Use of Fuzzy Analytical Hierarchy Process Coupled with Data Mining for Base Condition Assessment of NMDOT Culverts

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Culvert Asset Management Plan (CAMP)

- 3 yr NMDOT Funded Project
  - NMT & NMSU
- NMT Principal Investigators
  - Claudia Wilson
  - Isabel Morris
  - Wes Cook
  - Clint Richardson

Culvert Asset Management Plan (CAMP)

- External Survey of State Maintained Culverts
  - 50,706 culverts logged using handheld Trimble TDC600 GPS and User Input Data Dictionary
  - 40 students employed over three summers
- Primary Base Condition Assessment Focus
  - Reinforced Concrete Pipe Culvert
  - Concrete Box Culvert
  - Corrugated Metal Pipe Culvert

CAMP Survey Importance Attributes Structural and Non-structural Defects

	RCP	CBC	CMP
A	Deterioration*	Deterioration*	Corrosion
B	Siltation	Siltation	Siltation
C	Channel**	Channel**	Channel**
D	Scour	Scour	Scour
E	Physical Damage	Physical Damage	Physical Damage

* Deterioration of concrete: culvert interior/exterior, headwall, or wingwall, such as spalling, cracks, or exposed rebar/mesh.

** Channel condition to culvert inlet

Data Mining using Excel® “If” Statements

- NMDOT
  - Schema code
- Preliminary Data Mining
  - Material Type
    - Concrete, metal, wood, plastic
  - Concrete Shape
    - Circular, arch, box, ellipse
  - Selected Surveyed Attributes

Rating Scale Examples: Silting & Scour

Siltation Survey	Scale
Clean or less than 10%	1
10% to 30% silted	2
30% to 60% silted	3
60% to 90% silted	4
Greater than 90% silted	5

Scour Survey	Scale
Zero to less than 1 ft	1
1 ft to less than 3 ft	2
3 ft to less than 8 ft	3
Greater than 8 ft	4

Corrosion Scale: 1 to 4
CMP Physical Damage Scale: 1 to 4
RCP & CBC Damage Scale: 1 to 3
RCP & CBC Deterioration Scale: 1 to 3
Channel Condition Scale: 1 to 5

AHP vs FAHP Overview*

- AHP lacks the ability to deal with vagueness and uncertainty in subjective personal judgement through its single crisp value pairwise comparisons
- FAHP allows the decision maker to express approximate or flexible preference using triangular fuzzy numbers (TFNs) to achieve a higher level of accuracy and consistency of judgement than AHP
- Additionally, multiple experts may be integrated with FAHP to yield a synergistic aggregation of individual judgements based on a geometric mean of pair-wise comparison responses

