• Engineering facilities are constructed to meet the needs of society; for example, a highway is built to facilitate the movement of passengers and goods.

• In initiating a project, a number of questions have to be answered:
  1. should the facility be built in the first place?
  2. if yes, when should it be built?
  3. if yes, what capacity/size/configuration should be adopted?

• These decisions are made by following a systematic process:
  1. define the problem
  2. establish objectives and criteria
  3. generate alternative plans
  4. evaluate alternatives ←——→ Engineering Economics
  5. choose & implement
Focus of this tutorial:

1. briefly discuss some concepts of engineering economics

   i. interest

   ii. time value of money

   iii. life-cycle cost

2. highway costs and benefits

   i. tangible

   ii. intangible (externalities)

3. interest formulas and equivalencies

   i. present value, future value, annuity, interest rate

4. economic analysis methods

   i. NPV, Life-cycle cost, B/C ratio

5. comparison of alternatives

   i. cost-effectiveness

   ii. ranking and rating

6. examples and conclusions
Concepts of Engineering Economics:

- **interest rate**, is the rate of gain received from an investment
- **time value of money**, is the relationship between interest and time
- **inflation & deflation**, alter the purchasing power of money

- Cost Classification
  
  i. initial cost
  
  ii. operation and maintenance cost
  
  iii. fixed cost
  
  iv. variable cost
  
  v. incremental cost
  
  vi. sunk cost
  
  vii. life-cycle cost
Highway Costs and Benefits

1. Highway Costs

   • Tangible

   I. Agency Cost

      i. capital cost

         -preliminary engineering
         -ROW
         -roadway construction
         -major structures

      ii. maintenance cost

         -ROW
         -structures

      iii. operation cost

         -traffic service
         -snow control
         -highway police
II. Highway User Cost

i. Motor Vehicle Running Cost

-fuel consumption
-tire wear
-vehicle maintenance

*grades, Hz. curves, speed changes, roadway surface

ii. Value of Travel Time

-trip purpose
-environment: time of day, traffic volume
-use of which time saved is put
-amount of time savings

*based on federal minimum wage

iii. Traffic Accident Costs

-Type of accident: fatal, personal injury, property damage

*info. needed: acc. rate wrt. VMT, cost per accident

*design factors: Hz. curves, illumination, intersection,

speed, one-way streets
• Intangible

I. Societal Costs
   i. air pollution
   ii. noise problems
   iii. land use disturbance

II. Externalities

2. Highway Benefits

   User Travel Benefits (only tangible)

   I. savings in travel time

   II. savings in vehicle running cost

   III. savings in accident cost
Interest Formulas and Equivalence

Notation:

$I$: interest

$i$: annual interest rate

$n$: the number of annual interest periods

$P$: principal amount (present value)

$F$: future sum, $n$ interest periods hence

$A$: annuity, a single payment made at the end of each annual $i$ period

$G$: gradient, uniformly increasing series of payments

1. Single-Payment Compound-Amount Factor (SPCAF, F/P)

\[ F = P(1 + i)^n \]

Single-Payment Present-Worth Factor (SPPWF, P/F)

\[ P = F \left[ \frac{1}{(1 + i)^n} \right] \]
2. Equal-Payment-Series Compound-Amount Factor (EPSCAF, F/A)

\[ F = A \left[ \frac{(1+i)^n - 1}{i} \right] \]

Equal-Payment-Series Sinking-Fund Factor (EPSSFF, A/F)

\[ A = F \left[ \frac{i}{(1+i)^n - 1} \right] \]

3. Equal-Payment-Series Capital-Recovery Factor (EPSCRF, A/P)

\[ A = P \left[ \frac{i(1+i)^n}{(1+i)^n - 1} \right] \]

Equal-Payment-Series Present-Worth Factor (EPSPWF, P/A)

\[ P = A \left[ \frac{(1+i)^n - 1}{i(1+i)^n} \right] \]

4. Uniform-Gradient-Series Factor (UGSF, A/G)

\[ A = G \left[ \frac{1 - \frac{n}{i}}{\left( \frac{1}{i} \right) \left( 1+i \right)^n - 1} \right] \]
Nominal and Effective Interest Rates

\( r \): nominal interest rate per year (APR)

\( i \): effective interest rate in the time interval

\( l \): length of time interval (in years)

\( m \): interest periods a year

\[
i = \left(1 + \frac{r}{m}\right)^{lm} - 1
\]

Continuous Compounding

\( i_a = \text{effective annual interest rate} = e^r - 1 \)
Computing the Inflation Rate

annual change in inflation rate for 1994 = $\frac{CPI_{1994} - CPI_{1993}}{CPI_{1993}}$

