Fuller, D.O., Williamson. R., Jeffe, M., and James, D. 2003.

Multi-criteria evaluation of safety and risks along transportation corridors on the Hopi Reservation.

Applied Geography, 23 (2-3): 177-188.

Background

- Objectives:
  - to evaluate crash risk models
  - (To predict crash risk along transportation corridors)
- Risk factors:
  - Natural hazards
  - Terrain
  - Road conditions
- Criteria for the Hopi risk model
  - Slope steepness
  - Proximity to culverts
  - Proximity to intersections
  - Road curvature (sinuosity)
  - Proximity to washes

Method

- Create 11 predicted crash risk maps (i.e., 11 risk models)
- Evaluate the predicted risk
  - Compare risk scores of 135 non-crash versus 67 crash sites
  - t-test

idrisi32

- MCE
  - Overlays layers to create a suitability map based on standardized **factors**, factor weights, and/or **constraints**.
- FUZZY
  - Converts constraints to factors by evaluating the possibility that each pixel belongs to a fuzzy set based on a fuzzy set membership function.
- SAMPLE
  - Creates points using random, systematic, or stratified random sampling scheme.

MCE

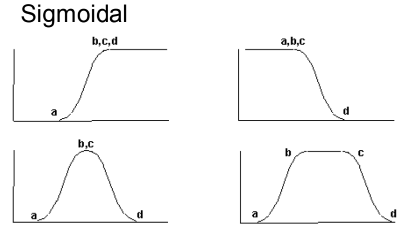
– Slope (from 10m DEM)
– Proximity to culverts (from DOQQ)
– Proximity to intersections (from DOQQ)
– Sinuosity (Count from rasterized road layer)
– Proximity to washes (from DEM)

Idrisi32 – FUZZY

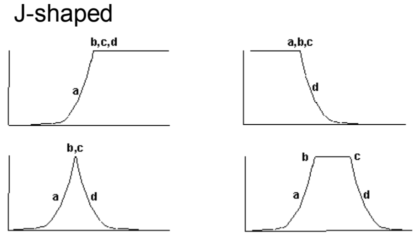
a = membership rises above 0
b = membership becomes 1
c = membership falls below 1
d = membership becomes 0

