THE PRIORITIZATION OF MOBILITY IMPROVEMENTS USING A MULTICRITERIA PRIORITIZATION ALGORITHM

Final Report

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16. Abstract

A prioritization process has been prepared by the University of California, Davis, for use by the Oregon Department of Transportation (ODOT) in selecting multimodal mobility improvement projects to fund, given a budget constraint. The process involves first, the evaluation of projects using a set of criteria, incorporating such factors as cost-efficiency and modal integration, and second, the processing of the evaluation scores through a ranking algorithm. The ranking algorithm presented is the Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS). TOPSIS has been previously implemented by the Washington State Department of Transportation (WSDOT), and due to issues that arose, modifications were made to the methodology in TOPSIS that were specific to the criteria used by WSDOT. Due to differing policy goals, these criteria are different from those recommended for ODOT. However, the issues that arose would apply to an ODOT implementation. TOPSIS was demonstrated using a sample set of project scores that were collected, and using several scenarios in which the evaluation criteria are weighted in different proportions, yielding unsurprising results. A process for determining final weights was demonstrated during a meeting of the Oregon Transportation Commission. Recommendations for further study are presented.

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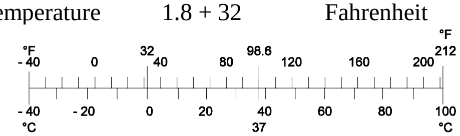
SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	millimeters squared	mm^2
ft^2	square feet	0.093	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometers squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3
NOTE: Volumes greater than 1000 L shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9	Celsius temperature	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
ha	hectares	2.47	acres	ac
km^2	kilometers squared	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celsius temperature	1.8 + 32	Fahrenheit	°F



* SI is the symbol for the International System of Measurement (4-7-94 jbp)

DISCLAIMER

THE PRIORITIZATION OF MOBILITY IMPROVEMENTS USING A MULTICRITERIA PRIORITIZATION ALGORITHM

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1.0 INTRODUCTION

This final technical memorandum details the final aspects of the prioritization process prepared by the University of California, Davis (UC Davis), for the Oregon Department of Transportation (ODOT). The procedure described in this memorandum can be used to prioritize a range of multimodal mobility improvement projects. Projects can be ranked using decision weights and an algorithm known as the Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS). Using the order, projects are funded from best to worst, under the specified budget constraint.

This paper begins with two overview sections: Section 2 is an overview of the set of sample projects used to test and describe the ranking algorithm and Section 3 is an overview of the evaluation criteria that have been selected by ODOT for use in the prioritization procedure. Next, the two versions of TOPSIS that have been used in the past by the Washington State Department of Transportation (WSDOT) are discussed in Section 4, along with some issues that arose in the implementation of TOPSIS-6 and modifications made to the current version, TOPSIS-8. A testing of the ranking algorithm is presented in Section 5, using seven different criteria weighting scenarios. In the first, all criteria are weighted equally; in the second through seventh scenarios, each criterion (with the exception of the economic development criterion, as will be explained in the section in turn is given 50% of the total weight, with the remaining weight being distributed equally among the other six criteria. Section 6 outlines the major points noted during a presentation of the ranking method to the ODOT Transportation Commission. Finally, a summary is presented in Section 7.

2.0 EVALUATION METHODOLOGY DISCUSSION

In parallel with traditional project prioritization methods, ODOT includes the ratio between a project's Net Present Value and its Total Costs (known as the NPV/C ratio) as one of seven different evaluation criteria. The additional criteria are used to capture many of the externalities not included in the benefit cost analysis used to derive the NPV/C. Each major evaluation criterion has a clearly defined set of data requirements and methods of analysis. A numerical score is computed for each project for each category. Finally, a weighted, cumulative score is given to each transportation project, ranking them in comparison to other projects.

Working in conjunction with a Technical Advisory Committee (TAC) composed of representatives from the Metropolitan Planning Organizations, ODOT headquarters and ODOT regions, six additional potential categories serving as screens and evaluation criteria have been identified for use in the evaluation prioritization process. A brief description of each is provided below.

2.1 LAND USE

Land use issues are of great importance to the State of Oregon as evidenced by statute and policy documents. As such, consideration of land use issues in transportation project selection is critical. Further, Oregon tries to reduce the demand for transportation services through its land use policies and transportation improvements that complement the effort may have transportation benefits not incorporated into standard models. Since the relationship between land use and transportation is complex and not well understood, it is difficult to define a single, quantitative evaluation measure, e.g., VMT/acre. Instead, two broad sub-categories are used to capture the land use transportation complexity:

a) Compatibility with local land use plans

   Reaffirms local and regional government's ability to determine relevant local land use issues.

b) Growth management

   Gives weight to the state's compelling interest of compact densities.

2.2 ENVIRONMENT AND RESOURCE

This criterion is intended to comply with the Oregon Transportation Plan (OTP) policy directive calling for environmental responsibility while recognizing legal requirements. This evaluation category includes both "natural" resources, such as water, flora and fauna and "cultural" resources, which includes historical landmarks, archeological sources and scenic byways. Both types of resources are indispensable components of Oregon's heritage. Because "natural" resources and "cultural" resources entail greatly diverse factors and methods of analysis, the

TAC has chosen to distinguish between these two types of resources with individual measures for cultural and environmental resources.

2.3 ECONOMIC DEVELOPMENT

Economic development is Goal 3 of the OTP. The stated goal is “to promote the expansion and diversity of Oregon's economy through the efficient and effective movement of goods, services and passengers in a safe, energy efficient and environmentally sound manner.” The policies supporting this goal are: A) balanced and efficient freight, B) linkages to markets, C) expanding system capacity, D) promotion of intermodal hubs, and E) support of tourism. This criterion is intended to carry out these goals of the OTP.

The TAC considered three types of criteria for assessing the potential for positive economic development effects as a result of a transportation improvement project. The three criteria considered whether or not the surrounding region was considered distressed, whether or not the improvement project supported a regional transportation strategy and finally, direct use of the distress measure computed by the Oregon Development Department. The TAC elected to implement a single binary measure based on consistency with a regional transportation strategy with the caveat that, in the long run, this criterion should be expanded to acknowledge regional development strategies and to account for the economic development benefits in addition to those included in the user benefits. However, it was felt that additional research is needed before these enhancements can be accommodated into the evaluation.

2.4 MULTI-MODAL

The authority for the multi-modal criterion is extensive. Development of alternative modes is emphasized in most of Oregon's planning documents as well as federal documents, such as ISTEA. Not only is it seen as a way to increase livability, but also it is possibly one of the primary means by which to reduce auto VMT and to relieve congestion. This is what Metro calls "Usage Potential "; increase modal share, reduce auto VMT and reduce congestion. Too, it is a means of increasing the security of Oregon's future transportation system, since alternative modes may use less petroleum products and are potentially less damaging to the environment. Implementation of this multi-modal concept is the intent of this criterion.

Alternative modes imply non-SOV automobile facilities, such as bicycle, pedestrian and transit facilities. They offer choice from the traditional auto-only mode. Livability within compact densities is an important component of many of Oregon's policy documents and alternative modes, particularly pedestrian-friendly ones, make for a safer, more livable environment with the potential for maintaining high densities. Closely tied to the idea of choice is the concept of connectivity, since connections that facilitate travel between modes offers the user more mode "choice". This criterion includes both a screen and ranking method. Each project is screened to ensure that minimum requirements are met. If the project does not meet these minimum requirements, the project is excluded from further consideration. Two indices of multi-modalism are considered as ranking criteria. The first considers the connectivity offered by the project while the second considers the expansion of mode choice.

2.5 COMMUNITY SUPPORT

Community support of state funded transportation projects is essential for ensuring state projects remain sensitive to local issues. Without local and regional support, local transportation issues will not be adequately represented. Although compelling local interest can not be captured in a single measure, community support is surely a reflection of that interest. Community support helps guarantee timely completion of projects that may otherwise become stalled by legal battles or community resistance. This criterion is intended to implement the OTP policies of public participation.

The ODOT TAC believed the level of community interest in a project is likely reflected in the rank that the project receives in the regional/local prioritization process. Although the rank received at the regional/local level encompasses much more than just the notion of local support, it can be translated into a point score in the state prioritization process and by so doing, capture the degree of regional/local commitment. Each region will be allotted points to assign to projects, by a method that reflects the degree of regional support.

2.6 ACCESSIBILITY

The intent of this criteria is to ensure the accessibility policies stated in the OTP are fully realized: "Minimum levels of service standards describe the performance for each mode that must be achieved in order to meet the goals of the Oregon Transportation Plan and carry out the policies for balance and accessibility". Accessibility measures the ease of travel to destinations on transportation systems and is a key component of Oregon's Transportation Planning. However, expanding routes to increase accessibility could compete directly with the OTP goal to reduce VMT. Moreover, "accessibility" could increase trip generation unless other factors are considered, such as more direct routing. Too, access via State Highway System, although a positive component for statewide accessibility might be considered a negative component for local accessibility because it may create local reliance on the state system.

Measuring accessibility directly is difficult because it entails complex trip generation and mode-destination interactions. At the state level, accessibility can be measured in terms of proximity and frequency of service. ODOT has assumed local and regional agencies are able to appraise their own accessibility needs, which, in turn, are reflected in the comprehensive plan and in the ranking of submitted projects. However, accessibility measures using units of distance and time can create "double-counting" when other criteria are included, particularly in the benefits category of cost efficiency. Therefore, accessibility will be measured using the minimum level of service concept as developed in the Oregon Transportation Plan and basic standards for minimum tolerable conditions.

3.0 OVERVIEW OF THE SAMPLE PROJECT SET

This section summarizes the worksheet evaluation status of the full sample project set being used to test and demonstrate the prioritization process. The project worksheets consist of one screening sheet and seven scoring sheets, one for each of the criteria described in Section 1.0. The screening sheet is used to eliminate projects that fail to meet both of two conditions relating to modal integration and community support. The seven scoring sheets evaluate the project on the basis of seven criteria: land use conformity, environmental resource impacts, cost efficiency, economic development, modal integration, community support and accessibility.

A set of 51 proposed projects was originally selected for use as sample projects for this phase of the prioritization process development. Descriptions of the sample projects are shown in Table 3.1.

As indicated by Table 3.1, there are a large number of roadway capacity improvements in the project set. Also included are several signal retimings, transit expansion projects and bicycle facilities; there is one transportation demand measure, a rideshare matching program upgrade.

A summary of available project scores and data for the full set of project worksheets is presented in Table 3.2, with the projects roughly listed in order of decreasing completeness.

As indicated by the table, there are many gaps in available Cost-Efficiency data, due to the scarcity of predictive benefit-cost analyses for proposed projects. To a lesser degree, many of the sample project worksheet packets contain blank or incomplete worksheets for the non-monetary criteria, as indicated by the “half-moon” and “new moon” symbols in Table 3.2. Under the Cost-Efficiency heading, specific types of costs and benefits included in the benefit-cost analysis are indicated by “full-moon” symbols, along with the numerical results of completed analyses.

The summary of project evaluations will proceed by first discussing the completed analyses performed on the sample projects. Subsequently, a discussion of the gaps in available information for the remaining projects will be presented.

