Evaluating High Capacity Transit Projects in the Tucson Region:

Developing a Model Using the Analytical Hierarchy Process

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ABSTRACT

This focus of this study is the selection of criteria and development of a decision-making model to evaluate high capacity transit projects. The study begins with a literature review to identify criteria that indicate successful transit projects. Ideas for potential criteria were also obtained from the evaluation models from other communities. Based on the literature review, the author selected eleven priority evaluation criteria to use to develop a model. The Analytical Hierarchy Process was selected as the approach to develop the model because of its usefulness in translating subjective criteria into quantitative values. A model was created with four general criteria and eleven sub-criteria. Using the Analytical Hierarchy Process method for paired comparisons, a survey was developed to solicit opinions on criteria weights. Ten transit and transportation professionals from across the country agreed to complete the survey. Each respondent's survey data was tabulated using the specific Analytical Hierarchy method, and criteria weights were defined for each individual respondent. Next, the results of all respondents were averaged to define a final weight for each general criterion and each sub-criterion. The result is a partial model utilizing the Analytical Hierarchy Process. The method is a useful one for evaluating potential transit projects because: it can be utilized by diverse stakeholders; it utilizes qualitative values; it clearly shows the priority of the various criteria and; it is easy to readjust the priorities if values change.

INTRODUCTION

Purpose

The Tucson region is on its way to implementing its first high capacity transit system: a modern streetcar. As construction of the streetcar system begins, the region is looking ahead to consider other high capacity transit projects for inclusion in the *Regional Transportation Plan*. To plan for future transit, Pima Association of Governments (PAG), the region's Metropolitan Planning Organization (MPO), commissioned the firm of Kittelson & Associates, Inc. to conduct a study of high capacity transit alternatives. High capacity transit may have an exclusive or shared right-of-way, and is characterized as transit that operates at a higher speed, carries more passengers, and stops less frequently than bus service. The Kittelson study, *Final Report: High Capacity Transit System Plan*, *September 2009,* provided recommendations for the next phase of high capacity transit investment for the region.

The concept for this paper originated in discussions with PAG staff, who are looking ahead to the next phase of high capacity transit investment. PAG staff expressed an interest in obtaining more information about potential evaluation criteria for transit projects, and methods for prioritizing the criteria. The goal of this paper is two-fold. First, it will provide feedback on evaluation criteria for high capacity transit projects. Second, the paper will illustrate how the Analytical Hierarchy Process may be applied to transit corridor evaluation. This study includes:

- A review of literature relevant to the evaluation of high capacity transit corridors;
- A discussion of evaluation criteria and proposed list of criteria;
- Development of an Analytical Hierarchy Process (AHP) model;
- A survey of transit professionals to solicit their opinions on how the evaluating criteria should be weighted for the model; and
- Conclusions for application to future transit evaluation studies.

Planning Characteristics of the Tucson Region

Urban Form

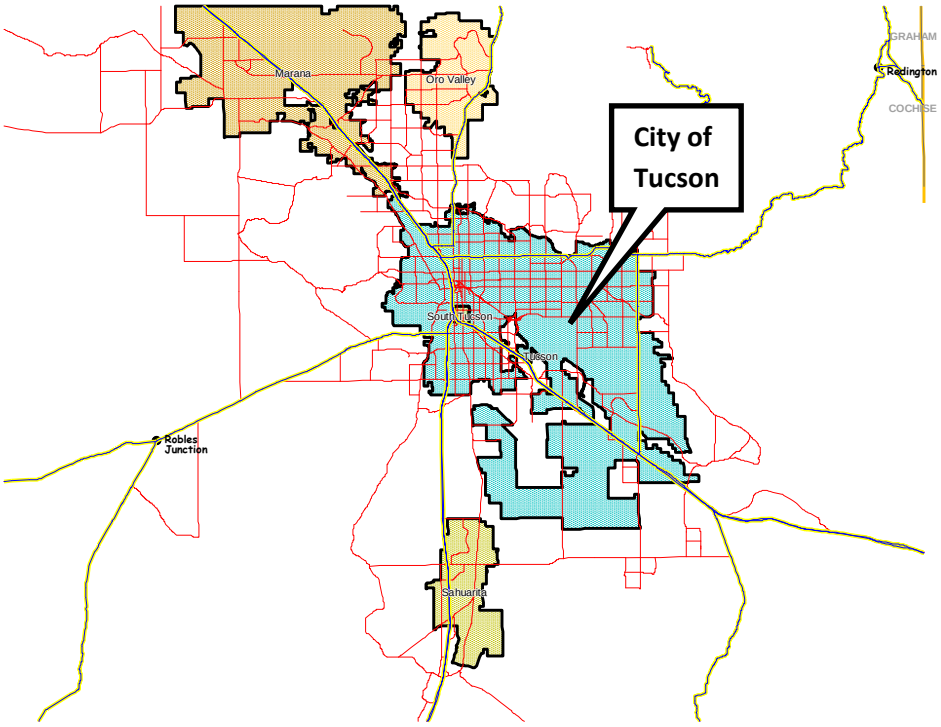
The City of Tucson is located in Pima County, Arizona. The region's planning area, also referred to as the Eastern Pima County region, is a large one, encompassing 9,189 square miles. It includes two cities, three towns, two tribal areas, and substantial unincorporated area. The City of Tucson currently encompasses approximately 195 square miles. The area's suburbs have not developed contiguously with the City; they are separated by unincorporated area. However, through annexations, the jurisdictions are expanding in area and becoming closer to each other.

The City of Tucson streets have developed in a grid pattern. The origin of this pattern the method of land surveying. Land was surveyed in one square mile sections, and major roadways have tended to develop along the section lines. The resulting street pattern is a large grid of major arterials, which have been filled in with collector and local streets.

