*2015 AMPO Annual Conference*
*October 20 – 23, 2015  Clark County, Nevada*
*Performance Measures – Part 2:  October 21, 2015  2:15 PM to 3:45 PM*

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# Portfolio Optimization Using Multiple Scoring Techniques

## A Case Study by the Pikes Peak Area Council of Governments

Pikes Peak Area Council of Governments
Communities Working Together

HDR

01 Multiple Criteria Decision Making

02 Weighted Score Method (WSM)

03 Analytic Hierarchy Process (AHP)

04 Technique of Order Preference by Similarity to Ideal Solution (TOPSIS)

05 Logic Scoring of Preference (LSP)

06 Selecting a MCDM Methodology

"A key feature of MAP-21 is the establishment of a performance- and outcome-based program. The objective of this performance- and outcome-based program is to invest resources in projects that collectively make progress toward the achievement of the national goals."

*https://www.fhwa.dot.gov/map21/factsheets/pm.cfm*

# 01 Multiple Criteria Decision Making

# Issues in Methods

- **Multiple investments can address the same need**
- **Some projects that do one thing well but can work against progress in other goals**
- **Some investments can work together to multiply effectiveness**
- **Some investments can work against each other**

## "Collectively…"

- Plans and TIPs are both portfolios of transportation investments

## "…national goalS…"

- Performance Scoring based on addressing multiple need areas

# PPACG Portfolio Optimization and Project Selection

- Many public investment decisions involve multiple objectives and goals
- Multiple Criteria Decision Making (MCDM) are used to rank and select among investment choices
- Basic input requirements to MCDM include:
  - **Evaluation criteria** that support identified goals and performance measures
  - **Scoring** of projects for all evaluation criteria
  - **Weighting** for all identified evaluation criteria

## PPACG Pairwise Comparison-Based Evaluation Criteria Weighting

| Evaluation Criteria | Weight | Normalized Weight |
|---|---|---|
| Preservation & Rehabilitation | 12.2 | 0.1220 |
| Mobility & Congestion Reduction | 10.2 | 0.1020 |
| Cost Effectiveness | 8.6 | 0.0860 |
| System Connectivity | 9.0 | 0.0900 |
| Safety | 10.9 | 0.1090 |
| System Security | 7.0 | 0.0700 |
| Environmental Justice | 5.2 | 0.0520 |
| Adverse Impact Reduction | 6.4 | 0.0640 |
| Economic Vitality & Freight Movement | 8.0 | 0.0800 |
| Infill & Redevelopment | 5.5 | 0.0550 |
| Protect Wildlife Habitat | 3.8 | 0.0380 |
| Protect Streams and Reduce Stormwater Runoff | 7.3 | 0.0730 |
| Air Quality | 5.9 | 0.0590 |

