A Pilot Program on Teaching Engineering Design Using Probabilistic Approaches

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Project Overview

- Current undergraduate ME curriculum
  - Idealistic engineering design
  - No consideration of uncertainty and risk in decision making
- Project goals of strategic initiative
  - Establish an information-based approach to engineering design
  - Prompt the development, implementation and assessment of novel approaches in engineering design education
  - Demonstrate that concepts of uncertainty, decision theory and optimization can be taught effectively
- Implementation
  - ME322 Engineering Design VI: theoretical concepts implemented as part of comprehensive group design project
  - Propagation of approach to entire engineering curriculum

Importance of Decision Making under Uncertainty

- Decision making
  - Widely used in industry
  - Often a difficult process
  - Large impact on project success
- Standardized method
  - Allows systematic design approach
  - Creates a common language between engineers and business managers
  - Provides general guidelines for any decisions

Decision Making Process

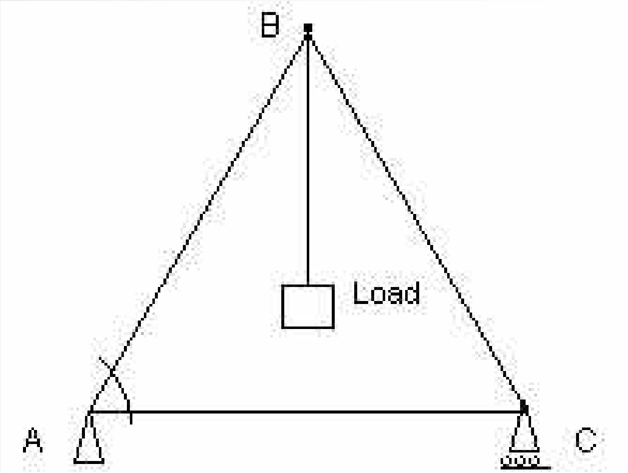
- Foundation
  - Probability theory
  - Common statistical distributions
  - Modeling methods (e.g. Monte Carlo method)
- Steps of decision making process
  - Define design objectives
  - Generate options (design alternatives)
  - Specify evaluation measures
  - Determine value scales for evaluation measures
  - Grade options and select best
  - Test decision using sensitivity analysis

Objectives and Options

- Determine project objectives
  - Goals, technical, organizational and budgetary constraints, limitations
- Generate option space
- Reduce available option space to a subset of options
- Define relevant parameters and corresponding variations for each option

Example: Objective

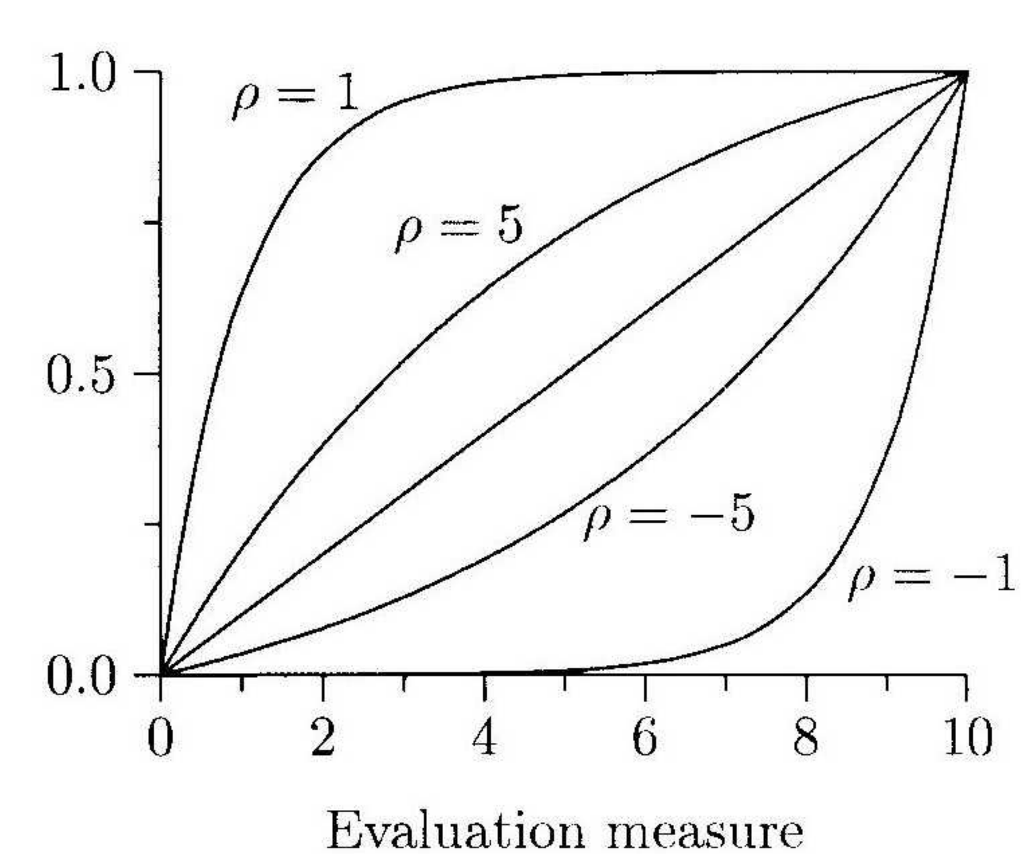
- Design a triangular truss to support 24,000 N
- Design options:



