Prioritizing Transportation Projects using an Integrated Multiple Criteria Decision-Making Method

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ABSTRACT:
Transportation project prioritization, a process of selecting projects for funding given multiple constraints, is a cumbersome and time-consuming process. This study presents a simplified methodology for ranking transportation projects using an integrated multiple criteria decision-making (MCDM) process for prioritizing transportation projects when there are multiple decision makers with multiple opinions and biases. The basis of this study is to apply the Analytical Hierarchy Process (AHP) and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) to help multiple decision makers for the selection of transportation projects in an environment where vagueness and subjectivity are handled with numerical values and processed in an automated fashion. The AHP is used to weigh a set of criteria through the use of pair-wise comparisons, and TOPSIS is used to obtain final project rankings. Even though AHP and TOPSIS are two widely accepted MCDM methods, few Transportation Policy Boards (TPB) have used this unique integrated approach for ranking transportation projects. The El Paso Metropolitan Planning Organizations (MPO) Transportation Improvement Program (TIP) was used as a case study for this research.

Keywords: Multiple Criteria Decision-Making, AHP, TOPSIS, Transportation Project Prioritization, Project Ranking, Transportation Policy Board
1 INTRODUCTION

Transportation infrastructure decisions that outline available resources and provide maximum benefits to the community hold tremendous value to the transportation profession. Decision makers attempt to reach their goals with well-timed and cost-effective decisions that invest limited available resources according to the anticipated needs of the region. Thus, it becomes increasingly important for decision-makers to use objective tools to make proper investment decisions. Most scenarios that involve decision making in the transportation field are complex and include multiple, often conflicting objectives, which cannot be measured in quantifiable units alone. For example, trading off high construction costs of a project versus safety benefits that a project will bring to the community is a challenge for all transportation projects and decision-makers struggling to quantify and weigh both criteria. In addition, there are often multiple decision-makers with different biases and agendas towards projects. Transportation policy boards and technical advisory committees are often comprised of several individuals with different backgrounds, and often reside in various areas of a community. These diverse groups of individuals compete for limited funding resources to provide much needed transportation improvements in their regions. Many times projects are ranked based upon the recommendations of outspoken board or committee members without fully exploring the direct, indirect, and cumulative benefits the project will provide. Furthermore, some of the decision making members are unwilling to input their opinions and recommendations for project ranking and as a result are often overlooked.

A proper ranking of transportation projects is a very important issue in that improper ranking can have unintended consequences on the overall performance of a transportation system. For instance, ranking a public transit project against other roadway improvement projects requires advanced knowledge and deep experience in transportation planning and traffic operations for both public and private modes of transport. Funding a public transportation project without the proper infrastructure to accommodate the necessary modes will undoubtedly be heavily scrutinized. For a proper and effective evaluation, decision-makers may need a large amount of data to analyze and consider many factors [1]. This process can be a hard task for many decision-making bodies that do not have the technical background to properly assess and understand the various measures used for performance evaluation. This performance evaluation and optimal selection of transportation projects have multi-level and multi-factor features and can therefore be regarded as multiple criteria decision-making (MCDM) [2].

There are multiple MCDM methods that exist today [3]. These methodologies can be categorized in a variety of ways such as form of model (e.g. linear, non-linear, stochastic), characteristics of the decision space (e.g. finite or infinite), or solution process (e.g. prior specification of preferences or interactive). The true goal in integrated decision making support is to provide the decision-maker with the ability to look into the future, and make the best possible decision based upon past and present information and future predictions [4]. With that said, some techniques are better suited for particular decision problems than others [5]. In general, the most popular ones are scoring models [6], Analytical Hierarchy Process (AHP) [7], Elimination and Choice Expressing Reality (ELECTRE) [8], and Technique for Ordered Preference by Similarity to Ideal Solution (TOPSIS) [9]. For transportation ranking purposes, various methods have been utilized.

