component.

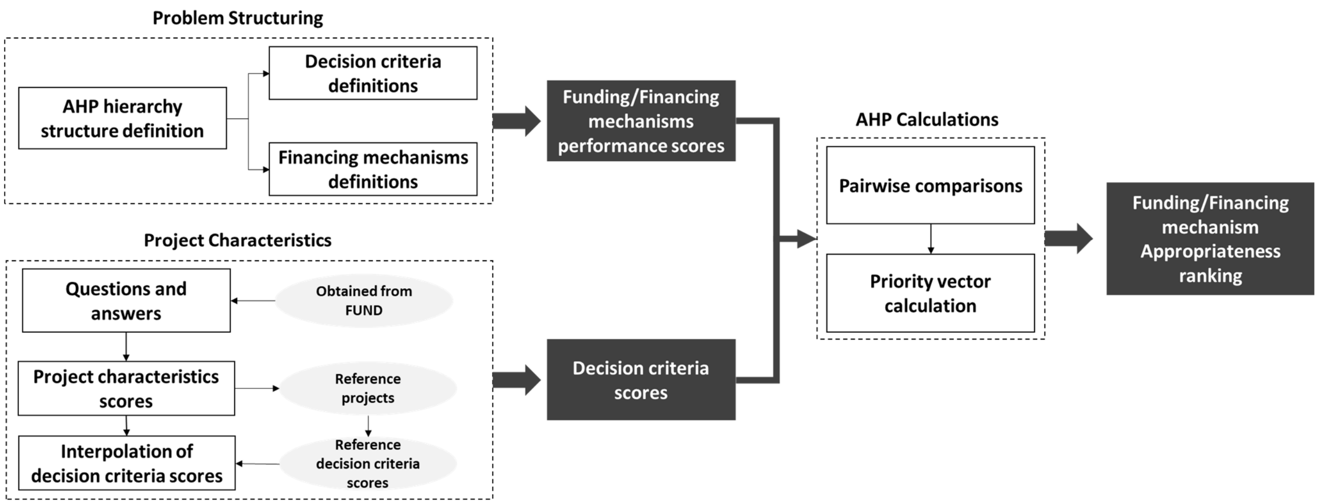



**Figure 1 AHP Framework for Funding/Financing Mechanisms Appropriateness**

*Problem Structuring*

The problem structuring block in **Figure 1** is associated with three definitional considerations, as discussed below.

The AHP hierarchy structure definitions (leftmost box within the "Problem Structuring" block in **Figure 1**) used for the AHP analysis are designed to address the main goal—selecting the most suitable funding/financing plans for user-specified projects. The overall objective is to rank funding/financing mechanisms, which is placed at the top level in the hierarchy (Level 0) as shown in **Figure 2**. Level 1 includes the criteria for evaluating the performance of alternatives, while the alternatives themselves are placed at the bottom level (Level 2) of the hierarchy.

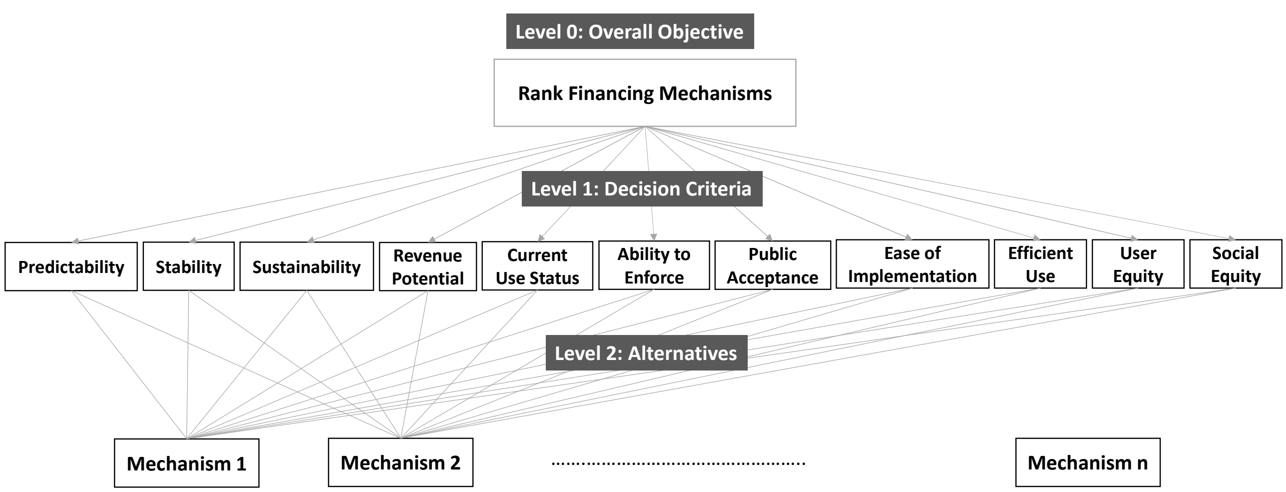



**Figure 2 Hierarchy Structure for AHP Analysis**

The decision criteria definitions (the top-right box within the "Problem Structuring" block of **Figure 1**) assist in providing a transparent mechanism to support results and evaluate the appropriateness of funding/financing mechanisms for transportation projects based on a set of criteria informed by our literature review. This list includes four main categories, with sub-categories, as presented in **Table 1**.

**Table 1 Funding/Financing Criteria Adopted in the Appropriateness Module**

| **Criteria** | **Description** |
|---|---|
| **Revenue Stream Considerations** | |
| Predictability | Predictability reflects the presence of sufficient information to make reliable predictions and reliably forecast any possible variations in revenue generation. |
| Stability | The stability criterion refers to the level of uncertainty and fluctuation in revenues that can impact an agency's ability to manage resources. Stable mechanisms are not expected to deviate significantly during periods of economic downturn or changes in travel behavior. |
| Sustainability | Sustainability reflects the degree or extent to which a mechanism can be adjusted to keep pace with inflation and funding demand changes. This also involves the scalability to meet funding demands. This measure can also reflect the timeframe during which the mechanism remains a viable revenue source. The authors took these considerations into account while deriving the sustainability of alternative revenue mechanisms. |
| Revenue potential | Revenue potential is a measure of an individual mechanism's ability to yield significant revenue. For the scope of this study, mechanisms' revenue potential is considered in the context of funding for the overall surface transportation system. Consequently, mechanisms must generate significant revenue, such as that achieved by the gas tax, to receive a high score. |
| **Implementation and Administration Considerations** | |
| Current use status | This criterion reflects whether a mechanism is currently in use at the specific state level, being considered, or completely new. |
| Ease of implementation | Ease of implementation reflects the complexity and cost of implementing and administering new funding mechanisms. |
| Ability to enforce | The ability to enforce reflects a mechanism's enforcement complexity and cost—it is a measure of the resources an agency has to invest to minimize payer evasion. |
| Public acceptance (Political viability) | This criterion reflects a mechanism's ability to gain public acceptance, which in turn has a direct impact on the political viability of the mechanism. The level of public acceptance is dynamic and can change depending on technological advances or educational efforts. |
| **Economic Efficiency and Impact Considerations** | |
| Promotion of efficient use | This criterion reflects the extent to which a mechanism promotes and incentivizes the efficient use of the system by influencing travel choices and behaviors. Efficient system use reduces additional infrastructure investment needs. This criterion is also tied with the mechanism's ability to reduce the adverse side effects of the transportation investment, such as pollution, noise, and congestion. |
| **Equity Considerations** | |
| User/beneficiary equity | User equity reflects the extent to which a mechanism charges those who directly use and benefit from the transportation infrastructure investment. |
| Promotion of social equity | Social equity reflects the fairness of tax or fee burden among different economic groups and geographic locations. Mechanisms that result in a disproportionate burden on lower-income groups would score low on this criterion. |