OPTION	1		2		3	
Fill Type	Hollow		Hollow		Hollow	
Radius [m] Outer/Inner	0.03	0.015	0.04	0.025	0.05	0.035
Radial Deviation [m]	0.005	0.005	0.005	0.005	0.005	0.005
Angle [deg]	65		62.5		60	
Angular Deviation [deg]	0.5		0.5		0.5	

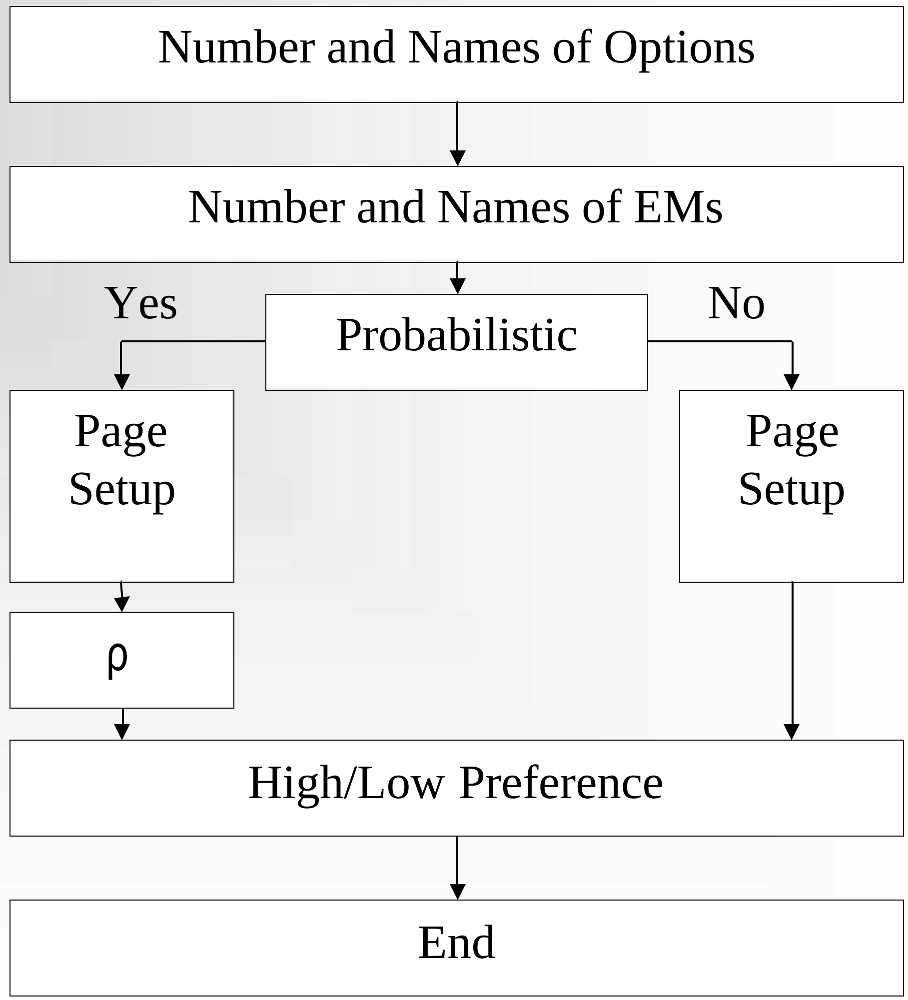
Evaluation Measures

- Definition: a numerical quantity to grade some design aspect or parameter
- Types
  - Deterministic
    - Value expressed as single number