The main objective of this research is to propose a simplified and systematic approach for ranking transportation projects among a set of available alternatives. Project ranking is both a
MCDM problem where many conflicting criteria should be considered in decision-making, and a
problem containing subjectivity, ambiguity and uncertainty in the assessment process. Therefore,
this research uses AHP to determine the weighting of a given set of criteria using pair-wise
comparison and TOPSIS to determine performance ratings of the feasible alternatives [10]. This
enables the decision-makers to rank projects in a way that will have a positive cost/benefit ratio
by providing a prioritized list of projects and improve the chances of success.

2 LITERATURE REVIEW

Transportation project ranking can be accomplished with or without complex modeling tools.
Ranking or prioritizing projects without modeling tools is typically based on heuristic methods,
rules of thumb or decision-makers’ personal experiences [11]. These methods are common in
current practice because they are easy to apply and do not require quantifiable data. However, as
the number of alternative projects and the performance measures used to analyze each projects
worth is increased, it becomes more difficult to make efficient decisions using these simple
methods. In addition, most decision-making bodies spend a substantial amount of time trying to
accommodate the needs and wishes of all parties when multiple decision-makers each have their
own preferences. For this reason, project ranking should incorporate advanced modeling tools to
help decision-makers arrive at final decisions using optimized methods [12].

The use of MCDM techniques, where multiple criteria are considered in a simple score
model, can be dated back for decades. Since then, the theory and applications have been
developed significantly [13]. For the purposes of transportation project ranking, decision criteria
are measured by attributes (performance measures) that are both quantitative and qualitative.
Quantifiable data consists of data that can be directly measured including travel time savings,
construction costs, reduction in air emissions and revenue generated. Qualitative measures,
which are more difficult to measure, can consist of subjective data including quality of life
improvements, mix of land uses, or improved accessibility to the region. Qualitative measures
are often questions that can be answered with “yes” or “no” answers.

2.1 Common Practices

The first step in transportation project ranking was to conduct an extensive literature review of
existing agencies around the country that use some sort of ranking process for project selection.
The project selection process between these various agencies ranged from simplistic to complex.
The Corpus Christi Metropolitan Planning Organizations (CCMPO) technical advisory
committee (TAC) uses a Project Prioritization Methodology (PPM) to rank projects on their
merits based upon tangible performance measures that are on the Transportation Improvement
Program (TIP). The CCMPO considers a project eligible if it:

- Is on the Metropolitan Transportation Plan (MTP) project listing or recommended for
  such listing by the MPO staff and TAC.
- Is on the street functional classification map.

Once it is determined that a project is eligible for ranking, the TAC uses a scoring
methodology which assigns points on the basis of information provided on a project submittal
form. Each project is scored based upon a specific set of criteria. Each criterion is allotted a
specific point total where each has specific performance measure questions. Projects are then
grouped into four classes: A, B, C, & D based upon score totals [14].
The Wilmington Area Planning Council (WILMAPCO) created a Prioritization Process to evaluate transportation projects using measurable criteria based on the goals of their long-range plan. It provides a quantitative method to compare projects proposed for the TIP and Regional Transportation Plan (RTP). WILMAPCO uses a three-step process to rank projects. The first step is to apply a set of screening criteria where each project is reviewed for consistency with the RTP and local, county and state transportation plans and land use plans. If the project is not consistent with local and regional plans, it will not be ranked or the RTP must be amended prior to ranking. The second step, which is conducted directly by the WILMAPCO staff, is to calculate a technical score for each project based on the three specific goals (criteria) which include quality of life, transport of people and goods & support economic growth and activity. The criteria are designed to be objective measures using data available to WILMAPCO staff. The third step is to derive a scoring system to rank projects where point values are given to specific performance measures defined for each criterion. Once all projects are scored, the TAC reviews summary scores of all projects for accuracy and proposes a ranking of projects based upon:

- Technical score developed by staff
- Cost effectiveness/life cycle costs
- Project recommended in adopted transportation plan
- Incorporate submitted agency rankings, ensuring that top local priorities receive higher priorities
- Urgency of project
- Match funding
- Special considerations & other issues not included in ranking

Once all projects have been ranked by the TAC, the WILMAPCO ranks all submitted projects based upon the same guidelines used by the TAC [15].