Key physical characteristics that have influenced development include mountains and washes. There are major mountain ranges to the north, east, and west of the city that form a basin that channelizes the runoff into valley below. Storm water runoff travels is concentrated in these washes and riparian corridors. These washes and riparian corridors are distinctive visual features that influence the location of development and transportation facilities.

The City of Tucson's downtown hosts primarily government, services, and cultural and tourism-related employment. The University of Arizona, located northeast of downtown, is a major employer and generates much of the activity in the City's urban core.

FIGURE 1: Planning Region



Demographics

The 2010 population of the City of Tucson was 520,116 (US Census). The population of the greater Tucson area, or the Eastern Pima County region, is nearly one million. Table 1 below illustrates City of Tucson population growth between 1930 and 2010. The City has grown nearly ten-fold since 1950; a phenomenal 368% of Tucson's population growth occurred between 1950 to 1960.

TABLE 1: City of Tucson Population Growth Between 1930 and 2010 (Pima Association of Governments, US Census)

	Population	***% + or -***
1930	*32,506*	*60.2*
1940	*35,752*	*10.0*
1950	*45,454*	*27.1*
1960	*212,892*	*368.4%*
1970	*262,933*	*23.5*
1980	*330,537*	*25.7*
1990	*405,371*	*22.6*
2000	*486,699*	*20.1*
2010	*520,116*	*6.9%*

High Capacity Transit Planning in the Eastern Pima County Region

Long Range Transportation Plan

In May 2006, the Eastern Pima County region achieved a landmark accomplishment: the region's voters approved a twenty-year, long-range *Regional Transportation Plan*. The Plan included 2.1 billion dollars in multi-modal transportation investment through 2025. It is funded through a .5% county-wide sales tax and other sources, with fiscal oversight provided by a newly established Regional Transportation Authority. The Plan allocated 534 million dollars, or 27.5% of the allocated Plan cost, to transit investments. It included the region's first high capacity transit project: a 3.9 mile modern streetcar system.

The *Regional Transportation Plan* was recently updated to the year 2040. The 2040 Plan includes projects to further advance high capacity transit in the region: intercity rail from Tucson to Phoenix; bus rapid transit corridors; and expansion of the modern streetcar system.

High Capacity System Transit System Plan: Final Report

As the public anticipates the streetcar construction, officials and planners are looking ahead to the next phase of high capacity transit. In September 2009, PAG published the *PAG High Capacity Transit System Plan*, prepared by the firm of Kittelson & Associates, Inc. (1).The report summarized current transit technologies and conducted assessments of potential transit corridors by conducting a corridor-scale analysis of population and employment density for each transit technology. The outcome was a list of corridors paired with recommended High Capacity Transit (HCT) technology, yielding a list of potential HCT alternatives.

Next, the project team compiled a list of fifteen HCT evaluation criteria (Table 2, below). As the report notes, four criteria were determined to be "primary" and assigned substantially higher weights (weight between 5-10) than the other nine criteria (weight=1). The most heavily weighted criterion, Daily Ridership/Mile, is a measure of transit usage, and also an indicator of potential revenue, a cost factor. The other three most important criteria, ROW Availability, Capital Cost/Mile and Operating Cost/Mile are also cost factors. Cost factors account for 15 of the 36 total points, or 42%, indicating that cost is the highest priority criterion in this model.

TABLE 2 Summary of Evaluation Criteria from Kittelson & Associates, Inc., Model

Evaluation Criterion	**Weight**
Daily Ridership/Mile	**10**
ROW Availability	**5**
Capital Cost/Mile	**5**
Operating Cost/Mile	**5**
Consistency with Regional Plans and Policies	1
Impacts on Other Transit Services	1
Land Use Compatibility/TOD Potential	1
Access to Major Attractors/Generators	1
Roadway Mobility/Congestion Impact	1
Environmental Impact	1
Rail Owner/Operators Cooperation	1
Impact on Title VI & Transit-Dependent Populations	1

Bicyclist & Pedestrian Impact	1
Infrastructure Needs	1
Image	1
TOTAL WEIGHTS	**36**

This paper proposes an alternative approach; to focus on a shorter list of key transit indicators. The selection of the indicators will be based on the findings from a literature review. The purpose of developing a more simple model is so that the criteria weights are clearly defined, and the relationship between criteria is clear. In order to accomplish this, a technique must be selected for developing a model that includes a process for defining weighted evaluation criteria.

REVIEW OF LITERATURE OF TRANSIT PROJECT EVALUATION CRITERIA

General Considerations

Communities that plan for transit face the challenging task of selecting a limited number of projects from a wide range of potential corridors and system alternatives. Transit planning is a long-range process that is informed by factors that are likely to change over time. The transportation planning organization must engage the community and leaders in a decision-making process. At some stage in the process, evaluation criteria should be defined. The evaluation criteria must predict a successful outcome for transit in a specific corridor. The definition of "success" may vary, but a general goal is to develop a system that will result in a ridership level that meets agency goals for an acceptable cost.

This study begins with a literature search to identify the criteria that researchers have found correlates with successful transit. This is not intended to be a comprehensive review of all literature on the topic, but rather to cover a broad range of possible transit evaluation criteria.

Evaluation Criteria

Federal Transit Administration Project Evaluation Criteria

The Federal Transit Administration (FTA) manages the federal evaluation process for the selection and funding of high capacity transit projects. In the study *Cost Effective Transit Investments*, Deakin et al found that as most communities commence evaluation of potential transit corridors, the federal criteria are a starting point, but state and local policy objectives are also accorded strong consideration (2). Therefore, it is prudent to consider how federal criteria fit into the local evaluation process.