  - Probabilistic
    - Value expressed as range/distribution
    - Requires risk inclination number (ρ)



Example: Evaluation Measures

- Cost (deterministic)
- Percent failure (deterministic)
- Critical load (probabilistic)



Value Scales

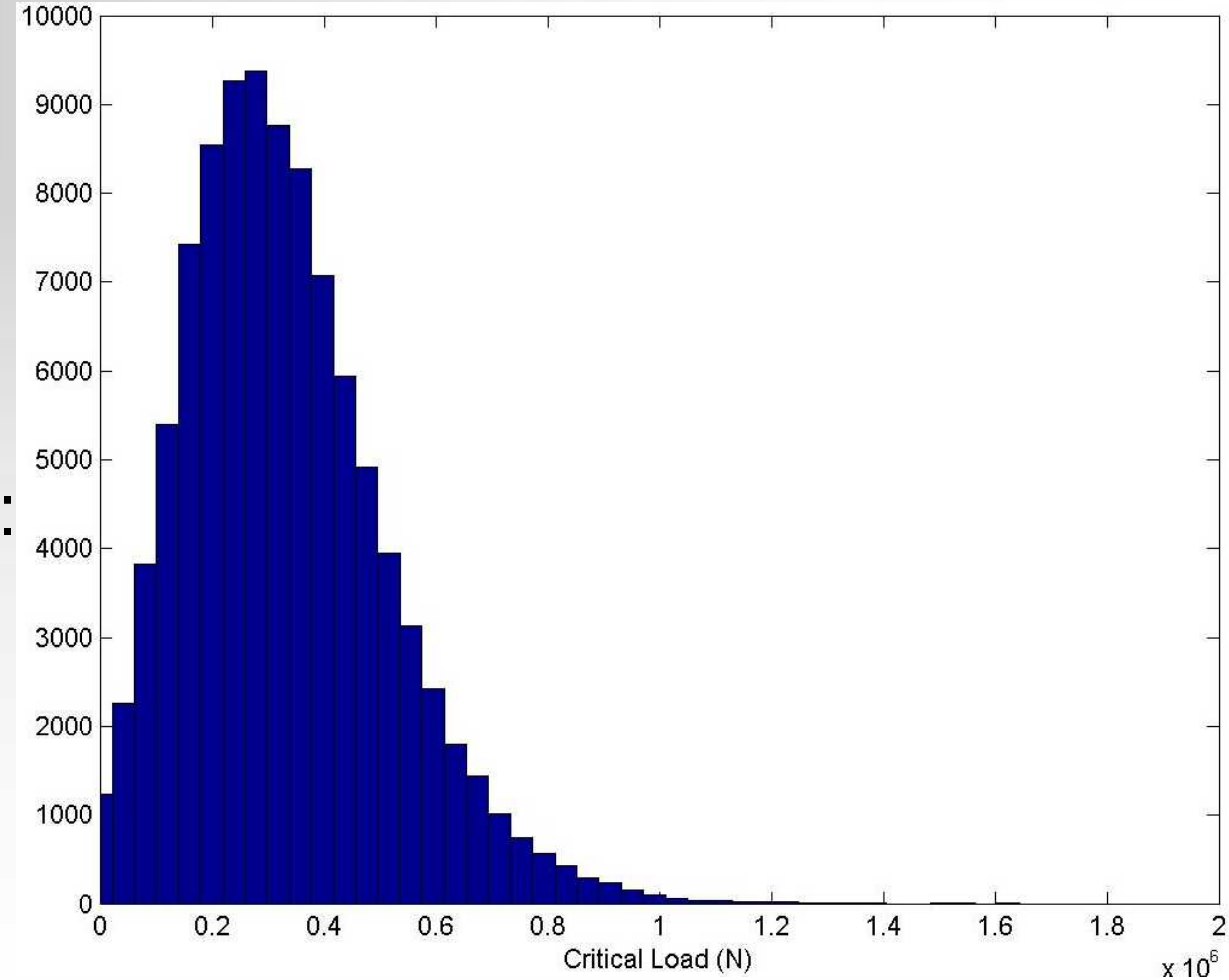
- Select a range for each evaluation measure
- Determine a score for each evaluation measure of each option