The El Paso Metropolitan Planning Organization (MPO) is a bi-state organization encompassing portions of two New Mexico counties and a single Texas county. The El Paso MPO had invested in developing a project select process (quantitative, qualitative or joint method) for the metropolitan transportation plan (MTP) and TIP for the past five years. Ultimately, design, testing, and visioning prompted the El Paso MPO to develop a regulatory approach to define criteria solely for the TIP. The El Paso MPO uses the Strategic Transportation Evaluation of Projects or STEPs which is designed to provide a systematic approach for the reexamination of projects in the short-range plan. Projects are grouped into a certain category as a function of project readiness. The four categories are cataloged below [16]:

**Level I** - These are projects that are ready for construction, have no administrative, environmental, or Letter of Authority issues or concerns, as required by the Federal Highway Administration (FHWA) or Federal Transit Administration (FTA). These projects are ready to be let or have already let.

**Level II** - These are projects that are still in the process of acquiring agreements, or environmental documents, or matching funds, but there are no foreseeable issues on acquiring these, as required by FHWA or FTA. All right-of-way (ROW) for these projects, if applicable, has been acquired.
Level III - These are projects that still do not have the entire ROW acquired for projects that require ROW, as required by FHWA or FTA. This category also covers projects that show serious discrepancies in acquiring agreements, or environmental documents, or matching funding, as required by FHWA or FTA.

Level IV - These are projects that do not have all three of the following; agreements, environmental documents, and ROW map for projects that require ROW, as required by FHWA or FTA.

While it is possible for projects to change category status twice a year, all discrepancies must be addressed and approved by the TPB. The STEPs allow the TPB to examine, accelerate, and prioritize needs under the American Recovery Reinvestment Act of 2009 (ARRA) and Transportation Investment Generating Economic Recovery (TIGER) program. The purpose of this investigation is to provide the public and decision-makers, within the El Paso MPO’s planning area, a sound and transparent tool to evaluate procedural and substantive operations in project selection, planning, and programming for future MTPs and TIPs.

3 RESEARCH METHODOLOGY

Criteria as well as methodologies used for project ranking were reviewed for commonalities and practicalities. Ultimately, researcher’s derived five common criteria to be used that would cover the goals and objectives of the decision-makers which included:

- Mobility – reducing the amount of congestion on existing infrastructure with additional roadway capacity or providing alternative modes of transport thus making the overall transportation service faster and more reliable.
- Financial Feasibility – to secure and efficiently and effectively apply financial resources for the construction, maintenance, modernization and appropriate expansion of the regional transportation system.
- Connectivity – defined as the ability to connect origins and destinations with a series of motorized routes. Connectivity can improve the quality of life by reducing roadway congestion, provide alternate direct/convenient routes, improve access to public transit and allow more efficient mix of land uses.
- Environmental – minimize transportation-related pollution or degradation of the environment, promote energy conservation, and support preservation of natural resources and community character. Environmentally sound projects for selection recognize the value of transportation projects that preserve the natural and cultural resources including visual, historic, archeological, aesthetic, noise as well as the reduction of air pollutants.
- Safety – Safety can be measured by the reduction of motor vehicle crashes per vehicle miles traveled. It is adherent that all city and state roadway construction must meet minimum safety guidelines; therefore, safety criterion for project selection implies that proposed projects will reduce the number of incidents by the reduction of congestion on existing infrastructure.