The FTA has developed a detailed methodology and specific evaluation criteria for transit project evaluation. These evaluation criteria are determined by federal legislation. The most recent legislation, SAFETEA-LU, continued the application of the evaluation criteria defined by the Transportation Equity Act for the 21st Century (TEA-21) in 1998. There are two primary programs for funding high capacity transit: New Starts and Small Starts. The New Starts program is the FTA's primary resource for funding fixed guideway transit projects that are locally planned and implemented. The Small Starts program provides resources for projects that are under $250 million, with fixed guideway for at least 50% of the project, or a bus corridor project that meets defined criteria.

The FY 2012 Evaluation Criteria note that projects selected for New Starts funding will be evaluated on the following criteria (3):

1. Mobility Improvements;
2. Environmental Benefits;
3. Operating Efficiencies;
4. Cost Effectiveness;
5. Transit Supportive Land Use;
6. Economic Development Effects; and
7. Other Factors (10).

Small Starts projects are evaluated on criteria 4., 5., and 6. In addition, federal legislation includes the directive that projects under each program be evaluated to determine if financing for construction, maintenance, and operations is sufficient, stable, and dependable. The evaluation criteria provided above also include several cost-related factors. So, not only must cost factors be considered, but the directive indicates that all the cost-related evaluation criteria must be subjected to a more rigorous analysis. emphasis on cost factors is now much higher than in the past.

Through TEA-21 legislation, Land Use has emerged as a key criterion in the federal evaluation process. The FY 2012 Evaluation criteria note the FTA explicitly evaluates Land Use and Economic Development Factors in project evaluation (10). The FTA's Land Use Factors include six criteria that are consistent with TOD principles, with an emphasis on existing TOD characteristics (4). The Economic Development Factors overlap with many TOD characteristics, but and emphasize implementation policies such as growth management, transit supportive corridor and zoning policies, and impact of transit on regional land use. Land use is now an important criterion in the federal evaluation process.

In summary, cost and land use are the highest priority criteria in the federal evaluation process. As the researchers Deakin et al noted, FTA project evaluation criteria are an important, but must be considered in conjunction with local goals and conditions (2). It is important to study these priority criteria, cost and land use, in more depth to understand how they can be applied to evaluate transit projects.

Mobility to Major Employment Centers

Transit systems provide an alternative to the automobile for people to access jobs. Deakin et al surveyed communities to determine what methods were used to evaluate transit projects. The authors concluded that supportive employment patterns should be a key consideration in evaluating transit investment (2). The authors also assessed New Starts criteria, and concluded that providing access to major job centers is the most realistic approach for attracting ridership (2). Providing transit access to redevelopment areas is also deemed important, but is secondary in comparison with access to employment areas.

The Center for Transit Oriented Development (CTOD) is a federally funded non-profit and national clearinghouse to research, evaluate, and promote best practices in transit-oriented development. The CTOD recently published two studies that address the impact of job sprawl and importance of linking employment centers with transit. *Transit Oriented Development and Employment* notes that recent studies conclude the presence of concentrated employment uses is the factor most closely associated with transit ridership (5). Authors Belzer et al note that the link between job patterns and transit planning has been underemphasized, and recommend that the integration of land use factors with employment be given higher emphasis in future transit planning. Based on these findings, the presence of concentrated employment uses should be included in this transit evaluation model.

Professor Reza Banai of the University of Memphis authored a paper that provides useful guidance for applying transit evaluation criteria to real-world decision-making. Banai studied the application of the Analytic Hierarchy Process (AHP) to transit route selection in Memphis. The paper

yields valuable information about the Analytical Hierarchy Process, which will be addressed later in this paper. It also provides valuable guidance for translating evaluation criteria into well-defined terms. For instance, the report defines a criterion of "Mobility to Employment" to characterize access to employment centers for the Memphis AHP model (6). The term mobility describes the ability and knowledge to access a desired destination for acceptable financial and time costs. Incorporating the term "mobility" is a useful way to describe transit service that provides a alternative travel mode for commuters at an acceptable cost. The term "Mobility to Employment" is an effective way to describe this tradeoff, and will be used in this model.

Mobility to Non-peak, Non-employment Activities

In their survey of transit agencies, Deakin et al noted that many agencies plan transit service to provide access to off-peak, non-employment destinations near key employment centers. The authors note that work trips constitute about 20% of total transit trips, whereas non-work trips account for about 80%. Such service planning enables transit providers to utilize available capacity during off-peak hours. The authors conclude that providing transit service for non-work trips may result in successful ridership, and suggest this factor be considered as an evaluation criterion (2).

The Tucson region has a large retiree and student population, two demographic groups that are may access more non-work activities at a higher rate than other groups. The factor *Access to Non-peak, Non-employment Activities* could be associated with high transit ridership in this region. The term "mobility" may be incorporated to describe the potential for desired and reasonable transit access to non-work destinations for acceptable time and cost. *Mobility to Non-peak, Non-employment Activities* will be used as an evaluation criterion in this model.

Mobility of Transit Dependent Residents

This criterion describes the provision of transit services to increase mobility for individuals with disabilities and/or low income, and senior citizens. Title VI of the 1964 Civil Rights Act requires that:

> "No person in the United States shall, on the ground of race, color, or national origin, be excluded from participation in, be denied the benefits of, or be subjected to discrimination under any program or activity receiving Federal financial assistance" (7).

Metropolitan planning organizations must ensure compliance with Title VI requirements in project development and planning. In addition, this criterion may identify transit services that will support the Jobs Access and Reverse Commute program objectives. Incorporating this criterion will help the MPO to meet these equity goals and requirements.