- Deterministic Evaluation Measures (EMs) for Example:

DETERMINISTIC EMs	HOLLOW #1	HOLLOW #2	HOLLOW #3	HIGH	LOW
Cost [$]	384.14	542.65	682.29	1000	350
Percent Failure	16.97	3.69	3.52	20	1

Example: Probabilistic Evaluation Measure

- Percent failure as modeled by Monte Carlo method using MATLAB: (cumulative distribution of critical load)



Option Grades

- Normalize option scores

$$f(\text{score}) = \frac{\text{score} - \text{Low}}{\text{High} - \text{Low}} \qquad f(\text{score}) = \frac{1 - \exp[-(\text{score} - \text{Low})/\rho]}{1 - \exp[-(\text{High} - \text{Low})/\rho]}$$

$$f(\text{score}) = \frac{\text{High} - \text{score}}{\text{High} - \text{Low}} \qquad f(\text{score}) = \frac{1 - \exp[-(\text{High} - \text{score})/\rho]}{1 - \exp[-(\text{High} - \text{Low})/\rho]}$$

- Determine weights for each EM
- Calculate final grade for each option

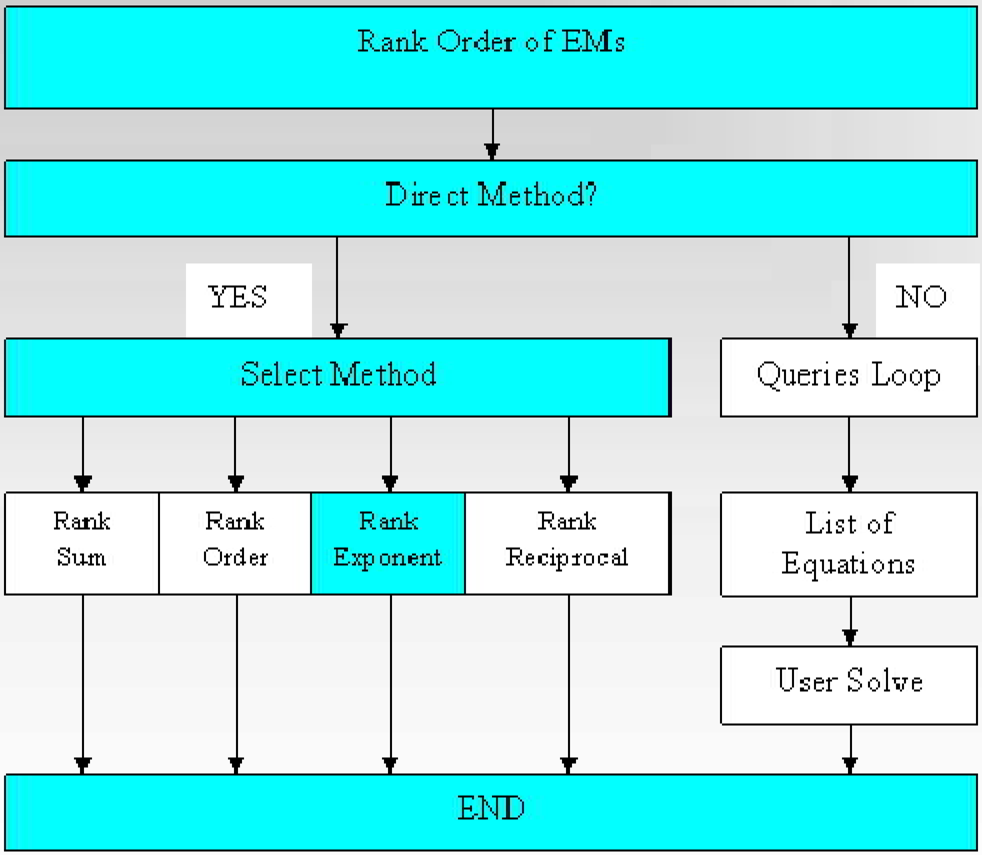
$$\text{FinalGrade} = \sum_{i=1}^{k} \text{Weight}_i \times \text{Grade}_i$$