Table 3.1: Descriptions of Sample Projects

Project	Description
7523	Medford TDM Rideshare
7252	Traffic Signal Coordination and Optimization
6906	NE Killingsworth - SE Flavel: Signal Retiming
0713	Pacific Way (Gearhart) - Dooley Bridge: Widening w/ Sidewalks
3466	Chrome Plant - Cedar Point: Reconstruction w/ passing lanes; ROW purchase; wetlands mitigation
7034	N. Medford Interchange Revision: Construct/Relocate Ramps
7219	US 20 @ Jct. US 395: Bridge & Intersection Reconstruction
4043	Lonnon Road - Fish Hatchery Road: Widening w/ Bike Lanes
7961	Pacific Highway W. @ Fischer Road: Bus Bypass Lane
8817	SW Front - SW Hamilton (Barbur Bike Lanes)
3416	Oregon Coast Hwy @ Nesika Beach Rd.: Left-Turn Refuge
2134	Kitson Ridge Rd - MP 47.7: Climbing/Passing Lanes
3889	Umpqua River Bridge: Structure Replacement & Realignment
5514	Dutton Road - Linn Road: Increase Capacity & Improve Safety
6475	Deschutes Market Road Overcrossing: New Interchange
6913	Downtown Park & Ride (Oregon City) w/ Shuttle
6930	Olalla Creek Bridge - Hoover Hill Road: Widening; Realignment; New Passing Lane
8236	Wilsonville Interchange (Unit 1): Reconstruction; Widening
0641	Cooper Cr. - Ukiah / Hilgard Hwy.: Widening & Resurfacing
0689	Hines Section: Widening & Bike Facilities
0758	Cooper Cr.: Realignment
0798	Eddyville - Cline Mountain: Realignment & Passing Lanes
0904	Picture Gorge - Dayville: Widening & Structure Replacement
0987	Zig Zag - Rhododendron: Widening & Left-Turn Refuges
1320	Jct. Klamath Falls / Lakeview Hwy: Widening
2871	Jewell Jct. - Osweg Creek: SMV Passing Lane Extension
2978	10th St. - Eastgate: Widening
3582	Wilson River Br. - Dougherty Slough Br.: Widening
3999	Tiller Trail Hwy: Reconstruction
4364	Council Creek - Quince (Hwy 47 Bypass): Rerouting by New Road Construction
4388	Clear Creek Canyon: Realignment
4442	Greeley Ramp - N. Banfield Interchange: New Lanes; Ramp & Frontage Rd. Reconstruction
4738	Section 223rd Ave - Troutdale
4886	Pacific Blvd. - 9th Ave Couplet (Albany): Construct Couplet
5254	S. Fork Cold Springs (Grange Hall): Realignment
5824	South Klamath Falls Hwy. @ Washburn Way: Interchange Construction
6131	SW 117th - SW 110th: Signal Relocation; Widening; New Bike/Ped Lanes
6254	Oaklea Dr. - Junction Highway 58: Reconstruction
6380	Windigo Pass - Diamond Lake Recreation Area: Widening; Climbing Lane; Resurfacing
6595	Hillsboro LRT Extension to Westside Corridor
6909	Webster Road - I-205 Bike Path
6957	East Idaho Avenue: New Signals; Raised Median; Widening
6966	Halsey St. - NE 223rd Ave/Glisan St.: Construct Connection
7208	Bend Parkway: Construct New Route
7977	Goshen - Immigrant Rd.: Widening
7991	W. 11th St. - Garfield, Eugene Unit 1 Part B: Construct Roadway; Widening
8288	Small Buses
8699	La Grande Corridor Transportation Improvements
8818	I-5 at I-84: Ramp Meters; Sampling Loops
8825	NW Burnside to NW Division: Bike/Ped Paths;
8832	Powell Loop - Binford Lake Parkway: Signal Interconnection; Development of Timing Plans

Table 3.2: Current Inventory of Project Worksheet Data

Project Key	Worksheet Scores: Screen	L/U	Environmental Resource: Nat'l	Cult'l	Total	Econ Dev	Mode Int	Com Sup * 1 Million	Access	Cost-Efficiency: Costs: c	o/m	pe	PV(C) / 1000	Benefits: tt	uc	acc	o/m	PV(B) / 1000	NPV/ C
7523	✓	5	0	0	0	0	9	0	2	●	●	●	$1,027	○	●	○	○	$234	-0.77
7252	✓	4	0	0	0	0	0	89	0	●	●	●	$1,285	●	●	○	○	$34,719	26.01
6906	✓	5	0	0	0	0	1	663	1	●	●	●	$174	●	●	○	○	$34,352	196.90
0713	✓	0	50	50	100	0	1	0	1	●	○	●	$23,280	●	●	○	○	$18,625	-0.20
3466	✓	-1	50	50	100	0	0	0	0	●	○	●	$8,804	●	●	○	○	$1,819	-0.79
7034	✓	1	50	50	100	0	0	12	0	●	○	●	$4,230	●	●	●	○	$35,898	7.49
7219	✓	-1	50	0	50	0	0	58	0	●	○	●	$1,442	○	○	●	○	$82	-0.94
4043	✓	1	0	50	50	0	3	0	1	●	○	●	$1,256	○	○	●	○	$3,042	1.42
7961	✓	4	0	0	0	0	0	0	1	●	○	●	$88	○	○	○	○	-	-
8817	✓	4	0	0	0	0	3	46	1	●	○	●	$1,950	○	○	✗	○	$0	-1.00
3416	✓	2	0	0	0	0	0	0	0	●	○	●	$435	✗	✗	●	○	$63,317	144.56
2134	✓	0	50	50	100	0	0	0	0	●	○	●	$4,710	○	○	○	○	-	-
3889	✓	-1	110	◗	◗	0	0	0	0	●	○	●	$14,464	○	○	○	○	-	-
5514	✓	1	50	◗	◗	0	0	0	0	●	○	●	$4,363	●	●	○	○	$15,436	2.54
6475	○	0	◗	50	◗	0	0	0	0	●	○	●	$5,980	●	●	○	○	$65,272	9.92
6913	✓	4	0	0	0	0	3	161	2	●	○	●	$589	○	✗	○	○	$0	-1.00
6930	◗	-1	○	○	○	0	0	0	0	●	○	●	$2,940	○	○	○	○	-	-
8236	◗	◗	○	○	○	○	◗	○	◗	●	○	●	$7,944	○	○	○	○	-	-
0641	◗	◗	○	○	○	1	◗	○	◗	●	○	●	$4,244	○	○	○	●	$52	-0.99
0689	◗	◗	○	◗	○	○	◗	○	◗	●	○	●	$3,031	○	○	○	○	-	-
0758	◗	◗	◗	◗	○	○	◗	○	◗	○	○	○	-	○	○	○	○	-	-
0798	○	◗	◗	◗	○	○	◗	○	◗	●	○	●	$15,637	○	○	○	○	-	-
0904	◗	◗	○	○	○	○	◗	○	◗	●	○	●	$4,098	○	○	○	○	-	-
0987	◗	0	○	◗	○	○	◗	○	◗	●	○	●	$5,926	○	○	○	○	-	-
1320	◗	◗	○	○	○	○	◗	○	3	●	○	●	$4,853	○	○	○	○	-	-
2871	◗	◗	50	0	50	○	◗	○	◗	●	○	●	$1,419	○	○	○	○	-	-
2978	○	2	10	50	60	○	◗	○	◗	●	○	○	$4,361	○	○	○	○	-	-
3582	◗	◗	○	○	○	○	◗	○	◗	●	○	●	$4,700	○	○	○	○	-	-
3999	◗	-1	◗	◗	○	○	◗	○	◗	●	○	●	$5,220	○	○	○	○	-	-
4364	◗	◗	◗	◗	○	○	◗	○	◗	●	○	●	$8,343	○	○	○	○	-	-
4388	○	◗	○	○	○	○	◗	○	0	●	○	●	$3,562	○	○	○	○	-	-
4442	○	2	50	100	150	○	◗	○	◗	●	○	●	$149,979	●	●	○	○	$2,800,578	17.67
4738	○	○	○	○	○	○	○	○	○	○	○	○	-	○	○	○	○	-	-
4886	◗	○	○	○	○	○	◗	○	◗	●	○	●	$10,725	○	○	○	○	-	-
5254	○	◗	50	0	50	○	◗	○	0	●	○	●	$1,048	○	○	○	○	-	-
5824	◗	◗	○	○	○	○	◗	○	◗	●	○	●	$4,865	○	○	○	○	-	-
6131	◗	3	50	50	100	○	◗	○	◗	●	○	●	$5,639	●	●	●	○	$432,216	75.65
6254	◗	◗	50	0	50	○	◗	○	◗	●	○	●	$2,580	○	○	○	○	-	-
6380	◗	◗	○	○	○	○	◗	○	◗	●	○	●	$5,147	○	○	○	○	-	-
6595	○	○	○	○	○	○	○	○	○	○	○	○	-	○	○	○	○	-	-
6909	◗	4	0	0	0	○	3	○	1	●	○	●	$287	○	○	○	○	-	-
6957	◗	◗	○	○	○	○	◗	○	◗	●	○	●	$6,534	○	○	○	○	-	-
6966	◗	○	○	○	○	○	○	○	○	●	○	●	$5,087	○	○	○	○	-	-
7208	◗	○	○	○	○	○	○	○	○	●	○	●	$29,183	○	○	○	○	-	-
7977	◗	○	○	○	○	○	○	○	○	●	○	●	$18,162	○	○	○	○	-	-
7991	◗	◗	○	50	◗	○	◗	○	◗	●	○	●	$30,095	○	○	○	○	-	-
8288	◗	5	0	0	0	1	7	○	1	●	●	○	$14,398	○	○	○	○	$0	-1
8699	○	○	○	○	○	○	○	○	○	●	○	●	$2,119	○	○	○	○	-	-
8818	◗	4	0	0	0	○	1	○	3	●	●	●	$644	○	○	○	○	-	-
8825	◗	4	50	0	50	○	◗	○	2	●	○	●	$3,070	○	○	○	○	-	-
8832	◗	◗	0	0	0	○	0	○	○	●	○	●	$49	○	○	○	○	-	-

○ = No Data
◗ = Data Incomplete
✗ = Negligible Effect
● = Data Complete

Costs: c = construction
o/m = agency operating & maintenance
pe = preliminary engineering

Benefits: tt = travel time
o/m = user operating & maintenance
acc = accidents

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3.1 COMPLETED PROJECTS

The summary of completed project worksheets is presented in a project-by-project fashion. In this way, the individual problems and solutions employed in each analysis may be presented. For each project, the specific improvements proposed are summarized, followed by a discussion of any analysis or problem resolution that was performed for each worksheet.

3.1.1 Project 0713: Pacific Way (Gearhart) – Dooley Bridge

This project involves a section of roadway from Gearhart, at Pacific Way, to Seaside, at Dooley Bridge, in Clatsop County. The section has been deemed substandard, experiencing problems such as poor circulation and unsafe access to local businesses. The proposed project will widen the roadway, while at the same time adding pedestrian sidewalks and a continuous turning median.

3.1.1.1 Cost-Efficiency

The Cost-Efficiency worksheet was the only worksheet that omitted essential information, specifically the monetized benefits estimates. However, a speed and volume table for the "Build" and "No-Build" scenarios, along with the length of the project segment, was included. It was indicated on the sheet that no other benefits, beside speed increases, were expected to result from the improvement. Further data, including average vehicle occupancy and the percentages of buses and trucks in traffic, were later collected to complete the travel time analysis.

In performing the analysis, it was assumed the average occupancy of buses was 13, calculated as the average of occupancies for several transit districts in the state. For each scenario, individual vehicle travel times were estimated by dividing the project length by the estimated travel speed. Difference in travel times between these scenarios was multiplied by each of the volume estimates for Year 1 and Year 20 to find the total savings in travel time. Using the assumption that an hour of an auto passenger's time is worth $10 and an hour of a truck's time is worth $50, average vehicle occupancies and traffic constitution percentages were used to assess the appropriate costs to these travel time savings. The result of the analysis was an estimated present value of benefits of $18,625,346. Calculated against the provided cost figures, the NPV/C ratio was –0.20.

3.1.1.2 Environmental Resources

The Environmental Resource worksheets included enough information to derive a final score; for each of the Natural Resource and the Cultural Resource sheets, a single impacted resource was listed. However, because the calculations were not completed on these sheets, additional resource impacts could still be recorded. For the purpose of deriving a useable score, it was assumed there would be no such further impacts, and the information provided was complete enough to calculate the environmental resource score. The resulting scores were 50 for natural resource impacts and 50 for cultural resource impacts, with a combined Environmental Resource score of 100.

3.1.1.3 Other Criteria

The worksheets for Land Use, Economic Development, Modal Integration, Community Support, and Accessibility were complete enough to derive final scores in each of the criteria. The resulting scores, along with this project's scores in the Cost Efficiency and Environmental Resource criteria, are shown in Table 3.3. Note that all Community Support scores have been multiplied by 1,000,000 for listing in the tables in this document. This was done because the unmultiplied scores fall in a low decimal range. The conversion is intended simply to ease viewing and comparison of the Community Support scores by placing them in a more tangible numeric range.

Table 3.3: Criteria Scores for Project 0713

Worksheet	Score
Screening	✓
Land Use	0
Environmental Resource	100
Cost Efficiency	-0.20
Economic Development	0
Modal Integration	1
Community Support x 1,000,000	0
Accessibility	1

3.1.2 Project 3466: Chrome Plant – Cedar Point

This capacity improvement project concerns a section of two-lane state highway between Coos Bay and Roseburg deemed capacity-deficient. In addition, a settlement area poses some danger of a potential slide. The project proposes to construct a new roadway on a new alignment with an added passing lane in each direction. Additionally, right-of-way for a future four-lane section will be purchased. Finally, the proposal includes wetlands mitigation areas.

3.1.2.1 Cost-Efficiency

The cost and benefit data provided included no final present values of benefits. However, a speed and volume table, along with the length of the segment, was provided similar to the table provided with the worksheet for Project 0713. Additional information later collected, including average vehicle occupancy and the percentage of trucks and buses in traffic, were used in conjunction with the given data to perform a benefits estimation.

Travel time savings for each vehicle in Year 1 or Year 20 were calculated by finding the difference in travel time for "No-Build" and "Build" scenarios. These savings were distributed to auto passengers and trucks according to the occupancy data and the percentages of trucks and buses in traffic. It was assumed the average occupancy of buses was 13 passengers per bus (i.e. the average of bus occupancy data available from seven Oregon transit districts). The analysis resulted in an estimated present value of travel time benefits of $1,811,641 and an estimated present value of user cost savings of $7,183. The resulting NPV/C ratio was –0.79.