In their survey, Deakin et al found social objectives to be a high priority, but access to jobs is the primary objective (2). The research concluded that mobility for elderly, children, and individuals with disabilities is a desirable benefit of transit, but not strong choice for selection criteria. The Wasatch Front Regional Council (Salt Lake City region) included a criterion for Economic Access for Disadvantaged persons to jobs (8). Based on these perspectives, this factor should be included in the transit evaluation model, with an emphasis on access to jobs.

Transit-oriented Development

Land use patterns that support transit are critical to optimizing transit system utility. Land use is a key input to several different criteria, for instance the mobility criteria. To evaluate the mobility criteria at the corridor scale, one would measure residential and employment density based on land use factors.

Deakin et al found that many transit agencies give high priority to projects with transit-supportive land use patterns or plans (2). However, while existing land use patterns may support transit, the term "Transit-oriented Development" (TOD) specifically describes development linked with transit systems. The Center for Transit Oriented Development uses the term to mean planning, policies, and implementation of mixed use development that is highly coordinated with transit services and non-vehicular options, such as walking and bicycling facilities (5).

Based on this literature search, transit-oriented development is an important evaluation criteria for transit corridor evaluation. In addition, the Federal New Starts criteria emphasize existing and potential for transit-supportive land use. However, the literature points out the challenges of clearly defining TOD for evaluation criteria. According to Renne and Wells, while most agree TOD is critical to transit corridor success, there is a range of opinion as to what TOD really is, and true TOD is difficult to achieve (9).

The CTOD notes TOD is often defined as high-density, mixed-use development within a half mile walk of transit stations. A well-coordinated TOD program should create a rich mix of residential, shopping, and employment land uses, to provide households with transportation choices. Long-range corridor and station area planning is critical.

Deakin et al found that many transit agencies have hired staff to work with jurisdictions to facilitate critical land use planning and funding partnerships. The goal is to "develop a shared understanding of the area's transit needs and related development objectives"(2). Solid coordination between the transit agency and jurisdictions to set common goals and establish implementation methods is required to activate transit-oriented development.

Effective TOD is supplemented by policies, incentives, and public-private partnerships. Policies include tools for mixed-use zoning; affordable housing; and density bonuses. Incentives include parking management programs or economic development incentives. The CTOD and others note that public-private partnerships are critical to implement economic development planning and coordination of the more complex aspects of TOD, such as land assemblage, funding, and infrastructure investment (5). Of the six FTA New Starts Land Use Evaluation Criteria, one criterion defines land use goals; the other five criteria define TOD implementation tools, further emphasizing the importance of this criterion.

The difficulty in achieving TOD is outlined by Renne and Wells. They note that successful TOD relies on a synergy between mixed uses, but achieving the synergy is uncertain, complex, and costly (9). Expert leadership is required to navigate a complex regulatory environment. They conclude that many challenges block implementation of true TOD.

This discussion confirms there is a wide range of possible TOD: from infill development at limited sites, to the well-integrated program of Portland, Oregon. To evaluate transit in a community, it is important to consider how TOD should be defined in that community. Tucson is new to the TOD arena, and does not have strong models of successful mixed-use development. The definition of TOD needs to be calibrated to the possibilities that can exist in this region. Although TOD implementation varies widely, it is an important evaluation criterion that should be included in this model.

Local Plans and Policies

In its transit evaluation process, Portland, Oregon used the criterion "Local aspirations" to reinforce that implementable plans and leadership are needed at the local level to execute TOD (10). This criterion is consistent with New Starts program criterion "Economic Development Factors," which refers to policies and programs for implementing TOD. This criterion is consistent with "TOD implementation." Although this criterion is not incorporated in this model, it could be a sub-criterion under TOD.

Growth Management

The term "growth management" refers to development policies that direct growth to areas with existing services and infrastructure. The FTA New Starts Land Use Evaluation Criteria note growth management as a transit-supportive policy. This could be an important criterion for rapidly growing regions such as Tucson. Although the criterion is not included in this model, it should be considered for future transit evaluation efforts.

Traffic Congestion

Deakin et al noted that of twenty-eight communities, only three cited specific environmental factors as evaluation criteria (12). One such criterion is the potential for transit to mitigate traffic congestion. This measure has two benefits: 1. reduced impacts to air quality due to decreased vehicular use; and 2. energy conservation. In addition, transit services that preclude the need for roadway expansion result in cost savings. Traffic congestion was an evaluation criterion in the Memphis AHP and Portland models. It is a particularly important criterion for non-attainment air quality areas and is included in this model.

Economic Development

Deakin et al noted that projected economic impact of a transit corridor is a potential evaluation criteria. Economic development is also a priority under the New Starts program. As noted above, this factors is also generally consistent with the TOD implementation criterion. To use this criterion in a model, the planner must be able to evaluate it at the transit corridor scale.

Transit-Supportive Infrastructure

The full potential of a transit system cannot be achieved unless transit-supportive infrastructure is provided so passengers may efficiently access a transit stop. Deen and Pratt note that a boost to transit service is provided when the service is located within convenient walking distance of the traveler's ultimate origin or destination (11). Efficient pedestrian and bicycle access to and from transit stops enhances service. Existing or planned infrastructure is required.

A key element of transit-supportive infrastructure is block size and layout. It is a common observation that neighborhoods with traditional grid infrastructure have substantially more pedestrian traffic than neighborhoods with suburban layouts. Smaller blocks with multiple, interconnected roads enhance pedestrian connectivity. McDonough et al note that barriers to pedestrian access reduce effectiveness of transit-supportive infrastructure (12). Factors such as freeways, rivers, fences, or private streets create total impedance; steep grades, a fragmented street grid, or heavily congested arterials create partial impedance.

Transit-supportive infrastructure is a critical component of Transit-oriented Development, and is included in this model as a sub-criterion of Transit-oriented Development.