# PPACG Portfolio Optimization and Project Selection

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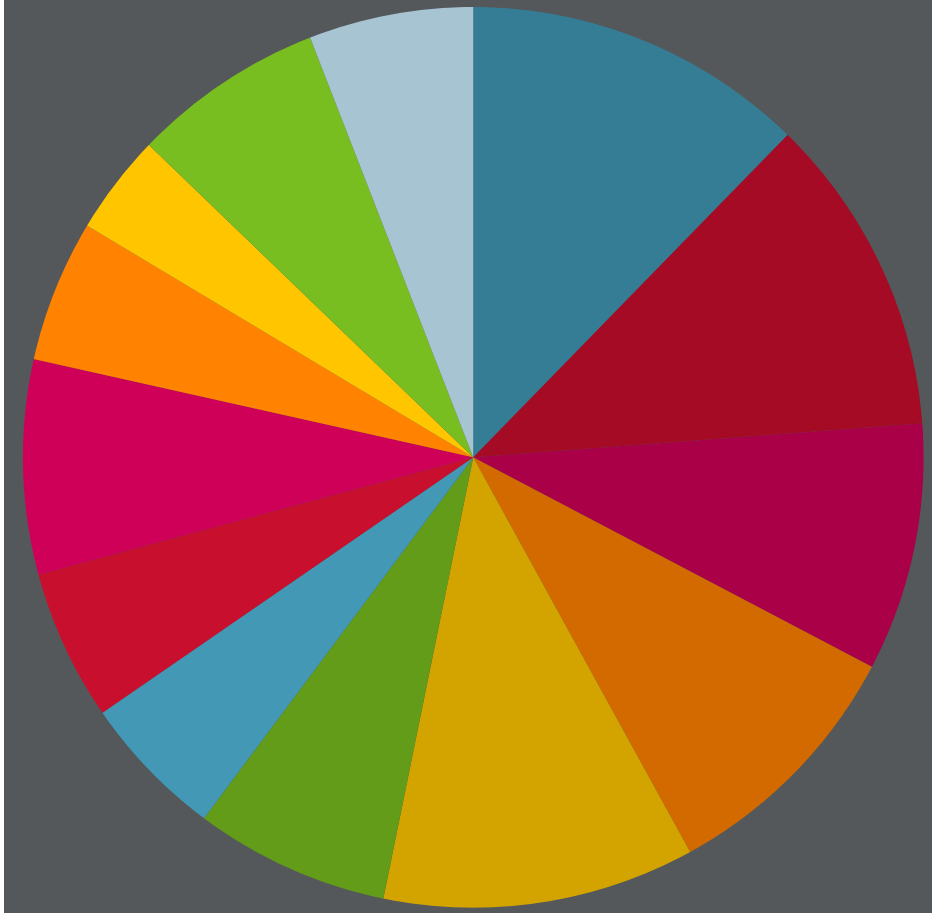
## PPACG Pairwise Comparison-Based Evaluation Criteria Weighting



# Multiple Criteria Decision Making Methods

- **W**eighted **S**core **M**ethod (WSM) 1940s
  - Simplest method, method currently used by the PPACG
- **A**nalytic **H**ierarchy **P**rocess (AHP) 1970s
  - **F**ocus on **R**anking **P**references
  - **U**se of **P**airwise **C**omparison
- **T**echnique of **O**rder **P**reference by **S**imilarity to **I**deal **S**olution (TOPSIS) 1981
  - Provides evaluation criteria flexibility (qualitative, quantitative, benefit and cost measures) can be evaluated together)
- **L**ogic **S**coring of **P**reference (LSP) 1996
  - Mimics flexibility of human decision making process – can specify degree to which multiple criteria should be met jointly versus independently

# Commonalities in Methods

- Determining **criteria** for the project scoring
- Determining **weight for each criteria**
  - Stated Preference Surveys
  - Analytical Hierarchy Process
- Obtaining the **score of project i for each criteria j for all i and j**

  •
  •
  •
- **Ranking projects**
- **Cutting projects** based on rank

The Analytic Hierarchy Process [1] is a structured decision-making technique in which a complex decision problem is broken into a hierarchy of more easily understood sub-problems that can be solved independently.