X-axis: input variable value
Y-axis: fuzzy membership value

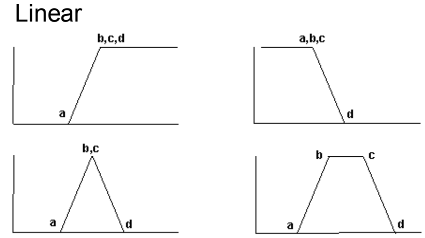
Sigmoidal



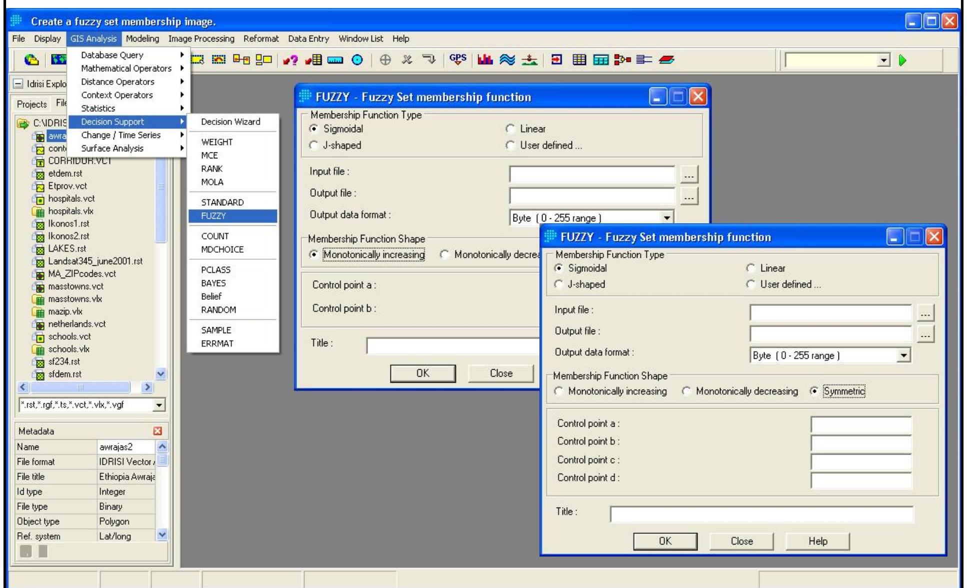
J-shaped



Linear



FUZZY



Standardized Risk Factors

	0 % risk (0)	100% risk (255)
Slope	< 10%	> 25%
Proximity	< 30 m	< 10 m
Sinuosity	?	?

Factor Weights

Risk Models

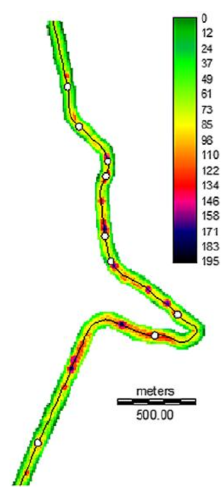
Table 1
MCE composite risk maps with normally distributed scores (values from 0–255). Test 4J is shown in Fig. 3

MCE test	Layers involved	Fuzzy functions	Factor weights
1J	1; 2; 3; 4; 5	L,L,L,L,J	0.2; 0.2; 0.2; 0.2; 0.2
1L	1; 2; 3; 4; 6	L,L,L,L,L	0.2; 0.2; 0.2; 0.2; 0.2
2J	1; 2; 3; 4; 5	L,L,L,L,J	0.25; 0.15; 0.1; 0.2; 0.3
3J	1; 2; 3; 4; 5	L,L,L,L,J	0.3; 0.2; 0.15, 0.25; 0.1
3L	1; 2; 3; 4; 6	L,L,L,L,L	0.3; 0.2; 0.15, 0.25; 0.1
4J	1; 2; 3; 4; 5	L,L,L,L,J	0.1; 0.25; 0.2; 0.3; 0.15
4L	1; 2; 3; 4; 6	L,L,L,L,L	0.1; 0.25; 0.2; 0.3; 0.15
6J	1; 2; 3; 4; 5	L,L,L,L,J	0.2; 0.1; 0.3; 0.15; 0.25
11	1; 3; 4; 5	L,L,L,J	0.25; 0.25, 0.25, 0.25
14	1; 3; 4; 5	L,L,L,J	0.2; 0.3; 0.3; 0.2
18	1; 3; 4; 5	L,L,L,J	0.1; 0.4; 0.4; 0.1

L, linear function; J, J-shaped function; 1, slope steepness; 2, proximity to culverts; 3, proximity to intersections; 4, curvature; 5, proximity to washes (J-shaped function); 6, proximity to washes (linear function).

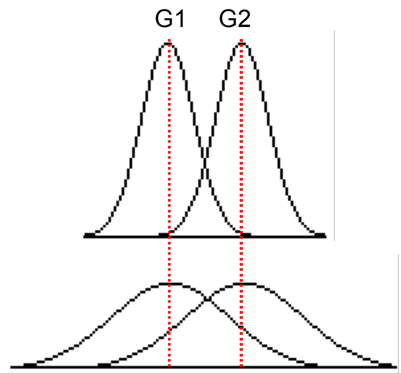
Which Model is the Best?

- 135 non-crash sites and 67 crash sites
- Are the predicted risk scores significantly different between crash and non-crash sites?



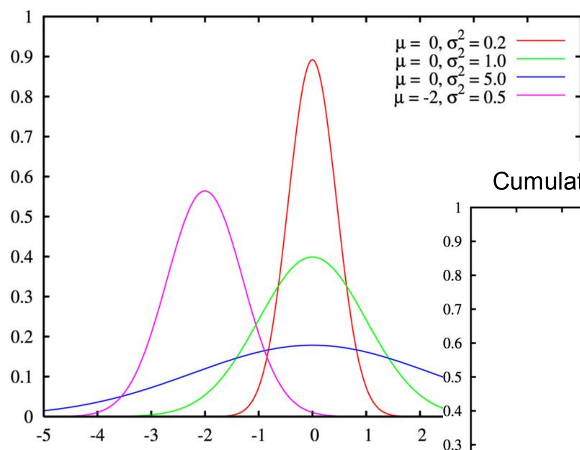
T-test

Are these two groups of observations significantly different?