Proximity to Other Transit Services

Some communities incorporated the evaluation factor "Proximity to Other Transit Service" in evaluation models. The Portland, Oregon region uses a similar criterion: "integration with regional transit system." This criterion may could also be a data input for the analysis of Mobility to Employment Areas. It is not included in this model.

Impact to Sensitive Areas

The Wasatch Front Regional Council (Salt Lake City) included a criterion for impact to critical areas (8). This criterion denotes potential for a proposed transit system to negatively impact natural environments or man-made environments or landmarks. This criterion is also used to indicate whether a project is "fatally flawed": the assessment that a project will result in such high impact that it should not be considered. This criterion was used in the Kittelson & Associates, Inc. model (1).

Cost Factors

Deakin et al noted that of 29 communities, all but one transit agency used cost factors in project evaluations (2). Their study further noted that of cost factors, most agencies focused on capital costs and operating costs.

Operating Costs

Operating Costs is a standard criterion to include if cost factors are part of transit evaluation. Operating Costs are an input to measure of Operating Efficiency, which is included as a criterion for FTA New Starts evaluation.

Capital Costs

If cost factors are considered, Capital Costs is a standard evaluation criterion. Capital Costs are one component of the FTA New Starts evaluation criterion, Cost Efficiency.

Right-of-way Availability

Right-of-way availability is a factor in capital costs. It could be a stand-alone factor, or a sub-criterion of capital costs.

Potential Transit Ridership

This criterion is typically utilized under cost factors to indicate potential revenue generation from transit fares.

Conclusions

This literature review confirms several findings. First, there is a select group of evaluation criteria that can be applied to indicate successful transit outcomes. Second, most communities seek federal funding for transit projects, so the FTA evaluation criteria are relevant. Third, each community must consider its own unique values and incorporate them into the evaluation process. For instance, a particular economic development strategy may be supported by the provision of transit in a particular location. An effective transit evaluation model should incorporate all three elements.

Recommended Evaluation Criteria

Based on this literature review, eleven priority transit evaluation criteria were selected to develop a model. Table 3 lists each criterion, provides a description of the criterion, and indicates the justification for including the criterion in the model.

TABLE 3 Priority Transit Evaluation Criteria

Evaluation Criteria	Description	Justification for Use
Mobility to Major Employment Centers	Major Employment Centers may be in CBD's, more recently developed employment clusters, or developing suburbs.	Primary goal of successful transit is to provide alternative mode for daily commute and is the most reasonable approach to attracting ridership
Mobility to non-peak, non-employment activities	Includes sports, services, airport, entertainment, education.	Non-work trips account for a large percentage of trips, and utilize available transit capacity during off-peak.
Mobility of Transit Dependent Residents	Potential for transit dependent riders to access employment and services	Supported by New Starts Evaluation Criteria.
Presence or potential for Transit Oriented Development (TOD)	• Mixed land use: corridors with both housing and jobs • Mixed use zoning • High density, compact land use and zoning • Possible Station area sites • Development/redevelopment sites	Survey by Deakin et al indicated all agencies give high priority to land use. TOD/Land Use planning factors are gaining in importance from both community perspective and FTA New Starts.
Infrastructure	• Existing, planned, or potential transit supportive Infrastructure (Pedestrian and Bicycle) • Minimal barriers and impedance to access • Block or street grid pattern conducive to pedestrian access and safety	Lack of appropriate pedestrian/bicycle facilities and a supportive walking environment is a disincentive for transit use.
Roadway Congestion Mitigation	Potential for decreasing vehicular use and congestion, resulting in air quality benefits and energy saved.	Highly congested roadways may encourage transit use. Transit service in such corridors can decrease congestion and improve air quality. Referenced in New Starts.
Environmental Impact	High score indicates high level of risk of natural resource impact	Most communities include this criteria; may be considered as a "fatal flaw."
Capital Costs	Planning, engineering, and construction costs.	Feasibility of overall program.
Operating Costs	Labor, equipment, and maintenance costs .	FTA New Starts puts strong emphasis on cost effectiveness and operating efficiency
Available Right-of-way	Available ROW substantially decreases project capital cost, preludes additional land costs.	Typically included in cost factors.
Transit Ridership	Indicates potential for revenue generation.	Input into operating efficiency.

DEVELOP A DECISION-MAKING MODEL: THE ANALYTICAL HIERARCHY PROCESS

Decision-making Models

Cost Benefit Analysis

Cost benefit analysis is a well-known tool for evaluating alternatives that was commonly used in the 1960-1970's. With this method, direct financial benefits are quantified, and indirect community, economic, and social benefits of a transportation project are analyzed and quantified, as well. In their survey of community decision-making models, Deakin et al found that despite a 1994 Executive Order requiring cost-benefit analysis for all proposed federal investments, none of the agencies used this method (2). The authors conclude the method has fallen out of favor, likely due to the difficulty of accurately and completely quantifying costs and benefits.

Analytical Hierarchy Process

Background

The Analytical Hierarchy Process (AHP) method was developed by Thomas Saaty for the purpose of evaluating alternatives that factor into complex decisions (6). In the AHP method, a structure is created to manage and prioritize a broad range of considerations and factors that are relevant to a specific decision. The method is often used to assist corporate and government decision makers. In some applications, the method involves very complex mathematics.

The AHP method is based on a hierarchical model. To develop the AHP model, one first defines the problem or goal, then proceeds to define all possible criteria that should be considered. The criteria are sorted into general criteria; sub-criteria that are nested below the general criteria may be included. It is possible that a general criteria may have many sub-criteria, or none. To complete an AHP model, weights for each criteria must be defined.