*Multi-criteria Decision Making Algorithms

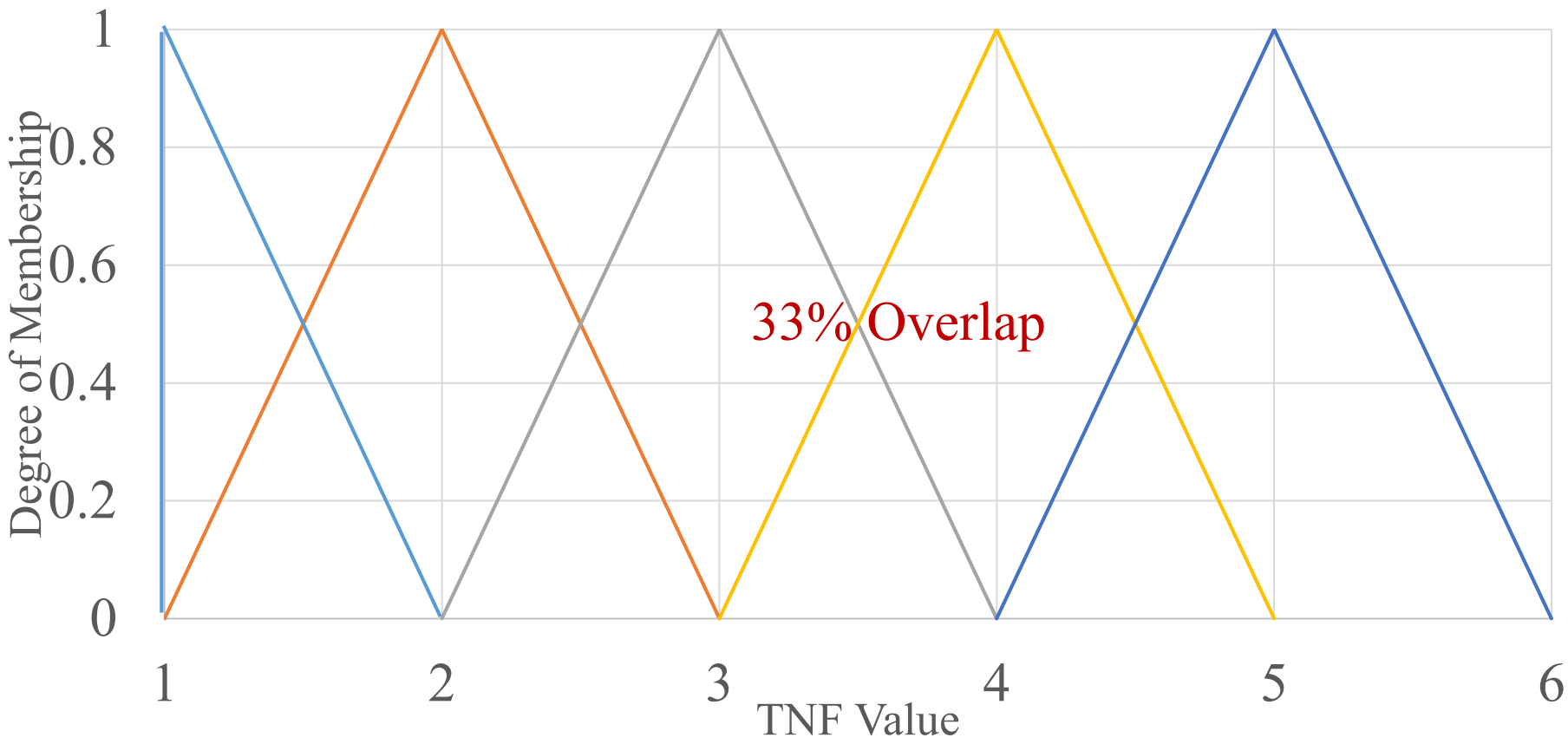
FAHP with Experts

- Pairwise Comparisons
  - 5 Attributes Require 10 Pairwise Comparisons
- Multiple Experts
  - NMDOT
  - Drainage Consultants
  - Potentially Neighboring State DOT

Linguistic Importance Scale & Triangular Fuzzy Scale Used

Linguistic importance scale	Triangular fuzzy scale
Exactly the same (I)	1,1,2
Slightly important (II)	1,2,3
Serious importance (III)	2,3,4
More serious importance (IV)	3,4,5
Absolute importance (V)	4,5,6

Triangular Fuzzy Scale



The overlap characterizes uncertainty of the responses within that numerical range
Attributes weights could be significantly different depending on the design of fuzzy membership functions; should preferably be lesser than 50%

FAHP Template for 10 Pairwise Comparisons

	Left Criteria is Greater Importance					Right Criteria is Greater Importance				
	5	4	3	2	1	2	3	4	5	
A			X							B
A							X			C
A				X						D
A					X					E
B								X		C
B		X								D
B						X				E
C					X					D
C								X		E
D			X							E

FAHP Steps

- Individual Pairwise Comparisons
- Integrated Fuzzy Comparison Matrix
- Relative Weight Vector Evaluation using Eigenvalue
- Aggregate Relative Weight to Crisp Attribute Weights
- Consistency Check

FAHP Weights District 5: Two Expert Raters

	RCP			CBC			CMP		
	1	2	Comp	1	2	Comp	1	2	Comp
A	0.142	0.069	0.099	0.049	0.171	0.100	0.157	0.336	0.234
B	0.214	0.201	0.213	0.083	0.155	0.115	0.236	0.130	0.171
C	0.287	0.372	0.335	0.288	0.415	0.372	0.274	0.228	0.251
D	0.184	0.186	0.178	0.369	0.138	0.245	0.206	0.193	0.208
E	0.172	0.171	0.175	0.211	0.121	0.168	0.127	0.113	0.135
CR*	0.046	0.035	0.023	0.104	0.000	0.025	0.191	0.201	0.086

*Consistency ratio (CR) is an important indicator for achieving the reliability of pairwise comparisons and should be less than 0.10.

Inter-Rater Agreement Coefficient

- Double Entropy Method
  - Spread of responses and frequency distribution of responses
  - Perfect agreement on a pairwise comparison 1.0
  - No agreement on a pairwise comparison 0.0
  - Inter-rater agreement coefficients in the range 0.6 to 0.7 may be considered as a reasonable cutoff for consensus, while values from 0 to 0.6 should be considered as unacceptable levels of agreement (Olenko and Tsyganok, 2016).

Inter-rater Agreement District 5: Two Raters*

Pair-Wise Comparison	RCP	CBC	CMP
1 A to B	0.78	0.78	0.05
2 A to C	0.78	0.51	0.16
3 A to D	0.51	0.16	0.78
4 A to E	0.78	0.31	1.00
5 B to C	0.78	0.78	0.78
6 B to D	1.00	0.31	0.78
7 B to E	1.00	0.31	1.00
8 C to D	0.51	0.05	0.51
9 C to E	0.78	1.00	0.51
10 D to E	0.78	0.51	0.78

*Double Entropy Inter-rater Agreement Coefficient.

Inter-rater Agreement District 5: Two Raters*

	RCP	CBC	CMP
Average	0.77	0.47	0.64
Stdev	0.16	0.30	0.32
COV	21.28	64.17	51.15

*A low COV means good agreement among decision makers on each criterion; or the extent of variability in relation to the mean of the judgments of the decision makers.

Base Condition Assessment CMP: District 1

Culvert ID	Silting	Corrosion	Scour	Damage	Channel	Base
10773	1	1	2	1	1	1.25
10675	1	1	1	1	4	1.40
10684	1	3	1	1	1	1.47
10703	1	2	2	1	1	1.48
10707	1	2	3	1	1	1.74
10673	3	1	1	1	4	1.75
10744	1	2	1	2	4	1.85
10712	1	2	1	4	1	1.86
10700	2	3	2	1	1	1.89
10846	1	3	3	2	1	2.18
10856	4	4	1	2	1	2.42
10855	3	4	1	4	1	2.67


"That's
all
folks!"