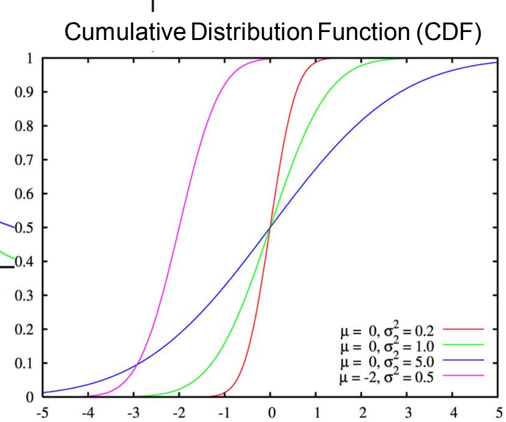


Why is normality important in t-test?

Normal Distribution



- Mean (μ)
- Stdev (σ^2)



Test for Normality

- Statistic
  - Kolmogorov-Smirnov (K-S)
  - Lilifors
  - Shapiro-Wilks
- Visual
  - DF (histogram) / CDF
  - Stemplot
  - QQ Plot

Stem-and-leaf Plot

Writing the data in numerical order may help to organize the data, but is NOT a required step. Ordering can be done later.	35, 36, 38, 40, 42, 42, 44, 45, 45, 47, 48, 49, 50, 50, 50
Separate each number into a stem and a leaf. Since these are two digit numbers, the tens digit is the stem and the units digit is the leaf.	The number 38 would be represented as Stem | Leaf 3 | 8
Group the numbers with the same stems. List the stems in numerical order. (If your leaf values are not in increasing order, order them now.) Title the graph.	Math Test Scores (out of 50 pts) Stem | Leaf 3 | 5 6 8 4 | 0 2 2 4 5 5 7 8 9 5 | 0 0 0
Prepare an appropriate legend (key) for the graph.	Legend: 3 | 6 means 36

Results

- More important factors:
  - Proximity to intersection
  - Road sinuosity (+ slope)

Table 2
T-tests showing the *t*-statistic and *p*-value for normally distributed MCE test data

MCE test	Route number	*t*-statistic	*p*-value
1L	17	−2.44	0.016*
1J	17	−2.29	0.020*
2J	17	−1.94	0.054
3J	17	−2.02	0.045*
3L	17	−2.05	0.041*
4J	17	−3.11	0.002*
4L	17	−3.16	0.019*
6J	17	−2.42	0.017*
11	264	0.60	0.548
14	264	1.35	0.180
18	264	3.18	0.002*

*Indicates statistical significance at 95%.

Risk Models

Table 1
MCE composite risk maps with normally distributed scores (values from 0–255). Test 4J is shown in Fig. 3

MCE test	Layers involved	Fuzzy functions	Factor weights	*p*-value
1J	1; 2; 3; 4; 5	L,L,L,L,J	0.2; 0.2; 0.2; 0.2; 0.2	0.016*
1L	1; 2; 3; 4; 6	L,L,L,L,L	0.2; 0.2; 0.2; 0.2; 0.2	0.020*
2J	1; 2; 3; 4; 5	L,L,L,L,J	0.25; 0.15; 0.1; 0.2; 0.3	0.054
3J	1; 2; 3; 4; 5	L,L,L,L,J	0.3; 0.2; 0.15, 0.25; 0.1	0.045*
3L	1; 2; 3; 4; 6	L,L,L,L,L	0.3; 0.2; 0.15, 0.25; 0.1	0.041*
4J	1; 2; 3; 4; 5	L,L,L,L,J	0.1; 0.25; 0.2; 0.3; 0.15	0.002*
4L	1; 2; 3; 4; 6	L,L,L,L,L	0.1; 0.25; 0.2; 0.3; 0.15	0.019*
6J	1; 2; 3; 4; 5	L,L,L,L,J	0.2; 0.1; 0.3; 0.15; 0.25	0.017*
11	1; 3; 4; 5	L,L,L,J	0.25; 0.25, 0.25, 0.25	0.548
14	1; 3; 4; 5	L,L,L,J	0.2; 0.3; 0.3; 0.2	0.180
18	1; 3; 4; 5	L,L,L,J	0.1; 0.4; 0.4; 0.1	0.002*