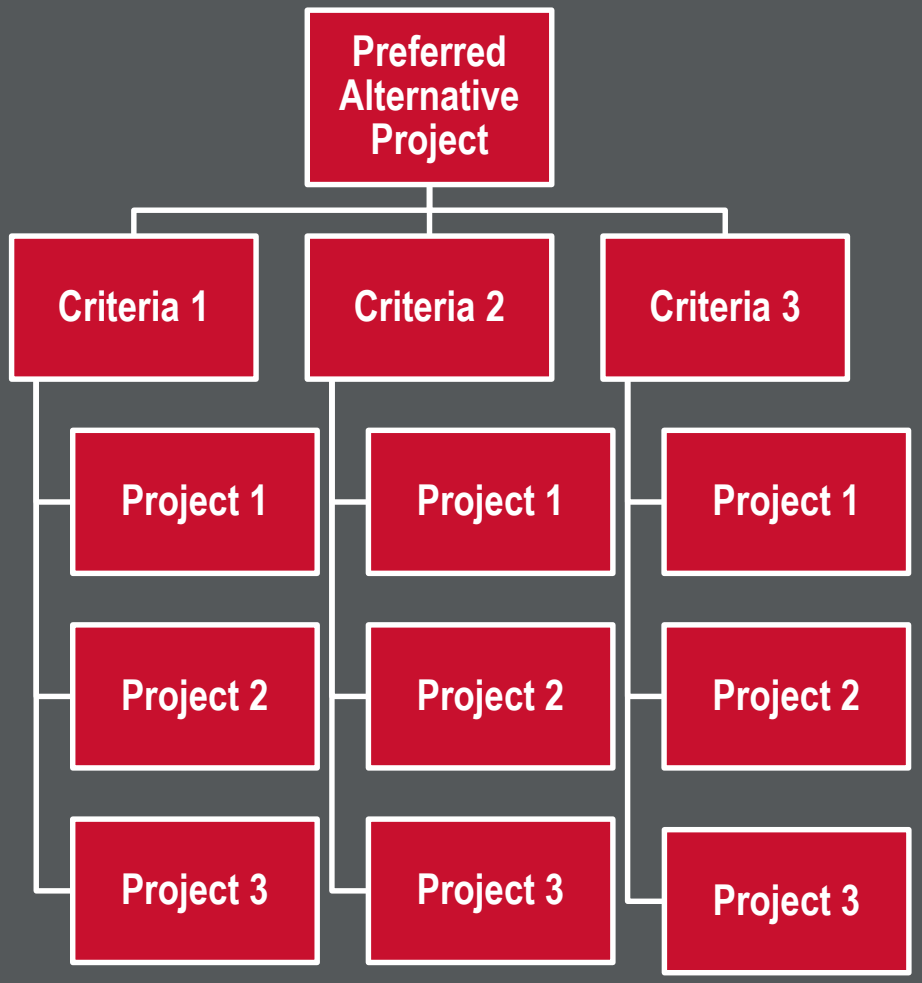
[1] *Thomas L. Saaty, 1980*

# 02 Analytic Hierarchy (AHP) Process

# Applying the Analytic Hierarchy Process

1. **M**odel the **P**roblem as a **H**ierarchy containing the following:
   - Decision Goal
   - Alternative Solutions
   - Criteria for Evaluating Alternatives
2. **E**stablish **P**riorities – develop ranking/weighting among hierarchical elements
3. **C**reate **S**et of **O**verall **P**riorities – compute weighted scoring
4. **C**heck **C**onsistency – of weighted scoring results
5. **M**ake **F**inal **D**ecision

**A Simple AHP Hierarchy:**
Selecting One Project from Three Alternatives Using Three Criteria



# Decision Problems Suitable for AHP Applications:

- **C**hoice of **P**referred **A**lternative
- **R**anking of **A**lternatives
- **P**rioritization of **S**et of **A**lternatives
- **R**esource **A**llocation
- **B**enchmarking
- **Q**uality **M**anagement
- **C**onflict **R**esolution

# Pairwise Comparison

- Used to establish ranks among project selection criteria
- Used to develop weighting – based on rank – for project selection criteria
- Final weighting is used to compute weighted scores for alternative projects

Pairwise Comparison [2] refers to any process of comparing alternatives in pairs to "judge" which alternative is the "preferred."