The financing mechanisms definitions (the bottom-right box within the "Problem Structuring" block of **Figure 1**) list all of the mechanisms available in the FUND database. To evaluate the mechanisms, we used a five-point scoring system based on a thorough review of the literature on this topic (*17–19*, *24*, *27–29*). A low score means the option ranks poorly and a high score means it ranks well under the associated criterion. **Table 2** presents the assigned funding/financing mechanisms performance scores (the output of the "Problem Structuring" block of **Figure 1**) for the case of Texas. While there are several cell values in the table, the scores can be customized based on individual states. For example, public acceptance of VMT fees has a very low score in Texas, but may be assigned a higher score in other states.

**Table 2 List of Funding/Financing Mechanisms Performance Scores for Texas**

| **Mechanism** | **Predictability** | **Stability** | **Sustainability** | **Revenue Potential** | **Current Use Status** | **Public Acceptance** | **Ease of Implementation** | **Ability to Enforce** | **Promotion of efficient use** | **User/ Beneficiary Equity** | **Promotion of Social Equity** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Customs Revenues: Partial Dedication | 4 | 4 | 5 | 4 | 1 | 3 | 5 | 4 | 2 | 3 | 3 |
| Indexed Fuel Tax | 4 | 4.5 | 3.5 | 5 | 0 | 3 | 4 | 5 | 4 | 4 | 3 |
| Increased Motor Fuel Tax Rate | 4 | 4.5 | 2.5 | 4 | 0 | 2 | 5 | 5 | 4 | 4 | 3 |
| Vehicle Miles Traveled Fee | 3 | 4 | 5 | 5 | 0 | 1 | 1 | 2 | 5 | 5 | 3 |
| Tax Increment Financing (TIF-TRZ) | 2 | 2.5 | 3 | 2 | 1 | 3 | 4 | 4 | 1 | 2 | 3 |
| Impact Fee | 3 | 1 | 1 | 3 | 0 | 3 | 3 | 4 | 1 | 2 | 4 |
| Congestion Charges | 3 | 2 | 4 | 3 | 0 | 1 | 1 | 3 | 4 | 4 | 2.5 |
| Cordon Pricing | 3 | 1 | 4 | 2.5 | 0 | 2 | 2.5 | 3 | 4 | 4 | 2.5 |
| Container Fees/Tax | 3.5 | 3.5 | 4 | 2 | 0 | 4 | 4 | 4 | 1 | 1 | 3.5 |
| Carbon Taxes | 2 | 4.5 | 3 | 5 | 0 | 2 | 5 | 4 | 3 | 4 | 2 |
| Freight Bill | 3 | 3.5 | 5 | 3 | 0 | 2 | 2 | 2 | 1 | 1 | 3.5 |
| Freight Charge: Ton or Ton-Mile | 2 | 3.5 | 4 | 4 | 0 | 2 | 1 | 1 | 3.5 | 1 | 3.5 |
| Facility-level Tolling and Pricing | 3 | 2 | 4 | 3 | 1 | 3 | 3 | 4 | 4 | 5 | 3 |
| Heavy Vehicle Use Tax | 3 | 4 | 4 | 2 | 0 | 3 | 4 | 3 | 3 | 4 | 3 |
| Imported Oil Tax | 2 | 2 | 2 | 3.5 | 0 | 3 | 3 | 4 | 3 | 2 | 2 |
| Sales Tax: Auto-related Parts and Services | 4 | 4 | 4 | 3.5 | 0 | 2 | 2 | 2 | 2.5 | 2 | 2 |
| Variable Parking Fee | 3 | 2.5 | 3.5 | 3.5 | 0 | 1 | 4 | 4 | 3 | 3.5 | 2 |
| Transportation Utility Fee | 4 | 5 | 4.5 | 1 | 0 | 2 | 3 | 5 | 1 | 3 | 2 |
| Electric Vehicle Fees | 3 | 3 | 5 | 2 | 0 | 4 | 2 | 4 | 3.5 | 5 | 4 |
| TIFIA | 4 | 4 | 1 | 3 | 1 | 2 | 4 | 4 | 1 | 1 | 1 |
| General Obligation Bonds | 4 | 4 | 1 | 2 | 1 | 2 | 4 | 2 | 1 | 1 | 1 |
| Revenue Bonds | 4 | 4 | 1 | 2 | 1 | 2 | 4 | 2 | 1 | 1 | 1 |
| Private Activity Bonds | 4 | 4 | 1 | 2 | 1 | 2 | 4 | 2 | 1 | 1 | 1 |

*Project Characteristics*

The "Project Characteristics" block in **Figure 1** is associated with the steps preceding criteria priority calculations, and involves extracting the project characteristics and correlating those with the level of importance of the decision criteria. Since the aim of the FUND database is to automatically relate project characteristics to criteria importance without requiring any user inputs related to criteria importance, it was essential to investigate the relationship between project characteristics scores and the decision criteria. The main outcomes of the "Project Characteristics" component in **Figure 1** are the decision criteria scores which are calculated from project characteristics using the process discussed later in this section.

Questions and answers (the top box within the "Project Characteristics" block of **Figure 1**) reflects the project questionnaire within FUND that asks the user a series of questions. Many of the answers offered are categorical (mostly ordered, such as low/medium/high), and map to a set of points that can be assigned to project characteristics. The set of questions and answer options provided by FUND to extract project characteristics are presented in the first and second columns of **Table 3**.