Once the five criteria were established, performance measures for each were evaluated based upon the goals and objectives of the decision-making body. The El Paso MPO’s
Transportation Project Advisory Committee (TPAC) was used as the decision-making body. The TPAC was created on March 23, 2007, to consolidate the Technical Advisory Committee and the Project Selection Committee, and has assumed the combined duties of the two committees it replaced. The TPAC has twenty-one voting members and nine Ex-Officio (non-voting) members. The TPAC reviews funding and technical information and makes recommendations to the TPB within federal and state guidelines. The MPO staff, which is an independent agency from the TPAC, is used to assist in establishing initial criteria, develop performance measures and gather data for each criterion. This external agency plays a critical role in the overall MCDM process and is responsible for data acquisition, conducting pair-wise comparisons, and overall maintenance of the project ranking model but does not participate in the actual ranking process.

3.1 AHP Pair-Wise Comparison

Before any project can be ranked through any mathematical computation, a systematic and objective way of weighting criteria was needed. AHP, developed by Saaty, was used to determine the relative weights or importance of a given set of criteria in a decision-making problem [17] as shown in Figure 1. This process made it possible to integrate judgments for qualitative and quantitative criteria combined [18].

A decision matrix was created where each decision-maker was asked to compare each criterion against another (Pairwise comparison). The pairwise comparison generally refers to a process of comparing entities in pairs to judge which of each pair is preferred, or has a greater amount of some quantitative property. The process is often referred to as a “divide-and-conquer” approach which allows decision-makers to estimate the importance of each criterion pair on a case by case basis. This method is useful if decision-makers lack hard data about each criterion, or if they feel much the same about all criteria. The pair-wise comparison method rates each
criterion relative to all other criteria within its ratings set. Subjective judgment or intuition is all that is needed to determine how one criterion compares to another. Pairwise comparison is essential when assigning weighted percentages to all criteria defined.

3.2 TOPSIS

TOPSIS is a practical and functional technique for ranking and selecting a number of externally determined alternatives through distance measures [19]. The basic ideal of TOPSIS originates from the concept of a displaced ideal point from which the compromise solution has the shortest distance from the positive ideal solution (PIS) and the farthest from the negative ideal solution (NIS). It simultaneously considers the distances to both PIS and NIS, and a preference order for each alternative is ranked according to their relative closeness and a combination of these two distance measures as shown in Figure 2. The PIS is a solution that maximizes the benefit criteria and minimizes the cost criteria, whereas the NIS maximizes the cost criteria and minimizes the benefits criteria [10]. TOPSIS assumes that each criterion wants to be either maximized or minimized, so the PIS for a criterion is the “max-value” of all the project alternatives considered, and the NIS is the “min-value” of the criterion for all project alternatives.

![FIGURE 2: EUCLIDEAN DISTANCE TO PIS AND NIS IN TWO-DIMENSIONAL SPACE [19]](image)

The following method developed by Hwang and Yoon is presented as a series of successive steps:

Step 1: Calculate normalize ratings. The vector normalization is used for computing $r_{ij}$, which is given as

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}, \quad i=1,\ldots,m; \quad j=1,\ldots,n$$

(1)
where \( r_{ij} \) is the normalized numerical value for each criterion, and \( x_{ij} \) is the numerical outcome of the \( x_{ij} \) alternative with respect to the \( j_{th} \) criterion.

Step 2: Calculate weighted normalized ratings. The weighted normalized value is calculated as

\[
v_{ij} = w_{j} r_{ij}, \quad i=1, \ldots, m; \quad j=1, \ldots, n
\]  

Step 3: Identify PIS and NIS. The \( A^* \) and \( A^- \) are defined in terms of the weighted normalized values:

\[
A^* = \{v_1^*, v_2^*, \ldots, v_j^*, \ldots, v_n^*\}
\]

\[
\left\{ \max_{j \in J_1} v_{ij}, \min_{j \in J_2} |i = 1, \ldots, m \right\}
\]

\[
A^- = \{v_1^-, v_2^-, \ldots, v_j^-, \ldots, v_n^-\}
\]

\[
\left\{ \min_{j \in J_1} v_{ij}, \max_{j \in J_2} |i = 1, \ldots, m \right\}
\]

where \( J_1 \) is a set of benefit criteria and \( J_2 \) is a set of cost criteria