Example: Option Grades

- MS Excel macros automatically calculate option grades

1					5		
2			TARGET	CERTAINTY EQUIVALENT	RHO		OPTION GRADE
3	Hollow #1	MU		62121	1475000		0.026569104
4		HIGH	3.50E+05				
5		LOW	55000				
6							
7		SIGMA		45669	800000		0.967880179
8		HIGH	2.00E+05				
9		LOW	40000				
10							
11	Hollow #2	MU		1.59E+05	1475000		0.376480928
12		HIGH	350000				
13		LOW	55000				
14							
15		SIGMA		99348	800000		0.652190272
16		HIGH	200000				
17		LOW	40000				
18							
19	Hollow #3	MU		3.25E+05	1475000		0.922544911
20		HIGH	350000				
21		LOW	55000				
22							
23		SIGMA		1.85E+05	800000		0.105721135
24		HIGH	200000				
25		LOW	40000				

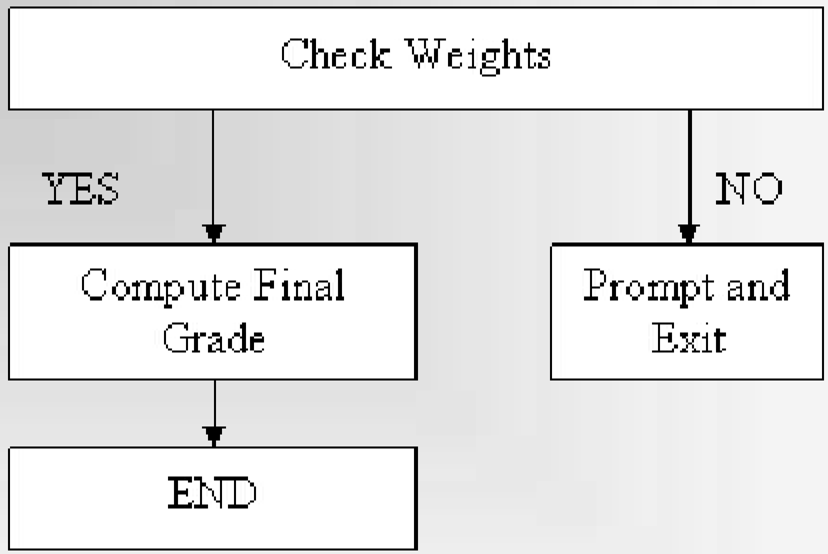
Example: Weights



$$\text{weight}_i = \frac{(K - r_i + 1)^z}{\sum_{j=1}^{K} (K - r_j + 1)^z}$$

	A	B
1	Evaluation Measure	Weight
2	Cost	0.3408
3	Critical Load	0.2583
4	Sigma of Critical Load	0
5	Percent Failure	0.4009