3.1.2.2 Other Criteria

All other worksheets were complete for this project. Scores for all criteria are shown in Table 3.4.

Table 3.4: Criteria Scores for Project 3466

Worksheet	Score
Screening	✓
Land Use	-1
Environmental Resource	100
Cost Efficiency	-0.79
Economic Development	0
Modal Integration	0
Community Support x 1,000,000	0
Accessibility	0

3.1.3 Project 4043: London Road – Fish Hatchery Road: Widening w/ Bike Lanes

The existing stretch of rural highway is narrow, unsafe, and below the current road standard for its classification; there is little or no shoulder width, causing safety problems for bicyclists, pedestrians, and vehicles parked in an emergency. As such, the proposed project intends to widen the existing lanes to the current standard, at the same time installing new curbs and bike lanes.

3.1.3.1 Cost-Efficiency

Initial costs for construction and preliminary engineering and periodic costs for operating and maintenance were used in the cost estimation. The result was a present value of costs of $1,256,406.

Because no travel time or user cost savings were expected, the benefits estimation was based solely on accident savings expected to result from the improvements, yielding a present value of benefits of $3,042,266. The resulting NPV/C ratio was 1.42.

3.1.3.2 Other Criteria

All other criteria worksheets were complete. The scores for all criteria are shown in Table 3.5.

Table 3.5: Criteria Scores for Project 4043

Worksheet	Score
Screening	✓
Land Use	1
Environmental Resource	50
Cost Efficiency	1.42
Economic Development	0
Modal Integration	3
Community Support x 1,000,000	0
Accessibility	1

3.1.4 Project 6906: NE Killingsworth – SE Flavel

This project pertains to a length of Highway 213 (82nd Street) that passes along urban streets of Portland. Outdated signal timings have led to unnecessary stops and delays. The project proposes to update the timing on 27 signals. In addition, five new loop count stations are to be installed to monitor traffic flow.

3.1.4.1 Screening

The second screening question, regarding SHAG sponsorship and approval, could not be applied to this project because SHAG did not exist when the project was proposed. The project passed the first screening question. For future projects, this will not be a concern, because SHAG is now in place.

3.1.4.2 Cost-Efficiency

The cost estimation was performed using initial costs for construction and preliminary engineering and periodic costs for operating and maintenance. The result was a present value of costs of $173,583.

The benefits estimation was based on travel-time and fuel savings estimations given in a study by Kittelson & Associates, Inc. Because the study did not specify the traffic distribution or average vehicle occupancies for buses and autos, the analysis was performed using the assumption of 95% autos and 5% trucks, with an average vehicle occupancy of 1.10. As a result, the estimated present value of benefits was $35,351,509. The resulting NPV/C ratio was 196.90.

3.1.4.3 Other Criteria

All other criteria worksheets were complete. The scores for all criteria are shown in Table 3.6.

Table 3.6: Criteria Scores for Project 6906

Worksheet	Score
Screening	✓ *
Land Use	5
Environmental Resource	0
Cost Efficiency	196.90
Economic Development	0
Modal Integration	1
Community Support x 1,000,000	663
Accessibility	1

** 2nd screening question was not applicable because SHAG did not exist when project was proposed.*

3.1.5 Project 7034: North Medford Interchange Revision

A left-turn movement of the existing interchange of Interstate 5 and Highway 62 has an adverse super at the beginning of the ramp, causing excessive congestion and potential for roll-over accidents. The project proposes to construct a free right-turn loop on-ramp to replace this ramp. Southbound on-ramps and off-ramps will be relocated to accommodate the new geometry. A bikeway will also be relocated, resulting in improved multi-modal access to a major shopping complex.

3.1.5.1 Cost-Efficiency

The cost-efficiency worksheet contained estimates of construction and preliminary engineering costs. It also contained a table of speeds and volumes of traffic in Year 1 and Year 20 under both the "No-Build" and "Build" scenarios, along with the length of the project segment. Supplemental information collected from ODOT included the average vehicle occupancy of autos and buses, percentage trucks and buses for traffic along the segment, yearly accident rates for the existing structure, and projected reductions in these accidents.

The estimation of travel time and user cost benefits used the same method used above for Projects 0713 and 3466. Travel time and user-operating cost savings were calculated based on the given speeds, and these benefits were allocated to trucks and private individuals based on the occupancy and traffic distribution figures. The occupancy of buses was assumed to be 13 passengers per bus, or the average of available bus occupancy data from state transit districts. Accident savings were found by calculating the difference in yearly accidents for each accident type, i.e. property damage only (PDO), injury, and fatal; multiplying each by the established cost value for that type; and finding the present value for 20 years of these yearly benefits. The resulting present value of benefits was found to be $35,898,256. The NPV/C ratio was found to be 7.49.

3.1.5.2 Other Criteria

The remaining worksheet data was complete. The scores for all criteria are shown in Table 3.7.

Table 3.7: Criteria Scores for Project 7034

Worksheet	Score
Screening	✓
Land Use	1
Environmental Resource	100
Cost Efficiency	7.49
Economic Development	0
Modal Integration	0
Community Support x 1,000,000	12
Accessibility	0

3.1.6 Project 7219: US 20 at Jct. US 395

The current geometry of this highway junction puts right-turners from U.S. 395 to U.S. 20 at an oblique angle. This geometry, coupled with the presence of two structures within the intersection, creates a visibility problem for drivers on this turning movement. In addition, traffic is forced to come to a complete stop, causing some delays. The project proposes to reconstruct the intersection with the odd approach angle removed, while eliminating one obstructing bridge structure. The other obstructing bridge is to be raised and its supports reconstructed.

3.1.6.1 Cost-Efficiency

This worksheet included only data on the costs of the project. It was initially noted on the worksheet time, user cost, and accident savings would not be quantifiable. However, data was later collected in the area of accident savings, which was deemed the most likely type of benefit that would result from the improvement. These data collected included estimates of yearly accidents, by type, for the existing interchange; and the estimated Accident Reduction Factor for safety improvements in the proposed project.

Because of data restrictions, the analysis of benefits consisted only of the estimation of accident savings. These were found by first calculating the number of accidents, of each type, that would be reduced each year by the presence of the improvements. These figures were multiplied by their respective cost figures for PDO, injury, and fatal accidents. Finally, the yearly benefits were converted to a present value of accident benefits.

The analysis resulted in a present value of benefits of $82,217. The present value of costs was $1,442,000, resulting in a NPV/C ratio of –0.94.

3.1.6.2 Other Criteria

The remaining criteria worksheets were complete. The scores for all criteria are shown in Table 3.8.

Table 3.8: Criteria Scores for Project 7219

Worksheet	Score
Screening	✓
Land Use	-1
Environmental Resource	50
Cost Efficiency	-0.94
Economic Development	0
Modal Integration	0
Community Support x 1,000,000	58
Accessibility	0

3.1.7 Project 7252: Traffic Signal Coordination & Optimization

This project concerns a system of 63 signals in the City of Gresham and parts of Multnomah County. The project proposes to develop a plan for coordinating and optimizing these signals, including interconnection, re-timing, and installing a master control system. Signals are to be retimed every five years.

3.1.7.1 Cost-Efficiency

The cost-efficiency worksheet contained monetary data on project costs, including the present value of construction and preliminary costs and the periodic value of operating costs. These were converted to a total present value of costs of $1,285,323.

The benefits data provided were not monetized, rather they were presented as estimated annual travel time (in hours) and fuel savings (in gallons), both of which were expected to be constant over the 20-year project period. Because the travel time analysis did not specify the average vehicle occupancy or the traffic distribution, the assumptions were made that traffic was 95% autos and 5% trucks, with an average vehicle occupancy of 1.10. No safety analysis was available.

The analysis, using available data and the stated assumptions, yielded an estimated present value of benefits of $34,719,370. The resulting NPV/C ratio was 26.01.

3.1.7.2 Other Criteria

The remaining criteria worksheet data was complete. Scores for all criteria are listed in Table 3.9.

Table 3.9: Criteria Scores for Project 7252

Worksheet	Score
Screening	✓
Land Use	4
Environmental Resource	0
Cost Efficiency	26.01
Economic Development	0
Modal Integration	1
Community Support x 1,000,000	89
Accessibility	0

3.1.8 Project 7523: Medford TDM Rideshare

This TDM project proposes to make several improvements to an existing carpool matching and employer outreach program operated by the Rogue Valley Transportation District in Medford. These improvements include upgraded software and hardware for the matching service, increased outreach efforts to local employers, and promotions for alternative commute modes, such as telecommuting.

3.1.8.1 Cost-Efficiency

The cost-efficiency worksheet contained a schedule of costs, including initial construction and preliminary engineering costs, along with annual operating costs. Monetized benefits were not provided, but estimates of daily automobile trip reductions (in VMT) and fuel savings (in gallons) were given. It was noted on the worksheet that no measurable safety benefit was expected.

The estimation of benefits focused on user cost savings, since accident and travel time benefits were expected to be either non-existent or unmeasurable. The fuel savings given were multiplied by the number of work days in a year (assumed to be 250) and the assumed cost of fuel to find an annual value of fuel cost savings. Converting this value to a present value yielded a present benefit of $234,093. The resulting NPV/C ratio was –0.77.

3.1.8.2 Other Criteria

The remaining criteria worksheets were complete. The scores for all criteria are shown in Table 3.10.

Table 3.10: Criteria Scores for Project 7523

Worksheet	Score
Screening	✓
Land Use	5
Environmental Resource	0
Cost Efficiency	-0.77
Economic Development	0
Modal Integration	9
Community Support x 1,000,000	0
Accessibility	2

3.2 INCOMPLETE PROJECTS

The remaining projects, for which complete analyses could not be performed, have many gaps in common. Thus, the summary of incomplete projects is presented here by focusing on each type of missing information, rather than on each project. These gaps are organized into one section for each of the eight worksheets.

3.2.1 Screening Sheet

The most common missing data item on this worksheet was the second screening question, which asks whether the project is sponsored and approved by SHAG. In all, 27 of the 51 projects were missing a response to this question. Nine additional projects were missing a response to both this question and the first question, which pertains to the integration of bicycle and pedestrian facilities into the proposed projects.

3.2.2 Land Use Worksheet

Of the 51 Land Use worksheets, 26 were complete, while seven contained no data. The projects with partial data on this sheet varied widely, but certain questions were left unanswered disproportionately to the others. The most common unanswered questions were questions 2.a. and 2.d. Question 2.a. asks whether the project is incompatible with land use plans for rural or resource development. Question 2.d. asks whether the project serves primarily commute traffic from outside urban growth boundaries. The next most common unanswered question was Question 1, which asks how compatible the project is with acknowledged comprehensive plans. All other questions were left unanswered by at least one project.

3.2.3 Environmental Resource Worksheet

The environmental resource worksheet is dependent on two preliminary calculation sheets: the natural resource worksheet and the cultural resource worksheet. Accordingly, if either of these calculation sheets is incomplete, the environmental sheet is forced to be incomplete as well. With only a few exceptions, the level of completeness between the two preliminary worksheets was similar for each project. For 24 projects, both calculation sheets, along with the environmental worksheet, were complete. For 17 projects, all three worksheets contained no data.

The remainder of projects were incomplete because of one of two problems: 1) necessary information was only partially provided, or 2) calculations were not completed, indicating the possibility that further data could be added. The first of these problems, in which either the Type of resource or the Distance to a resource is missing, cannot be remedied without gathering more complete information from the applicant. This is because the calculation for an affected resource depends on both the Type and Distance of the resource. If one has been provided without the other, then we know there is an affected resource, but we cannot use it in assessing a score.

The second problem is due to the ambiguity that arises from incomplete calculations. Several worksheets contained the necessary data to calculate a score, but because the calculations were left undone, data for additional affected resources could yet be provided. It is ambiguous whether there are indeed additional affected resources, or whether the calculations simply weren't performed due to time constraints or a misunderstanding of how to perform them. In these cases, a final score could easily be calculated, given the assumption that there are no additional affected resources.

3.2.4 Benefit-Cost Analysis

All but three of the projects included cost estimates of some kind. In most cases, these included construction and preliminary engineering costs, but no operating costs. In five cases, operating costs were included as well. The present value of costs for most projects was therefore a simple matter to calculate. However, none of the project worksheets contained monetized benefits estimations. The completed projects discussed above all involved some additional data collection and certain assumptions regarding traffic characteristics and the value of travel time, fuel, and accident savings. Moreover, for 42 of the projects, no benefits estimations were provided in any form, monetized or otherwise. The next step in assessing the benefits of these projects is to target specific data for the benefits categories in which the project is likely to have the greatest effect.