Project characteristics scores (the middle box within the project characteristics block of **Figure 1**) are designed to group the project question answers into a smaller set of coherent variables, capturing the major features of the project that could be related to the selection of financing mechanisms. Due to the nature of the definition, the project characteristic scores (PCS) are a function of project answers (one-to-multiple relationship). For example, "How long is the project construction period?" would indicate whether the project involves "long-term investment" and has a "large project scale." The current set of Project Characteristics *K* includes:

- Large Project Scale
- Exact Investment Timing
- Long-term Investment
- High Significance
- Innovation
- Project Sustainability Goals
- Project Equity Goals

The set of answers *A* is converted to *K* individual PCS using Equation (1).

$$p_k = \sum_{a \in A} w_{ak} \tag{1}$$

where

- $w_{ak}$ are the weights used for each transformation of the answer *a* to project characteristic *k*
- *A* is the set of all answers
- $p_k$ is the cumulative score for characteristic *k*.

The natural next step is relating the PCS to the importance of each decision criterion. To establish a relationship between the continuous $p_k$ (refer to **Table 4** for PCS examples) and criteria importance, four reference project examples (the top oval within the "Project Characteristics" block of **Figure 1**) were considered, each of which helps to display extreme characteristics so one can determine how each criterion is connected to each of the characteristics. The project profiles were carefully designed in collaboration with TxDOT to cover a comprehensive set of project characteristics commonly encountered. The characteristics corresponding to different project scenarios are summarized in **Table 3**. For instance, Project #1 is a large project, with a strict budget, long-term investment, and long construction phase.

**Table 3 Characteristics of Each Project Scenario**

| **Characteristic** | | **1** | **2** | **3** | **4** |
|---|---|---|---|---|---|
| Type | Federal | x | | | |
| | State | | x | x | |
| | Local | | | | x |
| Budget Size | Billions | x | | | |
| | Hundreds of Millions | | x | | |
| | Millions | | | x | |
| | Less than a Million | | | | x |
| Project Type | Maintenance | | | | x |
| | Operations | | | x | |
| | Construction | x | x | | |
| Exact Investment Timing (clarity of scope and likelihood of cost changes) | Cost change very likely | | | x | |
| | Cost change not likely | x | x | | |
| | Cost change has no impact on project | | | | x |
| Project Timeline (period of construction) | 2 or more years | x | x | | |
| | 1 to 2 years | | | x | |
| | Less than 1 year | | | | x |
| Long-term investment | 2 or more years | x | x | | |
| | Less than 2 years | | | x | x |
| Significance of Project | Highly significant | x | x | | |
| | Not significant | | | x | x |
| Prone to Start Time Delay | Start time delay likely | | | x | |
| | Start time delay unlikely | x | x | | x |
| Prone to Duration delay | Duration delay likely | | | | x |
| | Duration delay unlikely | x | x | x | |
| Innovative Construction or Delivery Methods | Yes | | x | | |
| | No | x | | x | x |
| Location: Urban or Suburban | Urban | x | x | | |
| | Suburban | | | x | x |
| Sustainability Objectives | Yes | | x | x | |
| | No | x | | | x |
| Equity Objectives | Yes | | x | x | x |
| | No | x | | | |
| Complexity/Experience (level of project team expertise required) | Experts | x | x | | |
| | Some experience | | | x | |
| | No experience | | | | x |

For each project profile, the PCS are calculated based on the relevant answers. Then, each criterion's importance is specified based on the experience of the research team and the literature. Consequently, each of the seven project characteristics will have importance scores for each of the eleven decision criteria. Ultimately, four matrices that show the reference decision criteria score (the bottom oval within the "Project Characteristics" block of **Figure 1**) for each project profile are determined. **Table 4** shows the project characteristics and criteria importance scores for Project Profile 1. For example, predictability receives a score of 5 when examined against the large project scale characteristic while it receives a score of 3 for the sustainability criteria because it is a medium-term investment. The reference decision criteria scores, such as those presented in **Table 4**, can be elicited from transportation experts through a Delphi survey. In each question in the survey, the decision-maker assigns a numerical value to the dominant factor that reflects its importance based on specific project characteristics. Since the Delphi survey had not been conducted at the time of this writing, the authors filled those matrices based on their knowledge, meetings with DOT experts, and the literature on the topic.

The same process is replicated for the three remaining reference projects to achieve **Figure 3** which shows the change in the criteria importance score as a function of the PCS corresponding to each of the considered characteristics. The relationships established in **Figure 3** are leveraged to automatically relate project characteristics to criteria importance within FUND through the Interpolation of decision criteria scores (the bottom box within the "Project Characteristics" block of **Figure 1**). For example, if a new project being studied has a "Large Project Scale" score of 1.5, then the characteristic scores of the four project profiles are used to obtain the upper and lower limit values and determine the required criteria importance scores via linear interpolation, as shown in Equation (2).

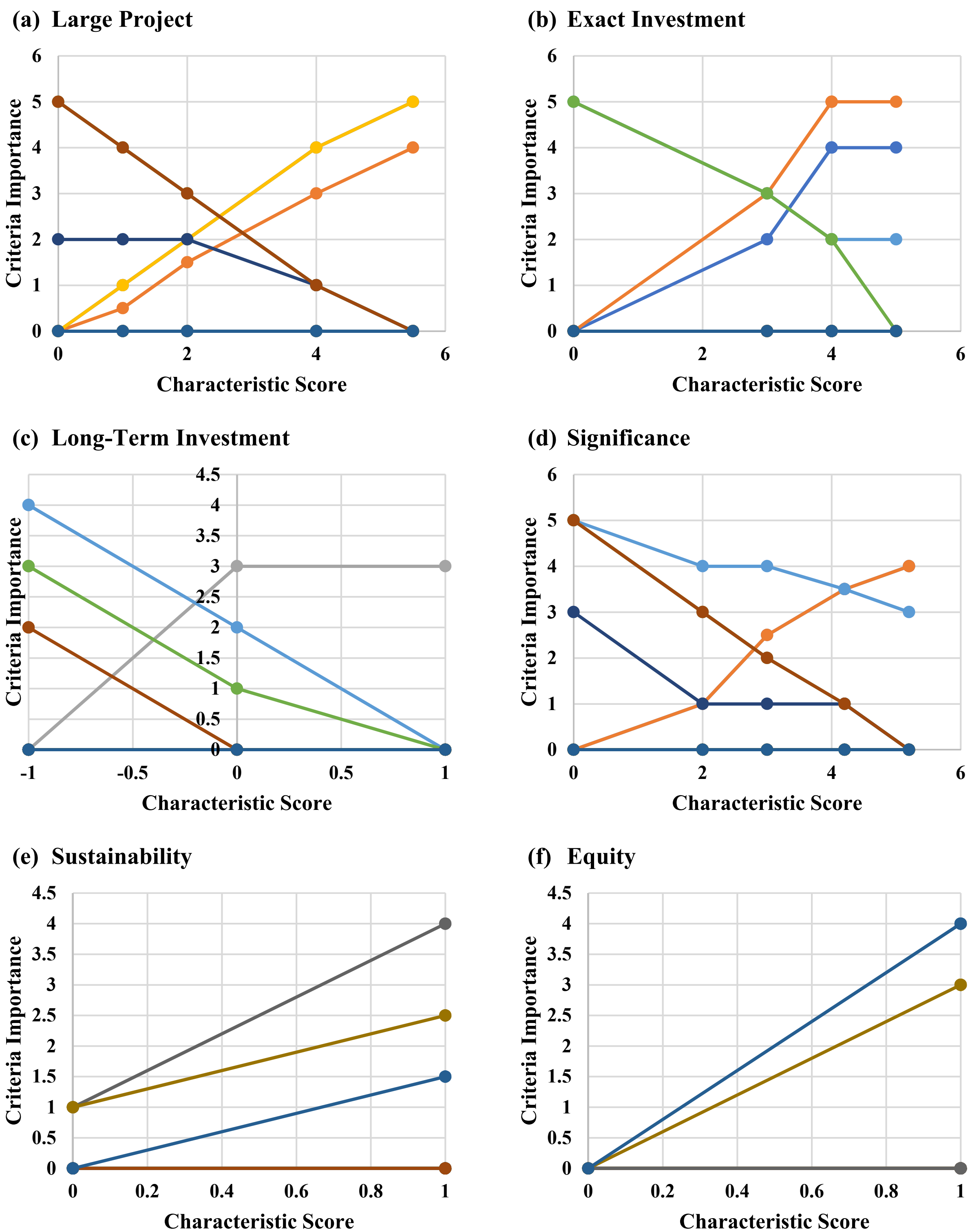
$$\text{Criteria Score} = \text{Criteria Score}_{lb} + \frac{(\text{CS} - \text{CS}_{lb})}{(\text{CS}_{ub} - \text{CS}_{lb})} \times (\text{Criteria Score}_{ub} - \text{Criteria Score}_{lb}) \qquad (2)$$