Step 4: Calculate the separation measures. The separation (distance) between alternatives can be measured by the n-dimensional Euclidean distance. The separation of each alternative from the PIS, \( A^* \), is given by

\[
S_i^* = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_{i}^*)^2}, \quad i=1, \ldots, m
\]

Similarly, the separation from the NIS, \( A^- \), is given by

\[
S_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_{i}^-)^2}, \quad i=1, \ldots, m
\]

Step 5: Calculate similarities to PIS

\[
C_i^* = S_i^- / (S_i^* - S_i^-), \quad i=1, \ldots, m
\]
Note that $0 \leq C_i^* \leq 1$, where $C_i^* = 0$ when $A_i = A^-$, and $C_i^* = 1$ when $A_i = A^+$

Step 6: Rank preference order. Choose an alternative with the maximum $C_i^*$ or rank alternatives according to $C_i^*$ in descending order.

The distance between the final rankings of projects is listed in descending order with values between zero and one which can be converted to an overall percentage scoring similar to test scoring. The TOPSIS method is a totally automated procedure that only requires decision-makers’ input when weighting criteria and performance measures. Decision-makers have no influence on final ranking other than the weighting of criteria, and therefore personal biases cannot influence final ranking.

4 PROPOSED MODEL

The proposed model for the ranking of transportation projects composes of both AHP and TOPSIS to objectively prioritize projects in an automated fashion where decision-makers do not have to rank projects individually each time they convene. This proposed model greatly reduces the time required to rank projects where the decision-making bodies’ only role is to determine the weighting of each criteria through pair-wise comparison for pre-defined criteria agreed upon. Once weighting has been completed, data from each criterion is input into the TOPSIS model by the external agency and all projects are ranked. Figure 3 depicts the entire process for project ranking.
4.1 Pair-Wise Comparison

To simplify the process further, the pair-wise process allowed two choices per comparison. Either one criterion is chosen over another, or they are both equal. This simplified comparison allows decision-makers to make immediate choices without going back and trying to make sure there is no contradiction between choices. For example, if decision-maker 1 determines that criteria A is more important than B, and B is more important than C, one would think that A is more important than C. In a real life environment when humans are subjected to immediate choice decisions without the opportunity to go back and review previous choices, contradictions will occur. However, it was determined that this approach would force evaluators to make choices that reflected their true opinions, beliefs and biases. Once all decision-makers had completed the pair-wise comparisons, a weighted average for all criteria was obtained. The final weighted criteria are used repeatedly each time the members convene. The decision-making body however can repeat the pair-wise comparison process if decision-makers are added, replaced or when criteria are changed.

Decision-makers ultimately agreed upon a set of criteria that would be used for the proposed model. The consensus was to use criteria that would be applicable for all transportation projects. The final criteria, which were defined in the previous section, were presented to the TAC members. After forming the decision hierarchy for the model, the weights of the criteria to be used in the proposed model were calculated using AHP. The TPAC members were asked to
conduct pair-wise comparisons for five defined criteria: mobility, financial feasibility, connectivity, environmental, and safety. Table 1 shows the results of the pair-wise comparisons for all 14 TPAC members. The finalized average weight for each criterion is listed on the far right.