3.2.5 Economic Development Worksheet

The economic development worksheet contains a single question that asks whether the project is consistent with a regional transportation strategy. The question was answered for 19 of the projects, of which two responded affirmatively and the rest responded negatively. The economic development worksheets for 32 of the projects contained no data.

3.2.6 Modal Integration Worksheet

The modal integration worksheet was complete for 21 of the projects, with scores ranging from 0 to 9. Only six of the modal integration worksheets contained no data, and one only contained an answer to the Question 4, regarding the addition of mode choices. The remaining projects contained varying amounts of information, but a vast majority of them (36 projects) left Question 3, on network segment completion, unanswered. Worksheets for several of these projects included a comment that the question of segment completion is not directly applicable to the nature of the project proposed because of its nature. For example, a rideshare matching program does not exist as a network, so any improvement of the program cannot be readily distinguished as a closure, a completion, or an extension. It may be necessary to establish a score value in this question that corresponds to the response "Not Applicable".

Other questions that were left blank for some projects included each part of Question 2 (on intermodal freight facilities) and Question 4 (on the addition of new mode choices). In addition, several parts of Question 1 (on intermodal passenger facilities) were left blank on at least one project.

3.2.7 Community Support Worksheet

The community support worksheet consists of a single calculation that depends on two inputs: the regional ranking score given to the project and the cost of the project. In all but five projects the cost of the project was available from the cost-efficiency worksheet. However, 34 of the projects were missing the number of regional points given to the project. Thus, for these projects the calculation could not be completed. It should also be noted that of the 17 completed community worksheets, 11 gave a Community Support score of zero; in every case, this was because the project received zero regional points. The remaining completed worksheet scores (after multiplying by one million) ranged from 12 to 663.

3.2.8 Accessibility Worksheet

The accessibility worksheets for 24 of the projects were complete, with scores ranging from 0 to 3. The worksheet contained no data for only six of the projects. Of the remaining projects, two questions were left blank predominantly more than the others were. These two questions were on improving Levels of Service in the areas of Statewide Highway Freight and of Interstate/Statewide Highway Vehicular Travel. Other questions that were left unanswered for some projects included Statewide Intermodal Freight, Statewide Rail Freight, and Statewide Pipelines.

4.0 THE RANKING ALGORITHMS: TOPSIS–6 AND –8

The priority programming process currently under development will use a ranking algorithm originally developed by researchers at the University of Washington and currently in use by the Washington State Department of Transportation (WSDOT). The algorithm, known as the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), evaluates projects based on user-defined criteria. These criteria may include such considerations as cost efficiency, community support, and environmental impacts. WSDOT first implemented TOPSIS in its 1995-1997 biennium planning period, using the sixth version of the algorithm (TOPSIS-6). For its 1997-1999 biennium, WSDOT used a modified version, known as TOPSIS-8. This memorandum describes the TOPSIS-6 algorithm, as well as the modifications made in TOPSIS-8.

4.1 OVERVIEW OF TOPSIS VERSIONS 6 AND 8

The TOPSIS procedure consists of several steps. These are shown in Table 4.1.

Table 4.1: TOPSIS Procedure Steps

Step	TOPSIS-6	TOPSIS-8
Project Scoring	WSDOT Worksheets	(←same as ver. 6)
Conversion of Scores	(none)	Use Tables to Constrain Otherwise Unconstrained Criteria
Normalizing Scores	Vector Normalization	(←same as ver. 6)
Weighting Scores	Multiply by WSDOT Weighting Factors	(←same as ver. 6)
Definition of Ideal Projects	Best and Worst Scores in the Ranked Set of Projects	Fixed at Best and Worst Possible Scores
Ranking Projects	Priority Index: Proportion of Distance to Negative Ideal to Total Distance to Ideal Projects	Two-Tiered: 1. B/C Ratio > 30 are Ranked at Top 2. Priority Index (←as in ver. 6)
Selecting Funded Projects	Add Best-to-Worst Projects Until Budget is Reached	(←same as ver. 6)

There were three major changes incorporated into version 8 of TOPSIS. First, a step was added to TOPSIS-8 in which all scores in each criterion were forced to fall into a constrained range for that criterion. In the WSDOT case, all but three of the criteria fell into a constrained range due to the scoring method. For two of the remaining criteria (the Wetlands impacts and Noise impacts criteria), conversion tables were used to force the unconstrained scores into a constrained range. The second change was that for projects scoring greater than 30 in the final unconstrained criterion (the Benefit-Cost Ratio) are now removed from the TOPSIS ranking process and placed at the top of the final ranking list. Next, Ideal Projects (benchmark projects against which TOPSIS compares the submitted projects) are now defined by the best and worst *possible* scores in each of the criteria, rather than the by the best and worst scores *actually achieved* in the submitted set of projects. The details and implications of these changes are discussed below.

4.2 TOPSIS-6 RANKING ALGORITHM

The TOPSIS-6 ranking procedure includes six steps:

1. Project Scoring
2. Normalizing Scores
3. Weighting Scores
4. Determining Ideal Projects
5. Ranking Projects
6. Selecting Funded Projects

Each of these steps is detailed below, using sample calculations for a hypothetical ranking scenario.

4.2.1 Step 1: Project Scoring

In project scoring, each proposed project is evaluated on the basis of a user-defined set of criteria. The ODOT set of evaluation criteria includes land use impacts, environmental resource impacts, cost efficiency, economic development, mode integration, community support, and accessibility. The project scores are determined by using standardized evaluation worksheets (see Appendix for evaluation worksheets). Scores for all projects to be ranked are transferred from these worksheets into a single spreadsheet such as the one shown in Table 4.2. The TOPSIS algorithm, a Microsoft Excel macro program, uses this spreadsheet as its input file.

Table 4.2: Sample TOPSIS Input Spreadsheet

REG	SR	Project	B/C Ratio	Comm. Suppt.	Wet-lands	Water Qual.	Noise	Mode Int.	Land Use	WSDOT Proj Cost ($)
5	240	Edison Street I/C	86.32	1	0.5	12.0	28	4	14	3,253,200
3	161	SR 161 / SR 167 Eastbound Ramp	66.50	5	0.5	12	0	8	14	505,336
1	99	35th Ave. W (Lake Rd.) to SR 525 NB Right Turn Lane	39.56	7	0.5	0.5	20	10	14	168,000
4	501	Mill Plain Extension	30.55	4	0.5	1.5	180	6	11	500,000
1	99	Airport Rd: I/S HOV Priority	19.19	0	4.5	7.0	103	10	14	200,000

Source: Jennifer Barnes, University of Washington

To illustrate the calculations involved in the TOPSIS algorithm, consider Example 1 (see Table 4.3), in which ten projects, numbered 01 through 10, are submitted to the state by three sub-regions of the state, Regions I, II, and III. The ten projects are evaluated on the basis of two criteria, Criterion A and Criterion B. For our sample set of projects, we assume the projects' scores for each of the criteria are those in Table 4.3. For the purposes of our example, these scores were randomly generated, ranging between 0 and 100 for Criterion A and between 0 to 10 for Criterion B.

Table 4.3: Example 1: Project Scores

Project Number	Region Submitting the Project	Criterion A (weight = 75%)	Criterion B (weight = 25%)
01	I	20	6.2
02	I	42	3.7
03	I	63	8.6
04	II	48	4.1
05	II	41	7.2
06	II	92	7.0
07	II	70	3.5
08	III	28	4.0
09	III	99	1.6
10	III	47	4.0

4.2.2 Step 2: Normalizing Scores

When the TOPSIS macro begins processing the project scores, it first normalizes the scores within each of the criteria. The normalization step uses a vector normalization method in which each project's score within a criterion is divided by the root-sum-of-squares of the scores for all projects in that criterion (see Equation 1).

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad \begin{array}{l} \leftarrow \text{criterion score for current project} \\ \leftarrow \text{sum of squares for criterion category} \end{array} \tag{4-1}$$

Normalization is used to eliminate the units of criteria scores, so that numerical comparisons can be made between the criteria. The effect of the normalization step is that the units of scores in each of the criteria are eliminated, so that all the criteria are dimension-less, and comparisons between criteria can be made. For example, if two of the criteria were Net-Present-Value (in dollars) and Area of Impacted Wetlands (in acres), these two criteria can now be related to one another without concern for the different units used to measure the criteria. For our sample list of projects, the scores appear to be in different units because Criterion A scores range from 0 to 100, while Criterion B scores range from 0 to 10. The normalized scores for our sample project list are shown in Table 4.4. Note that within each of the criteria, the *relative* scores of the projects are similar to the original scores in Table 4.3. However, these scores now all lie in the range of 0 to 1, regardless of the original score range.

Table 4.4: Example 1: Normalization

Project Number	Normalized Scores A	Normalized Scores B
01	0.105	0.364
02	0.221	0.217
03	0.331	0.505
04	0.252	0.241
05	0.215	0.422
06	0.483	0.422
07	0.368	0.205
08	0.147	0.235
09	0.520	0.094
10	0.247	0.235

4.2.3 Step 3: Weighting Scores

The weighting step uses weighting factors that have been assigned by the user based on the perceived importance of each of the criteria[1]. Weighting factors are a set of percentages that add up to 100%, with the most important criterion receiving the highest weighting factor. The weighting step simply multiplies all of the normalized scores in each of the criteria by the weighting factor for that criterion. In our sample list, the weighting gives 75% of the weight to Criterion A and 25% of the weight to Criterion B. Therefore, Criterion A scores are multiplied by 0.75 and Criterion B scores are multiplied by 0.25. The resulting scores are listed in Table 4.5. The effect of the weighting calculation is that roughly 75% of each project's potential is contributed by Criterion A and 25% of it's potential is contributed by Criterion B.

Table 4.5: Example 1: Weighted Scores

Project	Weighted Scores	
Number	A	B
01	0.079	0.091
02	0.165	0.054
03	0.248	0.126
04	0.189	0.060
05	0.161	0.106
06	0.362	0.103
07	0.276	0.051
08	0.110	0.059
09	0.390	0.023
10	0.185	0.059
I^*	0.390	0.126
I^-	0.079	0.023

I^**=Ideal Positive Project*

I^-*=Ideal Negative Project*

4.2.4 Step 4: Determining Ideal Projects

To evaluate the projects on the basis of all of the criteria, TOPSIS defines two theoretical "Ideal" projects that represent the *best* and *worst* projects possible, and act as benchmarks against which the submitted projects are compared. These best and worst projects are respectively known as the "Ideal Positive" and "Ideal Negative" projects. The Ideal Positive project's score in each criterion is established by finding the best score in that criterion from the submitted projects and giving that score to the Ideal Positive project; similarly, the worst score out of the submitted projects' scores is given to the Ideal Negative project. The actual scores of the Ideal Positive and Negative projects will depend on the group of projects being evaluated and are recalculated each time a new set of projects is evaluated. For our sample list, the Ideal Projects are shown in the last two rows of Table 4.4. Note that for each of the criteria, all submitted projects' scores lie between the Ideal Positive Project's score and the Ideal Negative Project's score.

[1] For the ODOT implementation of TOPSIS, the Technical Advisory Committee (TAC) will determine these weights.

4.2.5 Step 5: Ranking Projects

Now that the Ideal Projects have been defined, each project's numerical distance from these Ideal Projects is found using separation measures. The equations for the separation measures are expanded versions of the Pythagorean equation.

$$S_{A1}^{*} = \sqrt{\left(X_1^{*} - X_{1,A1}\right)^2 + \left(X_2^{*} - X_{2,A1}\right)^2 + \ldots + \left(X_m^{*} - X_{m,A1}\right)^2} = \sqrt{\sum_{i=1}^{m} \left(X_i^{*} - X_{i,A1}\right)^2}$$

$$S_{A1}^{-} = \sqrt{\left(X_1^{-} - X_{1,A1}\right)^2 + \left(X_2^{-} - X_{2,A1}\right)^2 + \ldots + \left(X_m^{-} - X_{m,A1}\right)^2} = \sqrt{\sum_{i=1}^{m} \left(X_i^{-} - X_{i,A1}\right)^2} \quad (4\text{-}2)$$

where: S^{*}_{A1} = Separation of Project A_1 from Ideal Positive Project; S^{-}_{A1} = Separation of Project A_1 from Ideal Negative Project; $X_{i,A1}$ = Score of Project A_1 in Criterion *I; X^{*}_{I}* = Score of Ideal Positive Project in Criterion i;X^{-}_{I} = Score of Ideal Negative Project in Criterion i and *m* = Number of Criteria

Effectively, this equation is used to calculate the overall diagonal "distance" between the project in question and the Ideal Project. Note that this diagonal distance passes through *m* dimensions of space, where *m* is the number of criteria being used to evaluate the projects. For Example 1, this diagonal distance is simply the diagonal through two-dimensional space, or a plane. The resulting separation measures are shown in Table 4.6.