where CS represents characteristic scores at respective upper bound *ub* and lower bound *lb*.

The outcome of the "Project Characteristics" component is the Decision criteria scores (the output of the "Project Characteristics" block of **Figure 1**) corresponding to each criterion.

**Table 4 Project Characteristics and Criteria Importance Scores Example for Project Profile 1**

| **Project Characteristics** | **Large Project Scale** | **Exact Investment Timing** | **Long-term Investment** | **Significance** | **Innovation** | **Sustainable Project** | **Equity Conscious Project** |
|---|---|---|---|---|---|---|---|
| **Project Characteristics Score** | 3.5 | 5 | 1 | 5.2 | 0 | 0 | 1 |
| | **Criteria Importance Score (Scale 0-5)** | | | | | | |
| **Decision Criteria** | **Large Project Scale** | **Exact Investment Timing** | **Long-term Investment** | **Significance** | **Innovation** | **Sustainable Project** | **Equity Conscious Project** |
| **Predictability** | 5 | 4 | 0 | 4 | 0 | 0 | 0 |
| **Stability** | 4 | 5 | 0 | 4 | 0 | 0 | 0 |
| **Sustainability** | 0 | 0 | 3 | 0 | 0 | 0 | 0 |
| **Revenue Potential** | 5 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Current Use Status** | 0 | 2 | 0 | 2 | 0 | 0 | 0 |
| **Ease of Implementation** | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Ability to Enforce** | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Public Acceptance** | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Promotion of Efficient Use** | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| **User/Beneficiary Cost** | 0 | 0 | 0 | 0 | 0 | 1 | 3 |
| **Promotion of Social Equity** | 0 | 0 | 0 | 0 | 0 | 0 | 4 |


(a) Large Project
Criteria Importance
Characteristic Score
(b) Exact Investment
Criteria Importance
Characteristic Score
(c) Long-Term Investment
Criteria Importance
Characteristic Score
(d) Significance
Criteria Importance
Characteristic Score
(e) Sustainability
Criteria Importance
Characteristic Score
(f) Equity
Criteria Importance
Characteristic Score

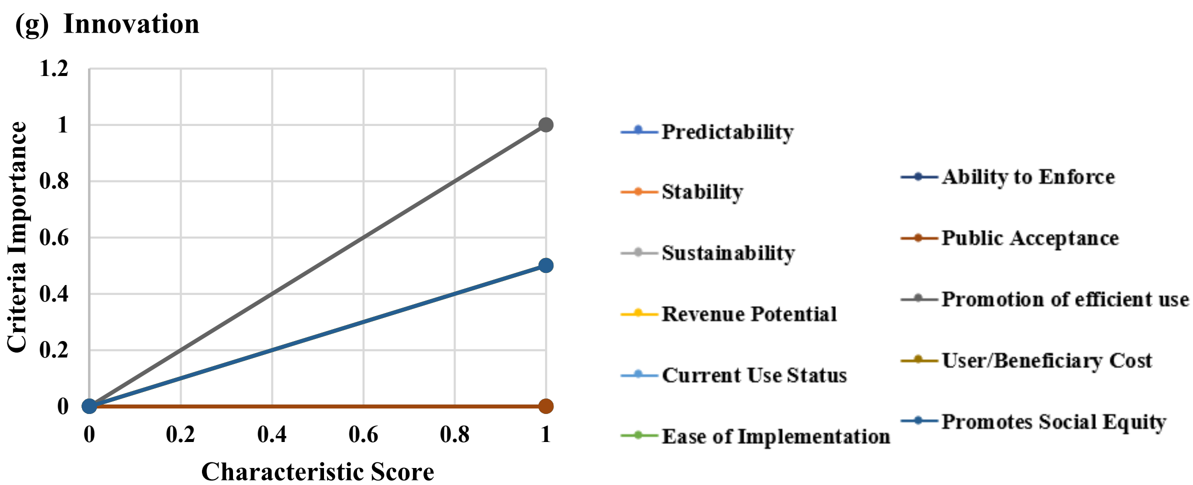



**Figure 3 Criteria Importance Scores as a Function of Characteristic Scores for: a) Large project, b) Exact investment timing, c) Long-term investment, d) Significance, e) Sustainability, f) Equity, and g) Innovation**

*AHP Calculations*

The AHP calculations in **Figure 1** are conducted to rank the funding/financing mechanisms. The decision criteria importance scores are converted to pairwise comparisons (the top box within the "AHP Calculations" block of **Figure 1**) to make them compatible with the AHP framework computations. This conversion is implemented over a three-step procedure.

The first step involves calculating the average criteria importance score for each criterion. This value is obtained by averaging the non-zero cells of each row in the criteria importance scores matrix (refer to **Table 4**), as shown in Equation (3).

$$Avg.imp.score_i = \frac{\sum_{k=1}^{N} Imp.score_{ik}}{N} \tag{3}$$

where $N = 7$ is the number of project characteristics considered.