The process for defining the weights is accomplished through paired comparisons. Each of the general criteria and sub-criteria are compared with each other. The stakeholder or survey respondent is taken through a survey and asked to compare each pair of criteria; to establish which is more important; and define its importance, or intensity, on a scale of 1 to 9 (13). The result is a table of scores that are calculated to define weights for each criteria. In a public decision-making forum, the scores of multiple respondents may be averaged to define overall weights. Political leaders, citizens, or professionals could all participate in defining criteria weights through the AHP process individually, or negotiated as a group (6). Since the weights are based on the values of the participants, there is no one perfect model. Once the weights for criteria are derived, the next step in is to define the alternatives or choices to be evaluated; these are integrated into the bottom of the model.

AHP is a well-accepted method for decision-making. However, it has its pitfalls: the survey respondent may provide inconsistent answers; inconsistencies must be addressed through statistical analysis; and model weights will vary based on the individual's values.

Selection of the AHP method

The application of AHP to transit corridor evaluation makes sense for several reasons. Professor Reza Banai described the application of AHP in the evaluation of transit corridors in Memphis. Banai noted that AHP is a helpful tool if decision makers are constrained by information, and need to use data in a more compensatory way, in a type of data fusion (author: unpublished data). The problem of evaluating

transit projects is a multi-criteria one, and could be approached in many different ways. Banai concluded that AHP was relatively easy to use for transit corridor evaluation, even with incomplete information (6). He found the predictions from AHP proved to be consistent with other processes. A quick internet search of the terms "Analytical Hierarchy Process" and "transportation" indicate AHP is achieving wider application to transportation problems. For these reasons, it made sense to use it for this model.

Develop an AHP Model

An AHP model may include both general and sub criteria. To develop this AHP model, the list of Priority Transit Evaluation Criteria was reviewed (Table 3). From this list, groupings emerged: general criteria, or headings, were created for these groups. For instance, several criteria related to mobility, and several to environmental factors. TOD merited sufficient importance to establish a third general criteria. Based on the literature review, the TOD category could be split into two criterion, land use/development and infrastructure, so those categories formed sub-criteria. The fourth general criteria was Cost Factors. Table 4 shows how the secondary criteria are grouped under each General Criterion.

TABLE 4 General and Secondary Criteria

General Criterion: Mobility Improvements
Secondary Criteria
Mobility to Major Employment Centers
Mobility to non-peak, non-employment activities
Mobility of Transit Dependent Residents

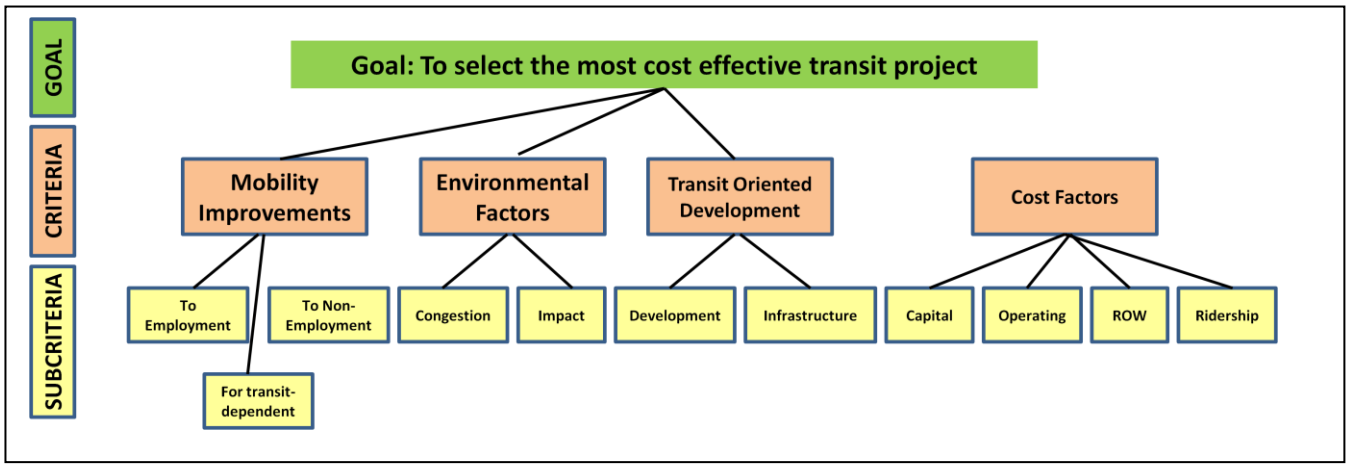
General Criterion: Presence of or potential for Transit Oriented Development
Secondary Criteria
Land Use and Development
Infrastructure

General Criterion: Environmental Factors
Secondary Criteria
Roadway Congestion Mitigation
Environmental Impact

General Criterion: Cost Factors
Secondary Criteria
Capital Costs
Operating Costs
Available Right-of-way
Transit Ridership

Figure 2 depicts the final model in the hierarchical AHP structure. The project goal equates to the problem to be solved, or decision to be made. The general criteria are shown in orange, with its associated sub-criteria in yellow.

FIGURE 2 AHP Model



Develop and Administer the Survey

In an AHP model, the criteria weights are derived from surveys in which respondents evaluate the importance of paired criteria. In a real-world application, citizens, professionals, or elected officials might be asked to take the survey to provide their opinions on criteria for ranking transit projects. For this study, a group of transit and planning professionals was selected from regions that are either comparable in size to the Tucson region, recently undertook a transit evaluation exercise, or are currently implementing high capacity transit. In this "non-probabilistic" selection method, judgment rather than random sampling was used to gather the samples. Of eighteen individuals invited to participate, ten completed the survey. Table 5 is a list of the cities with staff that completed the survey. This collection of completed surveys forms a cross-section of opinions from the country's transit and transportation professionals.