To find the ranking, a value known as the "Priority Index" is calculated for each project. The Priority Index is found by dividing the project's "distance" from the Ideal Negative Project by the sum of the distances between the project and each of the Ideal Projects (see 4-3).

$$PI = \frac{S^{-}}{S^{*} + S^{-}} \quad (4\text{-}3)$$

The resulting Priority Index values indicate how each project should rank relative to the other projects; a higher Priority Index indicates a higher-ranking project. For the sample set of projects, the Priority Indices are shown in the last column of Table 4.4. The final project ranking is based on the Priority Indices, with the projects with the highest Priority Index values receiving the highest priority.

Table 4.6: Example 1: Separation Measures & Priority Indices

Project Number	Separation Measures S*	S^-	Priority Index
01	0.313	0.067	0.177
02	0.236	0.092	0.281
03	0.142	0.198	0.583
04	0.211	0.116	0.355
05	0.229	0.117	0.337
06	0.036	0.294	0.890
07	0.137	0.199	0.593
08	0.288	0.047	0.141
09	0.103	0.311	0.752
10	0.216	0.112	0.342

S^* = Separation from Ideal Positive Project
S^- = Separation from Ideal Negative Project

4.2.6 Step 6: Selecting Funded Projects

Funding is allocated to the ranked list of projects, one project at a time, starting with the highest-ranked project. After each project is funded, the cumulative budget is checked to be sure that the budget limit has not been exceeded. If it has not, the next project in the list is funded and the new cumulative budget is calculated; if the budged limit *is* exceeded, then the project just funded is removed again so that the final set of funded projects stays within the budget constraints.

For our hypothetical list of projects, we will use an arbitrary budget of $40 million. Table 4.7 lists the projects again, sorted from highest-to-lowest rank. The fourth column of Table 4.7 contains randomly generated budgets for the individual projects. Based on this budget data, the fifth column of Table 4.7 contains the cumulative budget if each project plus the project above it are funded. By inspection, we can see that the highest cumulative budget that does not exceed $40 million is $39.0 million, shown on line 7. Therefore, we can fund the first seven projects in the list but not the last three.

Table 4.7: Example 1: Ranked and Funded Projects at a Budget of $40 Million

Rank	Priority Index	Project Number	Budget ($ million)	Cumulative Budget ($ million)	Funded?
1.	0.890	06	5.5	5.5	Yes
2.	0.752	09	8.9	14.4	Yes
3.	0.593	07	1.0	15.4	Yes
4.	0.583	03	7.9	23.3	Yes
5.	0.355	04	3.1	26.4	Yes
6.	0.342	10	8.0	34.4	Yes
7.	0.337	05	4.6	39.0	Yes
8.	0.281	02	6.5	45.5	No
9.	0.177	01	7.9	53.4	No
10.	0.141	08	2.3	55.7	No

4.3 ISSUES ARISING FROM IMPLEMENTATION OF TOPSIS-6

In WSDOT's 1995-97 biennium, some issues arose in the project rankings. Two of these issues were dealt with by modifying the TOPSIS ranking algorithm. The two issues were that:

1. The relative rankings for a subset of projects varied depending on the full set of projects in which the subset was evaluated;

2. Although heavily weighted, one criterion often had less of an effect on the overall rankings than was desired.

Both of these issues arose from a problem in consistently weighting the evaluation criteria. Although inconsistencies between different project lists arose both in the normalization step and in the definitions of Ideal Projects, it was found that the Ideal Project definitions were the major cause of this problem. To demonstrate, we will first look at an example where the issue of consistent rankings between different lists arises. Second, the same example will be used to address the issue of consistently weighting an important criterion.

4.3.1 Example of Inconsistent Criteria Weighting

The first issue was that the relative rankings of a subset of project depended on the other projects with which this subset was ranked. In particular, some regional agencies found that their projects would result in one ranking when evaluated on their own, but when ranked with projects from other regions of the state, their projects would fall into a somewhat different ranking relative to each other. Although the changes in rankings tended not to be severe, the inconsistency posed potential problems for regional officials because they may wish to choose which projects to submit to the state based on which ones perform best in a regional TOPSIS ranking. If the regional ranking does not accurately represent how the projects will rank in the statewide ranking, this becomes a difficult task.

Example 1 illustrates the inconsistent ranking of a subset of projects between the regional and statewide rankings. If we separate the four projects submitted by Region II and run TOPSIS on just these projects, the resulting ranking is slightly different from those projects' relative ranks taken from the statewide ranking, as shown in Table 4.8. When only Region II projects (Projects 04 – 07) are included in the ranking algorithm, Projects 04 and 05 are in reversed order in the relative ranking.

Table 4.8: Example 1: Region II Rank, Evaluated Alone vs. Evaluated in State-wide List

Project Number	Criterion A (weight = 75%)	Criterion B (weight = 25%)	Regional Ranking	Statewide Ranking
04	48	4.1	4	3
05	41	7.2	3	4
06	92	7.0	1	1
07	70	3.5	2	2

The difference in rankings is due to the presence or absence of other projects that are evaluated alongside the Region II projects. In the regional ranking, no other projects are considered, so the definition of Ideal Projects is based only on the scores of the four Region II projects. In the statewide ranking, six projects from Regions I and III are added to the list, and these projects' scores are utilized in the definition of Ideal Projects. As a result, the larger statewide project list will tend to give more extreme high and low scores to the Ideal Projects, since there is a larger set of projects from which to find the minimum and maximum scores. The change in Ideal Project definition results in a change in the effective weighting of the two criteria. Thus, two projects that excel in different criteria may switch places, as did projects 04 and 05.

To further illustrate the cause of this inconsistency, consider Example 2, with the set of projects whose scores are shown in Table 4.9. Although the scores in this list are highly exaggerated and unlikely to occur in practice, they are nevertheless a theoretical possibility. Further, they serve to illustrate the degree to which ranking changes can occur. In contrast to our earlier example, the two criteria in Example 2 are more evenly weighted, with Criterion A being weighted at 55%, somewhat more than Criterion B's weight of 45%. Note that the scores for projects submitted by Region II are complementary; progressing through the projects, the Criterion A score increases by 10-point increments and the Criterion B score decreases by 10-point increments. Because the Region II projects are complementary, their rankings will be highly sensitive to changes in criteria weights.

Table 4.9: Example 2 List of Projects

Project Number	Region Submitting the Project	Criterion A (weight = 55%)	Criterion B (weight = 45%)
01	I	30	100
02	I	31	99
03	I	32	98
04	II	35	65
05	II	45	55
06	II	55	45
07	II	65	35
08	III	78	2
09	III	79	1
10	III	80	0

Our main objective is to assign relative rankings to the four projects from Region II, projects 04 to 07. To accomplish this, we will perform two runs of TOPSIS—once with only Region II projects and once with Region I and III projects added. First, we run the TOPSIS algorithm on only projects 04 through 07, as would be done by Region II officials before submitting the projects to the state. The resulting ranking is shown in Table 4.10. Note that the projects' ranks are consecutive, with project 07 having the highest rank (1) and project 04 having the lowest rank (4).

Table 4.10: Example 2: Region II Project Ranking

Project Number	Normalized Weighted A Score	Normalized Weighted B Score	Separation from Ideal Negative	Separation from Ideal Positive	Priority Index	Regional Ranking
04	0.188	0.285	0.161	0.132	0.450	4
05	0.242	0.242	0.116	0.103	0.470	3
06	0.295	0.198	0.103	0.116	0.530	2
07	0.349	0.154	0.132	0.161	0.550	1
I Pos.	0.349	0.285				
I Neg.	0.188	0.154				

Next, the four projects are prioritized along with projects from the other regions, as would be done by state officials after projects have been received from all regions. The resulting ranking is shown in Table 4.11. The fifth column lists the rank numbers assigned to each project. Also, the relative ranks for Region II projects, resulting from the statewide ranking, are shown in parentheses. Note that these relative ranks are consecutive, just as they were in the regional ranking. However, in this case project 04 is the highest-ranking project and project 07 is the lowest-ranking project from Region II. In other words, the ranking order has been fully reversed by incorporating projects from the other two regions.

Table 4.11: Example 2: Statewide Project Ranking

Project Number	Normalized Weighted A Score	Normalized Weighted B Score	Separation from Ideal Negative	Separation from Ideal Positive	Priority Index	State-Wide (& Reg. II Relative) Ranking
01	0.092	0.225	0.153	0.225	0.595	3
02	0.095	0.223	0.150	0.223	0.597	2
03	0.098	0.221	0.147	0.221	0.600	1
04	0.107	0.146	0.159	0.147	0.481	4 (1)
05	0.138	0.124	0.148	0.132	0.472	5 (2)
06	0.169	0.101	0.146	0.127	0.466	6 (3)
07	0.200	0.079	0.153	0.133	0.465	7 (4)
08	0.239	0.005	0.221	0.147	0.400	10
09	0.242	0.000	0.223	0.150	0.403	9
10	0.246	0.000	0.225	0.153	0.405	8
I Pos.	0.246	0.225				
I Neg.	0.092	0.000				

The difference in ranking order in this case is a direct result of how the two criteria are *effectively* weighted in the regional vs. the statewide rankings. The effective weighting is only partially dependent on the *explicit* weighting that is imposed by the 55% and 45% weighting factors on Criteria A and B, respectively. It is also dependent on the definitions of the Ideal Projects. In the regional ranking, the definitions of Ideal Projects had no effect on the weighting, because the distributions of scores for each criterion were the identical. Figure 4.1 provides a geometric demonstration of how the projects in Region II were ranked. Projects 04 and 07, having the most extreme scores, define the Ideal Positive and Ideal Negative projects, as shown by the thin vertical and horizontal lines. These lines form a rectangle of score-space within which all the projects will fall. If the two criteria A and B were weighted equally, then this space would be square-shaped. However, because criterion A is weighted more heavily, the rectangle is wider than it is tall. As a result, project 07, which has a higher A-score but a lower B-score than project 04, attains the highest rank.

Four parallel lines are drawn in Figure 4.1 to aid in visually comparing the projects. These lines are placed to be perpendicular to the line connecting the Ideal Positive and the Ideal Negative Projects. Each of these lines is located such that it crosses through one of the four submitted projects. Note that Project 04 lies on the line closest to the Ideal Positive Project, indicating will receive the highest rank. Similarly, Project 07 lies on the line closest to the Ideal Negative Project, indicating it will receive the lowest rank.

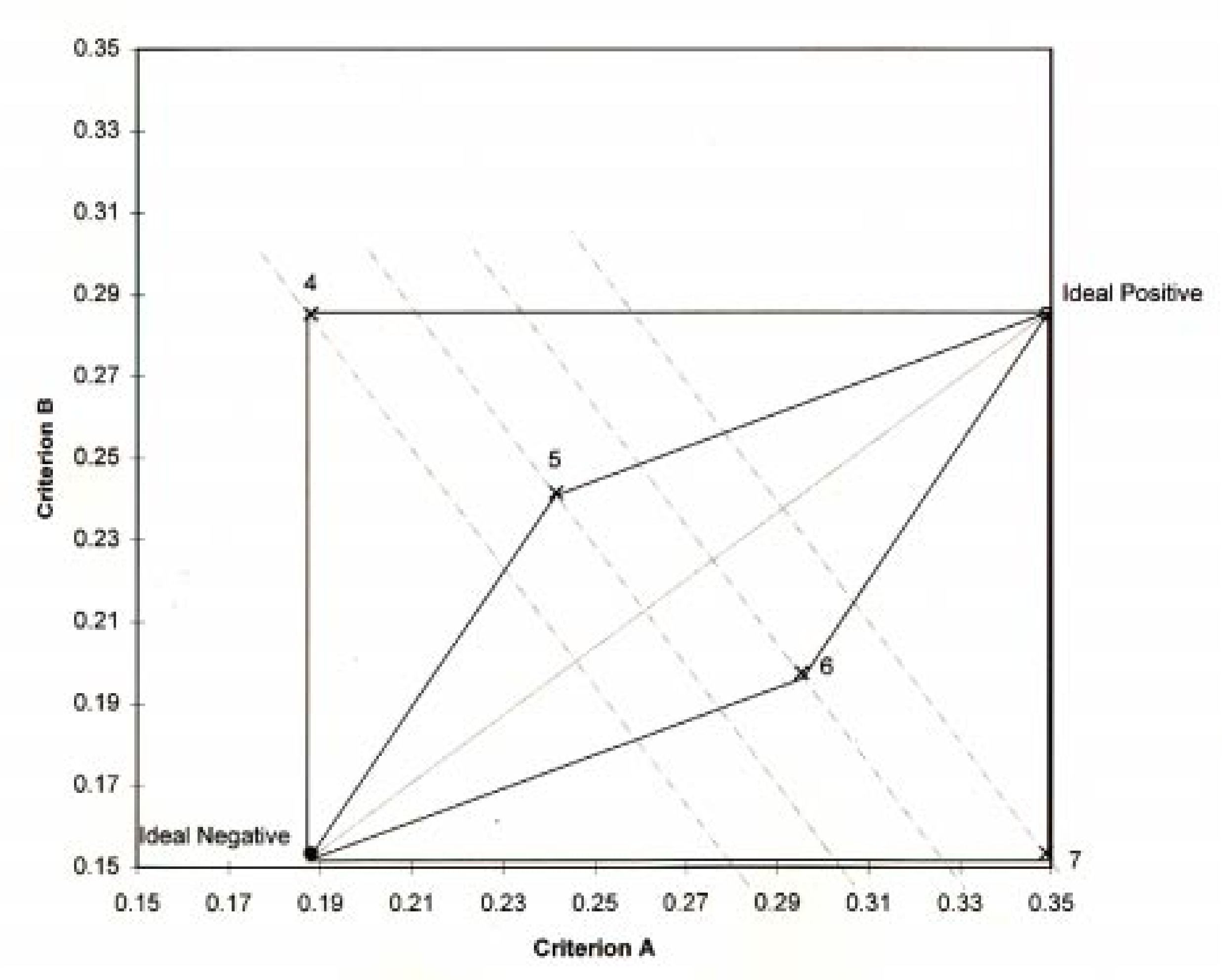

Figure 4.1: Example 2: Region II Projects

Four parallel lines are drawn in Figure 4.1 to aid in visually comparing the projects. These lines are placed to be perpendicular to the line connecting the Ideal Positive and the Ideal Negative Projects. Each of these lines is located such that it crosses through one of the four submitted projects. Note that Project 04 lies on the line closest to the Ideal Positive Project, indicating will receive the highest rank. Similarly, Project 07 lies on the line closest to the Ideal Negative Project, indicating it will receive the lowest rank.