Subsequently, the difference between the average criteria importance scores is calculated in a pairwise fashion, as presented in Equation (4).

$$\text{Absolute difference}_{ij} = \left|Avg.imp.score_i - Avg.imp.score_j\right| \tag{4}$$

Finally, the differences are converted to Saaty's 1–9 scale for pairwise comparisons according to their magnitude. Following the three steps, a pairwise comparison matrix for the decision criteria is determined and used to calculate the priority vector (or Eigenvector) (refer to the references provided in the MCDA and AHP Concept section for calculation details). The priority vector (the bottom box within the "AHP Calculations" block of **Figure 1**) shows the weights of the criteria while deciding on the most appropriate financing mechanism. The criteria weights are then combined with the financing mechanism alternative scores to obtain the global scores and final ranking of alternatives based on appropriateness.

**Implementation of the Revenue Projections Module**

The second contribution of this study and the FUND application is the Projections module. Similar to the previous TRENDS and INDOT models, the Projections module aims at obtaining cash flow diagrams for net revenues. Additionally, to understand the financial landscape of future projects, it is beneficial to leverage models that can be configured according to hypothetical future scenarios. The revenue projections are directly related to changes within the economic environment and funding availability over time. The inputs for computing these projections include population, employment, or vehicle ownership data projections. **Figure 4** depicts the general framework used for achieving the revenue projections for only a subset of the funding mechanisms.

Three types of inputs were considered in this module: non-revenue projections, assumptions, and policy testing variables. The predictions generated for the inputs required for revenue projection are referred to as non-revenue projections in this context. This corresponds to all the inputs that need to be estimated for every year within the analysis period, such as population or EV ownership.

The general assumptions include variables that affect the non-revenue and revenue projections but are assumed to remain constant during the analysis period. The third input type corresponds to policy testing variables which are used to experiment with different tax rates and fees to evaluate their effects on the net revenues. Only a few mechanisms were considered for the Projections module for simplicity.

The non-revenue projections and general assumptions were obtained from TxDOT publications to reflect their specific trends. Since the inputs are not generalizable for other locations, the details concerning their collection and their specific numerical values are excluded from this study for brevity.

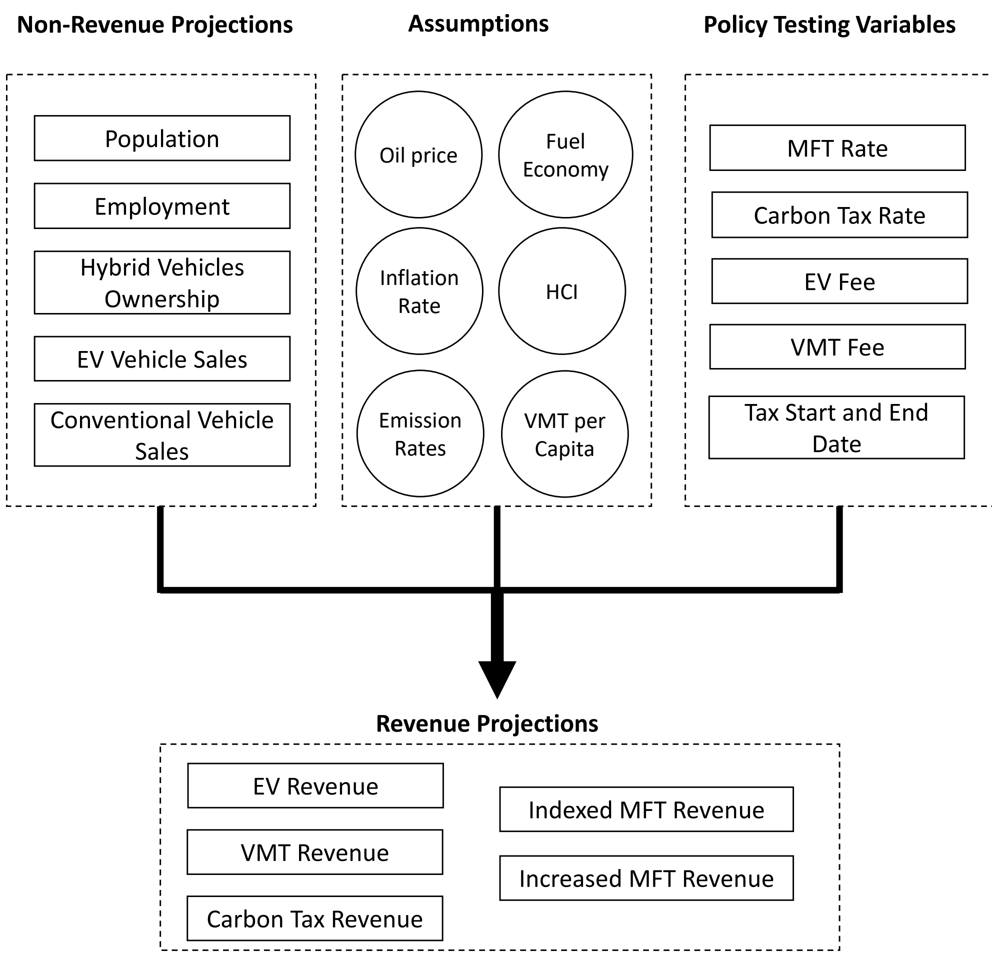



**Figure 4 Framework for Financing Mechanisms Revenue Projections**

### Tool Development

The FUND application that incorporates the Appropriateness and Projections modules comprises a Microsoft Access database that contains embedded Microsoft Excel spreadsheets which perform the technical computations and graphical displays for both modules. Linked with this are functions for collecting economic scenario and project characteristic parameters from the user that can be stored under named profiles within the same database. Project stakeholders chose this format because of its ability to contain both data and functionality that can be shared within an organization as a single file without the need for special back-end IT infrastructure.

Other innovations included the use of databases and scripting to create user-friendly, dynamic pages of questions and the injection of database-driven values into specific cells of the embedded Excel spreadsheets to automate the necessary computations. The use of Excel allows analysts to update core application functionality without the need for formal programming.

The authors have provided more information about the computations and potential uses of this application at https://github.com/ut-ctr-nmc/fund. It is anticipated that these can be utilized as a starting point for re-implementation of Appropriateness and Projections functionality for other DOTs, as well as to exemplify how such tools can be made possible using off-the-shelf office software commonly found on many desktop computers within government organizations.

## SCENARIO DEMONSTRATIONS

The FUND database application presents the user interface for Appropriateness and Projections modules described earlier.