TABLE 5 Survey Participants

City/Region	Agency	Reason for selection	Survey participant background
Arizona			
Tucson, Arizona	Tucson Department of Transportation	Construction begun on a modern streetcar system.	Transportation Planner
Phoenix, Arizona	Maricopa Association of Governments	Regional light rail, planned streetcar.	Manager System Programming
Flagstaff/N. AZ	Northern Arizona COG	Bus Rapid Transit planned.	Mobility Management Planner
South			
Tampa, Florida	Hillsborough Area Rapid Transit	Comparable population, also a high growth area	Service Planning Manager
Memphis, TN	Memphis Area Transit Authority	Used AHP for transit decisions	Manager of Planning
West			
Albuquerque, New Mexico	Metro Regional Council of Governments	Albuquerque deemed a "peer city" to Tucson - located in the Southwest; similar size; and rapid, high recent, growth rate.	Project Manager
Salt Lake City, Utah	Wasatch Front Regional Council	Region recently went through an evaluation process for high capacity transit	Transportation Planner
Denver, Colorado	Denver Regional COG	Region has light rail system	Long Range Transportation Planner
Oklahoma City, Oklahoma	Central Oklahoma Transportation and Parking Authority	Streetcar planning underway.	Planning Manager
Northeast			
Hartford, Connecticut	Capitol Region COG	Constructing Bus Rapid Transit system.	Transportation Planner

CONCLUSIONS

Data Analysis

Each survey was individually tabulated using the AHP method. Under this method, a table is created for each criteria group, and the criteria are listed in both row and column (6, 14.) To tabulate an individual's survey, scores are filled in from the paired comparisons: of the paired criteria, the criterion deemed most important is assigned an "intensity of importance" score of a whole number, and the criterion deemed less important is assigned an "intensity of importance" score as a fraction, as shown in Table 6A. This process is at first confusing, but soon becomes intuitive. The numbers in the table are totaled by column. Next, the values are normalized or standardized, also called obtaining the "Eigen Vector" (14). To normalize, a table with the criteria in rows and columns is set up again. Each value from Table 6A is divided by the column total from Table 6A. This yields a second table of normalized criteria values. Finally, the criteria are averaged by row, yielding the individual survey respondent's final, weighted criteria in the right hand column. These weights add up to 1.0. The process is repeated for all the sub-criteria.

TABLE 6A: Results of Paired Comparisons

General Criteria

	Mobility	Environmental	TOD	Cost
Mobility	1	7	5	5
Environmental	1/7	1	1/3	1/3
TOD	1/5	3	1	3
Cost	1/5	3	1/3	1
Total	**1.54**	**14.00**	**6.67**	**9.33**

TABLE 6B: General Criteria: Normalized

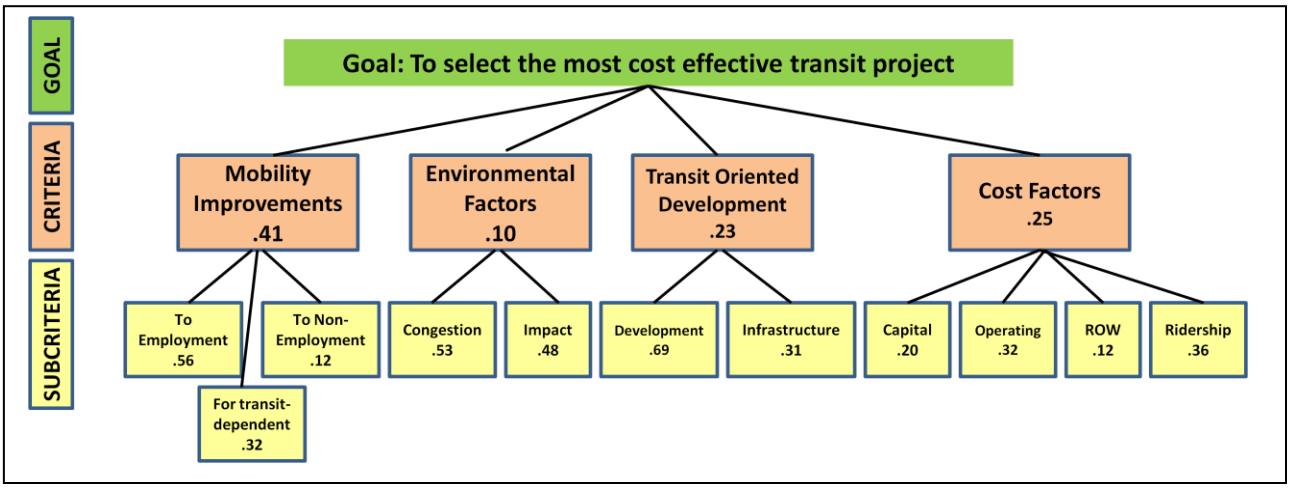
	Mobility	Environmental	TOD	Cost	Weight Avg
Mobility	0.648	0.500	0.750	0.536	0.608
Environmental	0.093	0.071	0.050	0.036	0.062
TOD	0.130	0.214	0.150	0.321	0.204
Cost	0.130	0.214	0.050	0.107	0.125
Total	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**

The individual survey results yield weights for each general criteria and sub-criteria, as shown in Table 7. After the results were tabulated for each individual survey, an average was obtained of all scores.