For the statewide ranking, the definition of Ideal Projects plays a larger role in weighting the two criteria. This is because the scores in the projects added to the ranked list have extreme values on one criterion but not in the other. Looking at the scores in Table 4.9, we can see that the projects from Region I have A-scores slightly lower than the Region II A-scores, but they also have B-scores significantly higher than the Region II B-scores. Similarly, the projects from Region III have moderately high A-scores and extremely low B-scores. Overall, the presence of Region I and III scores has expanded the range of B-scores much more than the range of A-scores has been expanded. A geometric demonstration of the statewide ranking is shown in Figure 4.2. The rectangle of score-space is now defined by projects 01 and 10. In contrast to the score-space in Figure 4.1, this new score-space is taller than it is wide, due to the extreme B-scores and the more moderate A-scores of projects 01 and 10. The proportions of this score-space indicate that criterion B is now more significant than criterion A. Of the four parallel diagonal lines (placed in the same way as the lines in Figure 4.1), the one closest to the Ideal Positive Project crosses through Project 04, and the one closest to the Ideal Negative Project crosses through Project 07. These lines indicate that out of the Region II projects, Project 04 will receive the highest rank and Project 07 will receive the lowest rank; Projects 05 and 06 will fall sequentially between them. In other words, the Region II projects will be ranked in the opposite order from how they were placed in the regional ranking.

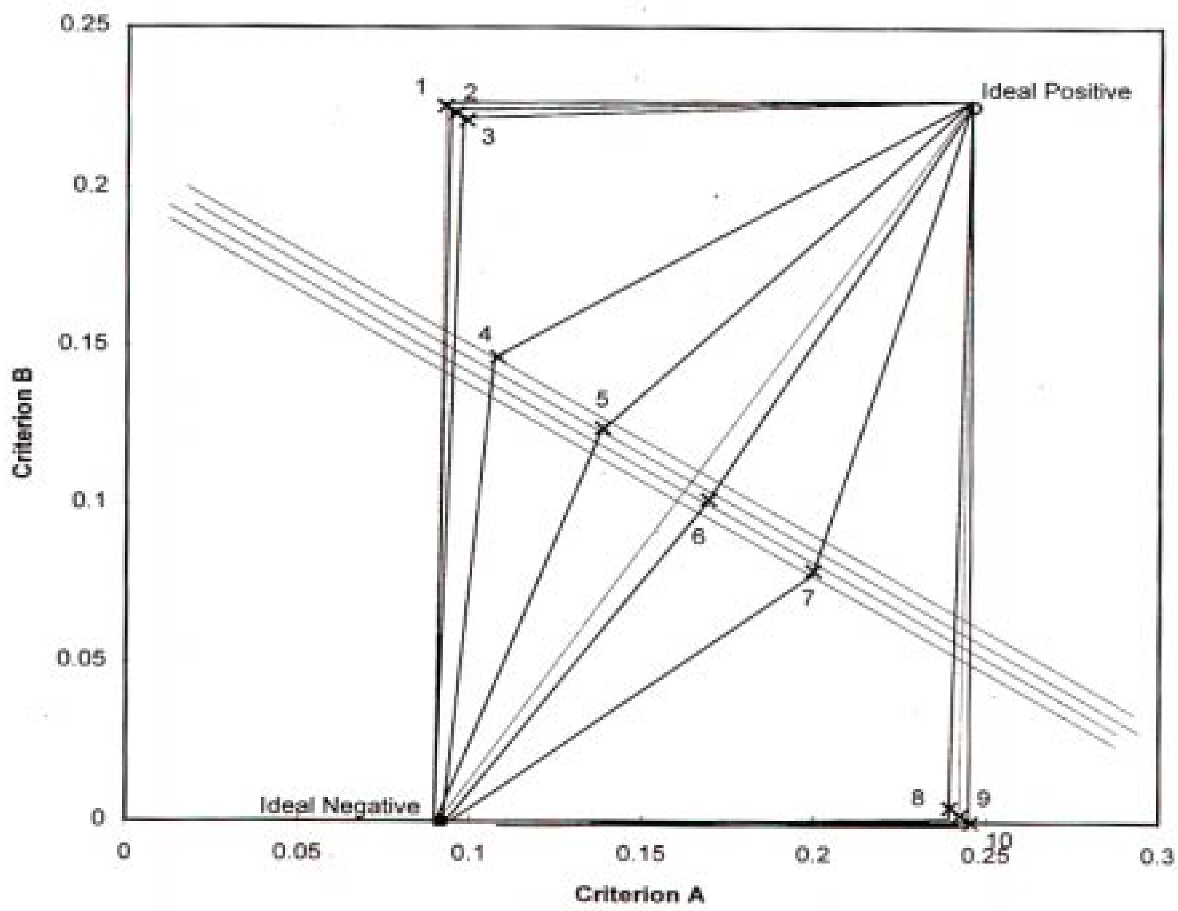

Figure 4.2: Example 2: Statewide Projects

4.3.2 Consistent Weighting of an Important Criterion

For WSDOT's 1995-1997 implementation of TOPSIS-6, one criterion was given 65% of the total weight, to reflect the high importance attributed to it by state officials. However, cases were found in the implementation where projects that were expected to excel on the basis of their this criterion's score did not do so. Concern arose over whether the criterion was being *effectively* weighted as the highest criterion. Example 2 above demonstrates this problem by showing how a criterion that is weighted heavily can have an effective weight that is lower than another criterion. Recall in the example that Criterion A was given a higher explicit weighting than Criterion B, but when the statewide ranking was performed, Criterion B was effectively more influential on the final rankings than Criterion A.

Both of the issues raised in WSDOT's 1995-97 implementation were attributed to the inconsistency in Ideal Project definitions. In the next section, we will examine how TOPSIS-8 was revised to address this problem by using explicit, fixed Ideal Project definitions.

4.4 MODIFICATIONS TO THE TOPSIS METHODOLOGY

The changes in TOPSIS-8 were driven by a need to make explicit the Ideal Project score definitions so that they would not vary depending on the particular list of projects being evaluated. The concept behind this change was that instead of basing the Ideal Project definitions on the best and worst scores *achieved* by the set of submitted projects, they would rather be based on the best and worst *possible* scores in each of the criteria. For four of WSDOT's seven criteria, identifying these extreme possible scores was a straightforward matter because the scoring process did not allow score beyond particular upper and lower bounds; for these criteria, the Ideal Project scores were set to equal these upper and lower score bounds. Each of the remaining three criteria were bounded at only one end: a lower bound of zero. In other words, the set of theoretically possible scores ranged from zero to positive infinity. Consequently, there was no obvious choice for the upper-end Ideal Project scores. The lack of an upper bound presented a problem for TOPSIS because the algorithm depends on having Ideal Projects with finite score values for the calculation of separation measures. To resolve this problem, artificial bounds were constructed using two types of modifications for the three unbound criteria.

The first modification was used to construct an upper bound for the most heavily-weighted criterion. It was decided that because this criterion was weighted most heavily, it would be appropriate to remove projects with extremely high scores in this single criterion from the TOPSIS ranking and automatically place them at the top of the final ranking list, with the projects of highest scores in this criterion leading the ranked list. The threshold at which projects were removed instead of processed through TOPSIS was based on project scores in WSDOT's 1995-97 biennium implementation. As a result of removing these projects, we can know that the remaining projects that are evaluated by TOPSIS will have scores falling between 0 and the given threshold score. Thus, these values could be used to define the upper and lower bounds of the criterion's score range, such that the Negative Ideal project has a score of 0 and the Positive Ideal project has a score equal to the threshold score.

The two remaining unbound criteria were also unconstrained at the positive end, i.e. score could theoretically be anywhere from 0 to postive-infinity; therefore an upper bound needed to be established in both cases. Constraints for these criteria were generated by developing conversion tables. Using these tables, the unbound original scores were categorized into a finite set of revised scores. The conversion table used for converting Wetlands Impacts scores is reproduced in Table 4.12. To use the tables, TOPSIS-8 takes the original score, finds the range in the left column of the table into which this score falls, and extracts the corresponding score in the right column as the project's revised score.

Table 4.12: Sample Conversion Table

Original Score	Revised Score
0 - 0.5	0.5
0.6 - 1.0	1
1.1 - 3.0	2
3.1 - 5.0	4
5.1 - 10.0	8
10.1 - 20.0	10
20.1 - 30.0	15
30.1 - 40.0	20
40.1 - 60.0	25
60.1 - 90.0	35
> 90.0	40

Source: Barnes, 1996

Notice that the last row in Table 4.12Table inputs all scores above 90 and outputs a score of 40. Thus, this row effectively provides the criterion with an upper bound of 40. Similarly, the last row of the Noise conversion table converts all original Noise scores of above 600 to a revised score of 200. Thus, the effective upper bound of the Noise criterion is 200. Now that these two criteria have finite upper bounds, the Ideal Projects can be given scores. In the case of these two criteria, lower scores are better and higher scores are worse. Accordingly, the Ideal Positive project was defined with a Wetlands score of 0 and a Noise score of 0, while the Ideal Negative project was defined with a Wetlands score of 40 and a Noise score of 200.

4.5 DEMONSTRATION OF THE TOPSIS-8 RANKING ALGORITHM

The modified ranking procedure, TOPSIS-8, includes seven steps (asterisks denote new and modified steps):

1. Project Scoring
2. Conversion of Scores & Removal of Projects Meeting Threshold Criterion*
3. Normalizing Scores
4. Weighting Scores
5. Determining Ideal Projects*
6. Ranking Projects*
7. Selecting Funded Projects

The particular conversion tables and threshold used in the modified TOPSIS-8 were specific to the criteria used by WSDOT, since they related specifically to their criteria. However, the concepts may be applied to other criteria as well. Consider Criterion A from Example 2. Although all the scores in this criterion fell between 0 and 100, it is conceivable that higher scores were possible. Therefore something must be done to constrain these scores. Further, let us say that Criterion A was found to have too little of an effect on the final ranking, despite its higher weight of 55%. In Table 4.9, notice that projects 08, 09, and 10 have the highest A-scores, yet when TOPSIS-6 is run, they achieve the lowest ranks, as shown in Table 4.11. We may resolve this problem by establishing a threshold A-score of 70, with higher-scoring projects being removed from the ranking and put at the top of the final list.

The other criterion, Criterion B, may be given an upper bound by using a conversion table such as the ones used by WSDOT to convert Noise and Wetlands scores. Here, we will use the conversion table shown in Table 4.13.

Table 4.13: Conversion of Criterion B to Bounded Scale

Original Score	Revised Score
0	0
1	1
2	2
3 - 5	4
6 - 10	8
11 - 15	10
16 - 20	15
21 - 30	20
31 - 40	25
41 - 60	35
> 60	40

As a result of the above changes to the methodology, we can now define explicitly the Ideal Positive Project as having an A-score of 70 and a B-score of 40; the Ideal Negative Project has an A-score of 0 and a B-score of 0. Next we will process the Example 2 scores in our revised TOPSIS procedure, beginning with project scoring.

4.5.1 Step 1: Project Scoring

The original project scores collected are the same as they were for TOPSIS-6, resulting in the same scores as shown in Table 4.9. The worksheets used to collect these scores should be the same as those used to collect scores for TOPSIS-6.