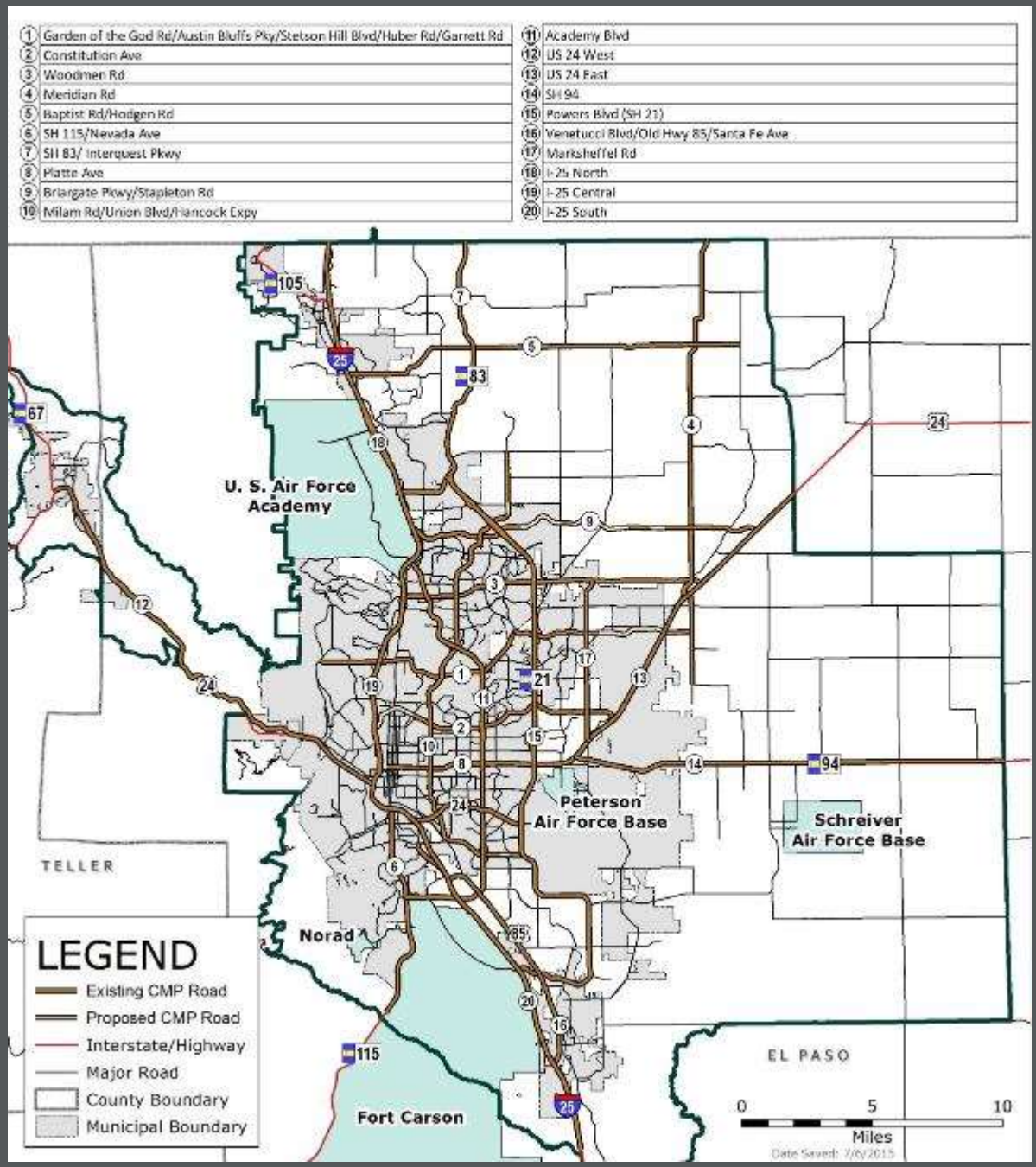
[2] *Law of Comparative Judgment; L.L. Thurstone, 1927.*

# PPACG Pairwise Comparison Application

For the 2017 Transportation Improvement Program (TIP) PPACG reevaluated Project Evaluation Criteria using Pairwise Comparison to develop refined weights.

| Evaluation Criteria | 2040 RTP Weighting | 2017 TIP Weighting |
|---|---|---|
| Preservation & Rehabilitation | 12.2 | 12.2 |
| Mobility & Congestion Reduction | 11.4 | 10.2 |
| Cost Effectiveness | 8.9 | 8.6 |
| System Connectivity | 9.3 | 9.0 |
| Safety | 11.2 | 10.9 |
| System Security | 7.0 | 7.0 |
| Environmental Justice | 5.2 | 5.2 |
| Adverse Impact Reduction | 5.4 | 6.4 |
| Economic Vitality & Freight Movement | 7.7 | 8.0 |
| Infill & Redevelopment | 5.1 | 5.5 |
| Protect Wildlife Habitat | 3.6 | 3.8 |
| Protect Streams and Reduce Stormwater Runoff | 6.9 | 7.3 |
| Air Quality | 5.9 | 5.9 |