L, linear function; J, J-shaped function; 1, slope steepness; 2, proximity to culverts; 3, proximity to intersections; 4, curvature; 5, proximity to washes (J-shaped function); 6, proximity to washes (linear function).

Comments

- The paper is not well written
- GIS for explanation/model validation
- Use the presented method to find the optimal factor weights

Gemitzi, Tsihrintzis, Voudrias, Petalas, & Stravodimos 2007

Combining GIS, multicriteria evaluation techniques and fuzzy logic in siting MSW landfills

Environmental Geology, 51: 797-811.

Background

- Multi-criteria decision considerations
  - Exclusionary constraints & non-exclusionary factors
  - Factor scores and weights
  - Manage uncertainty in decision
- Case study
  - Identifying the best sites for Municipal Solid Waste (MSW) landfills
  - Constraints (exclusionary criteria)
  - Environmental & socioeconomic factors (non-exclusionary criteria)

Methods

- Convert variables to fuzzy membership
- Do AHP to calculate factor weights
- Use order weights to adjust level of trade-off (risk) of the decision

Decision Criteria

Constraints

- Residential area
- Land uses
- Highways & railways
- Environmental protected areas
- Important aquifers
- Surface water bodies
- Springs and wells
- Exceptional geological conditions
- Distance from country borders & coastline

Environmental Factors

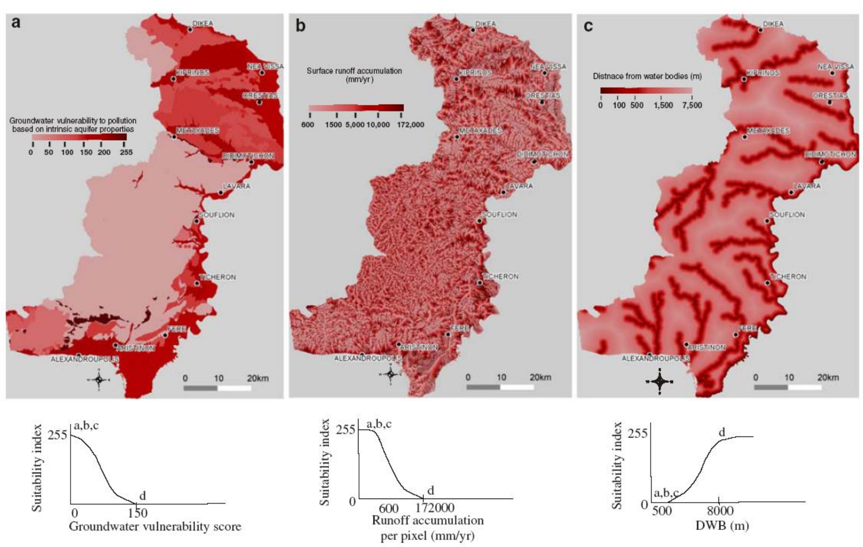
- Hydrogeology
- Hydrology
- Distance from water bodies