TABLE 7 Complete Survey Results

	Tucson	Hartford	Phoenix	Denver	Salt Lake City	Albuquerque	OK City	Tampa	Flagstaff	Memphis	**Average**
GENERAL											
Mobility Factors	0.53	0.61	0.56	0.17	0.51	0.50	0.25	0.17	0.16	0.59	**0.41**
Environmental Factors	0.08	0.06	0.13	0.27	0.15	0.16	0.04	0.05	0.05	0.05	**0.10**
Transit Oriented Development	0.23	0.20	0.12	0.10	0.07	0.08	0.60	0.43	0.41	0.10	**0.23**
Cost Factors	0.11	0.13	0.19	0.46	0.28	0.26	0.11	0.35	0.38	0.26	**0.25**
MOBILITY											
To Major Employment	0.59	0.48	0.45	0.33	0.77	0.63	0.75	0.65	0.18	0.78	**0.56**
To non-employment	0.08	0.11	0.23	0.12	0.09	0.11	0.16	0.06	0.11	0.15	**0.12**
For Transit-dependent	0.33	0.41	0.32	0.55	0.14	0.26	0.09	0.29	0.70	0.07	**0.32**
ENVIRONMENTAL											
Congestion mitigation	0.75	0.25	0.50	0.75	0.83	0.83	0.17	0.67	0.25	0.25	**0.53**
Environmental Impact	0.25	0.75	0.50	0.25	0.17	0.17	0.83	0.33	0.75	0.75	**0.48**
TOD											
Land Use/Devel	0.50	0.17	0.83	0.75	0.75	0.75	0.88	0.75	0.67	0.88	**0.69**
Infrastructure	0.50	0.83	0.17	0.25	0.25	0.25	0.13	0.25	0.33	0.13	**0.31**
COST											
Capital	0.31	0.17	0.13	0.48	0.21	0.28	0.13	0.15	0.13	0.05	**0.20**
Operating	0.24	0.36	0.22	0.21	0.05	0.22	0.45	0.44	0.45	0.57	**0.32**
Right-of-Way	0.05	0.10	0.13	0.10	0.18	0.16	0.14	0.07	0.14	0.11	**0.12**
Ridership	0.40	0.36	0.52	0.21	0.56	0.33	0.27	0.35	0.27	0.27	**0.36**

FIGURE 3 Partial Transit Evaluation Model



Analysis of Results

Table 7 presents the averaged values of the ten individual survey scores. The averaged weights became the final general criteria and sub-criteria weights for this model. Figure 3 represents the final, partial Transit Evaluation Model with weighted criteria. The AHP tabulation method ensures that the total of the scores for each criteria and sub-criteria category is equal to one.

The results show that of General Criteria, Mobility Improvements ranks as the highest priority criteria, with a value of .41. Transit-oriented Development and Cost Factors rank a close second, at .23 and .25, respectively. Environmental Factors ranked as the least important criteria for evaluating transit projects, at .10. The results of this model provide a well-defined hierarchy of criteria. This model is substantially different from the Kittelson & Associates model, which assigned the highest priority to cost factors.

Ten surveys is too small a sample to be statistically analyzed with confidence. An assessment of the results shows a fairly wide range of individual values in the Mobility category; four respondents ranked this criterion at .25 or less. The values for Environmental Factors fall within a narrow range of .04 to .27. Two respondents indicated that Transit-oriented development should be the most important criterion. Only one participant valued Cost Factors as most important.

In the Mobility Improvements category, Mobility to Employment is ranked highest at .56. This conclusion supports the findings of the literature review, in which access to employment was defined as the primary indicator of successful transit. Mobility for Transit-dependent individuals is second highest at .32, and is clearly of higher priority than the third criterion, mobility to non-employment destinations, which achieved a weight of only .12. It is important to understand that Mobility for Transit-dependent individuals is a priority; such transit service can support important community development goals, as well as federal Title VI requirements.

Under the Environmental Factors criteria, Congestion Mitigation and Environmental Impact are closely ranked, at .53 and .48, respectively.

Under the Transit-oriented development category, Land use/Development is ranked at .69, and infrastructure at .31. Transit-oriented development was consistently ranked highest; only one respondent ranked Infrastructure higher than Land Use.

Of the Cost Factors, Operating Costs and Potential Ridership ranked highest. These factors each represent cost and revenue generation potential of an operational system. Capital and ROW costs ranked lower. Overall, this indicates that generally, the survey participants felt that operating costs and revenues are more important criteria for evaluating a transit project than initial capital costs.

In a complete AHP model, a third row of potential transit project alternatives is added to the model (6). A series of rating intensity is defined for each criterion. For instance, Mobility to Employment might include three rating intensities: Low mobility, Moderate Mobility and High Mobility. There are various methods for applying scores based on rating intensity. The score would then be multiplied by the sub-criteria and general criteria weights, for a final project score.

Lessons Learned

The AHP process was relatively easy to apply, and proved to be an effective method to assign numerical values to subjective criteria. In a real world decision-making process, professionals, elected officials, or other stakeholders could provide their opinions that would be used to develop a model to rank transit projects. As Banai notes, the purpose of the model is to help planners structure the transit decision-making process so that federal criteria are incorporated, local priorities are clarified, and decisions are made in a transparent process (6).

In the early stages of defining this project, PAG staff expressed interested in obtaining additional information on evaluation criteria and approaches to evaluating transit projects. They wanted to know if all critical factors were considered, and thought it would be helpful to conduct an evaluation of transit projects that was unconstrained by cost factors. The model in this study was based on current research that identified key criteria correlated with successful transit. With the assistance of a group of transit professionals, a set of clearly-defined, weighted criteria for evaluating transit projects was obtained. The opinions of this group substantiate the results of the research, and concluded that Mobility Factors, not Cost Factors, should be the highest priority criteria. The advantage of the AHP method, with its grouped criteria, is that it can easily accommodate a change in weights; for instance, the Cost Factors criteria could be eliminated. In fact, AHP is a flexible method and could be an effective one for defining transit evaluation criteria for the Tucson region.

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