### Project Scenario: Large Project Example

To further demonstrate the capabilities of the database, an example project scenario is defined with these characteristics:

- Budget in billions of dollars
- Three-to-five-year construction period
- Investment stage within four years
- High priority
- Innovative construction methods
- Equity goals
- No sustainability goals
- Medium business density
- High complexity
- Not tolled
- Not appropriate to use bonds

An example of such a project could be a state-level bridge construction project that runs through a busy city corridor. These construction costs are significant due to the complexity and location of construction. Additionally, because it is high priority, it is possible to overtake other projects. **Figure 5** presents how the FUND database allows for running this scenario and viewing the Appropriateness results. After selecting the appropriateness module and a relevant project profile on the main page (refer to Step 1 in **Figure 5**), the application prompts a project characteristics' input form allowing for necessary profile adjustments. The image presented under step 2 in **Figure 5** shows a portion of the input form corresponding to the project budget.

The results page, shown in the bottom-left image, ranks and displays the most appropriate funding/financing mechanisms for the tested scenario. Steps 3 and 4 in **Figure 5** zoom into the results to show the details of the table which shows associated information and online resources. For this example, the Indexed MFT shows as the most promising. Furthermore, the detailed results presented in Step 5 of **Figure 5** provide further insight on the AHP process, displaying predictability and stability as most important in a funding or financing source, while the ability to enforce and ease of implementation are ranked as least important. Overall, users are able to use both results pages to better understand what criteria among the mechanisms should be most sought for this project. In the case where a new mechanism is not coded within this database, the criteria weights would likely apply to new mechanisms considered in the future.