# PPACG Project Location Map



# 03 Weighted Score Method (WSM)

# Weighted Score Method

- **Simplest methodology**
- Uses **multiple criteria** and **criteria weighting**
- Requires **consistent scale** for criteria scoring: either more is better (benefits) or less is better (costs)
- Best used to evaluate **stand-alone projects** using transportation and non-transportation performance measures
- Has **limited utility for portfolio optimization** - identification of the “best set of projects”

# Weighted Score Ranking Process

- Obtain the **scores** for each project i using criteria j for all i and j
  - **Use consistent scale** for all criteria: More is better or less is better
  - **Use consistent score range** for all criteria: The same score range or normalized scoring
- Compute the **sum of the weighted scores** for each project
- **Rank** projects by order of sum of the weighted scores
- **Cut** the selected projects list based on available funding

# Weighted Score Method Top Ranked Projects

| Rank | ID# | Project Name | Sponsor | Eligible Funding |
|---|---|---|---|---|
| 1 | 21 | Black Forest Road Improvements | El Paso County | Safety, STP-Metro, FASTER |
| 2 | 27 | Briargate Pkwy/ Stapleton Rd Connection | Fountain | PPRTA, STP-Metro, FASTER |
| 3 | 142 | Squirrel Creek Road Extension (Phases 2 and 3) | Colorado Springs and CDOT | STP-Metro |
| 4 | 110 | Powers Blvd. (SH 21) Widening | CDOT | STP-Metro |
| 5 | 72 | I-25 HOV Lanes | Colorado Springs | 7th Pot/FASTER |
| 6 | 123 | Route 6 Phase 4 Enhancements | El Paso County | TAP |
| 7 | 10 | Academy Blvd. | Colorado Springs | Bridge-On, Bridge-Off, STP-Metro, Safety, FASTER |
| 8 | 116 | Route 1 and 7 Phase 2 Enhancements | Colorado Springs | TAP |
| 9 | 120 | Route 16 Phase 2 Enhancements | Colorado Springs | TAP |
| 10 | 117 | Route 12 Phase 4 Enhancements | Colorado Springs | TAP |
| 11 | 121 | Route 6 Phase 2 Enhancements | CDOT | TAP |
| 12 | 105 | Powers Blvd. (SH 21) Freeway | El Paso County and Fountain | |
| 13 | 91 | Mesa Ridge Parkway Extension: Powers Blvd to Marksheffel Road | El Paso County | STP-Metro/PPRTA |
| 14 | 62 | Garrett Road | Colorado Springs | Safety, STP-Metro, FASTER |
| 15 | 6 | 8th Street Corridor Improvement Project | El Paso County | STP-Metro |

# 04 Technique of Order Preference by Similarity to Ideal Solution (TOPSIS)

# TOPSIS Method

- Supports evaluation of three criteria types:
  - Qualitative benefits
  - Quantitative benefits
  - Cost attributes or criteria
- Can be used to evaluate **benefits** (more is better), **costs** (less is better) or both
- Ranks projects based geometric distance (proximity) to the **ideal** project and (separation) from the **negative ideal** project, where:
  - The **ideal** alternative/project has the best score for all criteria
  - The **negative ideal** alternative/project has the worst score for all criteria

# TOPSIS Ranking Process

- Construct **normalized score** decision matrix
- Construct **weighted, normalized score** decision matrix
- Determine **ideal and negative ideal** projects
- Calculate **separation measures** (from ideal and negative ideal) for each project
- Calculate **measures of relative closeness to ideal** for each project
- **Rank** projects by order of closeness to the ideal project
- **Cut** projects from the selected projects list based on available funding