4.5.2 Step 2: Conversion of Scores

Before actually converting the scores, the projects with A-scores over the threshold value of 70 should be marked for omission from the TOPSIS algorithm, as shown in Table 4.14. Thus, Projects 08, 09, and 10 are omitted; they will be excluded from TOPSIS calculations and reincorporated in the final ranking. Now we apply conversion tables where needed. In our example, we use Table 4.13 to convert the B-scores. The converted scores are shown in the second and third columns of Table 4.14.

4.5.3 Step 3: Normalizing Scores

The converted scores are normalized in the same manner as in TOPSIS-6, using Equation 1. The normalized scores for our example are shown in the fourth and fifth columns of Table 4.14.

Table 4.14: Example 2: Calculations Using TOPSIS-8

Project Number	Converted Scores		Normalized Scores		Weighted Scores		Separation Measures		Priority Index
	A	B	A	B	A	B	S*	S^-	
01	30	40	0.259	0.411	0.143	0.185	0.190	0.234	0.551
02	31	40	0.268	0.411	0.147	0.185	0.185	0.236	0.561
03	32	40	0.277	0.411	0.152	0.185	0.181	0.239	0.570
04	35	40	0.303	0.411	0.166	0.185	0.166	0.249	0.599
05	45	35	0.389	0.360	0.214	0.162	0.121	0.268	0.689
06	55	35	0.475	0.360	0.261	0.162	0.075	0.307	0.804
07	65	25	0.562	0.257	0.309	0.116	0.073	0.330	0.818
08	A-score > 70 ⇒ removed from TOPSIS								
09	A-score > 70 ⇒ removed from TOPSIS								
10	A-score > 70 ⇒ removed from TOPSIS								
Ideal Pos.	70	40	0.605	0.411	0.333	0.185			
Ideal Neg.	0	0	0.000	0.000	0.000	0.000			

4.5.4 Step 4: Weighting Scores

The weighting of normalized scores is performed by multiplying these scores by the weighting factors, just as was done in TOPSIS-6. Here, we multiply A-scores by 0.55 and B-scores by 0.45. The resulting values are shown in the sixth and seventh columns of Table 4.14.

4.5.5 Step 5: Determining Ideal Projects

Ideal Projects in TOPSIS-8 are defined explicitly as the best and worst *possible* scores in each of the criteria. For constrained criteria, the Ideal Projects are defined by the inherent numerical bounds. In criteria where a threshold is used to remove high-scoring projects, the threshold itself is used to define the score of the Ideal Positive project. In criteria for which a conversion table is used to constrain the scores, the Ideal Projects are defined by the best and worst scores out of those listed in the "Revised Score" column of the table.

In our example, the A-scores of the Ideal Negative and Ideal Positive projects are 0 and 70, respectively. The upper bound is set at 70 because that is the threshold above which projects are removed from TOPSIS. The B-scores of the Ideal Negative and Ideal Positive projects are 0 and 40, respectively, because these are the lowest and highest possible revised scores found in the second column of Table 4.13. These Ideal Project definitions are listed in the last two rows of Table 4.14. Note that these scores must be normalized and weighted in the same way that the other project scores are normalized and weighted.

4.5.6 Step 6: Ranking Scores

The ranking procedure is two-tiered: first, the projects that were omitted due to high A-scores are placed at the top of the list, as shown in the second column of Table 4.15 by the A-scores in parentheses; second, the remaining projects are ranked in order of descending priority index, which is based on separation measures. Separation measures are calculated using Equation 2; for our example, the results are shown in the eighth and ninth columns of Table 4.14. The priority index is then calculated using Equation 3. The priority indices are shown in the tenth column of Table 4.14. The resulting ranking is shown in Table 4.15.

Table 4.15: Example 2: Ranked Projects Using TOPSIS-8 and a $40 Million Budget

Rank	Project Number	A-Score (if omitted)	Priority Index	Budget ($ million)	Cumulative Budget ($ million)	Funded?
1.	10	80	-	3.9	3.9	Yes
2.	09	79	-	9.5	13.4	Yes
3.	08	78	-	2.0	15.4	Yes
4.	07	-	0.818	3.0	18.4	Yes
5.	06	-	0.804	5.3	23.7	Yes
6.	05	-	0.689	9.9	33.6	Yes
7.	04	-	0.599	6.9	40.5	No
8.	03	-	0.570	5.1	45.6	No
9.	02	-	0.561	7.9	53.5	No
10.	01	-	0.551	9.6	63.1	No

A similar ranking was performed on only the Region II projects, resulting in the ranking shown in Table 4.16. Note that the regional ranking is identical to the relative ranking of Region II projects in the statewide ranking.

Table 4.16: Example 2: Comparison of Region II Rankings from TOPSIS-8

Project Number	Criterion A	Criterion B	Regional Ranking	Relative State-wide Ranking
04	35	65	4	4
05	45	55	3	3
06	55	45	2	2
07	65	35	1	1

4.5.7 Step 7: Selecting Funded Projects

The process of selecting funded projects is identical to that used in TOPSIS-6. First, a budget must be set; in our example, we use a budget of $40 million. Second, the cumulative budget for each project plus those ranked above it is calculated, as shown in Table 4.15. Finally, the list of cumulative budgets is examined to find the highest value that is less than the allotted budget; the corresponding project and all projects with higher ranks are then selected as funded projects. In our example, only the first six projects are funded.

4.6 IMPLICATIONS FOR ODOT

Much of the experience gained by WSDOT's 1995-97 implementation is useful in developing TOPSIS for use by ODOT. Most significantly, the specification of Ideal Projects in the earlier version of TOPSIS raised two issues: 1) how to arrive at consistent ranking orders between regional and statewide rankings, and 2) how to maintain the significance of a heavily weighted criterion. The first of these issues is of major concern to ODOT, since the agency uses the same funding procedure as WSDOT, in which regions submit project proposals to the state for funding. Because this process is the same, it is entirely possible that the same problem of consistent rankings would occur if TOPSIS-6 were implemented in Oregon. The second problem's relevance to ODOT depends on whether or not there is one single criterion with a weighting factor that dominates over the other weighting factors. If there is such a factor, then this problem is liable to occur as well.

Adding modifications similar to those found in WSDOT's TOPSIS-8 could mitigate both of these problems. However, the modifications are not directly transferable. The modifications in TOPSIS-8 apply specifically to the criteria of Cost-Efficiency, Noise Impacts, and Wetlands Impacts, which were the three unconstrained criteria for WSDOT. Since ODOT will use different evaluation criteria, these modifications cannot be applied "as-is." In ODOT's current set of criteria, there are three different unconstrained criteria: Net Present Value/Cost, Environmental Impact, and Community Support – if TOPSIS-8 is to be used, these are the criteria that need to be constrained when modifying TOPSIS-6. Depending on the chosen weights for these criteria, each of them can be constrained using one of the following two methods:

1. Define a threshold value at which higher scoring projects are removed from the TOPSIS ranking and given top priority. This can only be used for one criterion at a time, and it should only be used if the criterion is weighted significantly more than the other criteria.

2. Develop a conversion table that inputs unconstrained scores and outputs from a constrained set of revised scores.

Used appropriately, these remedies will likely mitigate some of the problems that ODOT may encounter in its implementation of TOPSIS.

5.0 TEST SCENARIO RANKINGS

A preliminary sample score set, consisting of eight completed projects described in section 0, was built for testing in TOPSIS-6. Eight different weighting scenarios were used in the test: in Scenario I, all criteria were weighted equally; in Scenarios II – VII, each of the criteria, with the exception of the Economic Development criterion, were in their turn given 50% of the weight, while the other five criteria equally shared the remaining 50%.

The specific scores found in the sample projects prevent us from using the Economic Development criterion in the TOPSIS calculations. This is because all scores in this criterion have the same score of zero. As a result, if this criterion were included in the TOPSIS procedure, the Priority Index calculation would result in divide-by-zero errors, since the distance between any project and each of the ideal projects would be zero. To prevent these errors from occurring, the following rankings were produced by omitting the Economic Development criterion from the actual TOPSIS procedure, and no scenario was developed using Economic Development as the dominant criterion. Because all scores in this criterion are the same, the criterion should have no effect on rankings; therefore, the results when omitting Economic Development should be the same as if it were included.

5.1 SCENARIO I: EQUAL WEIGHTS

The first test of TOPSIS-6 used equal weights for all of the criteria. The resulting ranking is shown in Table 5.1.

Table 5.1: Project Ranking with Equal Criteria Weights

Priority Index	Project No. & Type	Land Use	Env. Rsrc.	Cost Eff.	Econ. Dev.	Mode Integ.	Cmty. Supt.*	Access
0.651	6906: Signal Retiming	5	0	196.9	0	1	663	1
0.517	7523: TDM Rideshare	5	0	-0.77	0	9	0	2
0.325	7252: Signal Coord. & Opt.	4	0	26.01	0	0	89	0
0.267	4043: Widening, Bike & Ped. Lanes	1	50	1.42	0	3	0	1
0.181	0713: New Interchange	0	100	-0.2	0	1	0	1
0.125	7219: Interchange Reconstruction	-1	50	-0.94	0	0	58	0
0.111	7034: Interchange Reconstruction	1	100	7.49	0	0	12	0
0.000	3466: Road Reconstruction	-1	100	-0.79	0	0	0	0

**Community Support scores have been multiplied by* $1*10^6$

In general, the prioritization produced an unsurprising ranking. The highest-ranked project is an obvious choice; Project 6906 has the best achieved scores in the Land Use, Environmental Resource, Community Support, and Cost-Efficiency criteria. The second-rank project, Project 7523, has the best scores in the Land Use, Environmental Resource, Modal Integration, and Accessibility criteria. At the bottom end of the ranking is Project 3466, with the worst achieved scores in the Land use, Environmental Resource, Modal Integration, Community Support, and Accessibility criteria.

5.2 SCENARIO II: DOMINANT LAND USE CRITERION

In the next ranking, we give one criterion, the Land Use criterion, 50% of the total weight, and equally distribute the remaining weight among the other criteria. The resulting ranking is shown in Table 5.2.

Table 5.2: Project Ranking with Land Use as the Dominant Criterion

Priority Index	Project No. & Type	Land Use	Env. Rsrc.	Cost Eff.	Econ. Dev.	Mode Integ.	Cmty. Supt.*	Access
0.833	6906: Signal Retiming	5	0	196.9	0	1	663	1
0.763	7523: TDM Rideshare	5	0	-0.77	0	9	0	2
0.662	7252: Signal Coord. & Opt.	4	0	26.01	0	0	89	0
0.319	4043: Widening, Bike & Ped. Lanes	1	50	1.42	0	3	0	1
0.295	7034: Interchange Reconstruction	1	100	7.49	0	0	12	0
0.170	0713: New Interchange	0	100	-0.2	0	1	0	1
0.057	7219: Interchange Reconstruction	-1	50	-0.94	0	0	58	0
0.000	3466: Road Reconstruction	-1	100	-0.79	0	0	0	0

**Community Support scores have been multiplied by* $1*10^6$.

This ranking is different from the Equal-Weights scenario in that Project 7034 has risen two places. This change is direct result of heavily weighting the Land Use criterion. As we would expect, in this ranking we find that the projects are now exactly placed in order of decreasing Land Use score.

5.3 SCENARIO III: DOMINANT ENVIRONMENTAL IMPACTS CRITERION

In the next scenario, half of the total weight is given to the Environmental Resource criterion. All other criteria are weighted equally to fill the remaining weight. As a result of these weights, the projects are ranked as shown in Table 5.3.

Table 5.3: Project Ranking with Environmental Impacts as the Dominant Criterion

Priority Index	Project No. & Type	Land Use	Env. Rsrc.	Cost Eff.	Econ. Dev.	Mode Integ.	Cmty. Supt.*	Access
0.797	6906: Signal Retiming	5	0	196.9	0	1	663	1
0.714	7523: TDM Rideshare	5	0	-0.77	0	9	0	2
0.656	7252: Signal Coord. & Opt.	4	0	26.01	0	0	89	0
0.424	4043: Widening, Bike & Ped. Lanes	1	50	1.42	0	3	0	1
0.389	7219: Interchange Reconstruction	-1	50	-0.94	0	0	58	0
0.101	0713: New Interchange	0	100	-0.2	0	1	0	1
0.061	7034: Interchange Reconstruction	1	100	7.49	0	0	12	0
0.000	3466: Road Reconstruction	-1	100	-0.79	0	0	0	0

**Community Support scores have been multiplied by* $1*10^6$

In this case, there is only one reversal in order relative to the Equal Weights scenario, and this reversal is the same as found in Scenario II: Projects 7219 and 0713 have been switched. As in Scenario II, this new ranking is a direct result of the heavy weight given to one criterion, this time being the Environmental Resource criterion. Notice that the projects are now ordered in sequence of increasing Environmental Resource score; in the case of a tie between two projects, the order is the same as in the Equal-Weights scenario.