### TABLE 1: FINAL WEIGHTED AVERAGE FROM TAC MEMBERS

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>Final Weight</th>
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<tbody>
<tr>
<td>Mobility</td>
<td>.10</td>
<td>.20</td>
<td>.30</td>
<td>.30</td>
<td>.25</td>
<td>.40</td>
<td>.20</td>
<td>.25</td>
<td>.50</td>
<td>.18</td>
<td>.20</td>
<td>.10</td>
<td>.10</td>
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<tr>
<td>Financial</td>
<td>.20</td>
<td>.30</td>
<td>.36</td>
<td>.30</td>
<td>.25</td>
<td>.30</td>
<td>.10</td>
<td>.17</td>
<td>.40</td>
<td>.27</td>
<td>.10</td>
<td>.30</td>
<td>.30</td>
<td>.30</td>
<td>27%</td>
</tr>
<tr>
<td>Connectivity</td>
<td>.20</td>
<td>.10</td>
<td>.09</td>
<td>.10</td>
<td>.00</td>
<td>.17</td>
<td>.20</td>
<td>.30</td>
<td>.33</td>
<td>.10</td>
<td>.18</td>
<td>.00</td>
<td>.30</td>
<td>.20</td>
<td>16%</td>
</tr>
<tr>
<td>Environmental</td>
<td>.30</td>
<td>.20</td>
<td>.09</td>
<td>.00</td>
<td>.30</td>
<td>.08</td>
<td>.10</td>
<td>.00</td>
<td>.08</td>
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<td>.09</td>
<td>.40</td>
<td>.00</td>
<td>.00</td>
<td>12%</td>
</tr>
<tr>
<td>Safety</td>
<td>.20</td>
<td>.20</td>
<td>.18</td>
<td>.30</td>
<td>.10</td>
<td>.25</td>
<td>.00</td>
<td>.40</td>
<td>.17</td>
<td>.00</td>
<td>.27</td>
<td>.30</td>
<td>.20</td>
<td>.40</td>
<td>21%</td>
</tr>
</tbody>
</table>

### 4.2 TOPSIS

Once the final weighting has been established, raw data from the performance measures was collected and input to the model. Performance measures were determined based upon data that was readily available or projected. As shown in Table 2, several of the data from the performance measures was subjective, containing yes/no entries or alphabetical lettering. For qualitative performance measures, yes answers were given a value of 10 while no responses were given a value of 1. For level-of-service (LOS), numerical values were given between 0 and 5 (e.g. LOS A = 5, LOS F = 0) as shown in Table 3.

### TABLE 2: PERFORMANCE MEASURE DATA-RAW

<table>
<thead>
<tr>
<th>Project</th>
<th>VMR</th>
<th>VC Ratio</th>
<th>LOS</th>
<th>Travel Time</th>
<th>Capital Cost</th>
<th>O&amp;M Cost</th>
<th>Revenue</th>
<th>Funds Available</th>
<th>Existing Facilities</th>
<th>Intermodal Facilities</th>
<th>CO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project 1</td>
<td>1,300,000</td>
<td>0.89</td>
<td>C</td>
<td>6.48</td>
<td>$225,000,000</td>
<td>$300,000</td>
<td>$125,000,000</td>
<td>Yes</td>
<td>Yes</td>
<td>225</td>
<td></td>
</tr>
<tr>
<td>Project 2</td>
<td>1,255,000</td>
<td>0.75</td>
<td>B</td>
<td>6.44</td>
<td>$200,000,000</td>
<td>$225,000</td>
<td>$125,000,000</td>
<td>Yes</td>
<td>No</td>
<td>135</td>
<td></td>
</tr>
<tr>
<td>Project 3</td>
<td>1,255,000</td>
<td>0.89</td>
<td>D</td>
<td>6.36</td>
<td>$225,000,000</td>
<td>$300,000</td>
<td>$125,000,000</td>
<td>Yes</td>
<td>Yes</td>
<td>195</td>
<td></td>
</tr>
<tr>
<td>Project 4</td>
<td>1,150,000</td>
<td>0.91</td>
<td>E</td>
<td>6.36</td>
<td>$225,000,000</td>
<td>$300,000</td>
<td>$125,000,000</td>
<td>Yes</td>
<td>Yes</td>
<td>240</td>
<td></td>
</tr>
</tbody>
</table>