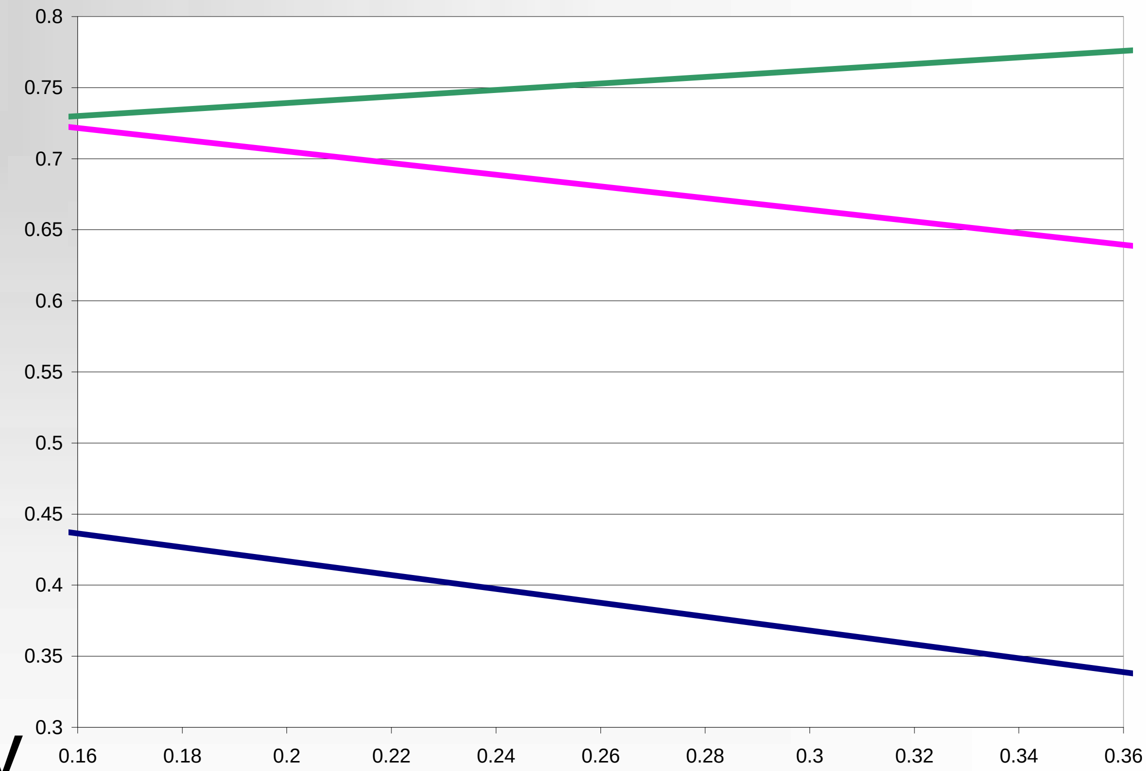
Example: Final Grade



	A	B	C	D	E	F	G	H
	Evaluation Measure	Weight	Hollow #1	Weighted Grade	Hollow #2	Weighted Grade	Hollow #3	Weighted Grade
	Cost	0.3408	0.932092	0.317693328	0.703615	0.239819502	0.488785	0.166596817
	Critical Load	0.2583	0.026569	0.006863001	0.376481	0.097247882	0.922545	0.238300355
	Sigma of Critical Load	0	0.96788	0	0.65219	0	0.105721	0
	Percent Failure	0.4009	0.159474	0.063925584	0.858421	0.344101079	0.867368	0.347687663
	Final Grade			0.388481913		0.681168464		0.752584835

Sensitivity Analysis

- Check if selected weights allow for a conclusive decision
- Example: For each EM, vary weight by 0.1 in each direction



Current Status and Outlook

- Materials prepared so far:
  - Software package (MATLAB, MS Excel)
  - User manuals
  - Lecture notes
- Limited version of approach to be piloted and assessed in undergraduate course in Spring 2005

Acknowledgment

This project is sponsored by the National Science Foundation under Grant No. 0234016.