# TOPSIS Top Ranked Projects

| Rank | ID# | Project Name | Sponsor | Eligible Funding |
|---|---|---|---|---|
| 1 | 72 | I-25 HOV Lanes | CDOT | 7th Pot/FASTER |
| 2 | 27 | Briargate Parkway/ Stapleton Road Connection | El Paso County | PPRTA, STP-Metro, FASTER |
| 3 | 142 | Squirrel Creek Road Extension (Phases 2 and 3) | Fountain | STP-Metro |
| 4 | 136 | SH 85 Widening | CDOT | |
| 5 | 210 | US 24 West/Ridge Road Overpass | CDOT | |
| 6 | 40 | Dublin Road Widening: Peterson Road to Marksheffel Road | Colorado Springs | STP-Metro |
| 7 | 91 | Mesa Ridge Parkway Extension: Powers Blvd to Marksheffel Rd. | El Paso County and Fountain | STP-Metro/PPRTA |
| 8 | 62 | Garrett Road | El Paso County | Safety, STP-Metro, FASTER |
| 9 | 110 | Powers Boulevard (SH 21) Widening | Colorado Springs and CDOT | STP-Metro |
| 10 | 74 | I-25 Widening | CDOT | 7th Pot/FASTER |
| 11 | 115 | Powers Boulevard: SH 83 to I-25 (at Northgate Rd) | Local, Private, CDOT | Local, Private, FASTER |
| 12 | 111 | Powers Boulevard (SH 21) Widening | CDOT | |
| 13 | 205 | US 24 East Widening | CDOT | |
| 14 | 113 | Powers Boulevard (SH 21)/Stewart Interchange | CDOT | |
| 15 | 71 | Highway 105 | El Paso County | Safety, STP-Metro, FASTER |

# 05 Logic Scoring of Preference (LSP)

# LSP Method

- Mimics human brain's decision making process
- Uses full continuum of logic functions OR (Yes/No) through AND to capture interdependencies among criteria and projects
- Requires construction of a decision model upfront – preference aggregation structure
- The model results are as good as the decision model – construction requires a collaborative process such as that used to develop evaluation criteria weighting

# LSP Logic Function Continuum

| Name | Symbol | c, 1-q | d,q | $r_2$ | $r_3$ | $r_4$ | $r_5$ |
|---|---|---|---|---|---|---|---|
| DISJUNCTION (OR) | D | 0.0000 | 1.0000 | + ∞ | + ∞ | + ∞ | + ∞ |
| STRONG QD (+) | D++ | 0.0625 | 0.9375 | 20.63 | 24.30 | 27.11 | 30.09 |
| STRONG QD (-) | D+- | 0.1250 | 0.8125 | 5.802 | 6.675 | 7.316 | 7.819 |
| MEDIUM QD | DA | 0.2500 | 0.7500 | 3.929 | 4.450 | 4.825 | 5.111 |
| WEAK QD | D- | 0.3750 | 0.6250 | 2.018 | 2.187 | 2.302 | 2.384 |
| SQUARE MEAN | SQU | 0.3768 | 0.6232 | 2.000 | | | |
| ARITHMETIC MEAN | A | 0.5000 | 0.5000 | 1.000 | 1.000 | 1.000 | 1.000 |
| WEAK QC | C-- | 0.5625 | 0.4375 | 0.619 | 0.573 | 0.548 | 0.526 |
| GEOMETRIC MEAN | GEO | 0.6667 | 0.3333 | 0.000 | | | |
| WEAK QC (+) | C-+ | 0.6875 | 0.3125 | -0.148 | -0.208 | -0.235 | -0.251 |
| HARMONIC MEAN | HAR | 0.7726 | 0.2274 | -1.000 | | | |
| STRONG QC (-) | C+- | 0.8750 | 0.1250 | -3.510 | -3.114 | -2.823 | -2.606 |
| STRONG QC (+) | C++ | 0.9375 | 0.0625 | -9.060 | -7.639 | -6.689 | -6.013 |
| CONJUNCTION (AND) | C | 1.0000 | 0.0000 | -∞ | -∞ | -∞ | -∞ |

# LSP Logic Function Example - Advantages

- Simple Binary logic - YES = 1 or 100%; NO = 0 or 0%
- For a simple weighted average of three projects:
  Total Preference = w1 *S1 + w2*S2 + w3*S3
- The scores (S's) and the weights (w's) have no logic:
  Weight (w) choices are ad hoc and the preference for one project or another can be just YES or NO (1 or 0 ), no matter what is the score.
- Results can be severely biased and do not link AND with OR preferences; the choices are still only YES or NO:
  Thus, if you want to "AND" (or add an EXTREMELY NECESSARY criterion for choosing), or if you want to append a useful but not extremely necessary criterion say A "OR" B, both of these functions lack the "MAYBE" character. A preference could be 65% A "AND" B and 35% A "OR" B.