Socioeconomic & design factors

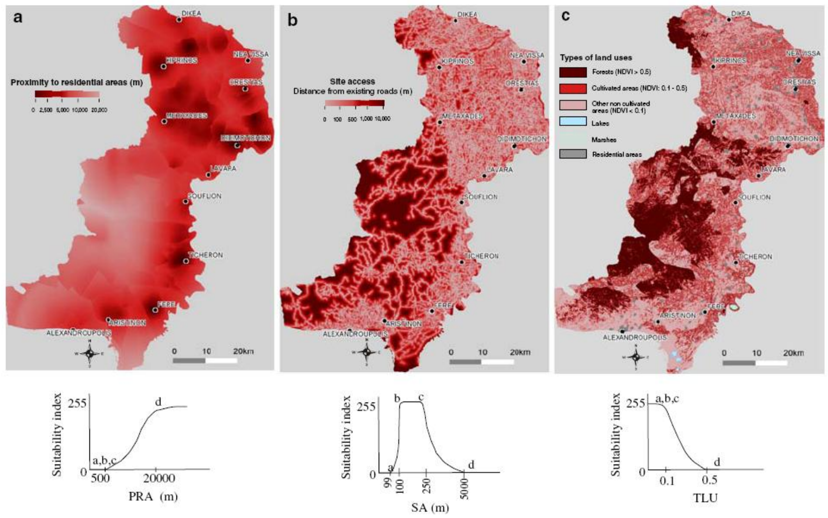
- Proximity to residential areas
- Site access
- Type of land use
- Proximity to waste production centers
- Site orientation
- Slope of land surface

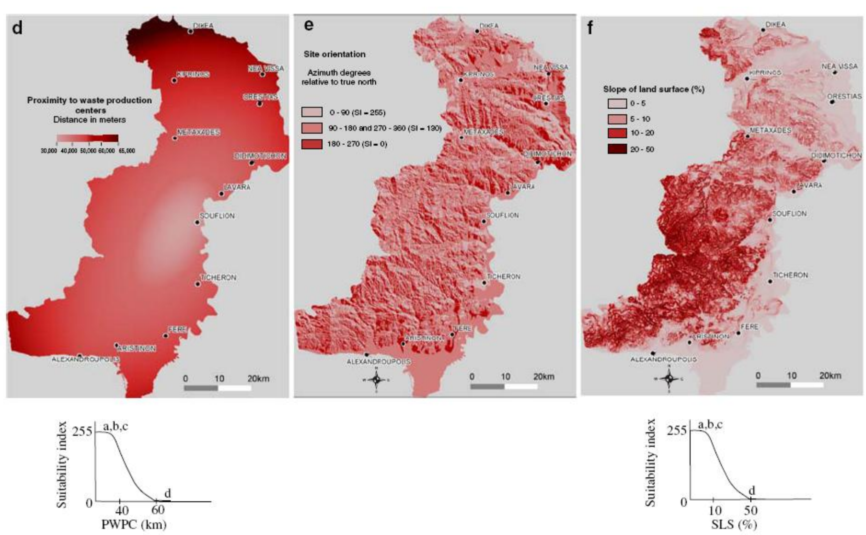
IDRISI FUZZY

a = membership rises above 0
b = membership becomes 1
c = membership falls below 1
d = membership becomes 0



Socioeconomic & Design Factors





Determining Factor Weights

- Assigned directly
- Analytical hierarchy process (AHP)

Analytic Hierarchy Process (AHP) (Saaty 1980)

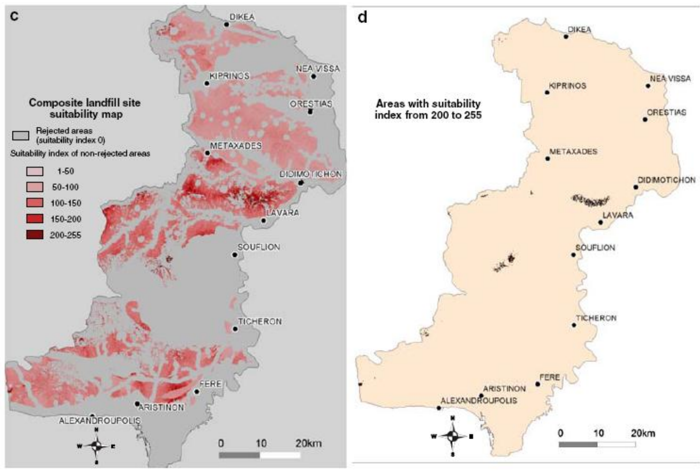
Pairwise comparisons:

To determine the weights for A, B, C

How important is *A* relative to *B*?	**Preference index assigned**
Equally important	1
Moderately more important	3
Strongly more important	5
Very strongly more important	7
Overwhelmingly more important	9

	A	B	C
A	1	5	9
B	1/5	1	3
C	1/9	1/3	1

Criterion	Geometric mean	Weight
A	$(1*5*9)^{1/3} = 3.5569$	0.751
B	$(1/5*1*3)^{1/3} = 0.8434$	0.178
C	$(1/9*1/3*1)^{1/3} = 0.3333$	0.071
Sum	4.7337	1



Ordered Weighted Average (OWA)

- OWA considers the **risk of making a (wrong) decision**.
- The risk of a decision is not the same as the risk of, say, ground water contamination given a certain hydro-geological condition.
- The risk of a decision refers to the consequence of making a bad decision (i.e., pick the wrong site for a landfill).
- If you want to reduce the risk of a decision, then you need to be more **conservative** in making a decision, that is, if one of the factors has a very low score (i.e., less suitable), regardless how high the scores of the other factors are, you should consider the site is not suitable. The site might have a satisfactory averaged score with the LWC method.

Multi-Criteria Evaluation

1. Boolean Intersection
   - Applied on constraints
   - AND, OR
2. Weighted Linear Combination
   - Sum of scores multiplied by factor weights
   - Allows full trade-off among factors
3. Ordered Weighted Average
   - Allows different levels of trade-off

Factor scores:
[174, 187, 201]

Order Weights			Result
Min (1)	(2)	Max (3)	
1.00	0.00	0.00	174
0.90	0.10	0.00	175
0.80	0.20	0.00	177
0.70	0.20	0.10	179
0.50	0.30	0.20	183
0.40	0.30	0.30	186
0.33	0.33	0.33	187
0.30	0.30	0.40	189
0.20	0.30	0.50	191
0.10	0.20	0.70	196
0.00	0.20	0.80	198
0.00	0.10	0.90	200
0.00	0.00	1.00	201

Ordered Weighted Average

Table 2 Example of order weight assignment

Moderate level of risk – moderate strict decision – full trade off				
Factors	HDG	HGR	DWB	
Order weights	0.33	0.33	0.33	= WLC
Rank	1st	2nd	3rd	
Low Level of Risk – very strict decision – no trade off				
Factors	HDG	HGR	DWB	
Order weights	1	0	0	~ MIN
Rank	1st	2nd	3rd	
High Level of Risk – no strict decision – no trade off				
Factors	HDG	HGR	DWB	~ MAX
Order weights	0	0	1	
Rank	1st	2nd	3rd	

Implementing Ordered Weighted Average in ArcGIS

- Raster Calculator

  r1 = rank(1, [factor1], [factor2], [factor3])

  r2 = rank(2, [factor1], [factor2], [factor3])

  r3 = rank(3, [factor1], [factor2], [factor3])

  owavg = [r1] * 0.5 + [r2] * 0.3 + [r3] * 0.2

MCE Example: Land Slide

	WLC		Min	Max	OWA
Soil Type	0.1	Rank1	1	0	0
Vegetation	0.3	Rank2	0	0	0.4
Slope	0.6	Rank3	0	1	0.6

Factor Scores: 0 – 100; 100 has the highest risk

	Site A	Site B	Site C	Site D	Site E	Site F	Site G
Soil Type	90	10	50	80	50	90	10
Vegetation	10	10	50	80	70	70	10
Slope	10	90	50	80	90	50	10
WLC							
Min							
Max							
OWA							

	Site A	Site B	Site C	Site D	Site E	Site F	Site G
Soil Type	90	10	50	80	50	90	10
Vegetation	10	10	50	80	70	70	10
Slope	10	90	50	80	90	50	10
WLC	18	**58**	**50**	**80**	**80**	**60**	10
Min	10	10	**50**	**80**	**50**	**50**	10
Max	**90**	**90**	**50**	**80**	**90**	**90**	10
OWA	**58**	**58**	**50**	**80**	**82**	**82**	10