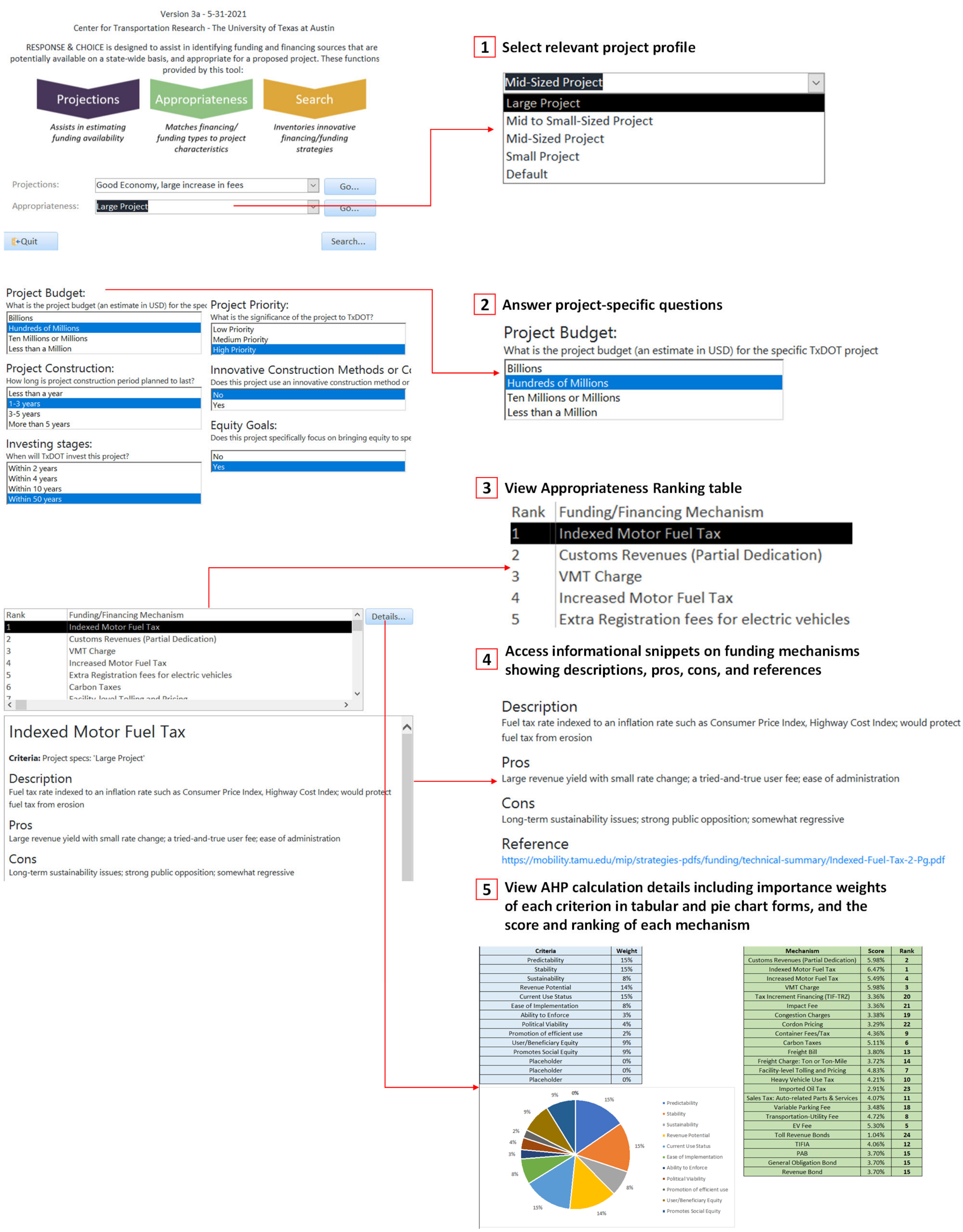



**Figure 5 Steps of Appropriateness Functions within FUND Database**

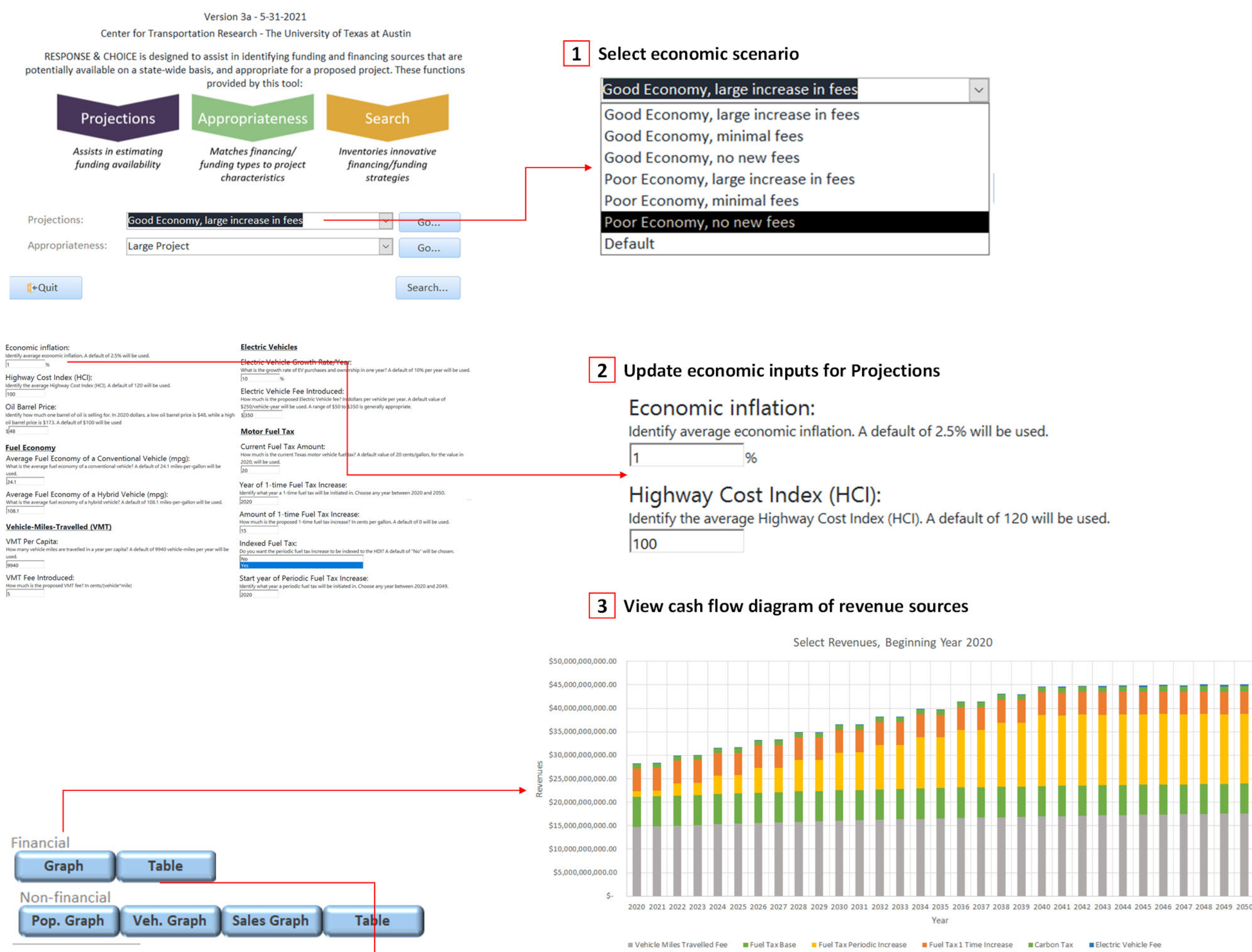
**Funding and Financing Revenue Projections**

The Projections module follows a similar process as the Appropriateness module. Here, profiles containing economic scenarios can be edited and saved. Then, on the results page, the first financial revenue graph shows revenue sources projected from year 2020 onward. Each revenue source is color-coded and separate. It is also possible to see a tabular view of the graph contents, as well as non-financial results. The specifics of these projections are coded in the embedded spreadsheet for population, employment, and vehicle sales growth rate for Texas and following the framework presented in **Figure 4**. To produce valid results for other states, users would need to modify the inputs to be compatible with their respective locale. The functionality of the Projections module is demonstrated in the context of an economic scenario with the following parameters:

- Inflation rate: 2.5%
- Highway Cost Index: 120
- Oil barrel price: $64
- Fuel economy inputs (24.1 miles/gallon for conventional vehicles and 108.1 miles/gallon for hybrid vehicles)
- VMT fee: 5¢/vehicle-mile
- MFT indexed increase: 5¢ every 3 years (starting in 2025)
- Electric vehicle fee: $250 per-vehicle every year
- VMT per capita: 9940
- EV growth rate: 10%
- Current MFT: 20¢/gallon
- Emissions rates: conventional (5.718 tons per year), hybrid (3.024 tons/year), electric (2.012 tons/year)

The economic status of January 2020 was selected, as it is the base year for these projections and calculations. **Figure 6** presents how the FUND database collects parameters, runs the scenario, and displays financial results. The database starts with the selection of the Projections module and the corresponding economic profile as shown in Step 1. The second step involves modifying the required inputs adjusting the selected scenario as needed. The results page displays the impacts of these new fees on the revenues from these sources over 30 years. The cash flow diagram presented in Step 3 within **Figure 6** shows that the periodic increase in the MFT makes a large increase in revenue over the years, but because there is no change in the VMT or carbon tax, the revenue base drops down with inflation. FUND also allows for the tabulation of the specific numbers related to the different revenue projections as presented in Step 4 within **Figure 6** for EV fees.

These projections and appropriateness scores can be used together to form a cohesive decision-making guide for policymakers, government employees, or consultants who are interested in learning how to connect funding/financing mechanisms with their specific projects.




4 View tabular representation of possible annual revenue per funding/financing mechanism (e.g., EV fee)

| Year | EV Fee | Year | EV Fee |
|---|---|---|---|
| **2020** | $ 12,746,300.00 | **2035** | $ 98,167,177.93 |
| **2021** | $ 16,788,675.31 | **2036** | $ 109,484,205.47 |
| **2022** | $ 20,828,786.88 | **2037** | $ 121,745,658.45 |
| **2023** | $ 24,905,356.02 | **2038** | $ 134,940,374.79 |
| **2024** | $ 28,748,471.42 | **2039** | $ 149,113,901.71 |
| **2025** | $ 32,735,683.75 | **2040** | $ 164,143,443.58 |
| **2026** | $ 36,947,946.19 | **2041** | $ 179,936,179.10 |
| **2027** | $ 41,367,469.72 | **2042** | $ 196,257,413.11 |
| **2028** | $ 45,988,503.25 | **2043** | $ 213,003,336.28 |
| **2029** | $ 51,074,689.11 | **2044** | $ 230,128,641.27 |
| **2030** | $ 56,785,018.21 | **2045** | $ 247,725,726.68 |
| **2031** | $ 63,195,842.40 | **2046** | $ 265,864,842.99 |
| **2032** | $ 70,461,740.51 | **2047** | $ 284,447,405.29 |
| **2033** | $ 78,637,320.11 | **2048** | $ 303,480,371.15 |
| **2034** | $ 87,861,124.85 | **2049** | $ 322,969,608.53 |
| | | **2050** | $ 342,888,623.06 |

**Figure 6 Steps of Projections Functions within FUND Database**

## CONCLUSION AND FURTHER IMPROVEMENTS

In this paper, we have developed a decision-making framework and interactive tool that can aid transportation agencies in systematically evaluating funding/financing mechanisms. The framework is housed within a Microsoft Access application called FUND that involves Appropriateness and Projections modules. In doing so, we provide transportation agencies with a workable platform to undertake careful funding/financing evaluations and effectively communicate findings to both policymakers and the public. Financing/funding concepts and rankings are conveyed using a simple, quantitative, multi-criteria, and systematic approach supplemented by visuals. The intent is that the proposed tool can serve as a valuable aid and a complement to additional subjective decision-making factors when comparing options and undertaking scenario analysis. A particularly salient aspect of our research and proposed tool is that it explicitly links project characteristics with the funding landscape, an issue that has received little attention in the literature but represents a critical element of decision-making.