5.4 SCENARIO IV: DOMINANT NPV/C CRITERION

When the Cost-Efficiency criterion, or the NPV/C ratio, is given 50% of the weight, with the remaining weight equally distributed among the remaining criteria, the result is the ranking is shown in Table 5.4.

Table 5.4: Project Ranking with Cost-Efficiency as the Dominant Criterion

Priority Index	Project No. & Type	Land Use	Env. Rsrc.	Cost Eff.	Econ. Dev.	Mode Integ.	Cmty. Supt.*	Access
0.870	6906: Signal Retiming	5	0	196.9	0	1	663	1
0.199	7523: TDM Rideshare	5	0	-0.77	0	9	0	2
0.176	7252: Signal Coord. & Opt.	4	0	26.01	0	0	89	0
0.092	4043: Widening, Bike & Ped. Lanes	1	50	1.42	0	3	0	1
0.063	0713: New Interchange	0	100	-0.2	0	1	0	1
0.055	7034: Interchange Reconstruction	1	100	7.49	0	0	12	0
0.043	7219: Interchange Reconstruction	-1	50	-0.94	0	0	58	0
0.001	3466: Road Reconstruction	-1	100	-0.79	0	0	0	0

**Community Support scores have been multiplied by* $1*10^6$.

This ranking is identical to the ranking in Scenario I, with one exception: Projects 7034 and 7219 have reversed positions. To explain this reversal, notice that Project 7034 has a significantly positive NPV/C ratio of 7.49, while Project 7219 has a negative ratio of –0.79. These two projects have reversed position because the added weight given to Cost-Efficiency has now overpowered Project 7219's superior scores in Environmental Resources and Community Support.

A surprising result of this ranking is the fact that Project 7523, with a NPV/C score of –0.77, has retained its second-place position above Project 7252, despite the high weight of that criterion and Project 7252's high NPV/C score. To understand this effect, one must consider the Modal Integration and Accessibility scores. In both of these criteria, Project 7523 has the highest score achieved in the project set; in other words, the project has defined the Ideal Positive Project in two of the seven categories. In addition, note that the project's Modal Integration score is far above any of the other projects' scores in that criterion; the other have scores between 0 and 3, while Project 7523 has a score of 9. This separation has the side effect of causing the criterion to be effectively more highly weighted. As such, the project scores high enough in the non-monetary criteria to maintain its position. This ranking result is an example of the effect discussed in Section 5, in which a criterion that is given a high explicit weight may not be given as high an effective weight, once the effect of Ideal Project definitions has been incorporated.

5.5 SCENARIO V: DOMINANT MODAL INTEGRATION CRITERION

In Scenario V, the Modal Integration criterion was given 50% of the total weight, while the other criteria were given equal weights using the remaining total weight. The resulting ranking is shown in Table 5.5.

Table 5.5: Project Ranking with Modal Integration as the Dominant Criterion

Priority Index	Project No. & Type	Land Use	Env. Rsrc.	Cost Eff.	Econ. Dev.	Mode Integ.	Cmty. Supt.*	Access
0.804	7523: TDM Rideshare	5	0	-0.77	0	9	0	2
0.324	4043: Widening, Bike & Ped. Lanes	1	50	1.42	0	3	0	1
0.266	6906: Signal Retiming	5	0	196.9	0	1	663	1
0.124	7252: Signal Coord. & Opt.	4	0	26.01	0	0	89	0
0.123	0713: New Interchange	0	100	-0.2	0	1	0	1
0.046	7219: Interchange Reconstruction	-1	50	-0.94	0	0	58	0
0.040	7034: Interchange Reconstruction	1	100	7.49	0	0	12	0
0.000	3466: Road Reconstruction	-1	100	-0.79	0	0	0	0

**Community Support scores have been multiplied by* $1*10^6$.

The ranking shown here is the result of four order reversals, all involving the first four projects. The major changes are that Project 4043 has risen by two ranks, while Project 6906 has fallen by two ranks. In the process, Project 7523 rose by one rank and Project 7252 fell by one rank. To understand this new ranking order, consider that the Modal Integration scores for these top four projects are now placed in decreasing order.

One unexpected result of this ranking order is that Project 0713 did not rise above Project 7252, despite its slightly higher Modal Integration score. However, when one considers the combined effect of other criteria, this result is not surprising: in the Land Use, Environmental Resource, Cost-Efficiency, and Community Support criteria, Project 7252 scores better than Project 0713. The ranking indicates that the score differences for these criteria must combine to outweigh the difference between Project 0713's Modal Integration score of 1 and Project 7252's score of 0.

5.6 SCENARIO VI: DOMINANT COMMUNITY SUPPORT CRITERION

Under Scenario VI, the Community Support criterion was given half of the total weight, with the other half evenly distributed among the remaining criteria. The ranking that results is shown in Table 5.6.

Table 5.6: Project Ranking with Community Support as the Dominant Criterion

Priority Index	Project No. & Type	Land Use	Env. Rsrc.	Cost Eff.	Econ. Dev.	Mode Integ.	Cmty. Supt.*	Access
0.869	6906: Signal Retiming	5	0	196.9	0	1	663	1
0.200	7523: TDM Rideshare	5	0	-0.77	0	9	0	2
0.176	7252: Signal Coord. & Opt.	4	0	26.01	0	0	89	0
0.093	7219: Interchange Reconstruction	-1	50	-0.94	0	0	58	0
0.091	4043: Widening, Bike & Ped. Lanes	1	50	1.42	0	3	0	1
0.063	0713: New Interchange	0	100	-0.2	0	1	0	1
0.042	7034: Interchange Reconstruction	1	100	7.49	0	0	12	0
0.000	3466: Road Reconstruction	-1	100	-0.79	0	0	0	0

**Community Support scores have been multiplied by* $1*10^6$.

This differs from the Equal-Weight scenario in that Project 7219 has advanced above Projects 4043 and 0713. In this scenario, the order of Community Support scores is somewhat puzzling: rather than descend consistently from the highest to the lowest score, we find that scores of zero are interspersed among diminishing non-zero scores. This ranking is another result of the combined effect several criteria can have on the final ranking. In this case, the Environmental Resource, Modal Integration, Land Use, and Accessibility scores combine to counteract the effect of the Community Support criterion. The even distribution of zeros and non-zeros in the

Community Support criterion and the clustering of Priority Index scores between 0.042 and 0.200 indicate that this criterion's effect and the aforementioned combined effect of other criteria are rather evenly matched.

5.7 SCENARIO VII: DOMINANT ACCESSIBILITY CRITERION

Finally, in Scenario VII, we weight the Accessibility criterion at 50%, while the other criteria equally share the remaining weight. The resulting ranking is shown in Table 5.7.

Table 5.7: Project Ranking with Accessibility as the Dominant Criterion

Priority Index	Project No. & Type	Land Use	Env. Rsrc.	Cost Eff.	Econ. Dev.	Mode Integ.	Cmty. Supt.*	Access
0.771	7523: TDM Rideshare	5	0	-0.77	0	9	0	2
0.538	6906: Signal Retiming	5	0	196.9	0	1	663	1
0.454	4043: Widening, Bike & Ped. Lanes	1	50	1.42	0	3	0	1
0.439	0713: New Interchange	0	100	-0.2	0	1	0	1
0.147	7252: Signal Coord. & Opt.	4	0	26.01	0	0	89	0
0.054	7219: Interchange Reconstruction	-1	50	-0.94	0	0	58	0
0.048	7034: Interchange Reconstruction	1	100	7.49	0	0	12	0
0.000	3466: Road Reconstruction	-1	100	-0.79	0	0	0	0

**Community Support scores have been multiplied by* $1*10^6$.

Relative to the Equal-Weight ranking, we find that three re-orderings have taken place: Projects 7523 and 6906 have reversed ranks, while Project 7252 has dropped two places. These adjustments are not surprising, when one considers that they are necessary to bring the Accessibility scores into a perfect descending order.

5.8 SUMMARY OF RANKING SCENARIOS

The results of the seven ranking scenarios are summarized in Table 5.8. Note that all scenarios in which one criterion has a dominant weight result in at least one shift in ranking order relative to the Equal-Weight scenario (Scenario I). In order of decreasing number of ranking shifts, the scenarios that differ the most from the Equal-Ranking scenario are those in which Modal Integration, Accessibility, and Land Use are in turn given half of the total weight. These results are difficult to interpret because they are a result of correlations between the criteria. To fully assess the influence of each criterion would require a larger set of sample projects and an in-depth sensitivity analysis.

Table 5.8: Summary of Project Ranking Orders

Project No.	Scenario (Dominant Criterion)						
	I (none)	II (Land Use)	III (Env. Rsrc.)	IV (NPV/C)	V (Mode Int.)	VI (Cmty. Supt.)	VII (Access.)
6906	1	1	1	1	3	1	2
7523	2	2	2	2	1	2	1
7252	3	3	3	3	4	3	5
4043	4	4	4	4	2	5	3
0713	5	6	6	5	5	6	4
7219	6	7	5	7	6	4	6
7034	7	5	7	6	7	7	7
3466	8	8	8	8	8	8	8
# Shifts from Scenario I	0	2	1	1	4	1	3

6.0 SUMMARY OF COMMISSION MEETING

The ranking procedure was demonstrated to the ODOT Transportation Commission during a Fall 1997 meeting. A Delphi Analysis was used to demonstrate a consensus-oriented process for determining how criteria weights can be assigned. For the Commission demonstration, seven individuals (representing both commissioners and individuals selected from the audience) were asked to participate by completing a worksheet assigning points, summing to 100, to each of the individual criteria. The results of this exercise are shown in Table 6.1.

As can be seen from Table 6.1, there is greater agreement on weights for criteria such as land use and economic development while less agreement exists on an acceptable weight for the efficiency criterion.

Table 6.1: Criteria Weights

Person	Criteria Weights (%)							
No.	Land Use	Env. Rsrc.	NPV/C	Ec. Dev.	Mode Int.	Cmty. Supt.	Access	TOTAL
1	10	15	10	15	15	15	20	100
2	10	20	20	10	10	20	10	100
3	15	15	15	15	15	15	10	100
4	10	15	10	10	15	25	15	100
5	20	5	20	10	5	20	20	100
6	20	10	30	10	10	15	5	100
7	15	10	40	5	5	10	15	100
Avg. (Std. Dev.)	12.50 (4.50)	11.25 (4.88)	18.13 (10.97)	9.38 (3.45)	9.38 (4.50)	15.00 (4.88)	11.88 (5.56)	

For those criteria in which the standard deviation was large, discussions could be undertaken to enlighten participants on the rationale associated with their individual weight assignments. For instance, such a discussion might be held on the weights assigned to the cost-efficiency criterion. After discussions, Ideally additional rounds of assigning weights would be completed until there was reasonable conversion on a single weight for each criterion.

The Commission noted several issues and questions arising from the ranking methodology:

- The need for a demonstration effort that includes a prior year's STIPs projects organized and ranked by project type and rural/urban designation;
- The potential difficulties of development projects ranking low when detailed design might be able to mitigate some of the issues creating the low ranking;
- The need to clearly identify how the ranking process will occur in the regions and how it will be integrated into the statewide programming effort, and
- The possibility that the existing criteria do not reflect all the important factors that should be taken into account during a ranking process.

7.0 SUMMARY AND RECOMMENDATIONS

This final technical memorandum has presented the various facets of the procedure developed for prioritizing mobility improvement projects in the State of Oregon. Version 8 of TOPSIS is currently not directly transferable from WSDOT's program to ODOT's program because the specific scoring methods differ between the two departments. It may be necessary in the future to incorporate modifications similar to those in TOPSIS-8 into a new version of TOPSIS for ODOT's use, such that subset rankings are consistent between different project sets and criteria are effectively weighted in proportion to their intended weights. Such potential modifications are the subject of research currently in progress at UC Davis. A small sample set of project scores has been built using available data. These projects have been successfully tested in the TOPSIS 6.0 ranking algorithm. Under the test scenarios for weighting the seven criteria, the algorithm yielded generally unsurprising results.

The following recommendations for further implementation of the ranking methodology should be considered:

- Projects from a previous STIP should be used to further test the ranking methodology. This includes new data collection and evaluation for these projects;

- Options should be developed for integrating the new ranking methodology into region and state programming efforts;

- Options should be developed for data collection and access and analysis that must be undertaken during the ranking process. In addition, ODOT has several databases that may help with such data analysis as using construction costs and traffic analysis from comparable projects to create more accurate and detailed estimates for new projects, and finally

- A workshop for the Commission should be held in the near future. This workshop should familiarize the Commissioners with the deliberations the committee undertook in developing the new criteria, options for how the ranking criteria can be integrated into current regions and state level programming efforts, and various personnel options for data collection and analysis. The Commission should also establish criteria weights during the workshop.

8.0 REFERENCES

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