### TABLE 3: PERFORMANCE DATA-NUMERICAL VALUES

<table>
<thead>
<tr>
<th>Project</th>
<th>VMR</th>
<th>VC Ratio</th>
<th>LOS</th>
<th>Travel Time</th>
<th>Capital Cost</th>
<th>O&amp;M Cost</th>
<th>Revenue</th>
<th>Funds Available</th>
<th>Existing Facilities</th>
<th>Intermodal Facilities</th>
<th>CO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project 1</td>
<td>1,300,000</td>
<td>0.89</td>
<td>3</td>
<td>6.48</td>
<td>$225,000,000</td>
<td>$300,000</td>
<td>$125,000,000</td>
<td>10</td>
<td>10</td>
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<td></td>
</tr>
<tr>
<td>Project 2</td>
<td>1,255,000</td>
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<td>6.44</td>
<td>$200,000,000</td>
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<td>1</td>
<td>135</td>
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</tr>
<tr>
<td>Project 3</td>
<td>1,255,000</td>
<td>0.89</td>
<td>2</td>
<td>6.36</td>
<td>$225,000,000</td>
<td>$300,000</td>
<td>$125,000,000</td>
<td>10</td>
<td>1</td>
<td>135</td>
<td></td>
</tr>
<tr>
<td>Project 4</td>
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<td>0.91</td>
<td>2</td>
<td>6.36</td>
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<td>$300,000</td>
<td>$125,000,000</td>
<td>10</td>
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<td></td>
</tr>
<tr>
<td>Project 5</td>
<td>1,255,000</td>
<td>1.00</td>
<td>1</td>
<td>6.36</td>
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<td>$300,000</td>
<td>$125,000,000</td>
<td>10</td>
<td>10</td>
<td>240</td>
<td></td>
</tr>
</tbody>
</table>
Some of the data can be considered as “costs” while others can be considered “benefits”. In other words, the higher the value for one performance measure would be beneficial to the ranking as opposed to another performance measure where the higher the value the worse. For example, the higher the construction cost is, the worse it would be ranked. However, the higher the average travel speed is on a given corridor, the higher the alternative would be ranked. These types of contradictions are taken into account during the TOPSIS procedure. This is known as normalization which refers to the division of multiple sets of data by a common variable in order to negate that variable’s effect on the data and allow underlying characteristics of the data sets to be compared. This can also be referred to as “bringing data from different scales to a common scale”. Normalization also removes units from all data sets and values are between 0 and 1. Table 4 below shows the weighted normalized scores for all performance measures used in the criteria.

### TABLE 4: WEIGHTED NORMALIZATION

<table>
<thead>
<tr>
<th>Project</th>
<th>VMT</th>
<th>VC Ratio</th>
<th>LOS</th>
<th>Travel Time</th>
<th>Capital Cost</th>
<th>O&amp;M Cost</th>
<th>Revenue</th>
<th>Funds Available</th>
<th>Existing Facilities</th>
<th>Intermodal Facilities</th>
<th>CO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project 1</td>
<td>0.0212</td>
<td>0.0212</td>
<td>0.0210</td>
<td>0.0210</td>
<td>0.0340</td>
<td>0.0400</td>
<td>0.0161</td>
<td>0.0160</td>
<td>0.0358</td>
<td>0.0460</td>
<td>0.0233</td>
</tr>
<tr>
<td>Project 2</td>
<td>0.0181</td>
<td>0.0222</td>
<td>0.0229</td>
<td>0.0211</td>
<td>0.0156</td>
<td>0.0002</td>
<td>0.0125</td>
<td>0.0238</td>
<td>0.0338</td>
<td>0.0046</td>
<td>0.0038</td>
</tr>
<tr>
<td>Project 3</td>
<td>0.0214</td>
<td>0.0308</td>
<td>0.0165</td>
<td>0.0219</td>
<td>0.0246</td>
<td>0.0054</td>
<td>0.0034</td>
<td>0.0030</td>
<td>0.0185</td>
<td>0.0338</td>
<td>0.0046</td>
</tr>
<tr>
<td>Project 4</td>
<td>0.0247</td>
<td>0.0238</td>
<td>0.0165</td>
<td>0.0220</td>
<td>0.0116</td>
<td>0.0080</td>
<td>0.0037</td>
<td>0.0354</td>
<td>0.0338</td>
<td>0.0460</td>
<td>0.0234</td>
</tr>
<tr>
<td>Project 5</td>
<td>0.0214</td>
<td>0.0189</td>
<td>0.0214</td>
<td>0.0214</td>
<td>0.0206</td>
<td>0.0214</td>
<td>0.0038</td>
<td>0.0115</td>
<td>0.0338</td>
<td>0.0460</td>
<td>0.0190</td>
</tr>
</tbody>
</table>