Naturally, the framework still lacks validation from practitioners in the field. Going forward, communications with subject matter experts through conferences, interviews, and surveys should be prioritized to expand the selection of project scenarios to cover a wider array of project characteristics and fine-tune the decision criteria scores. Such efforts are indispensable to ensure accurate and reliable results and, ultimately, state-level funding and financing decisions. For the time being, we expect that publishing a beta version of the tool to showcase the framework can spur the necessary discussions; this tool and supplemental information is available online at https://github.com/ut-ctr-nmc/fund. Future work can also target experimenting with MCDA methods other than AHP and comparing the reliability of the results.

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***Author Contribution Statement***

The authors confirm contribution to the paper as follows: study conception and design: A. Haddad, G. Blazanin, K. Perrine, and C. Bhat; data collection: A. Haddad, G. Blazanin, K. Perrine, and C. Bhat; analysis and interpretation of results: A. Haddad, G. Blazanin, K. Perrine, and C. Bhat; draft manuscript preparation: A. Haddad, G. Blazanin, K. Perrine, and C. Bhat. All authors reviewed the results and approved the final version of the manuscript.

**REFERENCES**


1. ASCE. Report Card for America's Infrastructure. https://www.asce.org/infrastructure/. Accessed July 15, 2021.

2. Ali, M., A. Dulcy, M. Fred, V. Antonio, and V. Vanessa. Assessment of Public Perceptions of Innovative Financing for Infrastructure. *Construction Research Congress 2012*. 2260–2269. https://doi.org/10.1061/9780784412329.227.

3. Heleman, J., and B. Wright. *Texas' Motor Fuels Taxes*. 2016.

4. Halbrook, S., and J. Donald. *Motor Fuels Taxes in a Changing Texas Transportation Scene*. 2019.

5. Board, T. R. The Fuel Tax and Alternatives for Transportation Funding. *Special Report 285*, The National Academies of Press, Washington, D.C., 2006.

6. Small, K. A. Using the Revenues from Congestion Pricing. *Transportation*, 1992. 19(4): 359–381. https://doi.org/10.1007/BF01098639.

7. Ubbels, B., P. Nijkamp, E. Verhoef, S. Potter, and M. Enoch. Alternative Ways of Funding Public Transport: A Case Study Assessment. *European Journal of Transport and Infrastructure Research*, 2001. 1(1): 73–89. https://doi.org/10.18757/ejtir.2001.1.1.2629.

8. Gu, Z., Z. Liu, Q. Cheng, and M. Saberi. Congestion Pricing Practices and Public Acceptance: A Review of Evidence. *Case Studies on Transport Policy*, 2018. 6(1): 94–101. https://doi.org/https://doi.org/10.1016/j.cstp.2018.01.004.

9. FHWA Center for Innovative Finance Support. Innovative Finance Quarterly. https://www.fhwa.dot.gov/ipd/finance/resources/general/if_quarterly/. Accessed July 13, 2021.

10.Varn, J., G. Eucalitto, and S. Gander. *Planning for State Transportation Revenue in a Coming Era of Electric Vehicles*. National Governors Association Center for Best Practices, Washington, D.C., 2020.

11. FHWA Center for Innovative Finance Support. *Value Capture Resources*. 2019.

12. Clegg, A. *State Transportation Funding Proposals*. 2019.

13. Pulipati, S. B., S. P. Mattingly, and C. Casey. Evaluating State Level Transportation Revenue Alternatives. *Case Studies on Transport Policy*, 2017. 5(3): 467–482. https://doi.org/https://doi.org/10.1016/j.cstp.2017.06.002.

14. Weinstein, A., J. Dill, T. Goldman, J. Hall, F. Holtzman, and J. Recker. *Transportation Financing Opportunities for the State of California*. 2006.

15. AASHTO. *Matrix of Illustrative Surface Transportation Revenue Options*. 2019.

16. Dye Management Group. *Texas Transportation Funding Challenge: Findings and Analysis*. 2009.

17. Cambridge Systematics. *Study of Indiana Transportation Infrastructure Funding Mechanisms*. 2015.

18. TTI. *How to Fund Transportation*. 2019.

19. National Academies of Sciences, Engineering, and Medicine. *Local and Regional Funding Mechanisms for Public Transportation*. Transit Cooperative Research Program Report 129, The National Academies Press, Washington, D.C., 2009. https://doi.org/10.17226/14187.

20. National Academies of Sciences, Engineering, and Medicine. *Future Financing Options to Meet Highway and Transit Needs*. National Cooperative Highway Research Program Web-Only Document 102, The National Academies Press, Washington, D.C., 2006. https://doi.org/10.17226/23200.

21. Persad, K., L. Loftus-Otway, R. Harrison, A. Cruz-Ross, P. Singh, S. Chi, and P. Franco. Evaluation of TxDOT's JACK Model for Revenue and Expenditure Projections. Report FHWA/TX-09/0-6395-CT-1, Center for Transportation Research, The University of Texas at Austin, 2009.

22. Castiglione, J., R. D. Ellis, and B. Glover. The Transportation Revenue Estimator and Needs Determination System (TRENDS) Model.

23. Cambridge Systematics, I., L. D'Artagnan Consulting, and Indiana University. INDOT Revenue Cost Model. https://www.in.gov/indot/3410.htm. Accessed July 13, 2021.

24. Atkinson, R. D., and N. S. T. I. F. Commission. Paying Our Way: A New Framework for Transportation Finance, Final Report, February 2009. 2009.

25. Broniewicz, E., and K. Ogrodnik. Multi-Criteria Analysis of Transport Infrastructure Projects. *Transportation Research Part D*, 2020. 83: 102351. https://doi.org/https://doi.org/10.1016/j.trd.2020.102351.

26. Ishizaka, A., and P. Nemery. *Multi-Criteria Decision Analysis: Methods and Software*. John Wiley & Sons, 2013.

27. Sorensen, P., L. Ecola, and M. Wachs. *Mileage-Based User Fees for Transportation Funding: A Primer for State and Local Decisionmakers*. Rand Corporation, 2012.

28. D'Angelo, D., T. Edun, P. Hovy, H. Ladley, S. Page, T. Bishop, and S. Natzke. *Value Capture Implementation Manual: Capitalizing on the Value Created by Transportation*. Report FHWA-HIN-19-004, Federal Highway Administration, Office of Policy and Governmental Affairs, 2019.

29. Merriman, D. F. Does TIF Make It More Difficult to Manage Municipal Bud Gets? A Simulation Model and Directions for Future Research. In *Municipal Revenues and Land Policies* (G.K. Ingram and Y-H. Hong, eds.) Lincoln Institute of Land Policy, Columbia University Press, Ch. 11, 2010.