# LSP Method

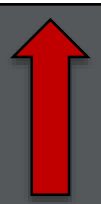
- Mimics human brain's decision making process
- Uses full continuum of logic functions OR (Yes/No) through AND to capture interdependencies among criteria and projects
- Requires construction of a decision model upfront – preference aggregation structure
- The model results are as good as the decision model – construction requires a collaborative process such as that used to develop evaluation criteria weighting

# Formal Logic Tables (YES=1, NO =0)

| A | B | A "AND" B |
|---|---|---|
| 0 | 0 | 0 |
| 1 | 0 | 0 |
| 0 | 1 | 0 |
| 1 | 1 | 1 |

ONLY YES ( APPEND) IF ALL CHOICES ARE 100% IN FAVOR

| C | D | C "OR" D |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 1 |
| 1 | 0 | 1 |
| 1 | 1 | 1 |



IF ANY CHOICE IS YES, THAT CHOICE CONTROLS THE RESULT.

LIFE IS JUST NOT THIS WAY: I MAY WANT "A" AND "B" TOGETHER WITH A 60% WISH VALUE BUT ALSO "D" OR "C" WITH A 67% WISH VALUE. LSP DOES JUST THAT – NO HARD "A" AND "B", OR HARD "C" OR "D", BUT A SPECTRUM OF PREFERENCES

# LSP Top Ranked Projects

| Rank | ID# | Project Name | Sponsor | Eligible Funding |
|---|---|---|---|---|
| 1 | 72 | I-25 HOV Lanes | CDOT | 7th Pot/FASTER |
| 2 | 71 | Highway 105 | El Paso County | Safety, STP-Metro, FASTER |
| 3 | 64 | Grinnell Boulevard | El Paso County | Safety, STP-Metro, FASTER |
| 4 | 60 | Fountain over Spring Creek Rehabilitation | Colorado Springs | Bridge-Off |
| 5 | 69 | Historic Bridges Repair and Restoration | Manitou Springs | Bridge-Off |
| 6 | 110 | Powers Boulevard (SH 21) Widening | Colorado Springs and CDOT | STP-Metro |
| 7 | 66 | Hancock Eastbound over Spring Creek Bridge Rehabilitation | Colorado Springs | Bridge-Off |
| 8 | 79 | Jones Road | El Paso County | Safety, STP-Metro, FASTER |
| 9 | 75 | I-25/Powers Blvd. (SH 21) North Interchange | CDOT | |
| 10 | 105 | Powers Blvd. (SH 21) Freeway | CDOT | |
| 11 | 62 | Garrett Road | El Paso County | Safety, STP-Metro, FASTER |
| 12 | 109 | Powers Boulevard (SH 21) Water Quality Improvements | CDOT | |
| 13 | 108 | Powers Boulevard (SH 21) Safety Improvements | CDOT | |
| 14 | 107 | Powers Boulevard (SH 21) Right-of-Way | CDOT | |
| 15 | 68 | Hancock Phase Westbound over Spring Creek Bridge Rehabilitation | Colorado Springs | Bridge-Off |

# 06

# How should we rank and select projects for the fiscally constrained Regional Transportation Plan?

# MCDM Method Comparison

**Model 1 – Analytic Hierarchy Process**

- Pairwise comparison used by PPACG to rank priorities

**Model 2 – Weighted Score Method**

- Easily understood and easy to apply
- Requires consistent criteria (benefits or costs)
- Does not capture interdependencies among criteria and projects

**Model 3 – TOPSIS Method**

- Less easily understood but easy to apply
- Allows evaluation of multiple criteria types
- Does not capture interdependencies among criteria and projects

**Model 4 – LSP Method**

- Model specification is relatively complex
- Allows evaluation of multiple criteria types
- Can capture  interdependencies among criteria and projects

# Questions?

Thank You!