$A^+ = 0.0247, 0.0252, 0.0229, 0.0220, 0.0491, 0.0034, 0.0037, 0.0541, 0.0338, 0.0460, 0.0038$  
$A^- = 0.0181, 0.0189, 0.0032, 0.0020, 0.0037, 0.0030, 0.0015, 0.0038, 0.0046, 0.0190$  

Once the weighted normalization process was complete, the next step was to identify the PIS and NIS. These are referred to as $A^+$ and $A^-$ which are depicted in the last two rows of Table 4 above. The $A^+$ and $A^-$ are defined in terms of weighted normalized values. The separation measures (distance) between alternatives were then calculated using the n-Euclidean distance. The separation of each alternative from the PIS is given in Table 5 and the separation of each alternative from the NIS is given in Table 6.

### TABLE 5 SEPARATION MEASURES FOR PIS

<table>
<thead>
<tr>
<th>Project</th>
<th>$S^*_{A^+}$</th>
<th>$S^*_{B^+}$</th>
<th>$S^*_{C^+}$</th>
<th>$S^*_{D^+}$</th>
<th>$S^*_{E^+}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project 1</td>
<td>0.0725</td>
<td>0.0985</td>
<td>0.1008</td>
<td>0.0784</td>
<td>0.0909</td>
</tr>
</tbody>
</table>

### TABLE 6 SEPARATION MEASURES FOR NIS

<table>
<thead>
<tr>
<th>Project</th>
<th>$S^*_{A^-}$</th>
<th>$S^*_{B^-}$</th>
<th>$S^*_{C^-}$</th>
<th>$S^*_{D^-}$</th>
<th>$S^*_{E^-}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project 1</td>
<td>0.0776</td>
<td>0.0517</td>
<td>0.0577</td>
<td>0.0958</td>
<td>0.0729</td>
</tr>
</tbody>
</table>
The distance between the alternatives was conducted and all projects were ranked based upon the final output from the TOPSIS model. Project 4 was ranked the highest, with project 1 ranked second, and project 2 was ranked last. Table 7 shows the finals scores ranked in descending order.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Score</th>
<th>Project</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.5501</td>
<td>Project 4</td>
</tr>
<tr>
<td>2</td>
<td>0.5170</td>
<td>Project 1</td>
</tr>
<tr>
<td>3</td>
<td>0.4449</td>
<td>Project 5</td>
</tr>
<tr>
<td>4</td>
<td>0.3641</td>
<td>Project 3</td>
</tr>
<tr>
<td>5</td>
<td>0.3440</td>
<td>Project 2</td>
</tr>
</tbody>
</table>

5 CONCLUSIONS

The evaluation and prioritization of transportation projects for approved funding is a cumbersome and time-consuming process. Decision-making bodies often find themselves lobbying for projects that will benefit constituents in their regions of the community. However, without an unbiased automated process, these decision-makers often find themselves petitioning repeatedly. Hence, an effective evaluation approach is essential to improve the quality of decision-making. The proposed methodology used a simplified version of AHP in conjunction with TOPSIS and proved to be very useful in terms of efficiency and time-savings. The pair-wise comparisons are done once and the weighted criteria are used repeatedly each time decision-makers assemble to rank projects. The TOPSIS model can also used repeatedly and updated with new data each time a new project is entered for ranking. In addition, qualitative data from criteria and the difficulty in determining how to put concrete values for qualitative responses was addressed. This approach is unique in that few agencies have actually integrated these two MCDM methods for project ranking. Although the proposed model in this research is applied for transportation project ranking, it can also be applied to other decision-making problems such as material selection, maintenance project selection or even ranking various funding mechanisms.

6 REFERENCES