The Purchasing Power of Money

Purchasing power_{1994} = $\frac{CPI_{1994}}{CPI_{1967}}$

Actual dollars: out-of-pocket dollars received or disbursed at any point in time (current dollars)

Constant dollars: hypothetical purchasing power of receipts and disbursments at some base year (deflated dollars)

constant dollar_{1985} = $\frac{CPI_{1967}}{CPI_{1985}} = \frac{100}{322.2}($1) = $0.310$
Economic Analysis Methods

*NPV* (Net Present Value): Net equivalent amount at the present, equal to the difference between an investment’s costs and benefits

- profitability expressed as a lump sum, not a rate
- unambiguous, direct index
- preferred technique; recommended by AASHTO

**IRR** (Internal Rate of Return): The interest rate that makes the costs equal to the benefits (or income)

- benefit or income is considered
- solution not unique; calculations not straightforward
- easy to understand intuitively

*B/C* (Benefit-Cost ratio): Expresses the ratio of equivalent present worth of benefits to the equivalent uniform present worth of costs

- concern over significance in relative values of B/C ratios
- definitions of benefits and costs can be ambiguous
- lack of understanding
**Example of Economic Analysis Methods:** A proposal is being considered to improve an existing road to reduce transportation costs. The cost of the project is $100,000. Present annual transportation cost for all traffic amounts to $127,000/year and would continue if no improvement is made. After the improvement, annual transportation costs are estimated to be $116,000/year. Life of the project 20 years. MARR (minimum attractive rate of return is 12%). Should the project be undertaken?

### NPV

All cash flow differences are discounted to their equivalent PV

\[
NPV = 10,400 \text{USPW}_{12\%,20} - 100,000 = -22,300 \Rightarrow \text{DO NOT undertake}
\]

### B/C ratio

\[
\frac{PW_{\text{benefits}}}{PW_{\text{costs}}} = \frac{77,700}{100,000} \Rightarrow \text{DO NOT undertake}
\]

PW of Costs = $100,000
PW of Benefits = $10,400 * USPW \text{F}_{12\%,20} = 77,700

### IRR

NPV = 0

PW of cost = PW of benefit \Rightarrow 100,000 = 10,400 * USPW \text{F}_{1\%,20} \Rightarrow

\Rightarrow \text{USPW F}_{1\%,20} = \frac{100,000}{10,400} = 9.62 \Rightarrow i = 8.3\% < \text{MARR DO NOT undertake}
EVALUATING MULTIPLE ALTERNATIVES

Economic Analysis

- involves efficiency considerations
- B/C, IRR, NPV
- pair-wise comparisons

Cost-Effectiveness Analysis

- non-monetary values can be included
- all costs and consequences explicitly identified
- tradeoffs of various impacts are assessed
- this approach is oriented toward a system of values, goals, and objectives
- Selection can be based on any of the following:
  1. satisfactory performance (effectiveness) at a fair cost
  2. satisfactory effectiveness achieved at lowest cost
  3. highest effectiveness within budget
**Ranking and Rating**

Several approaches are available. The most popular is Rank-Based Expected Value Method. The steps of the method are:

1. goals and objectives are ranked
2. each alternative is then ranked under each objective
3. combine ratings to provide a final rating
4. consider the probability of implementation, to provide a final score
### Evaluation Matrix

<table>
<thead>
<tr>
<th>Plan</th>
<th>Implementation</th>
<th>Probability of Implementation</th>
<th>Economy</th>
<th>Dislocation</th>
<th>Comfort</th>
<th>Access</th>
<th>Transit</th>
<th>Calculations</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.75</td>
<td></td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>(3x5+4x1+2x1+3x3+1x2)/0.</td>
<td>2.4</td>
</tr>
<tr>
<td>B</td>
<td>0.97</td>
<td></td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>(2x5+2x4+1x1+1x3+3x2)/0.</td>
<td>26</td>
</tr>
<tr>
<td>C</td>
<td>0.82</td>
<td></td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>(1x5+3x4+3x1+2x3+2x2)/0.</td>
<td>24.5</td>
</tr>
</tbody>
</table>
OPTIMAL TIMING CRITERIA

1ST Year Benefit Rule (criteria for optimality)

\[ Y_n = C_i - b_n \leq 0 \text{ (Defer)} \]
\[ \geq 0 \text{ (Start)} \]

where: \( i \): interest rate

\( C \): capital

\( b \): benefit computed the year project is opened

\( MARR \): Minimum Attractive Rate of Return

FYRR (First Year Rate of Return)

\[
FYRR = \frac{b_n}{C} \leq MARR \quad \text{ defer} \\
\geq MARR \quad \text{ start}
\]
EXAMPLES

1. Optimal Timing Criteria - example of a gravel road

2. Consideration of Accident Costs - user benefits evaluation